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Autonomous vehicles: public acceptance and impacts on urban areas

Ghada Tay

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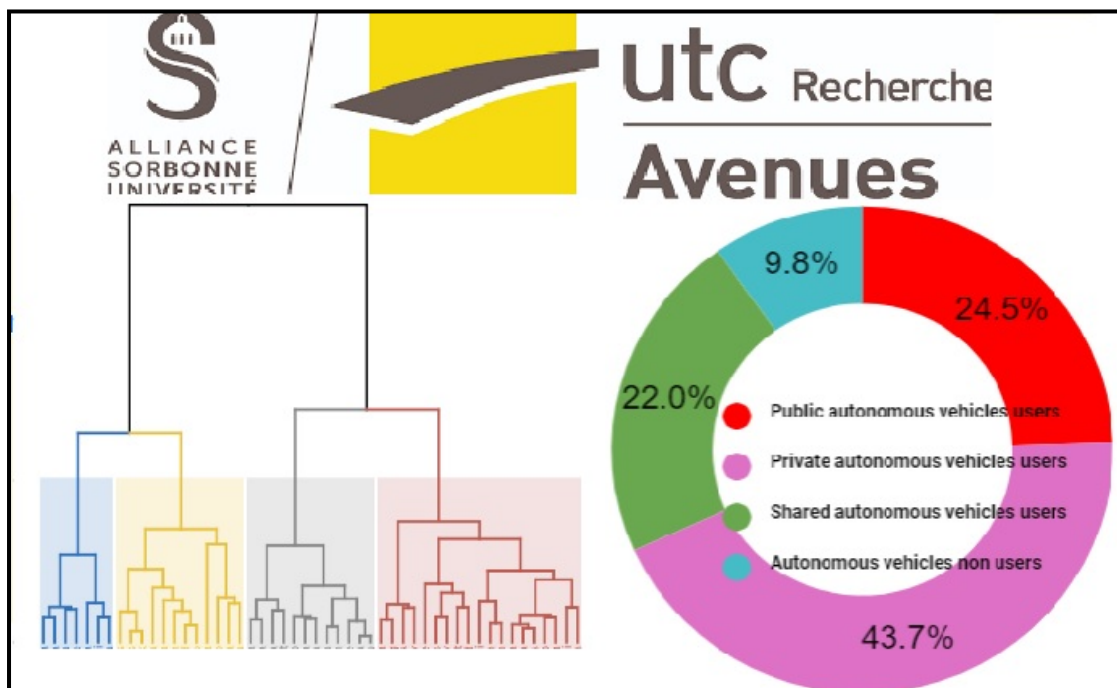
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Par Ghada TAY

*Autonomous vehicles: public acceptance
and impacts on urban areas*

Thèse présentée
pour l'obtention du grade
de Docteur de l'UTC



Soutenue le 18 décembre 2020

Spécialité : Urbanisme, Aménagement et Transports :
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Autonomous Vehicles: Public Acceptance and Impacts on Urban Areas

AVENUES Laboratory, EA 7284

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Abstract

In the era of smart and sustainable cities, autonomous vehicles (AVs) are gaining significant attention from both researchers and local decision-makers. AVs are expected to significantly shape mobility in the future, which would have a huge impact on urban development. The development of AVs covers not only technological and industrial evolutions but also territorial innovations which are now reaching maturity. Indeed, several experiments are currently being carried out by Tesla and Google. Not far from us, the UTC made the first test with a car traveling with a driver not interacting with the steering wheel or the pedals. This intelligent vehicle or AV is the next innovation in urban transport modifying both the use of private vehicles and the functionality of urban transport. However, to what extent(s) the use of AVs will effectively influence, positively or negatively, urban spaces and sustainable development policies. In this context, and through the example of the Agglomeration of the region of Compiègne (ARC), this thesis work focuses on the integration of AVs into urban space from the point of view of users. Through this prism, this research work will seek to better understand and extract the factors that can influence the adoption of these AVs as a fully-fledged mode of transport, or not, with a view to anticipating their impacts on the urban system.

In the absence of normative data on this subject, the construction of an ad-hoc survey is necessary. Hereby, this work is based on an ad-hoc questionnaire administered to the residents of the ARC, concerning their travel

habits, their perceptions and their willingness to use the AVs. Using a descriptive quantitative approach, the data collected was used to distinguish and identify different profiles of potential AVs users. Next, a multinomial logistic regression was performed to investigate the relationship between variables associated with acceptance and intention to use VAs in different modes. The results revealed that the sample can be divided into four subgroups of users: i. potential users of private autonomous vehicles (43.7%), ii. potential users of public autonomous transport (24.5%), iii. potential users of shared autonomous vehicles (22%) and iv. non-users of autonomous vehicles (9.8%). Data analysis has shown that confidence in AVs, perceived usefulness and past mobility behaviors significantly influence the adoption of AVs as private, shared or public modes of transport while socio-demographic status influences only the acceptance of autonomous shared and public transport.

In general, AVs could improve shared mobility and appear to be able to reduce vehicle ownership and the places dedicated to vehicles. This could lead to major changes in urban areas: less congestion, fewer pollutant emissions and vehicle accidents. In addition, the inclusion of autonomy in the transport system will have a radical impact on the current transport system and on the location of resident populations. This study shows that nearly 30% of the population could change their place of residence with the arrival of AVs. These elements are important data to consider in preparing for the arrival of the AVs in the urban areas.

Résumé

À l'ère de la ville intelligente et durable, les véhicules autonomes (VA's) attirent une attention considérable autant de la part des chercheurs que des décideurs locaux. On s'attend de plus en plus à ce que les VAs influencent considérablement la mobilité à l'avenir, ce qui aurait un impact considérable sur le développement urbain. Le développement des VA recouvre non seulement des évolutions technologiques et industrielles mais aussi des innovations territoriales qui arrivent aujourd'hui à maturité. En effet, plusieurs expérimentations sont actuellement menées par Tesla ou Google. Moins loin de nous, l'UTC a réalisé un premier essai avec une voiture circulant avec un conducteur n'interagissant ni avec le volant, ni avec les pédales. Ce véhicule intelligent ou VA constitue une prochaine innovation dans les transports urbains modifiant autant le rapport au véhicule personnel que les fonctions des transports urbains. Cependant, dans quelle(s) mesure(s) l'utilisation des VAs affectera-t-elle, positivement ou négativement, effectivement les espaces urbains et les politiques de développement durable. Dans ce contexte, à travers l'exemple de l'Agglomération de la région de Compiègne (ARC), ce travail de thèse s'intéresse à l'insertion des VAs dans l'espace urbain du point de vue des utilisateurs. À travers ce prisme, ce travail de recherche cherchera à mieux comprendre et appréhender les facteurs pouvant influencer l'adoption de ces VAs comme un mode de transport à part entière, ou non, en vue d'en anticiper les impacts sur le système urbain.

Faute de données normatives sur ce sujet, la construction d'un dispositif d'enquête ad-hoc est nécessaire. Pour cela, ce travail s'appuie sur un questionnaire ad-hoc administré auprès des résidents de l'ARC, concernant leurs habitudes de déplacement, leurs perceptions et leurs volontés d'utiliser les VAs. À

l'aide d'une approche quantitative descriptive, les données collectées ont été utilisées pour distinguer et identifier différents profils d'utilisateurs potentiels des VAs. Ensuite, une régression logistique multinomiale a été réalisée pour étudier la relation entre les variables associées à l'acceptation et l'intention d'utiliser les VAs dans différents modes. Les résultats ont révélé que l'échantillon peut être divisé en quatre sous-groupes d'utilisateurs: i. les utilisateurs potentiels de véhicules autonomes privés (43,7%), ii. les utilisateurs potentiels des transports publics autonomes (24,5%), iii. les utilisateurs potentiels de véhicules autonomes partagés (22%) et iv. les non-utilisateurs de véhicules autonomes (9,8%). L'analyse des données a permis de montrer que la confiance dans les VAs, l'utilité perçue et les comportements de mobilité passés influencent significativement l'adoption des VA en tant que modes de transport privé, partagé ou public tandis que le statut socio-démographique influence uniquement l'acceptation du transport autonome partagé et public.

En général, les VAs pourraient améliorer la mobilité partagée et semblent pouvoir réduire la possession de véhicules et la place accordée à l'automobile. Cela pourrait entraîner des changements majeurs en milieu urbain : moins de congestion, moins d'émissions des polluants et d'accidents des véhicules. De plus, l'insertion de l'autonomie dans le système de transport aura un impact radical sur le système de transport actuel et sur la localisation des populations résidentes. Cette étude montre que près de 30% de la population pourrait changer de lieu de résidence avec l'arrivée des VA. Ces éléments constituent des données importantes à considérer pour se préparer à l'arrivée des Vas dans le paysage urbain.

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Acronyms

<i>ADAS</i>	Advanced Driving Assistance System
<i>AIV</i>	Average Inertia of Each Variable
<i>ARC</i>	Agglomeration de la Region de Compiegne
<i>AV</i>	Autonomous Vehicle
<i>BLR</i>	Binomial Logistic Regression
<i>CCC</i>	Cophenetic Correlation Coefficient
<i>CT</i>	Cross-tab Analysis
<i>CTAM</i>	Car Technology Acceptance Model
<i>CV_s</i>	Conventional vehicles
<i>DDM</i>	Driving Decision Making Mechanism
<i>DM</i>	Dissimilarity Matrix
<i>DP</i>	Driving Pleasure
<i>DV</i>	Dependent Variable
<i>EAV_s</i>	Electric Autonomous Vehicles
<i>ETAM</i>	Extensions of Technology Acceptance Model
<i>F</i>	Familiarity
<i>GPS</i>	Global Positioning System
<i>INSEE</i>	National Institute of Statistics and Economic Studies
<i>IV_s</i>	Independent Variables
<i>KAV</i>	know Autonomous Vehicle
<i>MADAS</i>	Model of Acceptance of Driver Assistance Systems
<i>MCA</i>	Multiple Correspondence Analysis
<i>MLR</i>	Multinomial Logistic Regression
<i>NHTSA</i>	National Highway Traffic Safety Administration
<i>PAT</i>	Public Autonomous Vehicle
<i>PAV</i>	Private Autonomous Vehicle
<i>PB</i>	Past Behaviour
<i>PMB</i>	Past Mobility Behaviour
<i>PT</i>	Public Transport
<i>PU</i>	Perceived Usefulness
<i>PV</i>	Private Vehicle
<i>PW</i>	Project Workshop
<i>R&D</i>	Research and Development
<i>SAE</i>	Society of Automotive Engineers
<i>SAV</i>	Shared Autonomous Vehicle
<i>SDS</i>	Socio-Demographic Status
<i>SM</i>	Soft Mode
<i>TAM</i>	Technology Acceptance Model
<i>TAM2</i>	Extensions of Technology Acceptance Model 2

<i>TAM3</i>	Extensions of Technology Acceptance Model 3
<i>TIB</i>	Theory of Interpersonal Behaviour
<i>TPB</i>	Theory of Planned Behaviour
<i>TRA</i>	Theory of Reasoned Action
<i>TST</i>	Trust
<i>UTAUT</i>	Unified Theory of Acceptance and Use of Technology

Introduction

"In this era of digitization and smart technologies, the use of autonomous vehicles as a mode of transport is not a question of 'if' but 'when'."

*Chen Tsuhan
(Afable, 2019)*

Background

The current transport system has shown failure in satisfying the requirements of sustainable mobility and sustainable development, especially with the growing population. While rating on the top ten causes of deaths worldwide; 1.35 million deaths are due to road accidents each year (Kadam, 2020). Besides, according to the World Health Organization, road transport is responsible for 30% and 50% of particulate emissions in European cities and the OECD¹ cities respectively. The thing that raised the need for a change in the foundation of this system.

While the transport system faces many problems and its performance is gradually deteriorating, the concept of automation and autonomous vehicles is making its way into transport sector policies and development strategies. Autonomous vehicles

¹the OECD cities are a group of 37 cities from North and South America to Europe and Asia-Pacific

<https://www.oecd.org/about/members-and-partners/>

(AVs) are expected to radically change mobility patterns and improve the efficiency of transport systems (Apar, 2018). They are vehicles with the highest level of automation that allows them to move safely without a driver on board. They are seen as a great opportunity to increase road capacity, reduce accidents, reduce traffic congestion, reduce CO2 emissions, reduce fuel consumption, provide last-mile services, enhance transport accessibility, reduce travel time, reduce transport costs, etc., (Goldin, 2018b). This view has encouraged about 55 cities to commit to deploying AVs in their transport development strategies (Baron et al., 2018). Moreover, over 27 cities start preparing for AVs implementation by conducting surveys on issues raised by AVs as regulation, planning, adoption and integration (Bloomberg, 2017).

However, like any other innovation and technology, AVs are not expected to be immediately adopted by society even if they are promoted to bring tremendous benefits to the user and society. Individuals who would refuse to use AVs argue over issues such as safety, privacy, cybersecurity, personal independence, and reliance on technology. The way the public perceives AVs will influence their business development and implementation strategies. In order to determine their potential implementation and potential improvement, a study of public perception is essential. Public opinion is a strong indicator of how this new technology will develop and be integrated into our society.

In this research, the automation of passenger transport means is considered, the study investigates the social and behavioural aspect of AVs together with the impacts of AVs on the urban system. The thesis addresses the factors influencing the acceptance of AVs as private autonomous vehicles (PAV), shared autonomous vehicles (SAV) or public autonomous transport (PAT). It also provides quantitative evidence of the potential integration scenarios of AVs in the transport system, as well as, the changes that the urban system will undergo if AVs become adopted and integrated within the transport system.

Motivation

The strength of this study lies in its interdisciplinary aspects, which combine urban planning, transport management and data analysis in order to design future smart mobility. It aims to the integration of modern technology, i.e. autonomous vehicles, into the daily life of urban dwellers, it also investigates the potential of AVs in the urban areas.

The implementation of AVs is on the top of transport development relying on huge expectations concerning future mobility and sustainable transport (Gruyter, 2016). Scientific evaluation of the impacts of introducing AVs in transport systems has become one of the main issues for the current research and it is top on the European Commission agenda (Uhlemann, 2018). However, as these vehicles are not available to common users and are not allowed to roll our streets freely, real testing of their impacts are not possible. But, their impacts can be predicted by studying people's attitude towards these vehicles and how they are expected to use them when they become available; that is the main driver of the urban system changes. Therefore, a study of people's attitudes towards the implementation of such vehicles in their daily lives is inevitable. The thing that made researchers, governments, social actors, etc., investigate people's acceptance and perception towards AVs.

Hereby, to anticipate the future of automation in the transport system and predict the potential impacts of AVs on the urban system, it is essential to gain an in-depth understanding of social perception about AV. While there has been much research on AVs technical development to assure their high-performance operation, relatively little has focused on the social and urbanism side of their development and integration. Moreover, even in AVs acceptance related studies, the acceptance was considered in general where the public can accept all or any mode of AVs (Benleulmi and Blecker, 2017; Jiang et al., 2018; Kaur and Rampersad, 2018; Talebian and Mishra, 2018; Hulse et al., 2018; Nordhoff et al., 2018; Liljamo et al., 2018; Menon, 2015; Gabrhel, 2018),

none has focused on the acceptance of the different modes of autonomous transport (PAV, SAV and PAT). Knowing that the impacts of AVs on transport and urban systems are highly associated with the mode of transport to be used and individuals' travel behaviour changes. Moreover, acceptance of AVs could give a small sign of how people would react towards each autonomous transport mode but cannot draw the full picture.

Therefore, to scientifically evaluate the impacts of AVs and their potential development, it is important to build a complete picture of public acceptance of AVs in each of the transport modes, as well as, the profiles of different mode users to be able to encourage people to use the mode that is more beneficial for building a sustainable urban system and to predict acceptance in different areas based on similarities between population profiles.

Research objectives

This study intends to assess people's acceptability of AVs and support key stakeholders (transport authorities, local governments, civil society, etc.) about the opportunities and risks of AVs, as well as to develop exploitation plans and policy recommendations, paving the way for the smart implementation of AVs in case this will be proven useful for the users and for reaching more sustainable mobility. These targets are achieved by setting out the following objectives:

- identifying the factors influencing people's behaviour towards AVs and their acceptance of AVs as PAV, SAV, or PAT;
- finding which mode of autonomous transport (PAV, SAV or PAT) is preferred by the public and how to encourage potential users toward any of the modes.
- clustering the population according to their profiles and their chosen transport mode.

- anticipating the possible impacts of the implementation of AVs on the urban system based on potential users behaviour.

The study aims to investigate the acceptance of AVs in different modes. It also aims to elicit the potential mode of AVs to be used in the future. Seeking to better support people's mobility needs and to help in drawing the strategies to change people's preferences; if needed to guarantee the sustainability of the transport sector.

Organization of the dissertation

Besides this chapter, the dissertation is organized into the following chapters:

- chapter one presenting the state of the art on autonomous vehicles. It presents a literature review of the autonomous vehicles from the integration of automation technology in transport to our days where AVs are digging their way to the automobile market. As AVs are promoted to underpin the development of a sustainable urban system, a presentation of an urban system and sustainability were also provided, with the expected impacts of the implementation of AVs on them, as well as the presence of AVs in the policies for sustainable development at the French and European levels. The chapter also covers the AVs integration challenges, including ethical, cost, technical, legal, and social acceptance challenges. The social acceptance is very associated with the scope of this study, thus it was studied carefully with a revision of the acceptance theories used previously in the transport sector, which was essential to select the adequate variables influencing users acceptance of AVs to be studied in our research.
- chapter two presenting the survey conducted and methodology adopted in this study. The chapter presents the variables to be tested in the study along with the research questions and hypotheses. It also provides the research design and methodological steps followed to reach the research objectives, including a

description of the study area, sample selection, survey administration, survey design, pre-test and finally data analysis design.

- chapter three reporting the results and analysis of the collected data. The analysis started by checking the response rate to validate the methodology used, then a complete description of the sample and its representativeness of the population. After that, a cross-tab analysis was performed that studies the effect of the tested variables on the acceptance of AVs. Followed by a multiple correspondence analysis to reduce the dimensions of the variables and present the characteristics of the sample different profiles. Then, cluster analysis was performed to group the population into different clusters based on their socio-demographic profiles as well as travel behaviour and preferences. Finally, multinomial logistic regression was carried out to study the significance of the tested variables on the creation of each cluster.
- finally, the discussion and conclusion are presented. The chapter discusses the importance of the variables tested when considering the acceptance of AVs, the profile of potential users of different autonomous transport modes, and the expected impacts of the vehicles on the urban system. In addition, it compares these results with those of the literature. It also highlights the research implications, limitations, and future directions. Moreover, it ends by a summary of the research conducted and the results, giving the reader a broader view of the AVs and some issues that must be studied before their real implementation.

Chapter 1: The insertion of autonomous vehicles in the urban space: a revolution in the world of transport

"A good science fiction story should be able to predict not the automobile but the traffic jam."

*Frederik Pohl
(Steinmüller, 2013)*

The introduction of artificial intelligence and communication technologies to the technological industry, paved the way for science fiction stories to be more real than ever. A car without a steering wheel like that presented in the story of David Keller "The Living Machine" in 1935, became not only possible but also the most important topic in transport, as well as political and social sectors (Commission Européenne, 2018). The concept behind this dreaming car or autonomous vehicle (AV) has the ability to radically change transport. Hereby, what is this vehicle, can it be considered as a revolution in the transport system? How far are we from a real implementation? What are its impacts and interactions? Finally, what challenges is it currently facing? The answers of these questions are presented throughout this chapter.

1.1 Autonomous vehicles state of the art

In this section an overview of the AVs is provided. It presents the history of AVs along with their definition and technology, as well as, the autonomous transport levels and modes. It also contributes to understanding the current state of AVs and their market forecasting.

1.1.1 Autonomous vehicles overview: a new transport mode

In an effort to study the acceptability and impact of AVs, it is important to initially understand the concept of AVs and their potential uses. Hereby, this section presents how automation is introduced in the transport system, what AVs are and how they work.

1.1.1.1 The beginning of automation in transport

The history of autonomous vehicles dates back to 1921 when a remote-controlled vehicle was tested in public by engineers from the Radio Air Service in Dayton. The vehicle was controlled via radio signals from another vehicle 30m behind it (Heinzelman and Bronowitz, 2019). Later in 1953, the Radio Corporation of America laboratories developed the idea and built a miniature car controlled by wires laying on the floor of the laboratory. Since then, studies and research in the field of automation and remote control started (Joseph, 1960).

In the 1980s, several projects were launched serving the development of AVs. In Germany, Mercedes tested a vision-guided robotic van on a public road (Schmidhuber, 2009). In the United States, the Autonomous Land Vehicle project presented the first car using computer vision and robotic control to follow a road (Chander, 2018). Around the same period, the program for European traffic of high efficiency and

unprecedented safety for creating an AV was launched between numerous universities and car manufacturers, it defined the state of the art of AVs (EUREKA, 2016).

At the end of the 1980s, the world witnessed the biggest development in the AVs technology with the introduction of the first off-road map and sensor-based autonomous navigation by the Hughes Research Laboratories from one side and the use of neural networks for steering and controlling vehicles by the Carnegie Mellon University from the other side (Bimbraw, 2015). Since after, automation and automobile sectors evolved significantly. Nowadays, vehicles equipped with blind-spot assistance, crash avoidance, parking assistance, emergency braking, adaptive cruise control, lane-keep assistance and lane-departure warning are commercially available.

1.1.1.2 Definition of autonomous vehicles

Automation is the use of technology in operating a system without the aid of humans (Parasuraman and Riley, 1997). Similarly, AVs can be defined as vehicles that execute the driving function on their own instead of having a human driving. AVs can drive themselves from one location to another without the need of humans on-board; tracking a predefined or even a new trajectory under complex traffic conditions (Gruyter, 2016).

Autonomous vehicles are also called driverless or robot vehicle. Whilst a vehicle equipped with some automated features is called semi-autonomous, automated or self-driving vehicle, it can perform some advanced driving functions by itself, but still is not able to drive without the presence of a driver that has to intervene in critical situations. The deference between these vehicles is the level of autonomy to be discussed in section 1.1.2. Unfortunately, most people use these terms interchangeably and, even in research, the same term is used to refer to all levels of autonomy (Levinson, 2017).

Another term widely used is "connected automated or autonomous vehicles" that

could be interpreted as vehicles combining both connected vehicles technologies and automation technologies. Connected vehicles technologies allow vehicles to communicate with each other and with their surroundings for the sake of supplying a driver or a vehicle with useful information, in order to make safer or more informed decisions and avoid potentially dangerous situations (John et al., 2018). Such technologies are helpful in the case of automated vehicles because vehicles would not only count on their own instantaneously collected data about their surrounding and planned trajectory but also on data from other vehicles. For instance, counting on previous road roving vehicles shared data, a vehicle can avoid following or using a trajectory where there is a broken-down vehicle.

Furthermore, autonomous vehicles are not necessarily connected, which is the case of the AVs in testing that took place in several areas. Vice versa, connected vehicles are not automated, which is the case of most for the conventional vehicles that are connected at least to a GPS and could not perform any automated feature. However, if we imagine a world where all vehicles are autonomous, then the concept of a connected autonomous vehicle becomes necessary to ensure a maximum level of road safety (John et al., 2018). In accordance, the accident that occurred in Florida in 2016 using a Tesla car with autopilot mode -where the autopilot was unable to recognize a white tractor crossing the highway in front of it against a bright sky- could have been avoided if the car was connected to other vehicles on the road, where it would have received a signal from the tractor with its live location and an alert not to pass.

In the United States, autonomous vehicles and connected vehicles are seen as independent innovations, AVs do not require communication technology to operate, they are able to navigate autonomously on the road network without requiring information from other vehicles (John et al., 2018). In contrast, in Europe, these two systems are seen as complementary technologies (Hedhli, 2017), since, connected vehicles provide valuable information on the road ahead such as lane closures, road obstacles and new constructions that would enhance road choice and accident avoidance. In addition, AVs require some form of communication to keep software and data sets up to date

(Hedhli, 2017). In this study, the European view is adopted so AVs are supposed to be connected as well, and the autonomous vehicle is defined as a vehicle that relies on new technology and the received information to drive itself under any trajectory or traffic condition where a human driver can drive.

1.1.1.3 Functional view of autonomous vehicles

In order for a vehicle to be autonomous and to completely control operation safely, it requires massive data and a system of immense complexity to read these data, analyze them and give action plans. The process related to the decision-making and operating of the vehicle takes place in 4 steps as presented in figure 1.1:

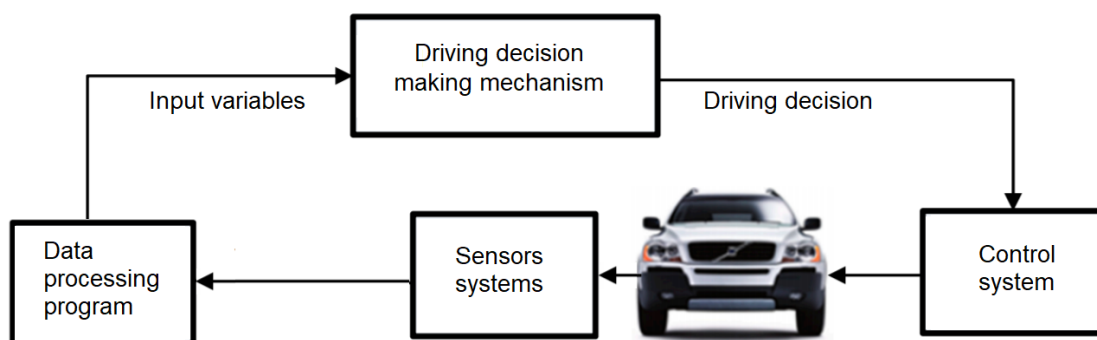


Figure 1.1: Schematic architecture of the driving decision-making process of an autonomous vehicle; source: Junyou et al. (2017).

- step 1: an AV must be able to both identify its location geographically and identify its location with respect to its surrounding (moving or static objects). This is done with the aid of sensors, in the first stage AVs use their sensors to build a 3-D mapping for the roads in order to use it later in navigation. After creating and saving the map the second stage begins, where the sensors keep on tracking the surrounding to update the map with real-time traffic information (Junyou et al., 2017). Figure 1.2 shows how an AV can sense its environment to define the nature of the obstacles and to help reading road signs, traffic lights, road markings and other useful signs;

- step 2: once the AV is able to locate and collect data about road conditions, the data enters its data processing program to be structured and processed to obtain the input variables required for the driving decision-making mechanism (DDM) (Junyou et al., 2017);
- step 3: based on the transmitted data from the data processing program, the DDM can start planning the accurate driving decision via its internal equipment based on the learning experiences and pre-saved scenarios. Here the vehicle does not take any physical activity but it plans the best possible journey, in terms of duration, distance, cost and above all the safety of the passenger and road users;
- step 4: after planning the journey and its needed actions, the control system will control the actuators to carry on the corresponding actions to start the trip where the vehicle acts autonomously and moves without human assistance. The system must be very reliable to guarantee the smooth running of the journey.

AVs carry hundreds of thousands of dollars worth sensors to enable them to perform the first and second stages of their operation. The main sensors are described in figure 1.2:

- The cameras ensuring a 360-degree vision for the car. Thanks to them, the vehicle can recognize road and safety marking elements such as traffic signs, road markings from one side, and distinguish the flashing lights of a vehicle to know its direction in the case of a conventional vehicle from the other side. Cameras can also be used in some more advanced cases to recognize objects around the vehicle through an image comparison system based on machine learning of the vehicle.
- Laser scanners or "LIDAR" (light detection and ranging) allow the vehicle to both detect and assess the distance of a moving or stationary object from it. Unlike the conventional radar system which uses radio waves to operate, LIDAR

uses infrared or visible domain waves. The principle is based on the emission of several of these waves which, when meet a solid object, are returned to the emitting system. The delay between transmission and reception makes it possible to assess the distance like a conventional telemetry system. In addition, LIDAR allows the vehicle to calculate the size of objects as well as, to establish three-dimensional maps of the surroundings of the vehicle. This is why this technology is prioritized over radar despite a much higher cost.

- Ultrasonic sonar, which uses sound waves at frequencies inaudible to the human ear, is based on the same operating principle as radar and LIDAR. It consists of a transmitter and a receiver and its use is relevant for short ranges due to the weak propagation of sound waves in the air. This system makes it possible to detect and model objects at a short distance from the vehicle, especially if used in cities due to the low speed. The faster the vehicle goes, the less accurate the sonar operates, that is because the speed of sound waves in the air is low. In addition, as the technology on which it is based is not recent, sonar is very inexpensive compared to the two devices presented above.

There are other technologies that can be used on AVs, but the three mentioned above are the most used to allow the car to locate and understand its environment.

1.1.2 Autonomous vehicles levels of autonomy and transport modes

Autonomous vehicles could be used to transport people or goods. In this study goods transport will not be considered since it requires an industrial perception rather than the public's. Thus, the focus will be on people transport, which can be of different autonomy levels and different transport modes that are presented in this section.

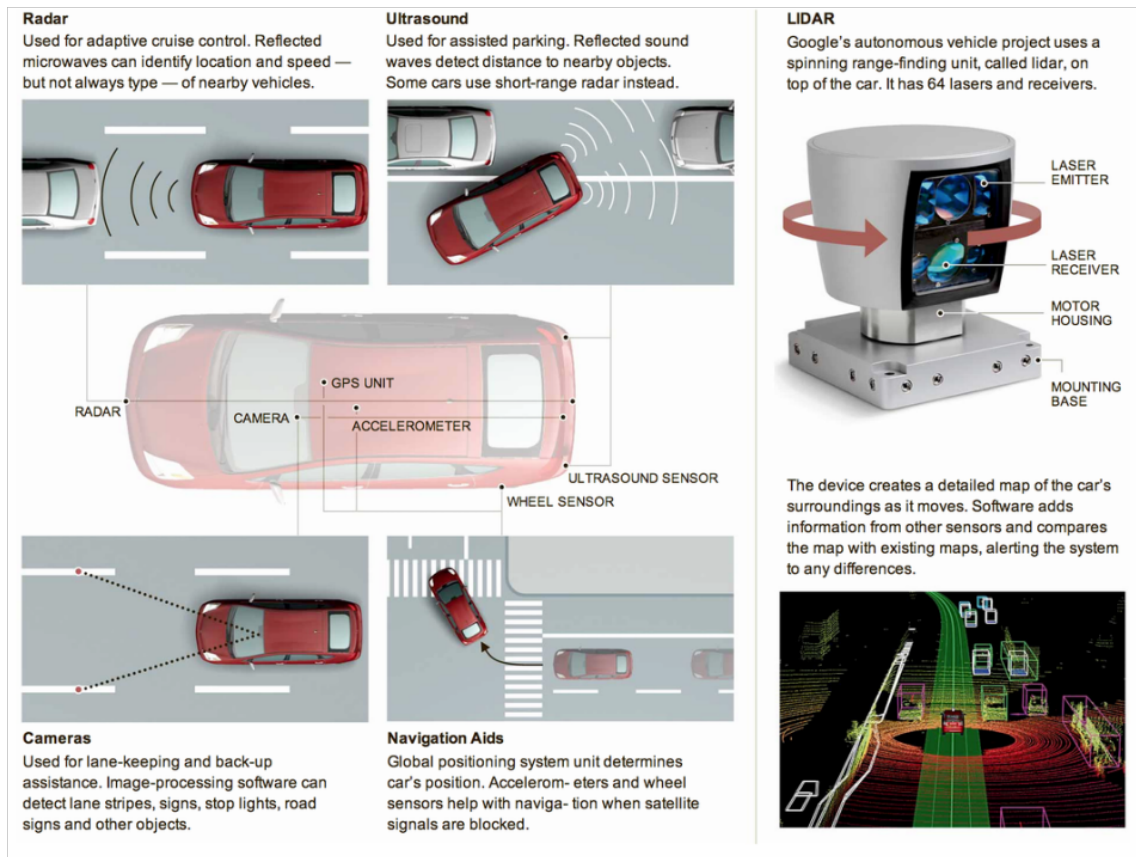


Figure 1.2: The sensors used in google autonomous car; source: Weebly (2020).

1.1.2.1 Autonomous vehicles levels of autonomy

In order to understand the different levels of autonomy in a vehicle, two taxonomies were proposed. In 2013, The National Highway Traffic Safety Administration (NHTSA)¹ presented five levels of autonomy based on the autonomy of primary vehicle controls. A year later, the Society of Automotive Engineers (SAE) proposed a six-level classification based on the vehicle available technology and human involvement in driving. The SAE autonomy levels are presented in figure 1.3 and defined as follow:

- level 0: all driving functions and decisions are controlled by the driver; he is fully responsible for all driving tasks.
- level 1: it frees the driver from managing the brake and accelerator pedals

¹<https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety>

that are carried by the vehicle. In France, this level 1 of autonomy is often linked to adaptive cruise control, which is popular in mid-range or even entry-level vehicles. This system is, for example, available as an option on the new Renault Clio, the best-selling car in France from 2013 to 2018 (Bekker, 2019).

- level 2: the vehicle manages the steering on its own and the driver no longer needs to manage the wheel. However, he must be under full supervision. Therefore, the driver remains responsible in the event of an accident. This level, which involves constant attention from the driver, is often or even exclusively reserved for driving on major axes (motorways, national and certain departmental). Currently, only premium brands can offer this type of driver assistance with a wide variety of technologies. In particular, we find options such as lane-keeping which identifies the lines of the road and prevents the driver from leaving the path by acting directly on the steering wheel. Note that this system is widespread and extends to mid-range vehicles as an option. The top-of-the-range German manufacturers (BMW, Daimler-Mercedes and AUDI), as well as Tesla, offer more advanced technologies based on advanced GPS mapping that allows the car to find its way in space, and sensors that allow the car to be able to fully manage the steering. However, these technologies are not standard on vehicles that are at entry-level prices. In addition, manufacturers are required to include driving control systems that may or may not detect the presence of the driver's hands and force them to get behind the wheel if this is not the case.
- level 3: it differs from the previous one mainly from a legislative point of view since it is no longer the driver who is responsible in the event of an accident. This leaves him free to do other things while being prepared to regain control in the event of an incident. Some cars available for sale today may technically be eligible for this level of automation. Nevertheless, the discussion on legislation around such autonomy level has not yet been concluded, especially in France where cars are therefore limited to level 2.
- level 4: the vehicle is responsible of the problems and decisions and the driver

no longer has to worry about them. The driver is supposed to be totally exempt from driving duties if he chooses so. However, there is still a driver seat with the necessary appendages for full control of the car. Today most of the tests carried out on open roads are located between level 3 and 4 of autonomy, with cars supposed to make the majority of the decisions, but in the presence of an alert driver ready to take back control in the event of a problem.

- level 5: the last level corresponds to the complete autonomy of the vehicle without the need for any human intervention. The vehicle is thus able to pick a passenger at his request and then return to park once it dropped off him. Unlike the previous level, in this case, there is no longer a driver seat and the expression "the roving salon" can be used; comfort and the activities that can be done inside the vehicle will become a priority.

However, experts believe that the massive commercialization of the 5th autonomy level vehicles is not coming soon.

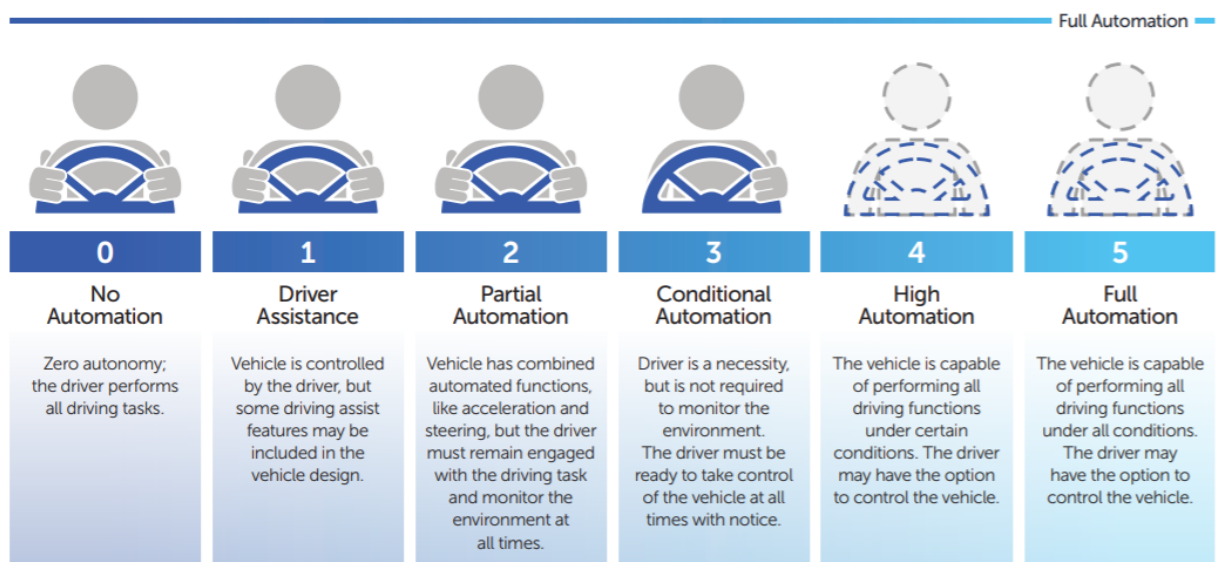


Figure 1.3: SAE automation levels; source: (NHTSA, 2017).

In this study, the focus is on the impacts of vehicle automation on the urban system

after inspecting people's acceptance of automation. Since accepting one automated system or two will not make a great difference but the huge difference lies in whether to give the control for a human (driver) or a software, then the focus will be on autonomy level 5 (will all autonomous functions possible). Indeed, the levels of autonomy defined by the SAE are still little known to the general public, who do not necessarily define an AV in the same way as engineers. In addition, we have assumed that it is level 5 that will have the most impact on the urban landscape and whose inclusion in population daily life will raise the most questions. Hereby, in this study, three levels will be used as shown in figure 1.4:

1. the non-automated vehicle: a vehicle of level 0, where the driving tasks and decision are all carried by the driver. The driver is the only responsible in case of an accident;
2. the automated vehicle: a vehicle of level 1,2,3 or 4, it shares driving decisions and actions with a human driver. The responsibility in case of an accident is still ambiguous and shared between driver and vehicle;
3. the autonomous vehicle: a fully-automated vehicle or a vehicle of level 5 that can perform all driving tasks without the need for driver supervision. Hereby, the passenger (since no driver) handles zero responsibility in case of an accident.

Finally, when we talk about AV, we also imply that the vehicle is connected, that is to say having an on-board communication system allowing it to collect information that it can record, process, operate and relay to other vehicles, infrastructure or network.

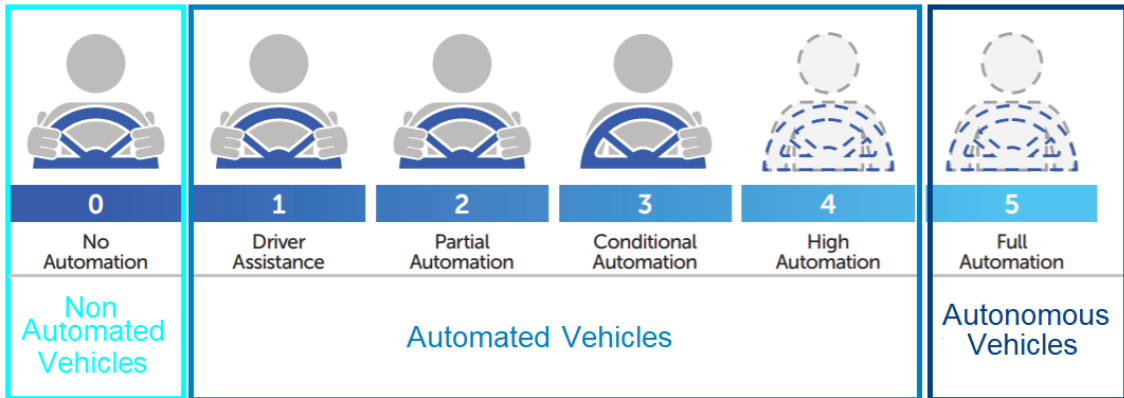


Figure 1.4: The vehicles autonomy levels in this study based on SAE levels

1.1.2.2 Autonomous transport modes

The movement of people on the territory can take two forms, the active mobility (such as cycling, walking, roller-skating, etc.) or the passive mobility which requires the use of motorized vehicles such as cars, trains, trams, etc. The latter can be public transport (PT), private transport as private vehicles or shared transport. PT is considered as a vehicle allowing the transport of several people simultaneously following a defined or regular trajectory (fixed roads) and using the same frequency (trip schedule). It is generally accessible via the purchase of a transport ticket. This transport can be carried out by a private company or a public body. More often, in France it is the public sector that is responsible for the management of public transport at their territory. Some private companies manage public transport networks throughout the territory (SNCF) or in large metropolitan areas (RATP). These companies are partly owned by the State, which thus ensures a coherent mobility strategy at the national level. Trains, buses, metros or trams are public transport examples frequently found in urban areas.

As opposed to public transport, private transport is designed to be used by a person or a group of people moving together (as family members or friends), it is not available for use by the general public. Thus it is more flexible in terms of time and trajectory

because it serves the need of the person or group operating it. In our days, private transport is the dominant form of transport in most of the world (Das, 2019). For example, in the United States, 86.2% of travels are made by private mode (Fucci and McGuckin, 2017). Private transport could be a vehicle owned by a certain person for his own (or his family) use, a rented vehicle for a specific goal, or an on-demand taxi.

Shared transport is an intersection or a hybrid between both public and private transport where it provides services to a relatively small number of people sharing similar trajectories at the same time. Therefore, the trip is shared between different people not necessary to know each other before. Services such as car-sharing, bike sharing, scooter sharing, on-demand ride services and ride-sharing fall into the category of shared transport (Shaheen et al., 2015).

Moreover, in the context of automation the modes of transport are the same with the difference that the operating vehicles are autonomous. Similarly, three autonomous transport modes can be found: public autonomous transport (PAT), private autonomous vehicle (PAV) and shared autonomous vehicle (SAV).

1.1.3 Autonomous vehicles nowadays

After understanding the concept of automation and AVs, their operation, their modes and levels, it is time to understand where we are on the AVs' implementation schedule. Hereby, this section will provide a description of the current state of AVs. It discusses how traditional car automakers are teaming together or with new companies to be more powerful in the automation field, the tests carried worldwide to proof the functionality and safety of AVs and the prediction of when AVs could become in the market.

1.1.3.1 Autonomous vehicles automakers

The desire to speed up the arrival of AVs also comes with pressure from actors in Silicon Valley, such as the manufacturer Tesla, the digital giant Google and its subsidiary Waymo or even certain mobility players such as Uber. However, the production of AVs is a sophisticated process that requires a combination of high technology, artificial intelligence and data analysis in order to manage the driving decision-making process (as presented in section 1.1.1.3) from one side, and traditional vehicle production skills from the other side (Bauhammer, 2019). These requirements encouraged traditional automakers, auto suppliers, computer science companies and technology companies to forge new alliances to be competitive in the race to produce safe AVs.

AVs require very careful testing to verify efficiency and insure safety. But, these testing will result in massive data that need computer and data science's companies to analyze. Moreover, the new vehicle control system needs leading companies in the field of high technology and artificial intelligence to create an intelligent autopilot program that is able to drive the car in a safe manner on new roads. Hence, companies such as Apple, Microsoft, Waymo, Alibaba, Baidu and Tencent entered the race (Bauhammer, 2019).

Another investment has been made in this field from shared mobility providers such as lyft and Uber who want their names to be leaders in the future of mobility. Lyft has partnered with Aptiv to provide AVs rides in Las Vegas which reached 5,000 rides in August 2018 (Blog, 2019a). Similarly, Uber and Volvo partnered on the manufacture and testing of AVs on real roads (Mercer and Macaulay, 2019); Uber vehicles are being tested on the autonomous mode in San Francisco and Pittsburgh.

Alliances are not limited to companies from different sectors but have reached companies from the same sectors, as some car manufacturers have cooperated together either to strengthen their companies or to reduce competition. For example, Mercedes-Benz and BMW which partnered to develop automotive technologies, and

Ford and Volkswagen that expanded an old alliance to include autonomous and electric vehicles (Mercer and Macaulay, 2019; Hawkins, 2019a). Moreover, these alliances have provided the resources needed for real testing and experimentation of automated vehicles.

1.1.3.2 Autonomous vehicles experimentation

In France, since mid-2016, there has been a significant increase in the number of requests for experimentation with autonomous shuttles, mainly for demonstration purposes. From the end of 2014 to the beginning of 2018, nearly 54 decisions authorizing the exceptional issue of registration certificates were issued, of which 23 were in 2017 (Maubant, 2018). With its Drive the Future plan, the car manufacturer Renault hopes to be able to bring 15 models with autonomous technology to the market by 2022. This manufacturer already offers autonomous concept cars like MORPHOZ (Hitti, 2020).

Automakers are also relying on public research to advance autonomous technology and initiate testing phases. Thus, many research centers and universities around the world are participating in the development of AV. In the United States, major universities have collaborated and are collaborating with large digital companies to develop and test AVs. For example, one of the first Google's AVs prototypes was created by a research team at Stanford University (Jain et al., 2013). In Europe, Germany owns more than 50% of the world's patents on autonomous driving and is at the forefront of AV research (Bardt, 2017). Germany is distinguished in particular by a coordinated effort between public authorities, industry and academic research. BMW and Daimler, the parent company of Mercedes-Benz, have signed a strategic cooperation agreement, which notably includes autonomous driving.

Furthermore, in France, many research on autonomous technology has been carried at the Université de Technologie de Compiègne (UTC), at the National Research Institute in Digital Science and Technology (INRIA) and at the Institut Pascal de

Clermont Ferrand. A test city was even carried out in Ain, on a former military base, the first test city in Europe dedicated to autonomous vehicles. It is the result of the grouping of 14 partners (Renault Trucks, Groupama, the Auvergne-Rhône-Alpes region, etc.) and cost nearly 20 million euros.

In order to make AVs commercially available, it should be proven that AVs are safer than human driving which requires testing AVs over more than 8 billion miles to prove their reliability in terms of deaths and injuries (Kalra and Paddock, 2016). To facilitate this testing and avoid accidents and troubles, simulations are being carried before road testing to train the software with everyday traffic conditions which are the standard scenarios, in addition to new scenarios where some rare-to-happen actions occur. Nowadays, lots of automated features have passed simulation testing and are being tested on roads.

In the United States, Waymo offers a service of several hundred AVs without driver and has deployed the autonomous technology for test phases in complex urban environments. In 2016, Uber promises to transport unmanned passengers as soon as its technology allows it (Pélata et al., 2019). The manufacturer Tesla is already equipping its cars with devices necessary for autonomous driving, which will be activated as soon as the regulations allow (INRIA, 2019).

In Germany, an automated vehicle from Mercedes-Benz had successfully driven 100 Km from Mannheim to Pforzheim in 2013. Recently, it was able to launch a fleet of 30 automated (level 4) ride-hailing services in San Jose on fixed roads along the San Carlos Street and Stevens Creek Boulevard (Hawkins, 2019b). In 2015, an Audi automated vehicle drove 900 km on the United States streets (from Silicon Valley to Las Vegas). In the same year, another Audi's automated vehicle with integrated technology from Delphi Company rolled a 5500 Km from San Francisco to New York City. Recently, Audi got permission to test 15 automated features on the Chinese Wuxi city roads (Fusheng, 2018).

The Russian-based internet corporation Yandex tested their AV prototypes on

Moscow's streets, they have completed 780 km while staying 99% in autonomous mode in 2018. A year later, the prototypes were being tested in Las Vegas streets as well (Blog, 2019b). Many other trials are taking place around the world to prove AVs safety, but each trial raises new obstacles (as safety issues, regulation, perception, etc.). This is what makes it hard to answer when will AVs be available for the public.

1.1.3.3 Autonomous vehicles market opportunities

Since the beginning of the nineteenth century, the concept of automated transport has more and more evolved in the research field, industry, and regional and international projects. The main challenge in our days is developing and testing vehicles with different automated levels. Automobile and information technology industries giants have been in a competitive race for having the first AV on the road.

From a theoretical point of view, the market saturation or even the availability of AVs in the market is not as soon as automakers first announced, the thing that goes in line with their recent declarations. In fact, predicting a new technology market saturation should be similar to previous technology development rate that follows the innovation S-curve in most automobile new technologies (Litman, 2017), see figure 1.5. Before appearing in the market, all products follow similar life-cycle stages; including development, testing, approval phases, marketing, improvement of product, expansion, maturation and then saturation of the market.

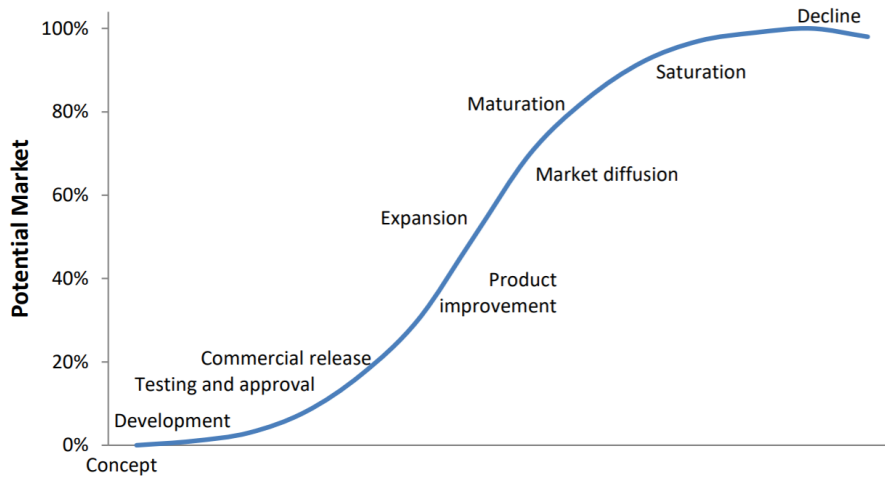


Figure 1.5: The innovation S-curve; source: Litman (2017).

Nowadays, many common vehicles are of level 2 and 3 autonomy. Several companies are testing level 4 or even level 5 projects. However, many technical improvements are needed before AVs of these levels of autonomy can be introduced to the end-user. Nevertheless, AVs have testing standards way higher than previous technologies. Particularly, this is due to security issues, laws that are not yet applied in many countries and to the costs of deployment of autonomous technology. These tests could be completed in the next few years, but only if this technology becomes stable and secure, which is not the current case.

In addition, the development of new technologies in the market depends on consumers demands. Although this is not clearly identified yet, older automotive technologies can help predict AVs' deployment, since of similar expected S-curve like:

- automatic transmission: developed in the 1930s and became accessible to all vehicles in the 1980s;
- airbags: introduced to the market in 1973, with very high costs and high dangerous risks, gradually they became affordable and safer, to end up integrating into many models in the 1990s and recently became common on all vehicles in circulation;

- hybrid vehicles: were commercially available in 1997 but were very expensive and unreliable, with time they became reliable but still expensive thus they are still not widely presented in the market;
- navigation systems: developed in the mid-1980s, they were available in the 1990s at very high costs (around 2,000\$). However, later on, their performance improved, and their prices relatively decreased (500\$), and moreover as the GPS and smartphones technologies evolved, many applications such as Google Maps or Waze developed their own navigation system at zero cost for the customer;
- electric vehicles: cars powered by a battery were created at the end of the 19th century but remained uncommon throughout the 20th century, recently many models of electric cars invaded the market, however, they represent only 1% of vehicle sales.

Technology	Deployment Cycle	Typical Cost Premium	Market Saturation Share
Automatic transmissions	50 years (1940s-90s)	\$1,500	90% U.S., 50% worldwide
Air bags	25 years (1973-98)	A few hundred dollars	100%, due to federal mandate
Hybrid vehicles	25+ years (1990s-2015+)	\$5,000	Uncertain. Currently about 4%.
Subscription services	15 years	\$400 annual	5-10%
Navigation systems	30+ years (1985-2015+)	\$500 and rapidly declining	Uncertain; probably over 80%.
Electric vehicles	100+ years	\$10,000 for high-performance	Probably 80%+

Figure 1.6: Deployment of different automotive technologies; source: Litman (2017).

Because AVs technology is much more complex than these technologies, their market penetration may take much longer (Lavasani et al., 2016). The implementation of new automotive technologies requires normally 3 to 5 decades to enter the market by at least 90%. Note that their development may be faster in some countries. In the study of Litman (2017), the development of autonomous technologies based on previous technologies' S-curves has predicted that level 5 of autonomy will be available on the market in the year 2030, as presented in the figure 1.7. This technology will initially have a very high cost and a limited performance. During the first decade, only the minority of vehicles will be entirely autonomous, with a market share that

should grow by the improvement of their performance. By 2045 almost half of the sales of new vehicles will be autonomous. Then market saturation will probably take several decades more since a significant proportion of drivers will prefer to use vehicles that are not autonomous due to their high costs or based on their preferences. These results were less optimistic than some predictions from experts in the automotive industry as in Arbib and Seba (2017) study where it was expected that by 2030 almost 60% of vehicles will be autonomous.

Stage	Decade	New Sales	Fleet	Travel
Development and testing	2020s	0%	0%	0%
Available with large price premium	2030s	2-5%	1-2%	1-4%
Available with moderate price premium	2040s	20-40%	10-20%	10-30%
Available with minimal price premium	2050s	40-60%	20-40%	30-50%
Standard feature included on most new vehicles	2060s	80-100%	40-60%	50-80%
Saturation (everybody who wants it has it)	2070s	?	?	?
Required for all new and operating vehicles	?	100%	100%	100%

Figure 1.7: Autonomous Vehicle Market Penetration Projections; source: Litman (2017).

From automaker point of view, the AVs were supposed to hit the market somewhere between 2019 and 2025 (Faggella, 2019). Most automakers had announced their plans to have or/and even start commercial production before 2025. Figure 1.8 presents some automakers expectations regarding when AVs will be available in the market.

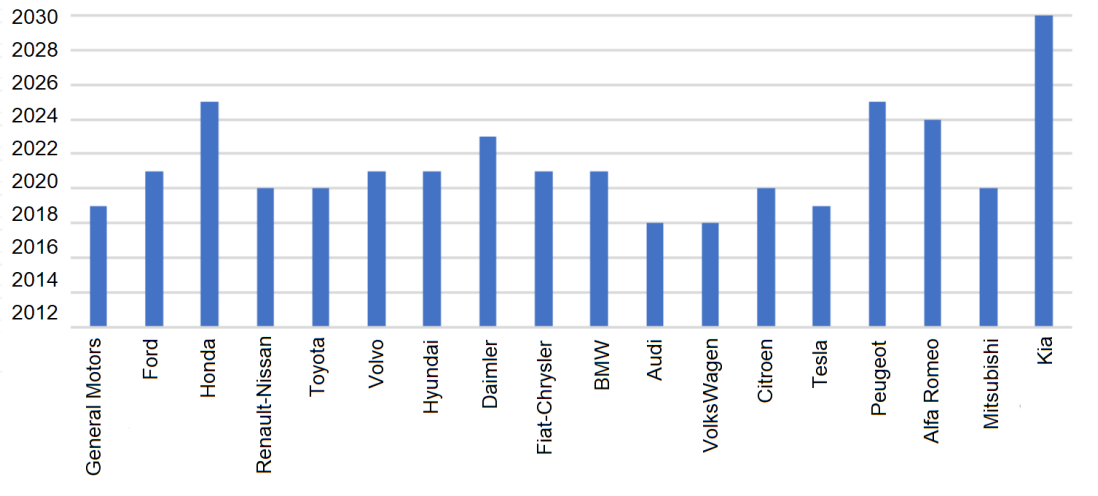


Figure 1.8: Car companies prediction for autonomous vehicles to hit the market; source: Francis (2018).

Lately, the focus has shifted from AVs manufacturing to testing on real roads in order to verify AVs ability and to test potential users and passengers perception. Nevertheless, testing level 2 and 3 automated vehicles (see figure 1.4) raised the alert on safety issues that should be tested carefully before having a vehicle without a driver, especially that these testing had resulted in several fatal accidents. Tesla autopilot models had five different fatal accidents where drivers passed out in the USA and China (Horwitz and Timmons, 2018; Yadron and Tynan, 2016; Green, 2018; Volz, 2019). Another accident occurred in 2018, in ArizonaUSA, where Uber's testing vehicle caused the death of a pedestrian (Troy and Daisuke, 2018). To this end, even if it is scientifically possible, the dream of having an autonomous vehicle that have no steering wheel, no pedals, no manual controls and no seat designed for a driver, but instead, have comfortable and luxurious salon seats, is still far reaching (Kolodny and Schoolov, 2019).

Aria Etemad, a project manager at Volkswagen Group Research said to Reuters *"We really thought at the beginning, it would be just maybe next year or so, but as we dig into that topic, we see huge complexities that we are facing "* (Shirouzu and Tajitsu, 2019). Similarly, most automakers had backed off from previously announced

timelines regarding AVs production (Faggella, 2019).

Even though it is not clear when AVs will hit the roads, their implementation strategies are taking huge attention from cities governance, automobile industries, associations, etc. Hereby, the term "Autonomous Vehicles" is used to present the future trend in urban sustainable transport systems (Goldin, 2018a; Gruyter, 2016).

As a conclusion, the AV is presented as the next major innovation in the field of transport, an intelligent, interconnected vehicle which, at its highest level of autonomy eliminates any human intervention. However, despite the great effort carried by research centers, industries and governments to pave the way for the safe and beneficial implementation of AVs, it is not seen to be soon. Hereby, it is impossible to confirm their impacts on the transport system. To this end, researchers are focusing on predicting the possible impacts leaning mainly on people's potential used mode of AVs as PAV, SAV or PAT as well as the possible scenarios of AVs integration that could make a revolution in the transport system.

1.2 Autonomous vehicles integration in the sustainable urban areas

We very often associate the world of autonomous mobility with mobility free from all constraints; very flexible and practical. A car of the future that would not belong to us and would come and get us at a simple request. However, AVs implications are not only related to mobility itself but can expand to reach different urban areas aspects. In this section we will answer the questions of the changes brought by the inclusion of AVs as a new mode of transport? How AVs are seen in the context of sustainability? And how they are integrated in sustainability policies?

1.2.1 Autonomous vehicles integration impacts on the urban areas

Autonomous vehicles are being promoted for their positive impacts (Clements and Kockelman, 2017a), but urban planners are sceptical of the extreme positive scenario that auto manufacturers are sponsoring. AVs have the ability to improve or worsen the current situation. For example, AVs can enhance shared mobility and thus reduce vehicle ownership, or the contrary, with no need for drivers licenses anymore, everyone can own a private vehicle and thus increase vehicle ownership. On the other hand, the introduction of the AVs will surely change the image of the city as we know it. Indeed, one of the first questions that can be asked is the question of homogeneity in the city. In fact, AVs require very complex technology to operate. The smoother the city, with clear signals and configurations, the more easily an AV can fit into urban space. Thus, one fears losing the originality of cities characteristics and limiting the informal uses of the urban space. This section will show how automation is expected to change the urban system by discussing the effects of automation on the transport system, as well as spatial planning, environmental and socio-economic aspects.

1.2.1.1 Impacts on transport

The importance of AVs lies in their ability to radically change the current transport system and mobility. They are able to solve most of today's mobility snags when used properly, they can enhance transit and shared mobility instead of single mobility. AVs affect traffic performance, traffic safety, mobility services and vehicle ownership as follows:

a. Traffic congestion

The severity of traffic congestion is caused mainly by the sensitivity of traffic flow, where one driver's simple unexpected action can affect the entire fleet behind him;

even a simple lane change or merge, the stop and go movement of a vehicle will force all the following vehicles to slow down or stop. Another important factor is the fact that our cities have become so dense that any new changes or new infrastructures works become so harsh. While population growth has swelled the mobility demand and is expected to increase in the future as aforementioned in section 1.2, making streets capacity not adequate with the new demands. According to INRIX (2019) studies, the average driver hours spent in congestion reaches 272 hours in Colombia-South America, in the year 2018.

AVs promote to eliminate human errors and road accidents which means a huge enhancement in traffic performance. The integrated advanced technology helps AVs control their speed in a manner that makes other vehicles follow at a compatible speed with no sudden brakes or oscillations that may speed traffic up to 35% (Hyldmar et al., 2019). They use existing lanes more efficiently through shorter headways and narrower lane positioning; without the risk of crashing. Therefore, and especially in platooning more vehicles can fit on the lane while keeping steady traffic. Thus, increasing road capacity and reducing congestion (Fagnant and Kockelman, 2015).

Using different communication systems (vehicle to vehicle and vehicle to infrastructure) provide the vehicles with information about road conditions, accidents, traffic conditions, obstacles and may provide alternative routes to avoid jams, would reduce traffic congestion by suggesting less congested roads and spread the load over different trajectories. With the help of these connectivity technology, the traffic lights would become less important where vehicles can choose the open streets all the time which leads to smoother traffic and fewer speed changes unless needed. In addition, shorter headways and start-up times at intersections lead to increasing vehicle flow, which means improving intersection capacity and waiting time at the same time.

Moreover, the way AVs will be used will have a significant impact on traffic congestion; so that in the case of PAV, the number of vehicles on the roads will probably increase (as will be explained later in this section) which means that the road capac-

ity will not be sufficient with the increase in demand, thus congestion will increase. Whilst, if using SAV or PAT, the number of vehicles should decrease, leaving large empty spaces on the roads that facilitate the movement of other vehicles. This concept was elaborated by a study of the MIT which estimated that a fleet of 300,000 SAVs could serve within 15 waiting minutes, all of Singapore's population (6 million people) during peak hours (Daniel J and Kockelman, 2015).

b. Traffic safety

According to Gruyter (2016), 56% of road accidents are due to human errors, more precisely, 40% of fatal crashes are results of drivers' unrespectful driving like severe driving and inappropriate behaviours as being under alcohol or drugs effects or fatigue. Thus, replacing human drivers by autonomous software should eliminate these errors and improve road safety, saving as many as thousands lives every year.

In fact, AVs rely only on advanced technologies that guarantee maximum driving efficiency as manufactured most of the time. While in case maintenance is needed, a prior warning could be launched avoiding on-road complexities. AVs are capable of reducing accidents not only due to humans unrespectful driving errors but also due to humans non-capability errors; including low experience, slow reaction time, overcompensation, etc. In situations where human reaction time is not enough to avoid a fixed or moving obstacle, AV having less reaction time can easily avoid the collision.

Improving safety and reducing accidents will help to change transportation capitals from car crashes to other investments in transport system; In the US, the annual economic cost due to car crashes is 300\$ billion, which in-case released, could be used in maintenance works, building new infrastructures, providing more competitive services, etc.,(Cambridge Systematics, 2011).

On the other hand, the presence of AVs will arise new safety issues which, on top comes hacking the automated software that could lead the vehicle to go on unplanned

driving mode or different directions, making the vehicle's passenger follow a new destiny drawn by the hacker, leading to fatal accidents, physical violence, blackmailing, theft and many other snags. Moreover, hacking does not just confine on changing routes but, it could also pop false alerts or messages which lead to traffic chaos, collisions, traffic jams, etc.

c- Mobility services and mobility as a service

AVs can pave the way for enhancing equality in mobility services by providing the same mobility options for all passengers groups. For example, elderly and disabled who are forced to have a companion on every trip and are not so comfortable in public transport would - with the help of AVs- be able to travel freely without prior arrangements and without companions. In addition, AVs can provide common mobility services for people living in rural areas where mobility choices are limited (Fagnant and Kockelman, 2015; Ram and Chandra, 2014).

The implementation of AVs has the potential to positively affect three of the main travel choices drivers; travel time, travel cost and the transport mode accessibility (Ram and Chandra, 2014). AVs make the value of time become of less importance since commuting time could be shifted from driving tasks for drivers and professionals to other activities such as; relaxing, job tasks, working, watching a movie, reading a book, etc. Travel costs will also be highly affected, it is expected to drop significantly; due to the absence of drivers and smoother traffic. The fact that AVs could be of different sizes (cars, shuttles, buses, etc.) make them more flexible and less restricted to fixed streets thus, can pick up/ drop off people in almost any place.

The savings from the reduction in travel and operational costs can be shifted to provide lower public transport fares, more operating hours, more personalized services and more frequent trips, therefore, improving transport services (Ram and Chandra, 2014). Thus, encouraging people toward shared mobility over private. Furthermore, reducing car ownership by boosting and facilitating public transport and sharing ser-

vices where an AV can serve multiple persons at the same time or the same trajectory. According to Fagnant and Kockelman (2014), one SAV can replace up to 11 conventional vehicles, i.e. one SAV can perform trips used to be carried out by 11 private conventional vehicles (CVs).

Autonomous transport is expected to enhance the quality of transport services. AVs can be used as a complementary or transit mode for public transport in urban as well as suburban areas. Currently, most governments focus on providing adequate public transport within urban areas while few efforts are placed for suburban areas or in between which is not surprising due to the low ridership and demand that lead to low earnings and low willingness to invest in these areas. Moreover, AVs can serve the less dense areas where public transport is not adequate by providing the first mile/last mile services.

d-Vehicles ownership

Recent studies have shown that the average cost of owning a car in the USA is around \$ 9,282 annually. Including price, fuel, maintenance, and insurance, which is often a waste of money as the vehicles are parked most of the time (about 95% of the time) (Karr, 2019; Morris, 2016). The inefficiency of owning a vehicle could discourage car ownership in the presence of AV vehicles that can provide the same facilities at a lower cost especially if they are shared and electric. Instead of owning a vehicle, an individual can purchase a transportation card or pay a subscription for the various modes available in the city such as buses, shared scooters, taxis, shared AVs, trains, etc.

AVs can lead to a decrease in the number of household-owned vehicles (Chourasia, 2019), as the same vehicle can be shared among household members. An AV can take all family members to work, school or any place they want at the same time or one person at a time and then return to take the other person. In the United States, a study of AVs impacts showed that 23% of respondents intend to reduce the number

of vehicles owned when AVs become available (Zmud and Sener, 2017a), in line with another study that has shown a significant decrease (about 43%) in household vehicle ownership with a shift to shared mobility (Chourasia, 2019).

Automation will give a huge boost to ride-sharing and ride-hailing services as the vehicle can drive itself in the most efficient tracks to reach customers in less time and at lower cost (Chourasia, 2019). The vehicle can also be connected to a platform that updates it to new users on the road for picking up without changing directions that can make the cost of the trip divided into multiple users instead of one. Moreover, AVs can be used in the form of taxis that can serve one person at a time for people who prefer a more flexible and reliable mode with more privacy and safety as there are no strange passengers in the cab. autonomous taxis can be more convenient than owning vehicles or using shared mobility; they are expected to be less expensive and can be shared with family members at the same time.

1.2.1.2 Impacts on spatial planning

As mentioned above, AVs have the potential to change traffic conditions, travel behaviour and definitely affect cities land use. The AVs efficient road use due to their high precision in driving (reduced headways and smooth flow) enhances road capacity and reduces street lanes needed in number and width, which could be used for enlarging or adding new biking, walking, common transportation, or green sides (Ram and Chandra, 2014). Almost 35% of the city land is used as roads thus, better road use will improve the quality of life in cities (Schlossberg et al., 2018).

Another space-saving could be through reducing or eliminating parking spots in urban cores; as AVs do not need drivers, they can drive themselves in far places and not necessarily close to the activities/centres locations. According to Martinez and Crist (2015), parking savings can reach about 85% to 95% in the case of 100% AVs. In the case of residential areas, spaces saved from parking and garages could be transformed into studios or accessory apartments for rents or family members

use. Whereas, another scenario is possible where the increased need in spots for pick up/drop off in the case of SAVs and parking spots in the case of growth in the AVs' ownership will increase the land use in cities centres and around job centres (Stead and Vaddadi, 2019).

In case of electric AVs (EAVs), fuel stations will be useless where EAVs can recharge in parking spaces which are supported by electricity through photovoltaic panels that help in generating electricity and shading the parking spots. The stations' freed land can serve as new shops, commercial centres, fitness centres, or new residential buildings.

Making travel more effortless by reducing driving stress, exhaust, time value and cost, facilitates far commuting; encouraging people to live in suburban areas or places far from cities and jobs centres (Ram and Chandra, 2014). Thence, releasing cities centres from current stresses and making cities more sprawl (Ram and Chandra, 2014). Reducing the proximity necessity will be reflected on land values which, in turn, changes the cities development patterns .

1.2.1.3 Impacts on the environment

It is important to highlight the potential environmental impacts of AVs and how the new mode could improve air pollution caused by transport. Meanwhile, The transport sector is responsible for a large proportion of air pollution and is responsible for 25% of total CO₂ emissions (Torok, 2008).

In order to make a real change in the environmental impact of transport, it is important to change the energy source used in vehicles for more green energy (Ram and Chandra, 2014). Even for electric vehicles that are ideally free of emissions, the source of electricity differs from one country to another which could be eco-friendly energy sources (solar, wind, and hydropower) or traditional petroleum fuels. Similarly, AVs would be of different energy sources, thus they would reduce environmental impacts

only in case of electric AVs in areas where electricity is produced from green-sources.

Regardless of the source of the used energy, AVs are well designed to apply eco-driving principles that could reduce fuel consumption and emissions by 20% (Igliński and Babiak, 2017). Moreover, AVs are expected to make traffic flow at more steady behaviour (less unexpected behaviours and less congestion) that leads to less fuel consumption. In fact, an enhancement in traffic behaviour as simple as a 20% reduction in vehicles acceleration/deceleration behaviour can reduce fuel consumption by almost 5% (Berry, 2010).

Nevertheless, in case SAVs were not the preferred mode, which is possible given that private vehicles may become more tempting than shared one, as a result of making travel more effortless and less restrictive (Ram and Chandra, 2014), more people would choose to own a personal AV; even those that couldn't have a vehicle before because they were not drivers, with the implementation of AVs they can easily possess. Consequently, encouraging automobile-oriented societies where kilometers traveled, fuel consumption, and traffic congestion are high and thus more emissions and polluted areas (Ram and Chandra, 2014).

1.2.1.4 Impacts on the socio-economic aspects

The development of the transport system with the integration of automation would affect the job opportunities in a paradoxical way by increasing engineering and research jobs and reducing driving jobs. Since the first appearance of the automation technology and jobs in the field of research and engineering, as well as jobs related to the integration of AVs in the society, have been untimely expanding (Apur, 2018). While when AVs will be in the market, jobs related to driving will be eliminated, affecting a large portion of society; according to Apur (2018), 15.5 million workers were classed in driving-related jobs a few years ago.

The trucking, shipping and logistics industries will benefit not only from a reduction

in the number of drivers and workers but also from improvements in work efficiency and productivity due to the capability of AVs to transfer more loads with lower costs, less time and less risk of accidents, leading to a remarkable increase in their revenue. Moreover, the wave of automation will positively affect the manufacturing and service industries as well, which will benefit from new business opportunities in fields of artificial intelligence, digitization, robots, data analysis, etc. (Raposo et al., 2018).

On the contrary, some sectors will be negatively affected when AVs are real. AVs are promising to make roads safer and reduce the number of accidents which is mainly due to drivers' mistakes, the thing that would cause major losses to the insurance companies (up to 60% of their annual revenue according to Clements and Kockelman (2017b)). Similarly, medical services and vehicle repair services will face some downfall in their business.

On a higher level, the increased use of infrastructure due to the increase in vehicle kilometer traveled (due to empty trips and far daily commuting due to changing living location) will increase the need for road maintenance, but at the same time, it will increase revenue from existing roads tolls that can reach 60% (Mares et al., 2018). Moreover, with AVs, fewer parking spaces will be required especially in crowded and expensive areas (in the city center and near commercial areas), which will reduce parking-related revenue (Maciag, 2017).

The effects of AVs cannot be confirmed unless they are used on the roads. However, their expected impacts can also be seen more broadly through enhancing urban systems performance and sustainability, which will be discussed in the next section.

1.2.2 Autonomous vehicles integration in the sustainable urban system

An urban system is commonly defined as a "*territorial complex consisting of a city and its surrounding suburban or rural areas, in addition to its connections with other cities, in the mobile and complex reality of their operations and their potential for mutability*" (Terrien et al., 2013). It can be thought of as a dynamic and complex system that evolves in space and time in an unpredictable way.

Usually, when considering any urban system, the population size, economic situation, and location should be defined (McGranahan et al., 2005). But, there is no international agreement or scientifically accepted criteria for defining the characteristics of urban areas and populations. Moreover, many urban researchers believe that the limits of an urban system are becoming arbitrary somewhat. For example, in France in 2012, the urban system of "Auxerre" had 200,000 inhabitants while the urban system of "Lyon-Grenoble" had about 4 million inhabitants (Berroir et al., 2012). To this end, recently the urban systems are focusing more on their economic situation and location which implicitly includes mobility and exchange.

In an effort to give a better definition of an urban system, in 1973, the geographers' Berry and Hall introduced a new concept called "the daily urban system" that encompasses the city and its surrounding area, where daily commuting occurs; including both work and leisure trips (Halás and Zuskáčová, 2013). Meaning that the urban area is determined based on the population mobility that is associated with urban settlements, populations, economic activities location, etc., that contributes to the density of the urban areas.

The complexity of urban systems is mainly due to the size of the population which creates pressure on the system to manage the different needs (mobility, services, work, activities, etc.). The population is mainly affected by natural increase and by urbanization that is the process of moving from rural to a settlement defined as urban,

looking for more services and job opportunities (Lahariya, 2008). Nowadays, urban areas host more than half of the world's population and this proportion is expected to reach 60% by 2030 and 85% by 2100 (United Nations, 2018; Goetz, 2019; OECD, 2015). The urban population is expected to nearly double in 80 years from about 4.35 billion in 2020 to 9 billion in 2100 (WHO's, 2016; OECD, 2015). Moreover, in 2030, it is expected to have more than 706 cities with a population of over one million, while there were 548 cities in 2018 (United Nations, 2018; Goetz, 2019).

The severe increase in urban population has created a major challenge to manage an urban system that could provide current residents with services beneficial to future residents too, as well as to provide their needs without compromising the needs of the future. Urban issues are now on top of many agendas dealing with global concerns (Taipale et al., 2012), with a major focus on protecting the environment and reducing excessive use of natural resources that have raised many concerns such as pollution, global warming and the lack of some essential resources, especially that according to the Living Planet, humans consume 30% more resources than the Earth can regenerate in a year (Subramanian, 2018), and as the population increases, consumption is expected to increase further. To this end, the need for a system that can provide the current population with their needs without leaving cons for the future generation to handle become a big concern, which comes in-line with the concept of sustainable development that is defined as “ the development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Lim and Taeihagh, 2018; Brundtland et al., 1987).

Sustainability objectives are set as the pursuit of higher living standards while maintaining a self-sufficient economic, social and environmental systems (Lim and Taeihagh, 2018). That highlight the main three pillars for the good practice of sustainability. Moreover, as previously mention (see section 1.2.1), AVs have the potential to have direct impacts on these three pillars, as well as indirect by modifying transport conditions and spatial distribution. Reducing traffic congestion means less fuel consumption and fewer emissions thus less environmental harm from transport,

less time spent in travelling making people freer and less stressful due to driving task thus enhancing social benefits, and from the other side it can eliminate the high costs of congestion that reach 103 billion euros and 33 billion euros a year in the US and UK respectively (Lim and Taeihagh, 2018). Moreover, reducing congestion gathered with other enhancement in driving as computers will perform driving tasks, will highly enhance road safety, reduce accidents and consequently deaths that enhance living standards in crowded areas. On the other hand, AVs may result in increasing urban sprawl and increasing rural areas' population, that can support the economy of small companies in these areas and reduce the tension on urban areas infrastructure and resources at the same time.

Hereby, the AVs can be seen as a good opportunity to achieve sustainability at the local and global scales. To ensure full benefit from the use of AVs, their incorporation must be ruled and guided by urban and environmental actors and governments. However, in the meantime and prior to real implementation, AVs have gained huge pace in sustainability policies relying on their potential benefits.

1.2.3 Autonomous vehicles integration in sustainability policies

The need for sustainability have been highlighted in addition to how AVs would help in attaining it. The importance of AVs in sustainability was also reflected from the presence of AVs in the policies and agreements of sustainability, which are implemented at the European and local (in France) levels that are presented in this section.

1.2.3.1 Policies at the European level

Since 2001, the world, including the European Union, has been promoting sustainable development with its three pillars. Several agreements and projects have been prepared to verify the good implementation of sustainability goals. On the interna-

tional level, there are two agreements at the top: the "Paris Agreement" and "Global Goals", which together with the "Energy Union" strategy at the European level form the basis of the European Union's strategies to achieve the sustainable development goals.

Recently, sustainable principles have become incorporated into most of the European Union's sectoral policies such as the transport sector, as its policies greatly support sustainable mobility which is one of the sustainable development goals. The "White Transport Papers" and "European Green Paper on Urban Mobility" emphasize the need for new technologies to achieve sustainable mobility and reach the "Europe 2020" goals for smart, sustainable and inclusive growth (Gavanas, 2019). AVs could be a potential solution for better mobility and sustainability, especially that the potential advantages of AVs are in line with the objectives of the European Council agreement in 2018 for the urban transport part, with the main objective to obtain a more connected Europe by enhancing mobility and regional information and communications technology through 1) promoting digital communication, 2) developing a sustainable, smart, multimodal transport network across the European borders and 3) promoting sustainable multimodal urban mobility (European Council, 2018).

In order to study the role of AVs in future mobility, several European projects were launched as the CyberCars project that aims to accelerate the development and implementation of the new automated urban transport system for movement of people and goods (Parent, 2007), the interACT project that aims to enable the safe integration of AVs into mixed traffic environments (Wilbrink et al., 2017), the CityMobil2 project that aims at fostering the implementation of the automated road transport system in European cities (McDonald et al., 2018), etc.

1.2.3.2 Policies at the local level

The French government seeks a sustainable urban development to comply with the Paris Agreement and the Global Goals. It has updated its public policies and invested

in projects to support the development of innovative ideas in line with environmental, social, economic as well as transport challenges. To mention some of these projects; the Investments for the Future program was first launched in 2010, works with 31 cities on urban projects aiming to build attractive cities that preserve the environment and the quality of life for residents. It also facilitates the emergence of new technical and technological solutions by supporting projects in the field of logistics, hybrid engines, rail transport, etc., (Vivapolis, 2019). In 2015, the "Industry Demonstrators of the Sustainable City" project was created, aiming to produce one or more innovative products in transport and energy, which enhances exchange flows between city stakeholders to reduce the use of primary resources (Vivapolis, 2019).

Moreover, in France, it appears that AVs can be a great opportunity to comply with their goals and plans to improve mobility while reducing their negative impacts on human lives. In order to achieve its goals, France has amended its legislation and established a framework for AVs testing, particularly in terms of traffic rules and driver responsibility (Idrac, 2018). It has committed to a controlled and responsible AVs development system, based on the following principles as presented in its report for the development of autonomous vehicles (Idrac, 2018):

- an experience-based, step-by-step approach
- road safety and cybersecurity issues outperform
- the importance of mobility, environment and acceptability
- the cooperation between public and industrial authorities to develop a regulatory framework
- the importance of European cooperation, especially with regard to certification and interoperability of systems, and research and innovation financing.

The benefits AVs are promoting and their presence in sustainable development policies at different levels underlines the importance of these vehicles. However, their

importance is not enough to bring them into the urban space. Unfortunately, the arrival of these vehicles faces many challenges in different aspects and not just the need for them.

1.3 Autonomous vehicles integration challenges

After highlighting the importance of introducing AVs in the urban system and sustainable development from one side, and the fact that the production of AVs seems feasible for researchers and automakers from the other side, it is important to highlight why this technology is not yet available. In fact, the production and mass market of these vehicles face several challenges that impede and delay their production. These challenges are presented in this section including ethical, legal, cost, technical and acceptable barriers.

1.3.1 Moral and ethical challenges

Safety should be a priority for AVs and their developers, and it seems to be. Technically an AV can outperform a human driver in the driving tasks but, what about the human tasks? A simple scenario would be at a fully occupied intersection, where the priority is not defined. In the case of human drivers, one driver would open the way for another driver to cross by face or hand signals. While in case of AVs, all the vehicles will be equipped with the same traffic laws that give priority for the vehicle on left or right and it would be difficult to distinguish which vehicle should pass first or which vehicle's algorithm should lead the situation.

Complexity arises with scenarios that may affect people's lives. AVs are programmed to avoid accidents, however, in some situations, accidents are inevitable due to unforeseen circumstances. The dilemmas of sacrificing human-life over several lives have been under study since 1967 (Wu, 2020), with "thought experiments" used

to understand the ethical view of causing death for some persons while saving the lives of others. The trolley problems are the most popular thought experiments and are applicable to AVs development (Wu, 2020). They study scenarios in which a runaway tram threatens lives and poses moral dilemmas for the experiment's participants. The most studied scenario is when a runaway tram driver can only steer from one narrow lane (five men work on it) to another lane (one man is walking on it). Moreover, anyone on the lane the driver takes will be killed (Wu, 2020). The question is should the driver stay on the same lane and kill five people or go to the other lane and kill one person? Which is not easily answered. Although most philosophers and people who undergo these experiments choose without hesitation to cross the less occupied path, there is no sure moral answer to such a dilemma; different people have given different answers to this ethical problem (Wiseman and Grinberg, 2018). If an ethical answer is agreed upon, it can be coded into the AVs program, thus providing the AVs with the decisions to be made in such situations (Wiseman and Grinberg, 2018).

If the case of sacrificing one life over several or a few passengers over a larger number of school students have been agreed on and defined in the vehicle system, other scenarios are still hard to distinguish the more ethical or morally accepted decision. A scenario where the vehicle must choose whether to sacrifice the lives of its passengers or equal lives for pedestrians, where both options are tragedies as shown in figure 1.9. For manufacturers, the decision is easier as they prefer to save the passengers lives since they are their clients over strangers' lives, in order to say that AVs are safe for clients to use. However, this could not be the public opinion. Therefore, these dilemmas and questions are still under-experiments and are of the big barriers of AVs usage.

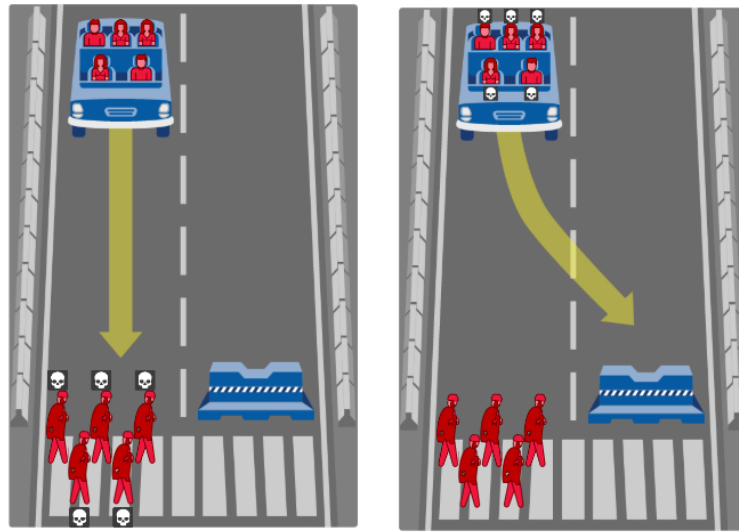


Figure 1.9: Social dilemma of autonomous vehicles; source Vincent (2018)

1.3.2 Legal challenges

Stakeholders have raised concerns about liability for malfunctions or damages that may result from the use of AVs. In fact, the responsibility of each actor remains ambiguous when an accident occurs, how and on what basis the accident will be evaluated in order to define each actor responsibilities. In the current system, drivers, auto manufacturers, government, service and insurance providers all have well-defined roles, but when using AVs, roles will mingle and fall into complex situations where setting new standards and regulations to deal with this new system is inevitable.

Moreover, since automation performs more and more driving functions, some responsibilities should be transferred from the human driver to the artificial driver which is the driving software or simply the vehicle itself. The thing that raised the need for updates in the liability and regulation of the new system before implementing automation in the transport system.

1.3.2.1 Liability

While talking about liability considering potential accidents of AVs, it is important to emphasize that the user and the owner of the AV do not have to be the same individual as vehicle and ride-sharing are very likely scenarios. The user is simply the person who rented the vehicle from the mobility provider or an individual who bought an AV while the owner is the latter.

In the context of the liability of autonomous vehicles, at the present time, no clear parties can be specified but three parties could be considered:

- **the operator:** it is the AV user or the person/company that gave the command to the AV to run (Jensen, 2018). The operator is responsible for damage or accidents caused by his/its fault but not in cases where the vehicle was in a complete autopilot mode and the operator was not required to take over control (Grieman, 2018). The operator responsibility remains unclear especially with low-level automation, as a change in control can happen at any moment;
- **the autonomous vehicle:** if the vehicle is in autonomous mode during the accident, thus, it has caused the error itself. But since it is not like individuals who can make decisions themselves, it is necessary to make an assessment of how the AV made the decision and the information that was available for it. However, although AV can learn from its experience, it basically depends on how it was initially programmed to behave in similar situations. Thus, the responsibility of a bad decision should be taken by the company that programmed the vehicle or provided the autonomous software used (Grieman, 2018). Moreover, the cause of the accident may be a malfunction in a certain part of the vehicle causing it to receive incorrect information (in the case of a broken sensor for example) or to act in an unexpected way contrary to what the vehicle program requires (in the case of a broken device), Which raises the responsibility of the car manufacturer (Grieman, 2018). The vehicle can be offered by the main manufacturer

or the assembler, who eventually relied on several parts manufacturers, in this case, responsibility must be shared or assigned based on the manufacturer of the original broken part;

- **the government:** it can run an insurance entity that insures all AVs (Grieman, 2018). It provides insurance without waiting for the private sector to enter the market. In this case, one entity would be responsible for all AVs accidents which help in reducing administrative work and time on proving who is right. Moreover, information about the vehicles and the accident would be handled by the government which could share it for general benefits for example, with auto manufacturers to improve a certain feature in their vehicles.

1.3.2.2 Regulations and legislation

Different countries around the world are modifying or changing their legislation to keep pace with the implementation of automation in the transport system. The goal behind this legislation is defined by NHTSA as "*regulatory efforts in this area must promote safety, remove any existing unnecessary barriers, remain technology-neutral, and enable a pathway for innovation that has the potential to save lives. Any initiative in the regulatory realm will seek to remove regulatory barriers and burdens that could unnecessarily hinder the safe and efficient implementation of advanced driving systems*" (Arbor, 2017). This topic is taking a huge room in the research in Europe as well as in the United States (Ilková and Ilka, 2017).

As previously mentioned the current stage in the implementation of AVs is testing vehicles with different levels of automation. Most of these testing takes place in a special environment equipped for such missions with artificial obstacles and pre-saved data. In order to study the true safety and effectiveness of these vehicles, real tests must be conducted going beyond test sites to reach real-world roads with real obstacles. The thing that is still difficult in most of the European cities where there is no legislation that allows the use/test of AVs on public roads without ad-hoc

legal permits (Kim et al., 2014), which suits the Geneva Convention and the Vienna Convention on road traffic that requires a human driver to be in control of the vehicle all the time (United Nations, 2007); some amendments to Vienna Convention have been added in 2016 to align with the AVs testing requirements where testing could be allowed in the presence of the driver and under certain conditions (Avary et al., 2019). As of April 2017, testing AVs on public roads in Hungary became legal and a track suitable for testing highly automated functions is constructed near Zalaegerszeg (Palkovics, 2018)

Moreover, in France, the Council of Ministers mentioned that AV is the essential stage towards good mobility, traffic regulation and security, and environmentally friendly transport, as well as, the key element in constituting the future of the automotive industry (Kapsule, 2020). Thus, highlighting the need for testing AVs. According to the council, the first test of AVs was difficult to develop because of the international rules of the highway code in force. that request to always have two hands on the steering wheel while driving.

In order to circumvent these regulations, the Council, therefore, voted for an ordinance which authorizes the putting into circulation of the autonomous car on the public highway in 2016 (Kapsule, 2020). For the moment, we only have tests, whether for autonomous or automated vehicles. But, it is an important step for companies that have considered marketing their cars without a driver in France. Thanks to this ordinance and the legislation which is gradually adapting, France would not be late in terms of AVs.

In the United States, the federal government system makes the situation completely different from that of Europe; actions can be from the central national government or a local state government. In 2016, the NHTSA updated federal guidelines for the safe development of automated driving systems in order to have an initial regulatory framework on AVs. The update includes performance guidelines, model state policy and potential regulatory tools (NHTSA, 2016), in addition to some instructions for

manufacturers and other entities for safe design, testing on public roads, and the deployment of AVs (NHTSA, 2016).

Whereas on the state level, as presented by figure 1.10 29 states had enacted AVs' related legislation. Most of them allow AVs testing on public roads only in the presence of a human driver who is capable of taking control of the vehicle in an emergency situation (NCSL, 2020). Moreover, in 2016, California transportation authorities made changes in their policies regarding AVs, allowing a pilot project to test AVs on public roads without the necessity of the presence of a human driver (Santiago et al., 2018).

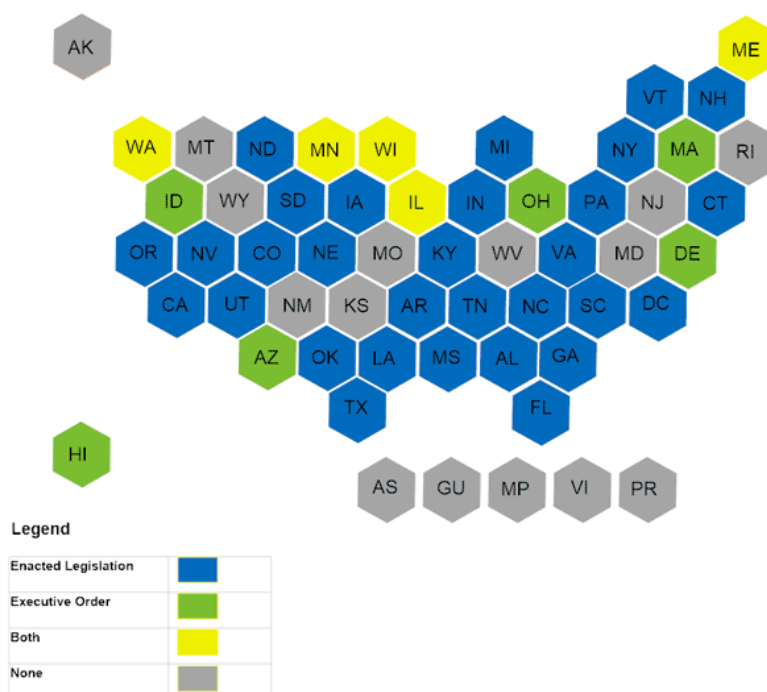


Figure 1.10: The states with autonomous vehicle legislation, source: NCSL autonomous vehicles legislative database

1.3.3 Technical challenges

If moral and legal barriers of AVs implementation are solved and agreed upon, then the next barrier to be considered is the technical challenge for producing an AV. Hereby, this section presents the immaturity or lack of required technologies as well

as privacy and cybersecurity issues.

1.3.3.1 Required technology

From a technical perspective, autonomous vehicles suffer from two technology challenges: the environment perception and decision-making capabilities.

The first challenge is to build a self-driving perception module that can perceive the environment accurately and reliably. This means, based on reliable sensory information (LiDAR, RADAR, Camera, etc.), the perception module should have the ability to model the environment (road, borders, static obstacles, dynamic obstacles), classify the objects and predict their motions better than the best human driver.

In the US, the current car fatality rate is about one death per 1 million hours of driving. If the driver was not drunk or was not texting, the rate probably decreases by a factor of 10. Effectively that means an AV's perception system should fail, at an absolute maximum, once in every 10 million hours of driving. But currently, the best driving assistance systems incorrectly perceive something in their environment once every tens of thousands of hours (Hao, 2019). Therefore, technically speaking, research is focusing on improving computer vision, creating redundancies in the perception systems and building highly detailed maps of the environment to make it even easier for a car to process its surroundings.

The second challenge is to build a self-driving decision-making module which based on the received information from the perception module can play not only the optimal trajectory but also the safest local motion. This means the global vehicle planner has to determine the best trajectory (shortest, free of congestion, etc.) while the local planner monitors the vehicle motion and surroundings to perform local actions (lane change, overtaking, roundabout, braking, accelerating) making the vehicle navigates safely, which is the most interesting point for both car manufacturers and passengers. Technically speaking, the complexity arises because of lack in identifying all possible



Figure 1.11: Complex roundabout; source Wadman (2017)

driving scenarios in the development stage (for example, the complexity of the UK roundabout in figure 1.11), which makes the vehicle responsible to learn new scenarios in real life, that is one of the most nowadays applications development using AI.

1.3.3.2 Privacy and cyber-security

"There is a core tenet tied to autonomous vehicles where you can't have safety without security"

Vice President of Business Development
at Green Hills Software

Autonomous vehicles use advanced technologies to outperform human drivers in the driving task. Taking critical decisions while functioning requires a large amount of data which could be generated or previously saved. The thing that makes the privacy of this data a prominent concern. AV vehicles generate data such as vehicle environment, location at a specific time, path and driver behaviour that must be protected from intrusion to protect passengers and prevent terrorist acts.

The challenge is to protect data from accessing the third entity while facilitating the necessary access to certain entities such as vehicle and components manufacturers, software providers, vehicle owners and passengers, insurance companies and first responders (in the event of an accident) (Canis, 2020). To date, there are no clear laws that prevent manufacturers and software suppliers from selling data about the vehicles and drivers to third parties (Canis, 2020).

Aside from data privacy, a more serious and dangerous aspect is cybersecurity. There are more than a dozen portals for entering and hacking a conventional vehicle's electronic systems including even primitive systems like the airbag, the lighting system, and the tire pressure monitoring as shown in figure 1.12 (Canis, 2020). Whereas, considering AVs that can communicate with other vehicles, infrastructure and the manufacturer, in addition to the previous portals, hackers can find plenty of other portals to send to the vehicle wrong messages or to over-control it and force it to go wherever they want.

In July 2017, a study of the Tesla Model S revealed weaknesses in Wi-Fi and 3G connectivity systems (Canis, 2020). The vehicle system was hacked, the touch screen was disabled as well as the windshield wipers during heavy rains. Hackers also remotely took control of the vehicle's brakes, proving that the technology was not ready yet.

1.3.4 Cost challenges

One of the key questions in the field of autonomous vehicles is the total cost and profitability of this innovation for both the technology developers and those who will take advantage of it. Nowadays, automakers and their alliances are investing tens of billions of dollars to allow vehicle autonomy which reflects the expected high price of AVs (Northrup, 2019).

Indeed, the cost of the AV Autopilot package is estimated to be more than 100,000\$

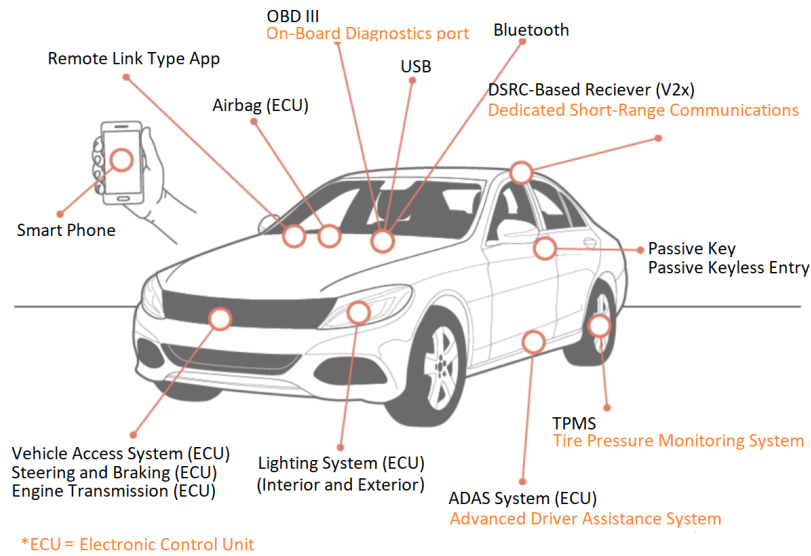


Figure 1.12: Possible portals for vehicle hacking; source Canis (2020)

depending on the types of equipment on-board and their functions (Karkafiris, 2020). However, this estimated cost does not include research and development (R&D) costs, but only the price of materials required to allow automated functions to operate. The former costs also a fortune as Waymo has proclaimed spending almost \$3.5 billion to finance its R&D (Roberto, 2020).

According to the Ptolemus Consulting Group, a specialist in questions of mobility and automation, the costs of purchasing the equipment necessary for the operation of a level 4 automated vehicle would not go under 100,000 dollars before 2022-2023 which does not allow to envisage possible marketing to large scale in the short or even medium-term (Bruneteau, 2019). Moreover, For the Google car; buying or producing the necessary sensors such as LIDARs, radar and cameras for the vehicle to sense its environment costs almost 200,000 euros (Hecht, 2018).

Nevertheless, the cost of AVs would vary according to how they serve the population, therefore, a distinction between AVs cost if used as private, shared or public transport is discussed.

1.3.4.1 Cost of autonomous private vehicle

A private autonomous vehicle (PAV) is mainly affected by production and infrastructure update costs. However, even if it currently seems more expensive than the conventional ones, but, the generalization of autonomy could significantly reduce the costs of production and therefore of purchasing this technology. The thing that has occurred several times in the history of the automobile. For example, a few years ago, who would think that the Renault Clio could have a rearview camera or adaptive cruise control by now! Following this scheme, the AVs could become accessible to the middle class in a while if the technology is very successful during its marketing.

Some studies estimate that the additional costs will be offset by lower insurance costs and lower fuel consumption (Haydin, 2018). However, these savings represent only 10 to 20% of the additional costs estimated by the contribution of AV to the market (Litman, 2017). Moreover, reducing the road accident which is of the main positive aspect in the implementation of AVs in France alone would save about 25 billion euros annually (Chapelon, 2008), which is the cost of accidents annually that is mainly due to the human driver as will be discussed later.

This indicates for the near future that the costs of a PAV will likely be in the range of 0.45-0.7 euro/km, this cost varies according to the type of vehicle considered but comes to an average of 0.3 euro/km (Chad, 2012), which is much higher than a conventional vehicle that cost around 0.1 euro/km as shown in figure 1.13.

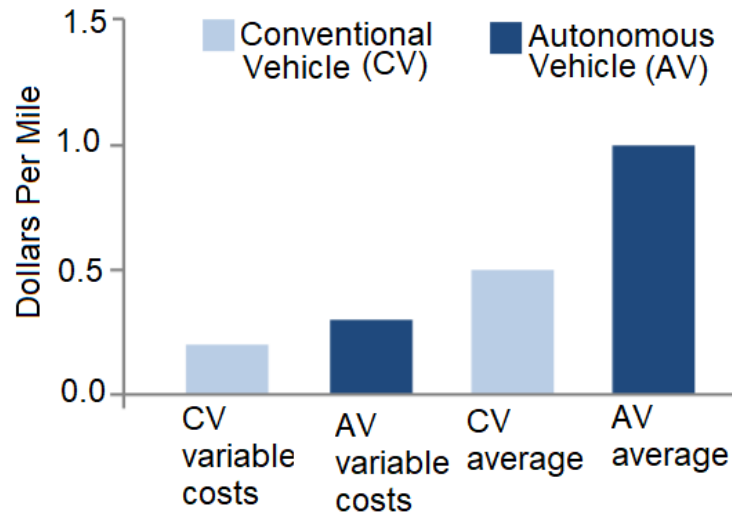


Figure 1.13: Cost comparison between autonomous vehicles and conventional human driven vehicles; source: (Litman, 2017).

1.3.4.2 Cost of autonomous shared vehicle

Regarding the cost of a shared autonomous vehicle (SAV), they are not linked to the cost of an AV only, but also, marketing cost, maintenance, infrastructure costs, etc., It should cost on average between 0.3 and 0.4 euro/km per passenger as estimated by Litman (2017), that is cheaper than conventional taxis with a driver (1.15 and 1.7 euro/km) or a trip offered by a ride-hailing company like Uber (0.85 and 1.4 euro/km) (Litman, 2017). Other studies predict that shared electric AV will cost less than 0.06 euro/km (Arbib and Seba, 2017). However, these estimates do not take into account certain costs such as cleaning or repair, trips with empty vehicles, insurance and taxes, and are therefore underestimated.

The cost of using a SAV was notably evaluated during a study carried in June 2018 (Saujot et al., 2018). In this study, the SAVs are supposed to be electric with a lifespan of 220,000 km. The results of the study show that the profitability of this transport system is mainly linked to vehicle occupancy rate; refer to figure 1.14 for elaboration. The more people served by the same trip and same vehicle, the less

expensive the SAV service. So if the SAV is used as a taxi (one person transported at a time), the system is not profitable. To increase the occupancy rate of vehicles, there are two actions:

- reduce the number of empty kilometres travelled to collect users from their locations. This requires ever more advanced management of data, ever more precise localization systems and the most optimal combination of different user requests ;
- maximize the sharing of trips: this criterion does not seem directly linked to autonomy, even though carpooling has become more popular in recent years, still many people have not yet crossed the threshold of sharing their path with strangers. Maximizing the sharing of trips should both lower the prices of the AVs for the company offering the service, as well as, lower the price of the ride for users.

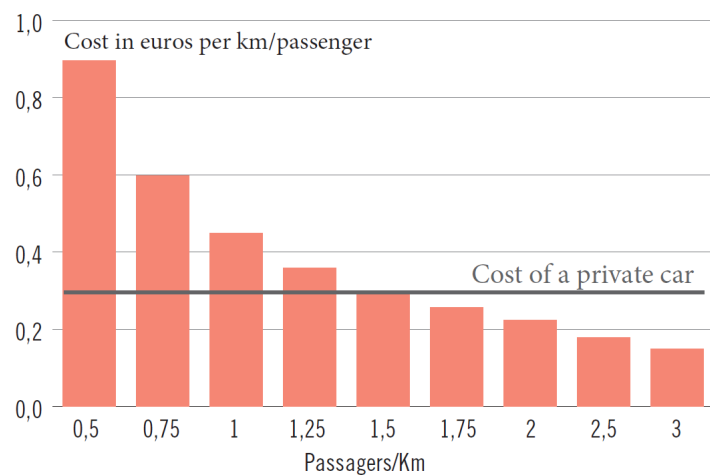


Figure 1.14: Cost per kilometre of a shared autonomous taxi journey according to the occupancy rate; source: (Saujot et al., 2018).

1.3.4.3 Cost of autonomous public transport

For a sector in crisis for many years, the question of the cost of public transport seems essential. Indeed, some local authorities, constrained by their budget, are obliged to reduce the supply of public transport, either in quality or in quantity. The integration of autonomy could modify certain economic components which structure the functioning of PT.

As with standard PT, autonomous public transport overall has a lower cost of use than other vehicles. This cost is estimated overall between 0.1 and 0.2 euro/km per passenger. The contribution of autonomy can affect demand for PT in many ways, including cost. Indeed, since the driver accounts for a large part of the cost of the journey, autonomy can significantly reduce the cost of public service. Furthermore, currently, almost 40% of the journeys are made empty (Litman, 2017), which results in a significant loss for the services in charge of PT. Autonomy, even partial, could tend to reduce this figure and therefore reduce the number of journeys made without passengers.

1.3.5 Social acceptance challenges

Acceptance is at the top of AVs challenges, even if AVs become available and affordable, its only the public acceptance and use of these vehicles that will determine the presence of AVs in their daily lives and mobility options. In fact, not all previously invented technologies were accepted by the public and used. Moreover, as mentioned before, the usage of this technology would have different impacts on our lives. Hereby, this section will consider the challenge of acceptance of AVs including the importance and complexity of acceptance studies, as well as, how acceptance is studied in the transport sector.

1.3.5.1 Importance of acceptance studies

The integration of AVs can have advantages and disadvantages, however, at the development stage, the work is to enhance the advantages and weaken the disadvantages, so that when AVs become available the advantages will fiercely overcome the disadvantages. Moreover, despite the efforts made to ensure the best safe beneficial operation of AVs when they become ready to rove our roads, many people are still doubting the ability of AVs to overcome problems like security and safety. According to Gartner study questioning a sample of 1,519 people from the U.S. and Germany, 55% of respondents will not consider riding in an AV, while 71% may consider riding in an automated vehicle but not AV, due to concerns related to security and technology failure (Forrest, 2018).

Acceptance of AVs is of big concern for automakers and stakeholders to ensure the arrival of AVs to the market. The difficulty in studying or forecasting acceptance when it comes to the transport sector is mainly due to not finding a consensus on a clear definition of acceptance. Whereas there is a consensus on the importance of acceptance studies in this field especially when considering information technology or advanced driver assistance systems, which comes straight before autonomous systems, but studies are still week in giving a unified or a generalized definition of acceptance (Regan et al., 2002; Adell, 2008).

Two commonly used definitions were found to suit the case of the acceptance of AVs. The first is defined by Adell (2008) for the context of driver support systems as *"the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving."*, and the second is provided by Ausserer and Risser (2005) in their study of intelligent transport systems and services acceptance; *"a phenomenon that reflects, to what extent potential users are willing to use a certain system. Whether a system will be accepted or not will depend on the way how user needs are integrated into the development of a system."*

As can be realized both definitions link acceptance to the intention of the individuals to use the innovative system when available and not actual usage. Which is the case in our study as AVs are not available yet and their use is not possible, thus we can not study the real acceptance but the intention to use AVs which in term predicts the future use.

1.3.5.2 Transport acceptance models

Acceptance is one of the most important steps in any product life-cycle, which will help in forecasting the market and modifying the product in a way that best response to potential users needs. Hereby, plentiful theories have been proposed to study the acceptance of new products and services (Lai, 2017). The theories explain users' intention to use a new system based on some psychological and behavioural factors (Jing et al., 2020; Momani et al., 2018). they study technology that has been developed in a certain product to understand whether people would like to use this product or not. Yet, the products should be in the market and tested by people, which is not the case of AVs. Therefore, some researchers tried to modify the already existing acceptance theories and models to make them adequate for advanced driver assistance systems and recently AVs acceptance. Figure 1.15 presents an overview of the derived theories and their used factors.

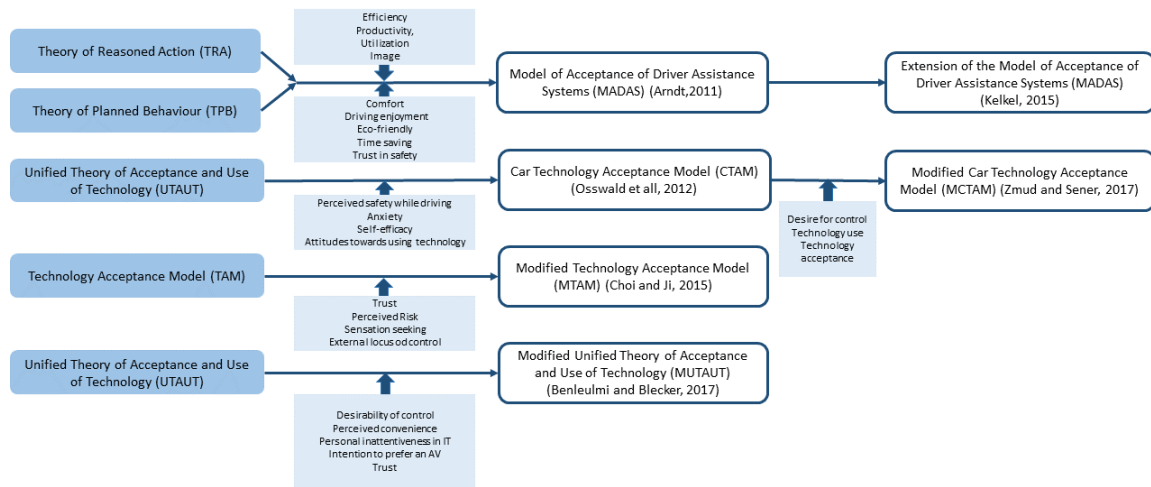


Figure 1.15: An overview of acceptance models in the realm of autonomous vehicles

In 2011, Arndt defined a model to use in his PhD thesis aiming to study driver acceptance of driver assistance, called "Model of Acceptance of Driver Assistance Systems" (MADAS) (Arndt, 2011). It is based on the theory of reasoned action and the theory of planned behaviour. Kelkel used this model later in 2015 to study the intention to purchase an AV (Kelkel, 2015a). In this model comfort, driving enjoyment, image, trust in the safety, and perceived product characteristics (efficiency, productivity, time-saving, eco-friendly and utilization) are proposed to have a relation with purchase intention moderated by attitude and subjective norms. 115 German respondents were surveyed to test the new model. The data analysis revealed that the positive direct effects of attitude and subjective norm on purchase Intention were supported and that efficiency and trust in safety both have a positive direct effect on Attitude and Subjective Norm and positive indirect effect on Purchase Intention. Whereas, the other variables were found insignificant in studying AVs purchase intention (Kelkel, 2015a).

A year after in 2012, Osswald developed the Car Technology Acceptance Model (CTAM) (Osswald et al., 2012), which incorporated UTAUT along with several other attitudinal constructs to make it applicable to the automobile context. It added the variables: perceived safety while driving: the degree to which an individual believes

that using a system will affect his or her well-being, anxiety: the degree to which a person responds to a situation with apprehension, uneasiness or feelings of arousal, self-efficacy: a person's belief in his/her ability and competence to use technology, and attitudes towards using the technology: an individual's overall affective reaction upon using a system.

A few years later, Zmud adopted a modified version of the CTAM to predict intention to use AVs (Zmud and Sener, 2017a). The newly adopted model (MCTAM) contains the CTAM variables except for facilitating conditions, because of the high level of uncertainty regarding facilitating infrastructure for AVs, in addition to the desire for control and demographic variables. As findings of this study, demographic variables were found not to be strongly related to intent to use except having physical conditions that prohibit driving. Whilst, currently owning a vehicle with highly automated features, perceived safety, desire for control and social influence seem to be important and significant in predicting acceptance.

Choi and Ji modified the Technology Acceptance Model to study individuals intend to use AVs (Choi and Ji, 2015a). In the new model, it is expected that behavioural intention is directly linked to perceived usefulness, perceived ease of use, trust, perceived risk, and sensation seeking. However, Trust plays several roles, it directly influences behavioural intention from one side and it is mediated by perceived risk and perceived usefulness from the other side. The results demonstrated that the model predicts well the intention to use AVs and all of its variables are significant. Perceived usefulness and trust seem to be the major important determinants of intention to use AVs (Choi and Ji, 2015a).

In the project funded by the European Union "CityMobil2", public acceptance of automated road transport was studied through a survey that was administered on-site during the operation of AVs (testing site in La Rochelle in France, and Lausanne in Switzerland). In this study, the UTAUT model was adopted. The results indicate that performance expectancy is the strongest predictor of intention to use AVs and social

influence and effort expectancy are also important variables in studying behavioural intentions (Madigan et al., 2016).

In the study of Benleulmi and Blecker, an online survey on AVs acceptance was conducted in the US and Germany; 313 valid answers were collected and analysed (Benleulmi and Blecker, 2017). They adopted some of the UTAUT constructs; performance expectancy, effort expectancy, social influence and hedonistic motivation (enjoyment) (Venkatesh et al., 2012). In addition to some variables from literature such as; the desirability of control and perceived convenience. Moreover, they had defined five types of risk (privacy, performance, safety, financial, socio-psychological) which are supposed to affect people trust in AVs which in turn is supposed to play a major role in the acceptance of AVs (Benleulmi and Blecker, 2017). This study found that all factors are significant in studying AVs acceptance except for performance expectancy and perceived convenience.

The factors that were found significant out of these different models can be presented under nine titles; as some factors are titled differently in different models but defined similarly. These nine factors are defined as follow:

- Perceived usefulness: the degree to which an individual believes that using a specific system or behaviour enhances his job performance (Thompson et al., 1991);
- Trust in AVs: the degree to which an individual believes that using a specific system will be safe and secure for himself and others;
- Social norms: the degree to which an individual believes that the people who are important to him believe that he should use a specific system (Fishbein and Ajzen, 1975);
- Attitude toward behaviour: an individual's positive or negative emotions about performing a behaviour or using a specific system (Fishbein and Ajzen, 1977);

- Effort expectancy: the degree to which an individual believes that using a specific system will be easy and effortless (Venkatesh et al., 2003);
- Affect towards use: an individual's feeling of pleasure, depression, anxiety, or hatred associated with the use of a specific system (Thompson et al., 1991);
- Compatibility: the degree to which a specific system or behaviour is perceived as being consistent with the values, needs, and past experiences of an individual (Moore and Benbasat, 1991);
- Experience: the degree of knowledge or skill that an individual has in using a specific system or technology (Momani and Jamous, 2017);
- Socio-demographic status: first appeared in the Unified Theory of Acceptance and Use of Technology; it includes age and gender (Popescu et al., 2017).

The fact that each model proposes different factors even though some are common, and that these factors have not all been tested in the context of AV, complicates the AVs acceptance study. Moreover, in this study, the acceptance of AVs is not considered in a general way, but there are three transport modes to be investigated that complicate the study even more. However, they are necessary to anticipate AVs impacts and their integration in urban areas.

As a conclusion, this chapter presents the research subject that is the AV, by providing a global view of how AVs were developed, their levels, potential used modes and operation. Moreover, it highlights the importance of AVs in improving mobility conditions as well as living conditions by promoting sustainable development in urban areas. The impacts of AVs can be anticipated in functions of the modes of automated transport to be used in the future. It is expected that if the majority of people use PAV, more vehicles will be roving the streets, producing more congestion and requiring larger street, thus affecting land use negatively. However, if AVs are mainly used as SAV or PAT, where shared mobility is encouraged and less vehicle-ownership

is produced, then the positive impacts of AVs are more possible to be seen in the future.

AVs can be seen as a new technology in the transport system or innovation that can facilitate mobility and travel conditions. Nevertheless, AVs can affect congestion negatively and reduce living areas if they are to be adopted in reserved lanes beside the CVs, where streets will be divided into separate lanes and the current traffic conditions will remain the same in CVs lanes. However, if people accept that AVs share the same lanes as CVs then the changes in urban spaces cannot be easily anticipated, but the need for new legislation and insurance strategies will be necessary. Depending on which scenario to be adopted, AVs can make a revolution in the urban system, if used alone without conventional vehicles where the entire urban space will change as well as the policies and legislation related to safety on roads. To this end, the different adoption scenarios of AVs beside the different modes can shape the urban space in different manners. We can imagine three scenarios if AVs become to market:

- scenario 1: cohabitation of AVs and CVs on the same road
- scenario 2: cohabitation of AVs and CVs but on separate roads (reserved lanes for AVs)
- scenario 3: all vehicles are autonomous (no CVs)

In scenario 1, the implementation of autonomy is partial and does not involve any major changes in the functioning of our societies and in the urban space. Scenario 2 is intermediate, involving re-modeling of the urban space but not complete changes in land uses. Whilst, scenario 3 represents a fundamental revolution in transport and land use, where everything we know today would no longer exist and would be 100% autonomous. The autonomy deployed on such a scale would imply that the urban system and its policies would be rethought. Proposing these three scenarios allows us not only to anticipate the intensity of the changes AVs will bring to the urban area but also assess the degree of acceptability to change, the degree of confidence in

new technologies, belief in innovation and technical progress. Therefore, considering these scenarios allows us to take the first approach to the integration of vehicles in urban space and their acceptability by users that are tested through a survey analysis presented in next chapter.

Chapter 2: Investigating the integration of autonomous vehicles through a survey: data and methods

"If you control the code, you control the world. This is the future that awaits us."

Marc Goodman

(Lee, 2013)

In this study, the methodology used to achieve our research objectives is as shown in the figure 2.1, it starts by defining the research objective. Then from the literature review, the variables to be investigated in order to understand acceptance in the context of autonomous vehicles are determined, and therefore, research hypotheses are set. In parallel, a study of the area in which the survey will be conducted with a description of the population is important in order to determine the sample and the survey administration method to reach the required sample. After specifying our objectives and sample, the questionnaire is designed and pre-tested to answer the research questions and test the hypotheses. The survey is then published, the collected data from this survey is cleaned up and used later in the data analysis phase.

This chapter describes the methodology used in this study and exposes the surveys already carried out on this subject. It presents the framework of the study to describe the survey developed for this study and discusses how it was developed, tested, and

disseminated. Moreover, Drawing on a wide range of work in technology acceptance studies in the fields of transport and automation and the growing field of automated and autonomous transport research, the chapter provides a justification of the research hypothesis and details the methods used to test these hypotheses and to answer the research questions.

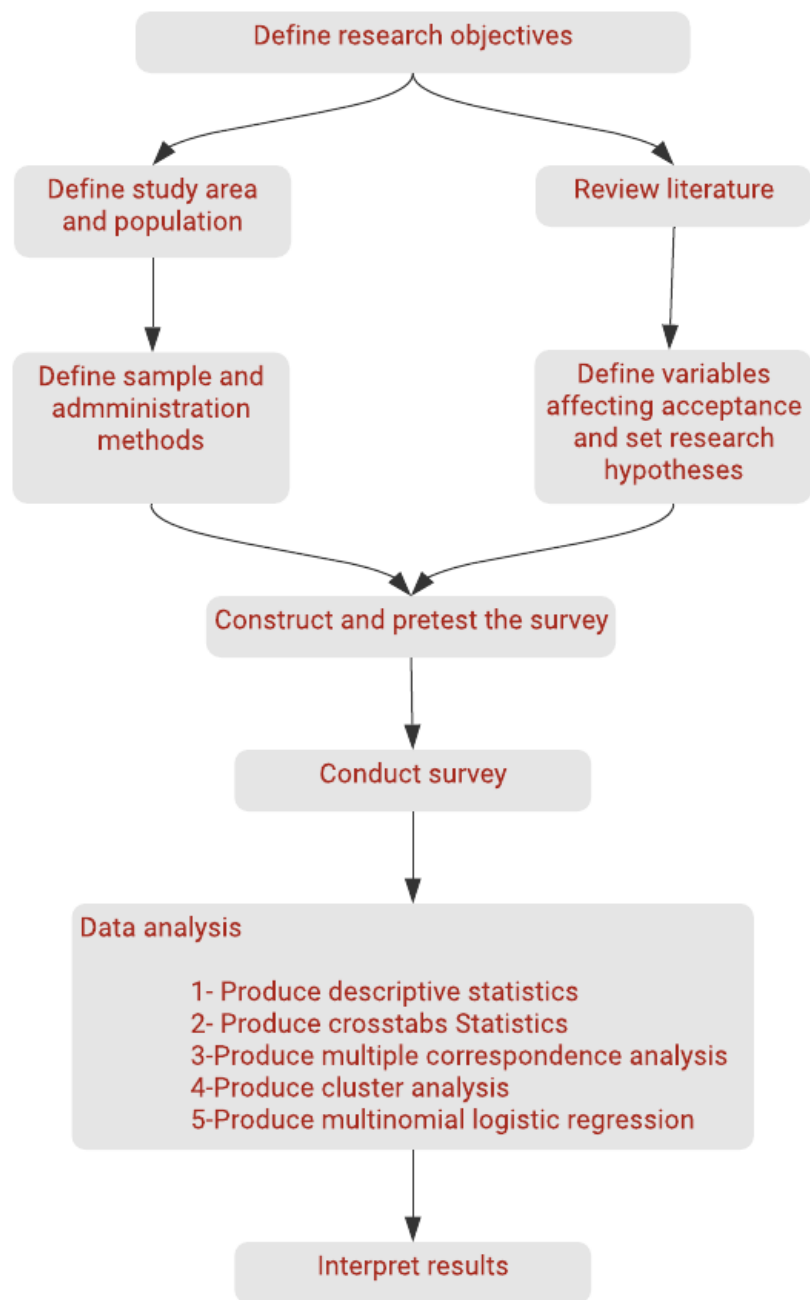


Figure 2.1: Research Methodology

2.1 Elements tested in the survey

The first step in a quantitative study is to set the factors to be tested in the research. Hereby, this section provides a review of surveys conducted on AVs in order to extract the important factors to be tested in our survey. It also presents the hypotheses and research questions of the study.

2.1.1 Factors influencing acceptance of autonomous vehicles

Autonomous vehicles have captured a large portion of the recent research, they have been highlighted as a trendy subject in automation, automobile, transport and urbanism studies. Therefore, in recent years, several studies had considered AVs, which provide us with bases for the current research since other surveys were previously conducted to study AVs impacts on future urbanism and individuals perceptions, adoption and concerns towards these vehicles. This section will present a summary of the previously conducted surveys and the factors that are important in studying AVs.

As AVs are expected to make a revolution in the transport systems all around the world, several researchers and analysts conducted studies to make a comparison of AVs' market penetration and to predict peoples' different needs and perceptions towards AVs. Some of these studies focused on a certain city, geographical location or closed environment (Bansal and Kockelman, 2017; Sanaullah et al., 2017), while, others widen their research project to reach several countries (Giffi et al., 2017; Berland, 2014; Menon, 2015). Figure 2.2 depicts the geographical coverage of the surveys. They were spread around the world with a high representation of the developed countries (Politis et al., 2017; Menon, 2015; Orfield et al., 2018; Bloom et al., 2017; Piao et al., 2016), especially, the USA which has the highest number of surveys (Zmud and Sener, 2017b; Prateek et al., 2016; Schoettle and Sivak, 2015), and a

modicum representation of the developing countries (Berland, 2014; Sanaullah et al., 2017). This outcome was expected, since in future AVs will first appear in developed countries, which have started testing, promoting and, even, developing legislation concerning the use of AVs.

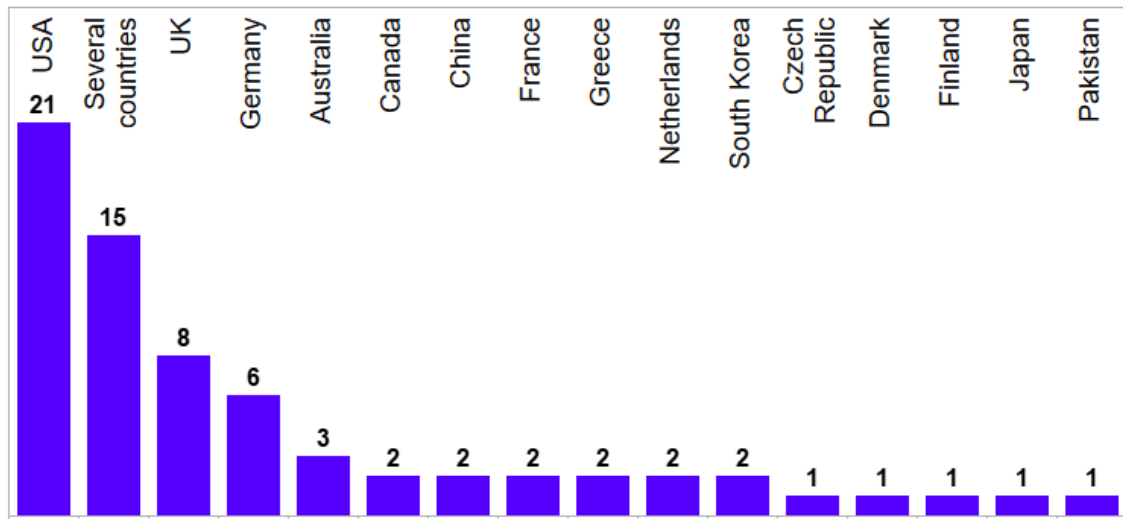


Figure 2.2: Distribution of the Surveys around the World

The majority of these surveys were targeted to a certain group of people or typology such as experts; being more open and familiar with AVs current and expected future situation (Klaus, 2013), drivers (Brown, 2017), vehicles-owners (Jiang et al., 2018), universities' and companies' members (Hyde et al., 2017), specific event attendants as the visitors of Lawrence Hall of Science is a public science museum in Howard and Dai (2014) study. However, the number of respondents varies from 30 to 23,000 people; the surveys with the minimum number of respondents (30 drivers in Hauslschmid et al. (2017), 32 drivers in Silberg (2013) and 107 people in Howard and Dai (2014)) were launched as paper-based surveys or questions on a tablet, while all the other surveys were conducted online.

The majority of surveys were administered online to reach a high number of people and reduce the effort needed for distribution (Giffi et al., 2017; Gabrhel, 2018). Some researchers chose to distribute their surveys by themselves through e-mails, website,

direct contacts, channels, etc., (Kaur and Rampersad, 2018; Talebian and Mishra, 2018), others chose to take advantage of survey panels (Bloom et al., 2017).

In order to answer their objectives, some studies choose to rely on behavioural theories that showed their efficiency in explaining public attitude and intention to use different technologies even in the transport section (Pronello and Gaborieau, 2018), like Car Technology Acceptance Model in Zmud and Sener (2017b), the Model of Acceptance of Driver Assistance Systems in Kelkel (2015b), and the Technology Acceptance Model in Wu et al. (2019); Choi and Ji (2015b). Some studies relied on questions collected from prior surveys (Hulse et al., 2018; Nordhoff et al., 2018), Another designing method was followed by Payre et al. (2014), who decided to take advantage of interviews and prior surveys questions to conclude the best questions for his study.

Appendix A provides an overview of the AVs' surveys reviewed as part of this work and show their characteristics. The surveys were sorted according to their objectives into five categories: 1) perception of benefits of AVs; 2) confidence in AVs; 3) acceptance of AVs; 4) willingness to pay for AVs, and 5) changes in travel behaviour and user preferences. In each group, the list of surveys is provided, including the study information about the study year in which the survey was conducted, the location, the sample, the distribution method, the methodology adopted in each study and finally, a column reporting the factors investigated in each survey and proved to be effective in analyzing public's perception and acceptance of AVs.

Reviewing previously conducted surveys on AVs highlighted some factors that are important to investigate when studying acceptance and perception of automated transport. Some of the factors are common with the acceptance models studied, while, others were born from the need to study AVs and their special characteristics. These factors and their role in studying AVs acceptance are presented in this section.

2.1.1.1 Socio-economic and demographic variables

In most of the surveys, socio-economic and demographic variables were tested, especially, gender, age, living area and educational level that appeared to have a strong influence on acceptance even if they were not used in previous acceptance models (except gender and age in UTAUT).

There is a consensus that men believe that AVs are better than conventional vehicles (Hyde et al., 2017), more enjoyable and make travelling less disquieting (Hohenberger et al., 2016; Regan et al., 2017). While, females showed less intention to use AVs (Konig and Neumayr, 2017; Zwerver, 2016; Piao et al., 2016; Hulse et al., 2018); except in the study of Silberg (2013).

Furthermore, young people even if being less aware of the technology are more fervent about AVs than elderly (Nielsen and Haustein, 2018; Becker and Axhausen, 2017; Prateek et al., 2016; Konig and Neumayr, 2017; Hawes, 2017; Abraham et al., 2017; Zwerver, 2016). Young people who have accompanied technological development - not necessarily automated technology - are more open to using new technologies, more willing to try new products and embark on a new adventure. The low willingness of older people to use AVs is a pity, since, when people get older, they lose sight, rationality, or the ability to drive hiking or frequent trips, which makes AVs very useful for them.

People with higher incomes are better able to afford and maintain these new expensive vehicles but, unfortunately, they are less willing to use AVs as compared to people with low incomes who are very excited to use them (Nordhoff et al., 2018; Bazilinksy et al., 2015; Forum and Group, 2015). When it comes to education, the expectation that people with higher education level are more open with technology and familiar with AVs is true, thus, they have markedly more positive attitudes towards AVs than people with lower education levels (Liljamo et al., 2018; Menon, 2015; Gabrhel, 2018).

Another important factor is the living location, where people living in mountains and rural areas, who do not have a variety of transport modes available for them, are more willing to adopt AVs as to use time more efficiently and have a more comfortable and reliable mode of transport. This positive correlation is proven in Power (2012) and Brown (2017) studies. While, the contrary is also possible and examined in Liljamo et al. (2018) and Konig and Neumayr (2017) studies, which states that people living in urban dense areas are more enthusiastic to use AVs than people in rural areas, since, using AVs could release them from spending hours of driving searching an available parking spot.

2.1.1.2 Attitude

As mentioned before, attitude is of the bases of acceptance studies, the same thing appears from the reviewed studies. However, as long as AVs are not available on roads and their impacts cannot be measured, people wonder the benefits' AVs are about to bring for the transport system. According to Orfield et al. (2018) study, a high per cent of respondents voted for different advantages of using AVs; 80% expected fewer crashes, 78% expected reduced the severity of crashes, 60% expected shorter travel time, 72% expected less traffic congestion, and 89% expected lower vehicle emissions. Reducing the stress of driving appeared to be an important benefit as found in Hawes (2017) study. Providing mobility for disabled and elderly was on the top of inquired benefits (UKAutodrive; Living-Lab, 2018).

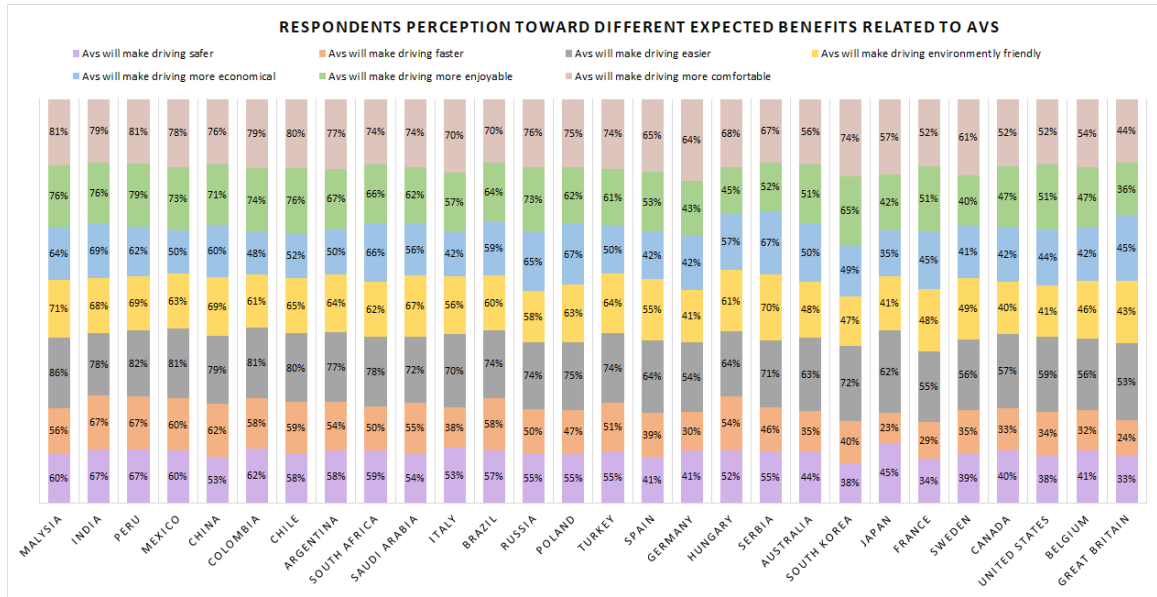


Figure 2.3: Comparison Between 28 Countries; data taken from (IPSOS, 2018) Study

In general, most of the respondents believe that AVs are going to change transport system for better, whether by the above advantages or reducing energy consumption, meeting driving needs, improving navigation, making driving faster, etc., (Ilias and George, 2018a; Piao et al., 2016; Degenhart, 2015). For a comparison of benefits' perception in 28 different countries see Figure 2.3 and for more information refer to (IPSOS, 2018).

2.1.1.3 Familiarity

Familiarity is another important factor analysed in the previous studies but not highlighted or tested in standard acceptance models. It is studied according to 1) whether the questioned person had heard about or know what is AVs before answering to the surveys, and 2) if he had the opportunity to try some automated features while driving or travelling.

The rapid developments of technology in the field of automation and vehicles lead to the integration of advanced automated features in most of our current - not too old

- vehicles, raising the familiarity of public with the basic automated features. Since, automated transport already exist in some public transportation systems such as airport shuttles, universities' campuses' buses, etc., a considerable number of people had experienced this, showing a strong positive intention to adopt AVs (Pakusch and Bossauer, 2017).

A high percentage (more than 70%) of respondents from different studies knew what AVs are or at least had heard about them prior to the studies (Ilias and George, 2018a; UKAutodrive, 2017; Konig and Neumayr, 2017; Orfield et al., 2018). However, a high number of respondents expressed their need to know more about AVs and their potential benefits (Tennant et al., 2016; Hawes, 2017). According to Sanbonmatsu et al. (2018) and Menon (2015), people with a higher level of awareness of automated features have a stronger intention to use AVs. The same result was confirmed by Gabrhel (2018), who stated that previous experiences with automated features increase the probability of using AVs in the future.

In a cross-national survey conducted by Schoettle and Sivak (2014b), the percentage of people with prior knowledge of AVs considered high, where, 87% of Chinese respondents signify familiarity with AVs, followed by 73.8% of the Indian sample, then, 70.9% of the American sample, then, 66% of the British sample and 61% of the Australian sample, with the lowest percentage in Japan (57.4%) which is still relatively high.

2.1.1.4 Affect towards use

The adoption of AVs, which are supposed not to have steering wheel and pedals, means eliminating human interventions and even the ability to drive. Leaving driving lovers afraid of losing the pleasure of driving (Pakusch and Bossauer, 2017; Payre et al., 2014). Thus, welcoming the option of taking over control at any time (Berland, 2014). The majority of respondents found manual driving to be the most enjoyable mode of driving (Kyriakidis et al., 2015). Whilst, for a few respondents, AVs ride

could be pleasurable and enjoyable more than conventional ones, the thing that may accelerate the time needed for the implementation phase. Nordhoff et al. (2018) found the public rating for the perceived enjoyment of taking a ride in an AV is 4.90 on a scale of 6.

The current transport situation and conditions could be the bases on what they build their decision when considering new transport modes, the thing that raises the need to consider habits or past experience in acceptance studies. The habits could be regarding, travelling distance, travelling mode, parking, past accident experience and many more.

Five out of six studies found that as the daily travelling distance increases people will be more willing to adapt AVs, as a sort of relaxing, reducing efforts on roads and using time in different tasks other than driving (Shabanpour et al., 2017; Menon, 2015; Kyriakidis et al., 2015; Clerkin, 2017; Shabanpour et al., 2017). On the contrary, Konig and Neumayr (2017) concluded that the more the vehicle is used and necessary in one's life, the less he would be willing to change for a new mode of transport (as AVs). People who usually use public transport are more willing to use AVs while people who use owned vehicles; easy to find/use and more reliable mode, prefer to stick with their current vehicles and are less looking for AVs.

Moreover, people who faced some troubles in the traditional travelling mode are more willing and open for the new mode of transport, which could solve this. For example, drivers with difficulty finding parking spots are more looking to adapt AVs that can drive themselves autonomously (Nordhoff et al., 2018). Or, people who experienced road accidents are more willing to adopt AVs (Shabanpour et al., 2017) to free themselves from future responsibilities. However, according to Menon (2015), the opposite is possible; people who had accidents before become more sceptical and less trustful in technology and, thus, less likely to adopt AVs.

2.1.1.5 Trust

Autonomous vehicles (AVs) are promoted as a solution to safe driving, which is a major challenge for our society. According to the NHTSA ¹ statistics, human errors commit almost 90% of road accidents. In critical situations, the majority of these accidents occur because the driver has either underestimated the current risk, wrongly faced the situation, or his reaction was late (DOT, 2010). Therefore, eliminating human drivers should make roads safer, but it is not proven that substituting human drivers by an AV is the correct solution. From here, the question of safety and people's trust in AVs raised and investigated through studies.

In general, people believe that AVs could make roads safer and reduce accidents (Degenhart, 2015; Ilias and George, 2018a; Bansal and Kockelman, 2018; Living-Lab, 2018; Howard and Dai, 2014). According to IPSOS (2018) study, which investigated trust in AVs in 28 different countries, 51% of the studied sample think that AVs would make driving safer. In this study, India and Peru (67%) were on the top of countries believing in the ability of AVs to make streets safer, on the contrary, The United Kingdom (33%) and France (34%) showed a very low trust followed by The United States (38%), South Korea (38%) and Sweden (39%). The 21 remaining countries vary from 41% to 62 % (IPSOS, 2018). Moreover, As shown in Figure 2.4 there is an overall increase in people trust on AVs as all countries show a reduction in the percentage of people not trusting the safety of AVs from the year 2017 to 2018 (Giffi et al., 2018).

¹<http://www.nhtsa.gov/>

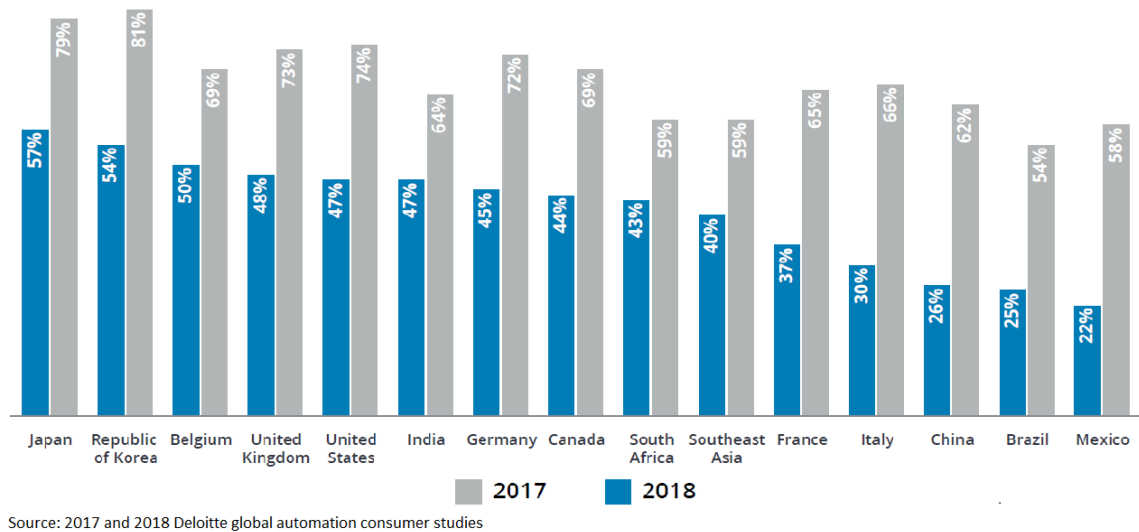


Figure 2.4: Percentage of consumers who think AVs will not be safe (2017 Vs.2018)

Public shows a high level of concern when it comes to safety whether it is road safety (technology failure), information security (privacy, cybersecurity) or personal security (physical aggression). Moreover, it appears that trust in AVs' safety is one of the most important factors influencing people's intention to use an AV.

When it comes to AVs, some people do not trust the technology itself. So that, for certain groups, AVs could malfunction (Tennant et al., 2016), automation software may not be reliable (Business, 2018), or even face equipment or system failure (Schoettle and Sivak, 2014a; Prateek et al., 2016; Bansal and Kockelman, 2018). It is more difficult to imagine the transit state from conventional vehicles to AVs. The public became more concerned about this state than the only AVs state (Hyde et al., 2017). Some believe that AVs lack the common sense necessary to interact with human drivers (Tennant et al., 2016). Others find it uncomfortable to drive or be present alongside an AV (Tennant et al., 2016; Intel, 2018; Gerzema, 2018). Moreover, the extra feeling of safe spouts from people faith in AVs' driving capacity, increases risks taken by riders and pedestrians such as omission the use of seat-belt or pedestrian become less cautious around AVs, therefore, making AVs less safe.

Using AVs that can connect to each other and to external servers could facilitate the job for hackers to take over control, and even if not for bad target, it could mean giving the option for some sectors to threaten someone's privacy by sharing his data. High concerns about privacy and information security issues were raised by most of the questioned samples (Business, 2018; Kyriakidis et al., 2015; Bloom et al., 2017). Whilst, a few per cent of people showed positive intention to share their data for the good target; to avoid crashes and enhance trajectory followed (Kürpick, 2018; Bansal and Kockelman, 2017).

Public assented that they would always keep aware of the road while using AVs (Giffi et al., 2018; Tennant et al., 2016). More than 70% of respondents questioned stated that they would like to use AVs but with the option of taking control whenever they would like to (Addady, 2016; UKAutodrive; Living-Lab, 2018). However, when people were asked if they would let their children use AVs without supervision, a consensus on not allowing them was found (Clerkin, 2017; Vallet, 2014; Forum and Group, 2015). People cannot trust AVs their children's lives, these little creatures that cannot help themselves in the case of an accident, no one is ready to accept the idea of a child being killed by a machine.

In the case of shared AVs, a new concern appears that is passengers' personal security. Sharing a room with strangers is not always welcomed (Bansal and Kockelman, 2018), especially with unbalanced ones. However, it seems that females are more afraid of strangers than males (Clerkin, 2017) and that public fear a stranger at evening/night time more than at daytime (Piao et al., 2016).

2.1.1.6 Willingness to pay

In order to have AVs, new technologies should be integrated into conventional vehicles, which are still considered relatively new and expensive. The thing that expects AVs to be so expensive in the early stages of the implementation, affecting the rate of adoption of these new vehicles. 34% of respondents in Gabrhel (2018) study stated

that they would not use AVs because of the expected high prices.

In 2018, Deloitte Global Automation Consumer conducted a study on AVs across 15 global markets (Giffi et al., 2018). They found that a significant percentage of people in different countries are not willing to pay for AVs (ex: 50% in Germany, 38% in the US, 31% in Japan) and even consumers who showed a willingness to pay mentioned a pittance amount compared to the expected cost of the new features. Which means people are hesitant to commit to relatively high price vehicles. Another cross-national study was conducted to understand the acceptance of AVs (Schoettle and Sivak, 2014b), found that respondents in China and India had most positive opinions towards AVs, expressed greater interest in using AVs, and were willing to pay the most for them as compared to the U.S., the U.K. and Australia, whereas, Japanese respondents generally had neutral opinions and were willing to pay the least for AVs.

According to Giffi et al. (2017), the US consumers' willingness to pay for automated features has declined by 30% from 2014 to 2016, from 1,370\$ to 925\$. While in Casley et al. (2013) survey 71% of respondents showed a will to pay more than 4999\$ to purchase an AV, about the same (4900\$) as in Daziano et al. (2017) and 5,857\$ in Bansal and Kockelman (2017). Texans people showed more willingness to pay, almost 7,589\$ for AVs Bansal and Kockelman (2018). The amount increased to 30,000\$ (only for 5% of the sample) (Kyriakidis et al., 2015). Whilst a representative sample from all over the world were unwilling to pay anything extra for AVs than conventional ones (Schoettle and Sivak, 2014a; Konig and Neumayr, 2017; Kyriakidis et al., 2015).

2.1.1.7 Behavioural intention

In general, the studies revealed a relatively high overall intention to use AVs. Piao et al. (2016) claimed that about 63% of surveyed people would consider taking automated buses even when both automated and conventional buses are available. Similarly, 77.6% of Germans said that they could imagine themselves using public AVs

regularly in the future (Pakusch and Bossauer, 2017). Furthermore, more than 75% of respondents showed a high interest in using and buying AVs in Sanaullah et al. (2017) and Addady (2016) studies. The number of respondents willing to use AVs in future in different studies is lower than the latter but is still considerable and reflects general positive intention (Payre et al., 2014; Hawes, 2017; Menon, 2015; Ilias and George, 2018a). While only a limited number of studies found that the higher percentage of their samples were not willing to use AVs (West, 2018; Tennant et al., 2016).

2.1.2 Research questions and hypotheses

This study intends to assess people's acceptability of AVs and support key stakeholders (transport authorities, local governments, civil society, etc.) about the opportunities and risks of AVs, as well as to develop exploitation plans, paving the way for the smart implementation of AVs in case this will be proven beneficial for the users and for reaching more sustainable urban system. These targets are achieved by answering the following research questions:

1. What are the factors that influence people's acceptance of autonomous vehicles?
2. Which mode of autonomous transport (private, shared or public) is preferred by the participants and what are the profiles of the users of each mode?
3. What are the potential impacts of AVs on the urban system? that are mainly affected by the travel behavioural changes, the used mode of transport and the expected changes in living locations.

To answer these questions, six variables (socio-demographic status, familiarity, past behaviour, perceived usefulness, affect toward use and trust) were extracted from the previously conducted surveys and tested in our survey. The willingness to pay that was found important in AVs studies but was not previously studied in acceptance

models, was excluded in our study. Regardless of the importance of materialistic aspects in adopting new technology, it is almost impossible to evaluate or predict the price and cost of AVs now. In fact, no AV of level 5 is available yet so estimating the current cost is very complicated (Endsley, 2019). Moreover, AVs are using new technologies and equipment that seems to be very expensive now, but are expected to become cheaper with time and with the mass production of such equipment. Thus, seeking a clear, non-confusing survey with unbiased answers we decided not to include this factor in our analysis.

The use of AVs cannot be real tested while AVs are not yet available, therefore, the intention to use AVs is tested instead, along with the six factors that are considered as independent variables that affect the acceptance of AVs. The factors with their hypotheses are as follows:

1. **Socio-demographic status (SDS)** including age, gender, professional activity, household size and the number of vehicles owned.

H1: SDS has a significant effect on the users' intention to use AVs.

2. **Familiarity (F)** tested as the participants' knowledge about AVs and the advanced driving assistance systems (ADAS).

H2: F has a significant positive effect on the users' intention to use AVs.

3. **Past behaviour (PB)** or habits tested as the current mobility, including trip duration, trip frequency, travelling mode, trip cost, satisfaction with current travelling mode, etc.

H3: PB has a significant effect on the users' intention to use AVs.

4. **Perceived usefulness (PU)** testing the perception about the benefits of AVs, such as using travel time more effectively, improve route navigation, improve security, reduce travel time, improve trip comfort, improve privacy, affect the number of accidents, etc.

H4: PU has a significant positive effect on the users' intention to use AVs.

5. **Affect toward use** or simply the effect of AVs on driving pleasure (**DP**).

H5: DP has a significant effect on the users' intention to use AVs.

6. **Trust (TST)** including trust in ADAS, driverless metros and trams, the global positioning system (GPS) and mobile navigation application, new technologies, cybersecurity in AVs.

H6: TST has a significant positive effect on the users' intention to use AVs.

Based on these hypotheses and the research questions the survey was then designed to best respond to the research objectives.

2.2 A survey of medium-sized towns: the case of the agglomeration of Compiègne region

This section presents a view of the area where the survey was conducted. It also provides information on the design of the survey to answer our research questions and the dissemination strategies used to reach our targeted sample.

2.2.1 Description of the study area

The aim of this thesis is to conduct a representative study that can be generalized to a large number of French cities. Therefore, we choose to study a large area with a diversity of population profiles and a variety of available and used transport modes to be comparable to different populations later. However, at the same time, we had to be careful about how large the size of the area should be since conducting a study on a mega-cities means spending massive resources to reach a representative sample. Therefore, and due to our limited research resources, the study area is set to be a medium-sized city.

Since the research is carried out at the "Université de Technologie de Compiègne (UTC)" that is located at Compiègne and in order to facilitate the dissemination process, the study area was chosen to be Compiègne from one side, and from the other side, Compiègne is a medium-sized² city (<500,000 inhabitants) which constitute the most important class in Europe in demographic terms (Giffinger et al., 2007). Compiègne is a city in the Oise department in the north of France, a royal and imperial city, a scene of major events in French history and the site for the signing of the two armistices on November 11, 1918 and June 22, 1940. The city embraces around 40,200 inhabitants in an area of 53.1 km² (INSEE, 2016).

Furthermore, As our survey focuses on the mobility and travel habits of individuals, we decided to enlarge the study area to include all the agglomeration of the Compiègne region (ARC) where daily movements take place. Indeed, many people have to move from one city to another seeking work, shopping, leisure activities, etc. The ARC brings together a group of 22 municipalities (84,305 inhabitants) around Compiègne, representing an area of 265 km². The agglomeration promotes travel by offering users public, urban and peri-urban transport, free of charge. However, the use of private vehicles remains important compared to other means of transport.

The survey was supposed to be a paper-based in-field study conducted by twenty project workshop students in the department of urban engineering at the UTC. The thing that makes it difficult to visit and question people in different locations of the 22 cities. In addition, several cities have very similar profiles: the number of inhabitants, gender, commercial activities, etc. To this end, we decided to reduce the number of cities to a maximum of 10 including Compiègne, which is the biggest one among them.

In order to have results representative of the territory of the ARC, even if not all municipalities were to be taken into consideration in the study, we had to reduce the

²According to INSEE (2016), the medium-sized city is a centre of a medium or large urban area, comprising, therefore, more than 5,000 jobs, with a population of fewer than 150,000 inhabitants, which is not the prefecture of a former region.

number of municipalities to be studied by eliminating cities with similar profiles thus, preserving diversity in the study area. For example, Jaux and Venette are two very similar cities on many criteria so only one city will be studied since the other one will be the image of the former.

2.2.2 Representativeness and dissemination strategies

To determine the most relevant municipalities to be selected, we conducted an analysis based on various social, demographic, and mobility criteria with the aim of identifying the profiles of the ARC cities residents and transport means available to them. In other words, we tried to create city ID cards to choose the most different cards. Cities data is found on the INSEE³ and Oise Mobilités⁴ website. The criteria we analyzed are the following:

- the number of inhabitants in the city, from INSEE site;
- the population by age group (30-59) that is the major group, from INSEE site;
- the working place for inhabitants whether in the city or outside, from INSEE site;
- the mode of transport used for commuting, from INSEE site;
- the available transport means, from OiseMobility site.

First by using a multi-criteria analysis, we assign weights for the six criterions: 1) number of inhabitants, 2) number of inhabitants with age between 30 and 59 years (the major age group in the ARC), 3) number of active people (people that work), 4) percentage of people working in or outside the city of residence, 5) the commuting mode whether public transport (PT), private vehicle (PV) or soft mode (SM), and 6)

³<https://www.insee.fr/fr/statistiques>

⁴<https://www.oise-mobilite.fr/>

the available means of transport (urban, peri-urban, departmental public transport and mobility as a service) that were involved in the decision process . The weights were calculated as a standard rating system. This technique makes it possible to have a homogeneous weighting score for each criterion, which facilitates comparative analysis. A scale from 0 to 10 was chosen for this analysis, which does not represent a qualitative aspect of the criterion, but it gives weights to the criteria in order to establish a gauge and then highlights the differences or similarities between cities.

For the criterion of the number of inhabitants, the scores were assigned as follows: zero corresponds to zero inhabitants and 10 corresponds to the city with the most inhabitants (here Compiègne with 40,258 inhabitants), each city is then assigned a score by following a linear model. However, as many cities have a small population compared to Compiègne, many of them have a score of less than 1. This highlights a class of low-density cities facing Compiègne; being the only city with a score higher than 3. This method of assigning scores remains the same for each criterion.

Similarly, scores were assigned for the percentage of people aged between 30 and 59 years old, the percentage of active people in the city, the percentage of inhabitants working in a city other than the one where they reside, the percentage of inhabitants commuting to their work by private vehicle, by public transport or using soft modes. Where zero is awarded if the percentage is zero and 10 for the highest percentage, else a linear model is followed.

However, For the criterion available means of transport, the score 10 is awarded when the city is served by all the possible means in the ARC: urban, peri-urban, departmental public transport and MAAS and zero if the city does not have any means, else a linear model is followed as other criteria.

The allocation of scores for each criterion made it possible to analyze the differences between cities in a more visual way, where a color scale from green (score=0) to red (score=10) was assigned for each criterion in a city, as can be seen in figure 2.5. Thus, creating a color profile of each city (line) which helps in grouping similar cities.

	Number of inhabitants	Group age 30-59	Active population	Working location	Commute PV	Commute PT	Commute soft mode	Available PT or MAAS
Amancourt	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Béthisy-Saint-Martin	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Béthisy-Saint-Pierre	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Bienville	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Choisy-au-Bac	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Clairoix	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Compiègne	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Janville	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Jaux	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Jonquières	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
La Croix Saint Ouen	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Lachelle	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Le Meux	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Margny-lès-Compiègne	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Néry	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Saint Vaast de Longmont	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Saint-Jean-aux-Bois	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Saint-Sauveur	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Saintines	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Venette	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Verberie	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Vieux-Moulin	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18

Figure 2.5: Multi-criteria analysis of cities profiles

After grouping the cities with a similar multi-criteria profile, only one within a group was kept, the aim being to reduce the number of cities to 10 maximum to meet the procurement constraints by highlighting cities profiles that cannot be considered under a single indicator. In this analysis, nine groups were found with their representative cities Compiègne, Janville, Bienville, Saint-Jean-aux-Bois, Margny-lès-Compiègne, Saint Vaast de Longmont, Béthisy St Pierre, Verberie and Jaux.

In parallel, a matrix multi-criteria analysis was carried for the same objective. The idea is to study the diversity in the values of each criterion. Considering the same criteria as previous analysis, we started with mode used for commuting, but only public transport and private vehicles were compared since they are the most used. Then the working place whether in the same city where they reside or outside, followed by the percentage of active people. Before continuing for other criteria, it was found that the first three matrices are sufficient to compare with the previous analysis result.

Table 2.1: The matrix analysis of cities profiles

Commute by Private vehicle					
		< 70%	70% > < 80	80% > < 90%	> 90%
Commute by public transport	< 3%			St-Jean-aux-Bois	Janville Lachelle Néry St-Vaast-de-Longmont
	> 3% < 5%			Béthisy-St-Pierre Jaux La-Croix-St-Ouen St-Sauveur Stines Verberie	
	> 5% < 10%			Armancourt Béthisy-St-Martin Choisy-au-Bac Clairoix Jonquières Le-Meux Vieux-Moulin	
	> 10%	Compiègne Margny-les-Compiègne	Bienville Venette		
Working Location					
In the same city where they live					
		< 10%	> 10% < 20%	> 15% < 20%	> 20%
Outside the city where they live	< 70%				Compiègne St-Jean-aux-Bois
	> 70% < 80%			Verberie	Le Meux
	> 80% < 90%		Armancourt Jonquières Vieux-Moulin Lachelle Néry Stines Jaux Choisy-au-Bac Margny-Les-Compiègne	St-Vaast-de-Longmont St-Sauveur Clairoix Venette Béthisy-St-Pierre La-Croix-St-Ouen	
<i>Continued on next page</i>					

Table 2.1 – <i>Continued from previous page</i>					
	> 90%	Janville Bienville Béthisy-St- Martin			
Percentage of people that work					
	< 70%	> 70% < 75%	> 75% < 77.5%	> 77.5% < 80%	> 80%
	Compiègne St-Jean- aux-Bois Vieux- Moulin	Janville Ar- mancourt Coisy-au- Bac	Bienville Jonquieres Bethisy-St-Martin St-Sauveur Clairoix Jaux Venette Bethisy- St-Pierre	St-Vaast-de-Longmont Lachelle Néry Le- Meux La-Croix-St- Ouen Margny-lès- Compiègne	Stines Verberie

The matrices are presented in table 2.1, presenting the percentage of people using public transport against people using private vehicles for commuting, the percentage of people work the cities where they live against people working in cities different from where they live, and the percentage of people that work, together with the list of cities in each group that allow grouping the cities based on the three built matrices, to end up with a group of 10 cities that seem to be different enriched with diverse inhabitants profiles. By comparing both methods, relatively similar results were found; eight cities were highlighted by both methods while only three were not agreed upon; as presented in table 2.2, where cities not agreed upon are colored red. The matrix analysis will, therefore, have made it possible to validate and consolidate the multi-criteria analysis results.

As a conclusion, both methods gave similar results, however, following our goal to reduce the number of cities as possible while preserving the diversity in the ARC inhabitants' profiles, the results of the multi-criteria analysis were adopted and only nine cities out of twenty-two are studied. The chosen cities, as well as the ARC

Table 2.2: The results of the multi-criteria analysis and the matrix analysis

Multi-criteria analysis	Matrix analysis
1-Compiègne	1-Compiègne
2-Janville	2-Janville
3-Bienville	3-Bienville
4-Saint-Jean-aux-Bois	4-Saint-Jean-aux-Bois
5-Margny-lès-Compiègne	5-Margny-lès-Compiègne
6-Saint Vaast de Longmont	6-Vieux Moulin
7-Béthisy St Pierre	7-Béthisy St Pierre
8-Verberie	8-Verberie
9-Jaux	9-Jaux
	10-The Meux

peripheries, are presented in figure 2.6.

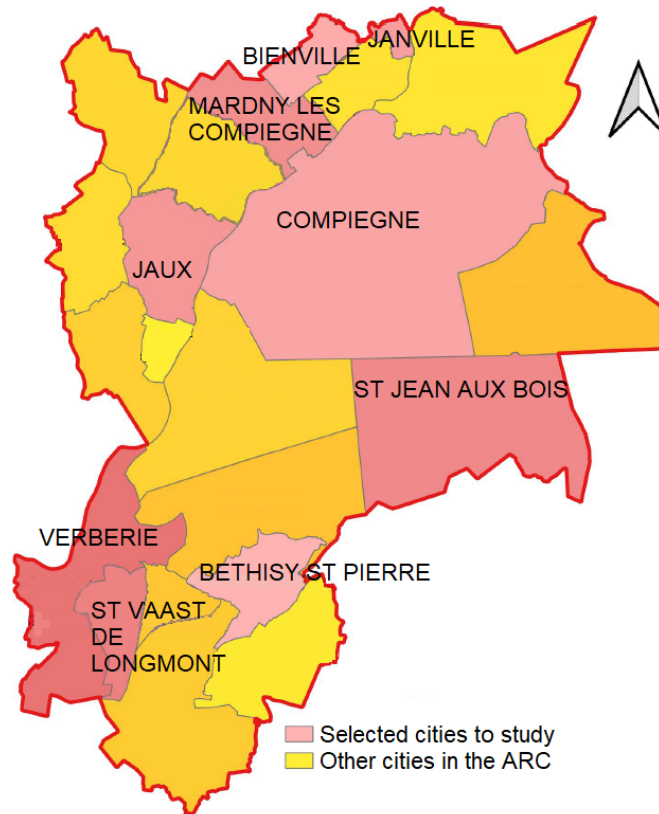


Figure 2.6: The agglomeration of the Compiègne region; selected cities to study

2.2.3 Survey design and pre-test

There is consensus that questionnaires are the most appropriate method for studying acceptance and underlying constructs (Kelkel, 2015b). Moreover, it is an effective and economical tool for gathering insightful information about the population. However, if not designed well, the data collected will be useless. According to Malhotra and Singh (2010), the survey should be designed in such a way as to try to obtain accurate and complete information about the research problem. The most important part of the survey study is creating questions that accurately measure respondents' opinions and behaviours.

In this study, the introductory statements were designed to motivate the respondents to participate in the study. Moreover, the questions were kept simple, clear

and short to avoid any misunderstanding or confusion. The survey aims to get in-depth information related to opinions, intentions, attitudes, lifestyles and preferences of the participants. Seeking to understand if people would accept AVs, the factors affecting their acceptance and if AVs become real which mode people would prefer shared, private or public, in order to draw a conclusion on the possible impacts of the autonomous transport system on the urban system.

In order to facilitate the follow-up and understanding of the survey, it is formed of six sections as follows:

- Mobility in a standard week: including questions about the most important trip, the mode of transport used, the frequency of the trip, the distance, the reasons for choosing a particular mode over others, satisfaction with the chosen mode, etc. This section aims to understand participants' travel behaviours and their preferences with respect to daily movements.
- Trust in autonomous transport: including questions investigating confidence in new technology, cybersecurity, navigation systems, etc. In order to assess the participants' relationship with technology, in terms of cybersecurity and types of equipment built into the AV.
- Acceptance of autonomous vehicles: Participants were asked about their knowledge of AVs and ADAS, their willingness to use AVs, etc. The purpose of this section was to check whether the respondent would accept AVs in the future and what changes could enhance their acceptance.
- Public transport and automation: like the use of public transport, reasons to use or not public transport, advantages of autonomous public transport, etc. Directing the imagination of respondents towards the future where public transport could be autonomous, including a transition part from AVs to PAT.
- Perceptions towards the implementation of AVs: such as questions regarding freed time, advantages of AVs, concerns towards AVs, etc. This provides us

with a greater understanding of respondents' opinion and perceptions about the consequences of the arrival of AVs.

- Personal data: the classic category that is found in any survey, including questions about the participant socio-demographic profile. It is important to know the profile of the respondents to be able to make adjustments, or simply to see if there is a relation between different profiles and acceptance of AVs.

After completing the first version of the questionnaire, the pre-test stage was conducted before the questionnaire was published for the defined sample. According to Sekaran and Bougie (2016), pre-testing is an essential part of survey design in order to validate the questionnaire and avoid participants' confusion and misinterpretations as well as to detect any errors and ambiguities. Pre-testing was conducted between PW members, relatives and teachers responsible for PW, it helped test both online and phone opening phrases to attract respondents and the questions.

The pre-test phase was important to adjust our questions to become clearer, simpler and explain the goal of the study in a simple way so that people who had heard about self-driving cars before and who had never heard about them before could participate and understand the questionnaire. Moreover, this stage was crucial for setting survey time and managing not to last more than ten minutes. In fact, when conducting free research without material profit for volunteers in the study, it is difficult to find people willing to spend more than fifteen minutes filling out a questionnaire. At the end of this phase, the final version of the questionnaire including the aforementioned sections became ready to be shared with the public; the survey is presented in appendix B. Figure 2.7, presents the final layout of the online survey.



Figure 2.7: The survey layout

2.2.4 Sample selection and survey dissemination

After defining our study area, reaching a representative sample became our target; how many people to question? and how to reach these people? Starting from the size of the population we are seeking to represent and thanks to the Cochran's Approach we succeeded to calculate our sample required size using the following equations (Cochran, 1977), the sample size was estimated to be 1068 respondents after cleaning the received data.

Sample Size:

$$SS = \frac{Z^2 * p * (1 - p)}{c^2}$$

Where:

SS= sample size

Z = Z value = 1.96 for 95% confidence level

p = percentage picking a choice = 0.5 if unknown

c = confidence interval = 3% = 0.3

Correction for Finite Population:

$$ASS = \frac{SS}{1 + \frac{SS-1}{population}}$$

Where:

ASS= Adjusted sample size for finite population

Population= population size = 84,305


To reach our sample a dissemination strategy was first prepared to be a paper-based in-field survey conducted by twenty students of the project workshop (PW) at “Université de Technologie de Compiègne (UTC)” for three days. The students were to be grouped in pairs and stand in places where people gather to contact a large number of people each day. For Example, the university campus, city centers, commercial centers and bus stations.

However, the violent increase in the spread of coronavirus around the world during the distribution phase forced us to change the strategy, as it became impossible to conduct a field survey. Therefore, a new method has been adopted that includes creating an online survey using google form that could be disseminated on social media and in parallel contacting the residents of the study area by phone to answer to the survey.

Le Parisien

Seriez-vous favorables aux véhicules sans conducteur à Compiègne?

Des étudiants de l'Université de technologie ont créé un questionnaire pour connaître l'avis des habitants sur la mise en place de transports autonomes. Ils ont un mois pour s'exprimer.



CVL Lycée Pierre d'Ailly is in Compiègne et son agglomération.
May 2 · 🌐

Prenez quelques minutes pour aider nos étudiants !

20 étudiants en génie des systèmes urbains de l'UTC (dont certains viennent du Lycée Pierre d'Ailly) travaillent sur un projet d'insertion des véhicules autonomes dans l'espace urbain de l'Agglomération de la Région de Compiègne

Ils ont conçu un questionnaire visant à recueillir l'avis de la population de la zone de l'ARC sur l'insertion d'un tel type de moyen de locomotion dans un futur plus ou moins proche : <https://forms.gle/7Y5eMVEaPpmVd1vF8>

Les réponses seront classées et analysées pour produire une base de données inédite sur cette problématique.

Alors participez à leur projet en répondant à ce questionnaire. Et le partage n'est pas de refus ! 😊

Insertion des véhicules autonomes dans l'espace urbain de l'Agglomération de la Région de Compiègne


Madame, Monsieur,

Dans le cadre de notre projet pédagogique en Génie Urbain à l'Université de Technologie de Compiègne, nous réalisons une enquête exploratoire sur les véhicules autonomes en milieu urbain.

Ce questionnaire a pour objectif de :

Compiègne Actu
April 21 · 🌐

Compiègne : seriez-vous favorables aux véhicules sans conducteur ? - Le Parisien




LEPARISIEN.FR

Compiègne : seriez-vous favorables aux véhicules sans

Maire chez Ville de Compiègne
3mo · 🌐

20 étudiants en génie des systèmes urbain de l'UTC - Université de Technologie de Compiègne travaillent sur l'insertion des #véhicules #autonomes dans l'espace urbain de l'Agglomération de la Région de Compiègne 🚗 🚲 ...see more

See translation



UTC - Université de Technologie de Compiègne
15K like this · Community College

Apr 14 · 🌐 · [Ils ont besoin de vous !] 20 étudiants en génie des systèmes urbain travaillent en atelier projet sur l'insertion des véhicules autonomes dans l'espace urbain de l'Agglomération de la Région de Compiègne. Ils ont conçu un questionnaire qui vise à recueillir l'avis des résidents de l'ARC sur l'insertion d'un

Figure 2.8: The means of disseminating the survey

Online and as depicted in figure :2.8, the survey was published on “Le Parisien” newspaper, on the ARC and the UTC social networks and the Linkedin page of the

mayor of Compiègne. It also has been distributed to mailing lists of "Département du Génie des Systèmes Urbains" at the UTC, "Ecole Supérieure de Commerce de Compiègne" and "Lycée Pierre d'Ailly de Compiègne". In addition to contacting some associations and clubs to help in disseminating the survey within their members like: the "club de course à pied", the "Association pour le Maintien d'une Agriculture Paysanne", skating club Compiègne-Oise and the rotary club.

Telephone survey was conducted in order to increase as possible the responses with a varied sample that corresponds to the people who could have been surveyed in the field. In particular, it was necessary to target people who did not have access to the digital means and the elderly that could not reply to our survey online; in order not to have under-representation of this category and to diversify the sample.

The stage of collecting phone numbers began with reliance on the division of cities or municipalities as developed by INSEE⁵ where each city is divided into IRIS⁶ zones based on the number of residents and cities with a population of less than 2000 were IRIS for themselves. Given that a city like Compiègne is likely to have a greater diversity of people surveyed due to its size, compared to other cities, the IRIS zones seems to be so effective in this case. Therefore, we end up having a total of 30 IRIS zones, including 19 IRIS for Compiègne, 4 IRIS for Margny-lès-Compiègne and 7 cities are IRIS for themselves. To search for phone numbers, we decided to take 40 phone numbers per IRIS, which resulted in 1,200 phone numbers being collected across the white pages.

Thereafter, 10 phone numbers were chosen on 4 different streets of IRIS, always with the goal of trying to diversify the sample. Once the phone numbers were obtained, the call phase could start, each IRIS zone having 40 phone numbers was assigned to a PW member, however, as there are only 20 students in this PW, then only 20 IRIS were contacted out of 30. To this end, a target was set to contact 900 people over

⁵INSEE; Institut national de la statistique et des études économiques, <https://www.insee.fr/fr/accueil>

⁶IRIS: Ilots regroupés pour l'information statistique, <https://www.insee.fr/fr/information/2017499>

the phone.

The questionnaire was disseminated online and by phone for 35 days; from 9th of April 2020 to 13th May 2020. However and despite the effort done to respond to the sample size required, the sample collected as illustrated in figure 2.9, was of size 666 that became 591 after cleaning the collected answers ; 61 by phone and 530 over the internet.

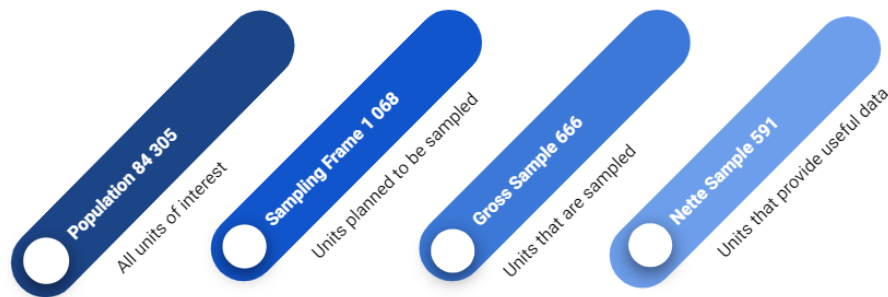


Figure 2.9: Sample Size

2.3 Data analysis design

Data collection is a critical step in any investigative research, however, in order to ensure that the data collected yield useful results that help answer research questions, an appropriate analysis design must be followed. A good data analysis design should start with cleaning up the collected data including removing duplicate or irrelevant observations, filter outliers, missing data processing, and recording. Thereafter, the data will be ready to proceed with the design of a customized analysis appropriate to the case study. The methodology developed in this study will therefore aim to respond to our research questions. It is made up of several large groups in which different analytical techniques (as tabulation and cross-analysis) and methodologies (as significance test and multivariate analysis) were used. The data analysis is made of the following three steps:

- analytical methods: including descriptive analysis, crosstab and significance test, used to analyze general trends and test the genericity of the data collected as well as select the most significant variables;
- descriptive methods: including multiple correspondence analysis (MCA) and hierarchical cluster analysis (HCA), used to analyze underlying structures in the data to identify if there are typical profiles of potential uses of AVs, in order to test and select emerging profiles of potential users;
- explanatory methods: multinomial logistic regression (MLR) used to bring out explanatory factors to better understand what makes individuals lean towards one or the other of the modes of transport.

In this section, the aforementioned steps for analyzing the data are presented along with their explanation.

2.3.1 Analytical methods

Analytical methods were used to understand the data collected and the relations between variables. They are used to describe the sample and check whether it is representative of the population. In addition, they are used to understand the current mobility conditions of the sample (traveling mode, frequency, duration, etc.), their socio-demographic profiles (age, profession, city, etc.), their preferences (mode of autonomous transport, integration scenarios, use of traveling time, etc.) and the relation between the independent variables and the acceptance of AVs.

Starting with descriptive statistics that are used to describe the basic features of the data in the study. They provide simple summaries about the sample and the tested variables. Moreover, they help in highlighting the differences between the values of the variables. Together with graphical analysis, they form the basis for almost any quantitative data analysis (Trochim and Donnelly, 2001).

Then crosstab was performed, also known as contingency table analysis, is used to analyze categorical and nominal data. It is a multi-dimensional table with two or more variables, recording the number of respondents that have chosen a certain value of the variables in the cells of the table. It provides insight into the relationship between the variables.

After building the contingency table, a Chi-square statistic is used for testing the statistical significance of the relationship. The chi-square independent test is used when both variables are categorical (Long and Cheng, 2016). It is used to determine whether or not the two variables are independent, with a null-hypothesis: both variables are independent/ unrelated and an alternative hypothesis stating that both variables are dependent and related. The key element in this technique is to calculate the expected frequencies that would appear if the null-hypothesis was true and the variables are independent and then obtaining the value of chi-square which is the measure of the difference between the expected frequency and the observed frequencies that are obtained from our sample. If the null hypothesis is accepted, then the statistical test will be non-significant and the result is that there is no relation between the variables which means that they are independent. Else, if the null hypothesis is rejected, then the alternative hypothesis is accepted and the results of the statistical test will be statistically significant, thus there is a relation between both variables. That means in our study that the independent variable (one of the six defined variable) affect the acceptance of AVs.

2.3.2 Descriptive methods

Two descriptive methods were used to study underlying variables and to cluster the sample into different groups based on individuals profiles and expected autonomous transport mode to be used. The first method is the MCA and the second is the HCA that are presented in this section.

Table 2.3: An indicator matrix for two variables and four individuals

Individuals	A1	A2	B1	B2	Total
1	1	0	1	0	2
2	0	1	1	0	2
3	1	0	1	1	3
4	1	1	0	1	3
Total	3	2	3	2	10

2.3.2.1 Multiple correspondence analysis

MCA is also known as optimal scaling, appropriate scoring, dual scaling, homogeneity analysis, scalogram analysis, and quantification method (Abdi and Valentin, 2007). It is an extension of the “correspondence analysis” and a generalization of “principal component analysis” when the studied variables are categorical instead of quantitative (Fithian and Josse, 2017). Its importance lies in enabling relationships between both row and column variables, as well as between the values of each variable. It is used to reduce dimensionality when dealing with categorical data. In MCA, the variables are located in a low-dimensional space as points and the distance between the points reflects the similarity between categories points; the points that are close to each other means their categories are similar in distribution (Abdi and Valentin, 2007).

The MCA starts by producing an indicator matrix out of the categorical variables, which corresponds to a table containing rows and columns as binary nominal data. In other words, it is important to express the nominal variables in terms of ratio scale distances. Table 2.3 represents an indicator matrix of 4 rows/individuals and two variables (A and B) each with two values (A1, A2 and B1, B2), the individual scores 0 for a certain value if this value does not represent him, else it scores 1. Thus, the scores of each individual are represented by a row containing zeros and ones according to the individual selection of variables’ values.

After creating an indicator matrix full with zeros and ones, it is important to

transform these values into meaningful distances between points in a cloud (ratio scale chi-2 distances), in order to be able to calculate the new factors and their eigenvalues seeking to reduce the dimensionality. The indicator matrix is then transformed into distances matrix that allows the extraction of the eigenvectors. Each eigenvector explains a share of the total cloud variance, and the sum of all eigenvectors counts for 100% of the variances in the cloud. Seeking to reduce dimensionality to facilitate analysis and comprehension of the data, while reserving the maximum variances represented by the data, the eigenvectors with the highest degree of variance are chosen. For more details on the concepts of the MCA and how it works please refer to Di Franco (2016), Le Roux and Rouanet (2010) and Nenadic and Greenacre (2005).

2.3.2.2 Hierarchical cluster analysis

Cluster analysis is used to enrich understanding of the respondents' demographic background as well as their attitudes and perceptions. It aims to group similar respondents profiles under the same cluster. Thereafter, the characteristics of each group can be investigated by examining its composition. CA is a multivariate method that aims to group a sample of individuals, subjects or objects based on the available measured (studied) variables in a number of different clusters (groups) in a way that makes the individuals in the same group more similar to each other than those in other groups. This is used in our case to identify distinct groups of potential AVs users so that, the preferred autonomous transport mode to be used can be distinguished for each group.

The first step in clustering is to calculate the dissimilarity matrix, which represents how different the points in a data set are from each other. This measurement will be used later to cluster the closet point together in the same cluster while separating the furthest ones. Building a dissimilarity matrix depends on the type of data used since it calculates the distances between individual data points. It is easy to calculate distances between numerical data points, for example, using Euclidean distances. While

the distances between the categorical data points are more difficult to calculate even when using the Gower distance, However, using programming packages, it becomes as simple as running a few codes.

After computing the dissimilarity matrix is important to choose which clustering method to use; hierarchical methods or non-hierarchical methods. The former joins nearby points into a cluster, and then successively adds nearby points to the nearest cluster, it builds a connectivity plot or a dendrogram that can be used to decide the number of clusters. Whereas for the non-hierarchical methods or the K-means the desired number of clusters is specified in advance with assigned centroids for each cluster then the distances between clusters are calculated and new clusters are formulated. Here, the hierarchical clustering is chosen since it is more flexible and it needs fewer hidden assumptions about the distribution of the underlying data.

Hierarchical methods include 1) the agglomerative methods where objects start by being in separate clusters then start to enlarge the groups by combining close groups, this is done repeatedly until all objects become in one cluster; and 2) the divisive methods where all objects start from being in the same cluster then they start separating and becoming narrower by excluding farther points, this is done until each object become in a separate cluster which is the opposite of the former method. However, the final number of clusters is chosen out of all cluster solutions in each method. In this study, the agglomerative methods are adopted.

Moreover, at this step, another decision should be taken that is the method to be used to determine which clusters should be joined at each stage. In hierarchical agglomerative methods, several linkage methods can be chosen (Cornish, 2007). The main methods are as follow:

- single linkage or nearest neighbour: the distance between two clusters is calculated as the distance between the two nearby objects in these two clusters. This method is relatively simple but, it doesn't take account of cluster structure, thus it may result in building long and straggle clusters.

- complete linkage or furthest neighbour: the distance between two clusters is calculated as the distance between the two furthest objects in these two clusters. This method compact clusters of similar size but, as the former, it doesn't take account of cluster structure and it is sensitive to outliers.
- average linkage: the distance between two clusters is calculated as the average of all distances of any pair combination between these two clusters. This method is considered among the most robust methods.
- centroid linkage: the distance between two clusters is calculated as the distance between the two clusters centroids. As the former, this method is considered among the most robust methods.
- ward's linkage: the distance between two clusters is calculated as the sum of all distances of any pair combination between these two clusters. This method builds clusters of approximately equal size and is sensitive to outliers.

It is recommended to use more than one method and compare the resulted clusters so that the analysis can end up with much more believable results. Moreover, the cophenetic correlation coefficient can be used to help in determining which linkage method would result in a better clustering. In statistics, the cophenetic correlation coefficient (CCC) is used as a measure of how well the dendrogram has preserved the pairwise distances between the original data points (Sokal and Rohlf, 1962). The closest the CCC is to 1 the better the linkage method is.

The final step in cluster analysis before interpreting the result is to determine the number of clusters. There are several ways of determining the number of clusters. However, in this study, the number of clusters will be chosen based on the number of clusters just before a large jump in the dendrogram that is just before joining relatively far apart clusters. The dendrogram illustrates the process of gathering clusters together, it shows the clusters that have been joined at each iteration and the distance between clusters at the time of joining. The aim of clustering is to join similar

and close clusters, that is to say, joining clusters when the distance between them is small, however, when the distance is large we should stop joining more clusters.

This section introduces the main concepts and steps in applying MCA and CA. These steps will be performed on the collected data in the next chapter, and their results will be used in the exploratory analysis later.

2.3.3 Explanatory methods

After respondents are grouped into clusters based on their socio-demographic as well as travel-related characteristics and perceptions towards AVs, the next step is to take a closer look at how groups are affected by the six independent variables that are supposed to affect acceptance by applying multinomial logistic regression (MLR). In this study, the categorical dependent variables are the clusters and the independent variables are the predefined variables.

Multinomial logistic regression is used to predict a nominal dependent variable (DV) given one or more independent variables (IVs). It is an extension of binomial logistic regression (BLR) to allow for a dependent variable with more than two nominal or unordered categories (Liao, 1994; Long and Freese, 2006). Like BLR, MLR uses maximum likelihood estimation to evaluate the probability of categorical membership. Moreover, MLR can have IVs of different types (nominal and/or continuous) and can have interactions between them to predict the dependent variable.

In a BLR model, the analysis is done by modeling the odds for falling in one of the two categories (values). In other words, the probability of falling in the first category in relation to the probability of falling in the second category. Similarly, MLR is done by modeling the relationship between the probabilities for each pair of categories. This is done by modeling the odds of falling within one category instead of another out of more than two categories. Let's suppose that we have J values for the DV that is the type of autonomous vehicles to be used and let Π_j be the probability for

a randomly chosen individual to fall into category j (where $j=1, \dots, J$), thus the sum of $\Pi_j s$ is 1. In MLR analysis, the interest is to find if the IVs have an effect on the probabilities of $\Pi_j s$.

In MLR, a baseline category should be determined in order to study how the set of IVs affects the odds for falling into a certain category versus the baseline category. The baseline category (J) can be selected arbitrarily when using software (Hosmer Jr et al., 2013). In the analysis, $J-1$ different logistic models are obtained that pair the baseline category with all the remaining categories. Thus, $J-1$ odd ratios are calculated, where the categories are compared with these ratios, and the model is linearized to obtain logistic models. Note that, the choice of baseline category does not affect the parameter estimates for comparing two categories. The steps and results of this analysis will be presented in next chapter.

In summary, this chapter is presented to explain the procedure used to design a survey to investigate peoples acceptance of AVs, their preferences, preferred autonomous transport mode and potential impacts of AVs. A review of acceptance models and survey and studies concerning AVs had allowed us to choose six independent variables that can influence peoples decision to use AVs or not, these independent variables are socio-demographic status, familiarity with driving and ADAS, past behaviour, perceived usefulness, driving pleasure and trust in the new technology. These variables in addition to the targeted sample characteristics were considered while designing the survey. The sample was chosen from the ARC area, it was not restricted to certain group or profile of people, however, due to the dissemination restraints with the presence of COVID-19 and not allowing infield investigation, the sample was contacted by phone and social media means, hereby most of the people contacted are young to middle-aged but little are elderly that are not so familiar with social media.

After disseminating the survey for 35 days a sample of 666 respondents was collected that became 591 after cleaning the data and deleting incomplete, biased and repeated data. The screened data has to undergo the data analysis design set for this survey

that includes three steps: analytical analysis, descriptive analysis and exploratory analysis. The plan is to use the frequency analysis, crosstab and significance test to build a view of the distribution of the sample on the different tested variables and to test the significance of the relationship between independent variables and AVs acceptance in general. Then, apply MCA and HCA to reduce the variables we are dealing with and to build profiles of users based on their socio-demographic and mobility behaviour, as well as, to cluster (group) the sample into different groups of AVs potential mode users. Finally, use MLR to study which out of the independent variables chosen before are significant in making individuals lean towards one cluster than the other. The next chapter presents the results of applying the analysis design set in this chapter.

Chapter 3: Integration of autonomous vehicles in urban areas as seen by the ARC residents

"By a small sample, we may judge of the whole piece."

*Miguel de Cervantes
(Cervantes, 2018)*

In this chapter, the data collected comes to make sense in studying AVs acceptance and impacts, it reveals the profile of the sample as well as that of each autonomous transport mode potential users. It also presents the individuals' preferences for the AVs' integration in the urban area. Hereby, the results of our study are reported starting from the response rate, the description of the social and demographic characteristics of the sample and the sample representativeness, followed by a reflection of the data analysis section in the previous chapter.

3.1 Survey characteristics: analysis and significance

The analysis section begins by reviewing the main feature of the survey data collected including response rate, sample description, and representation. Followed by a descriptive analysis of each group of questions and then a tabular analysis to test the

relation between the various variables under test.

3.1.1 Main features

This section is very important to understand the possibility to generalize our findings and to support the dissemination method used during the survey. It tests the diversity in the profiles of the respondents contacted and replied. Hereby, it gives us an idea of the typology of the people we have interviewed, which influences the results mightily.

3.1.1.1 Response rate

As previously mentioned in section 2.2.4, the survey was disseminated through two means; 1) online by publishing the questionnaire on different social media platforms, contacting some associations and emailing students at the university and other educational institutions, and 2) orally by contacting some of the ARC residents by telephone. Figure 3.2 represents the number of answers for the survey through both methods and the number of cleaned answers after deleting irrelevant, duplicated and biased answers. As the sample that received our questionnaire online cannot be known, then we decided to check the response rate for people contacted by phone only.

In order to study if phone-questionnaire was effective and important in this study, we checked the responses obtained through phone calls and their response rate. We found that out of the 278 people contacted by phone, 54.7% answered the calls. However, as depicted in figure 3.1, 43.4% out of the 54.7% that answered the call, accept to answer the questionnaire. To end up with 66 answers collected from calling 278 people, thus a percentage of almost 24% which is considered a very low response rate.

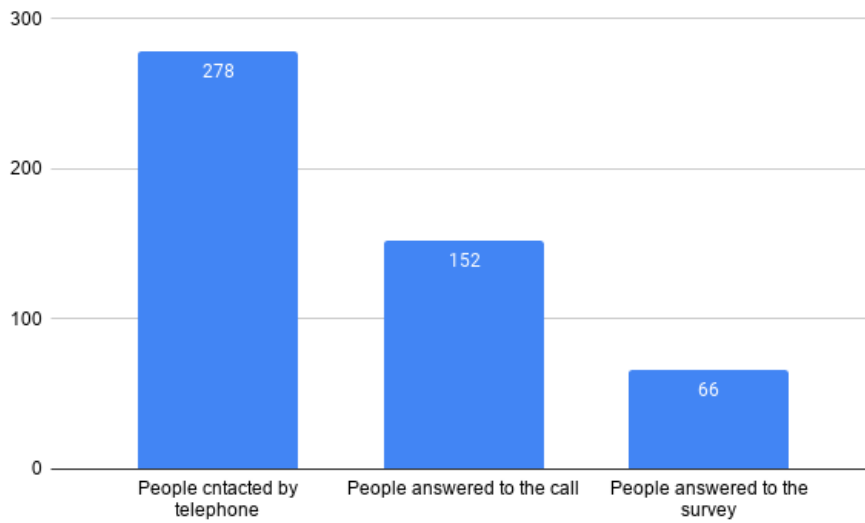


Figure 3.1: The number of people contacted by phone, answered the phone call and answered the survey

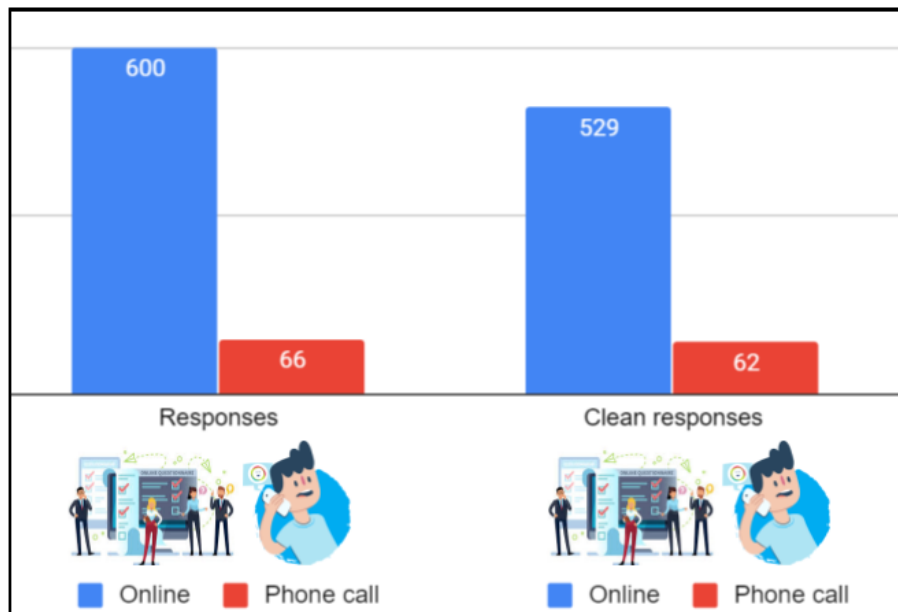


Figure 3.2: The number of respondents for the survey (online and by phone)

Nevertheless, the interest in disseminating the survey through calling people was not aiming just to increase the number of respondents but also to increase the variety of respondents profile and to reach people that are not easily reachable online that are

mainly people who do not use social media frequently. The thing that was confirmed by reviewing the professional activity of the people answering the survey on the phone where, the retired people were the most represented (40%), as shown in figure 3.3. Whereas, they are not well represented by the online sample as will be shown in the next section, thus we can say that contacting people by phone helped the research to be more representative of the population and to enrich the profile of the respondents.

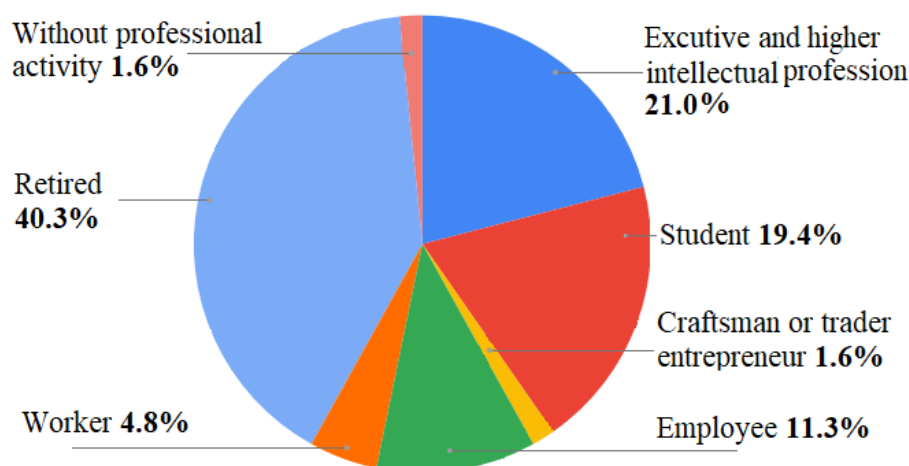


Figure 3.3: The professional activity of the phone sample

3.1.1.2 Sample description

After distributing the survey in the ARC for 33 days we end up with 591 clean responses ready to be studied. The distribution of the sample is presented in table 3.1. As can be noticed from the table, the sample was mainly coming from the city of Compiègne (76.1% n=450), the biggest city and the center of most economical, commercial and social activities in the study area, followed by Jaux (10.3% n=61) then Margny-les-Compiègne (6.5% n=38) while the other six cities count together for almost 7% of the sample.

The gender of respondents was known for all the 591 surveys, with a balance between females (51.3% n=303) and males (48.7% n=288) with slightly more female respondents than male. When the respondents reached the age question they were

asked to indicate their age as intervals. Interval [18 – 24] was the most cited (55.7% n= 329), which is expected because the survey was distributed by students thus, the most contacted people whether by email or social media are people from the students entourage thus, of similar age group. There is also a good presence of people belonging to the age groups [25 – 39] and [40 – 54] with 14.9% and 13.9% respectively. However, young people (Less than 17 years old) and elderly (More than 80 years old) are not well presented in this study with percentages 1.0%(n=6) and 1.7%(n=10) respectively.

The majority of respondents (55.2%; n=326) reported that they are students, this is to be expected as the survey was disseminated by students in a university research. However, the rest of the participants are distributed between executive and higher intellectual profession (20.3% n=120), employee and workers (9.3% n=55), intermediate profession (3.9% n=23) and craftsman or trader or entrepreneur (2.5% n=15). Here the importance of calling people to collect answers appeared where retired people that are elderly and mostly away from social media counts for 6.9% (n=41) of the sample which is hard to attain by online surveys alone.

Moreover, the respondents were also asked about their household composition to find that the majority lives alone (33.8% n=200) and as the members of households increase, the percentage decreases to reach 4.9%(n=29) for a household of more than 6 members. In these households, 38.9% own two vehicles or more, 33.8% own one vehicle and 27.2% do not have any vehicles. The number of diving licenses per household is two for 37.5%(n=222) of the sample, one for 35.9% (n=212) of the sample, three or more for 21.5% (n=127) of the sample and no license for 5.1% (n=30) of the sample. That highlights that the sample we are analyzing is mostly composed of drivers living in families or at least with someone else.

Table 3.1: The sample description

Sample description		Total	Percentage
Sample		591	100,0%
City	Compiègne	450	76,1%
	Jaux	61	10,3%
	Margny-les-Compiègne	38	6,5%
	Saint-Jean-aux-Bois	11	1,9%
	Bethisy-St-Pierre	9	1,5%
	Bienville	8	1,4%
	Saint-Vaas-Longmont	5	0,8%
	Verberie	5	0,8%
	Janville	4	0,7%
Gender	Female	303	51,3%
	Male	288	48,7%
Age	Less than 17	6	1,0%
	[18-24]	329	55,7%
	[25-39]	88	14,9%
	[40-54]	82	13,9%
	[55-64]	47	8,0%
	[65-79]	29	4,9%
	More than 80	10	1,7%
Professional activity	Executive and higher intellectual profession	120	20,3%
	Student	326	55,2%
	Craftsman or trader or entrepreneur	15	2,5%
	Employee	46	7,8%
	Worker	9	1,5%
	Intermediate Profession	23	3,9%
	Retired	41	6,9%
<i>Continued on next page</i>			

Table 3.1 – <i>Continued from previous page</i>			
Sample description		Total	Percentage
	Without professional activity	11	1,9%
Household Size	1	200	33,8%
	2	152	25,7%
	3	83	14,0%
	4	82	13,9%
	5	45	7,6%
	More than 6	29	4,9%
Number of vehicles	0	161	27,2%
	1	200	33,8%
	2 or more	230	38,9%
Number of driving license per household	0	30	5,1%
	1	212	35,9%
	2	222	37,5%
	3 or more	127	21,5%

3.1.1.3 Sample representativeness

In order to be able to generalize the results of this study, the sample should be a good representative of the ARC population, which is the case since a sample of 591 is representative of the population of the nine questioned cities of 60175 inhabitants with a confidence level of 4% and a confidence interval of 95%. However, not only the size of the sample that matter when it comes to representativeness but also the diversity in the sample profile with respect to that of the population. Therefore, a statistical test was obtained by comparing the frequencies of various demographic variables of the sample to those of the population obtained by the National Institute

of Statistics and Economic Studies (INSEE) in 2017.

The comparison was based on the sample distribution in the ARC cities, gender, age, professional activity and the number of owned vehicles, with a few modifications on the age groups since they were not the same on the INSEE site so we had to merge some groups as shown in table 3.2. The Chi-squared test was performed on each factor with:

- null hypothesis: the participants form a random sample and the observed sample reflects normal variability in the population; the sample is representative of the population.
- alternative hypothesis: the participants form a non-representative sample of the population.

The socio-demographic status variables frequencies together with the Chi-squared test results are reported in table 3.2. As can be noticed, the sample is a good representation of the population in term of gender distribution with p-value > 0.05 which is expected since the gender distribution in our sample is (48.7% and 51.3%) and the population (48.22% and 51.78%). But, it is not representative in term of city distribution, professional activity, number of vehicles owned and age.

As a conclusion, the size of the sample is big enough to represent the ARC inhabitants but the diversity in the profiles is not well manifested in the sample. Therefore, the study results can be generalized in the ARC but with special attention to the socio-demographic characteristics. Moreover, the results can be used to compare with different studies in the future.

Table 3.2: Comparison between the sample and the population profiles distributions in percentage

	Variable	S	P	Chi-squared test results
City	Compiègne	76.1	66.9	X-squared = 149.63 df = 8 p-value = 2.2e-16 <0.5 Reject the null hypothesis
	Jaux	10.3	4.3	
	Margny-lès-Compiègne	6.5	13.6	
	Saint-Jean-aux-Bois	1.9	0.5	
	Bethisy-St-Pierre	1.5	5.2	
	Bienville	1.4	0.8	
	Saint-Vaas-Longmont	0.8	1.1	
	Verberie	0.8	6.5	
	Janville	0.7	1.1	
Gender	Female	51.3	52.1	chi-square = 0.061799 df = 1 p-value = 0.8037 >0.05 Accept the null hypothesis
	Male	48.7	47.9	
Age	[15-29]	61	25	X-squared = 432.44 df = 4 p-value = 2.2e-16 <0.05 Reject the null hypothesis
	[30-44]	16	23	
	[45-59]	13	23	
	[60-74]	7	19	
	More than 74	3	10	
Professional activity	Executive and higher intellectual profession	20.3	10	X-squared = 824.09 df = 7 p-value = 2.2e-16 <0.05 Reject the null hypothesis
	Students	55.2	16	
	Craftsman/entrepreneur	2.5	2	
	Employee	7.8	14	
	Worker	1.5	11	
	Intermediate profession	3.9	12	
<i>Continued on next page</i>				

Table 3.2 – <i>Continued from previous page</i>				
Variable		S	P	Chi-squared test results
	Retired	6.9	24	
	Without activity	1.9	10	
Number of vehicles	0	27.2	19	X-squared = 67.238
	1	33.8	50	df = 2
	2 or more	38.9	31	p-value = 2.509e-15 < 0.05 Reject the null hypothesis

3.1.2 Descriptive analysis

This section presents the results of the descriptive analysis that displays respondents' attitudes and preferences. It is important in describing the sample and the various variables tested in the survey, moreover, it reveals the associations between the variables. In addition to the socio-demographic variables presented previously, the respondents were asked several questions about their current mobility behaviour, their intention to use autonomous vehicles on different modes, and their perceptions and attitude towards AVs. The survey questions can be grouped under eight headers as follow:

3.1.2.1 Familiarity with automation and AVs

In this survey, familiarity with AVs was studied based on two aspects, whether the respondents had heard about AVs before the study or if they had used Advanced driving assistance system (ADAS), as they are essential for the AVs functionality. The majority of respondents (92.83%) stated that they know what AVs are. Moreover, as shown in figure 3.4, 49% of the respondents already used some of the ADAS functions

while driving; the ADAS functions and the percentage of people that used each of them are reported in figure 3.4 as well.

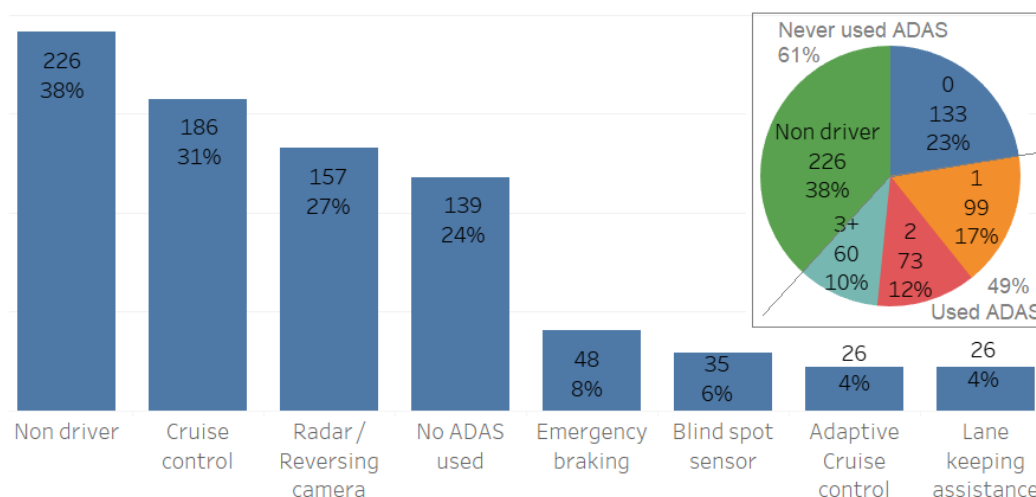


Figure 3.4: Advanced driving assistance system (ADAS) functions used by respondents and the number of used functions

3.1.2.2 Past mobility behaviour

In order to build an idea about the past travel behaviour of the respondents which is essential to predict their potential future travel behaviour, the respondents were asked to describe their most important trip in a week. Their answers are presented in figure 3.5, which shows the significance of the most important trip where 60.41% of the respondents iterate this trip more than six times a week and 21.67% iterate it five to six times. The figure also shows that most of the respondents' trips are not much far, where 60.75% of the trips take between 5 to 15 minutes and 8.02% are for less than 5 minutes, while the trips that take longer time are less reported.

Figure 3.5-(c) reports the used travel mode for the most important trip. As can be seen, 41.96% of trips are done using private vehicles (PV) and 3.05% by professional vehicles that are used privately, which is an indicator that the sample is a car-loving sample or that the public transport in the study area is not good enough to compete

the PV; as only 14.38% of the respondents use urban public transport and interurban trains. The rest of the trips are done walking (24.70%), cycling (13.71%) or by skateboard and scooters (0.51%). Moreover, in order to integrate the travelling mode in the other analysis, the travelling modes were grouped in three groups: private vehicles (PV), public transport (PT) and soft modes (SM) including all non-motorized modes, as presented in figure 3.5-(d).

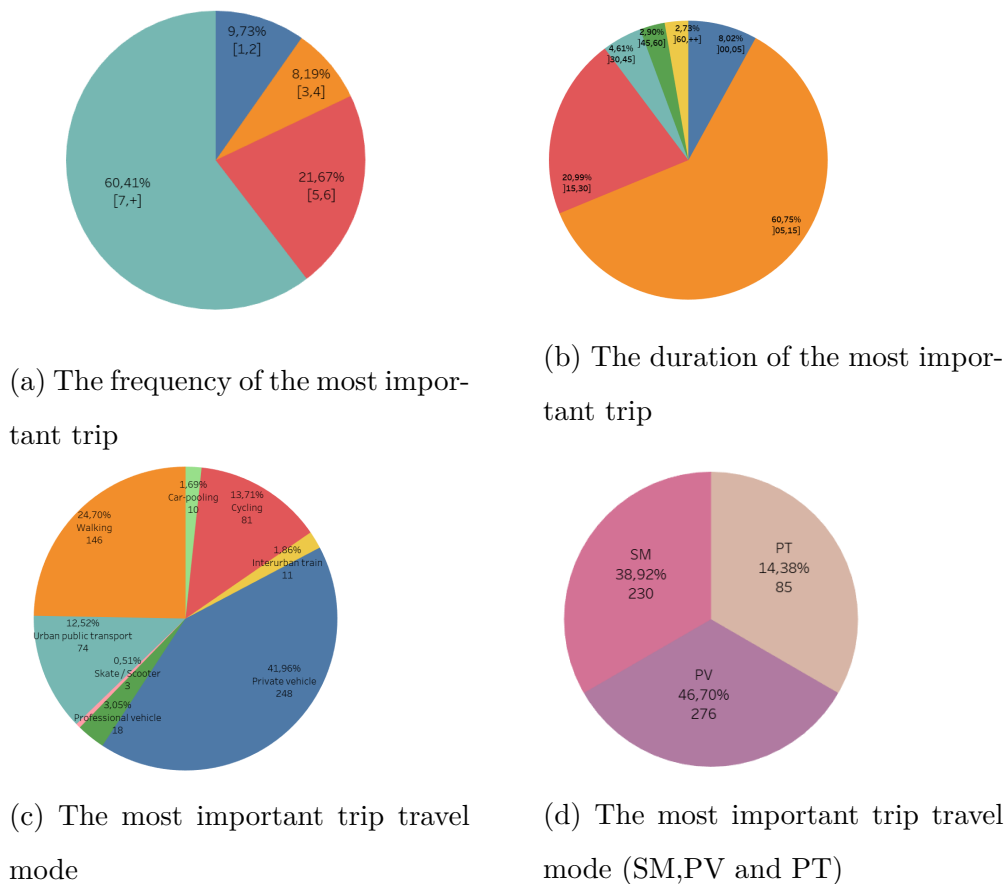


Figure 3.5: Frequency distribution of the most important trip frequency, duration and travel modes (SM, PV and PT)

The reasons for choosing one mode over the other were also questioned. As presented in figure 3.6, PV -the most used mode (46.70%)- is chosen by the ARC population mainly for respecting the users' independency, being comfortable and for not having other alternatives. Whilst, the second reported mode the SM (38.92%) is

reported for being environmentally friendly, independent and practical. Finally, PT modes are used by 14.38% of the respondents since they are of low cost or free, practical and the only possible mode.

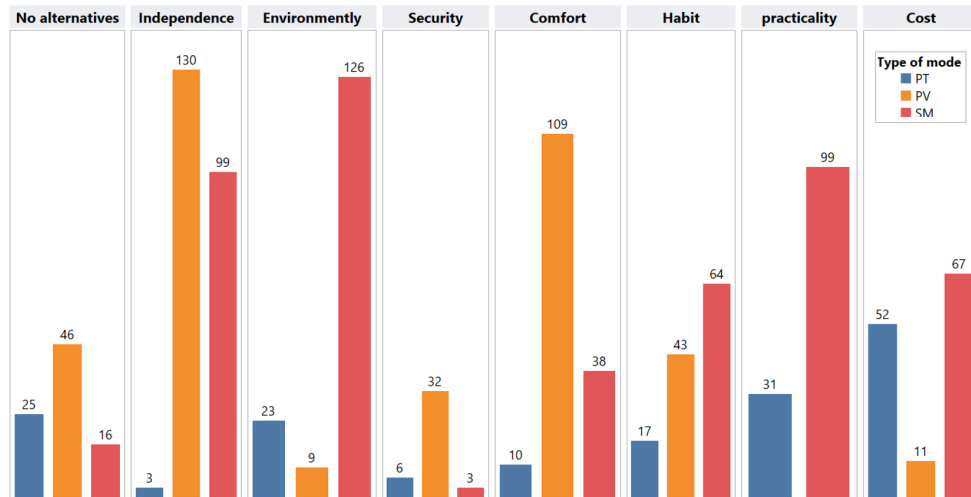
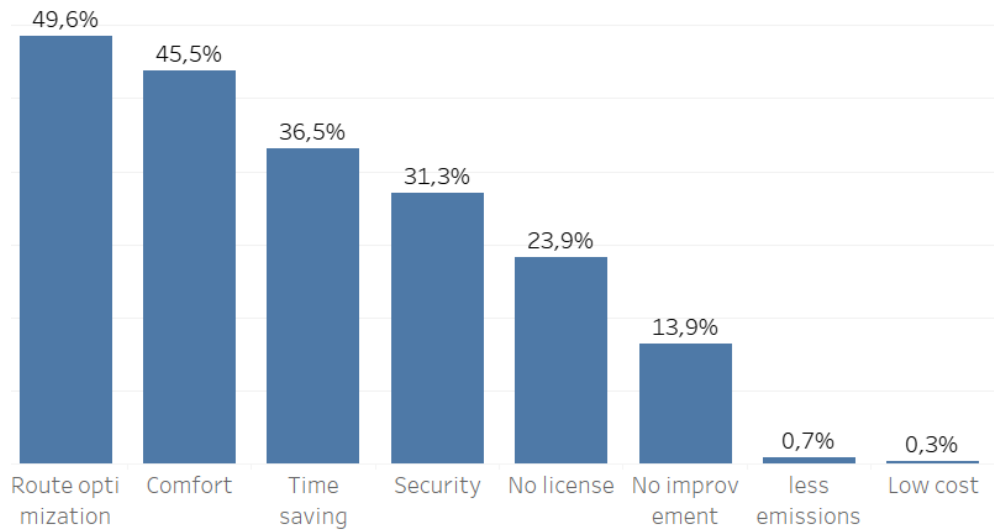


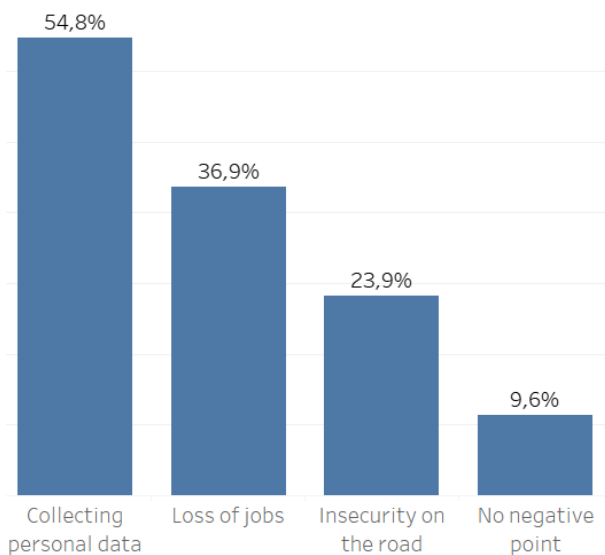
Figure 3.6: Reasons for choosing the most important trip travel mode for SM,PV and PT

3.1.2.3 The perceived usefulness of autonomous vehicles

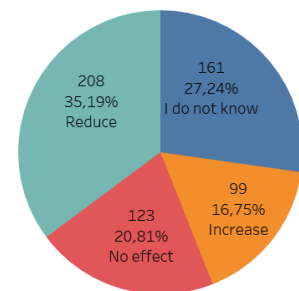
AVs are promoted by automakers as the future of sustainable, safe and smart mobility. However, automakers are not the only users of AVs, thus, a study of public perception about the benefits and concerns of AVs was necessary. Figure 3.7 represents the frequency distribution of participants answers for three questions related to the expected impacts of AVs (positive and negatives).



(a) Participants perception of the advantages of autonomous vehicles



(b) Participants perception of the disadvantages of autonomous vehicles



(c) Participants perception of the impacts of autonomous vehicles on road accidents

Figure 3.7: Participants perception of the impacts of autonomous vehicles

The majority of participants believes that AVs will enhance route navigation (49.6%) relying on advanced technology and especially connectivity, comfort (45.5%), traveling time (36.5%), security (31.3%), etc., as in figure 3.7-(a). On the contrary, AVs will be a big concern when it comes to collecting personal data (54.8%), losing jobs

as drivers and other related jobs (36.9%) and insecurity on the road (23.9%). While AVs effect on the number of road accidents was studied as a single question, to find that 35% of the people think AVs will reduce the accidents, 16% believe the opposite while the others were neutral.

3.1.2.4 Driving pleasure in autonomous vehicles

Driving pleasure was raised by previous studies (refer to section 2.1.1) and thus it was tested in this study. Figure 3.8 shows that almost 55% of the participants are concerned with the fact that AVs will reduce the act of driving. Thus, this factor can have negative impact on the acceptance of AVs as more than half of the sample have selected it.

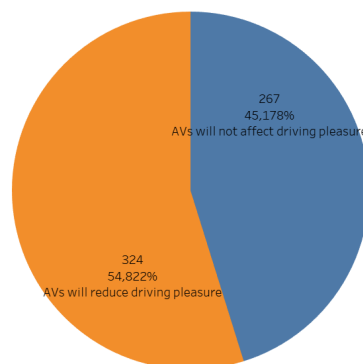


Figure 3.8: Effect of autonomous vehicles on driving pleasure

3.1.2.5 Trust in new technologies

Trust is a very important factor when it comes to accepting autonomous vehicles, AVs are going to change the standard travelling system by making vehicles controlled by codes and not humans. Giving software the control of the vehicle (with our lives in the vehicle) is not an easy-to-take decision. Trust was studied as trust in technologies similar to that used in AVs, refer to figure 3.9.

A generally positive view is found where 76.6% of the surveyed people stated that

they trust driverless metros and trams, 71.6% trust GPS and navigation applications, 65.1% trust ADAS and 21% trust cybersecurity to prevent hacking which is one of the main concerns about AVs performance. However, only 4.4% of the sample stated that they do not trust any of these technologies, which is a relatively low percentage especially if compared with other studies (refer to section 2.1.1).

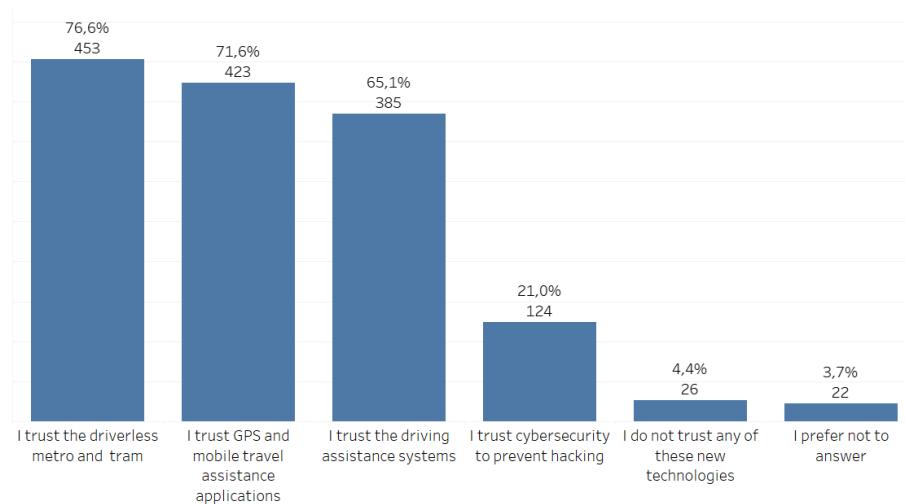


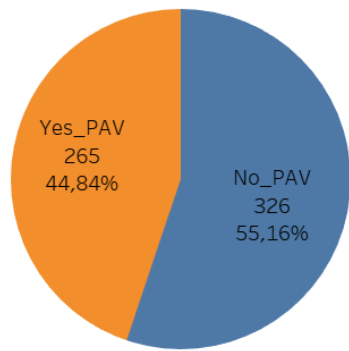
Figure 3.9: Respondents trust in techniques similar to those to be integrated into autonomous vehicles

3.1.2.6 Intention to use autonomous vehicles (private and shared)

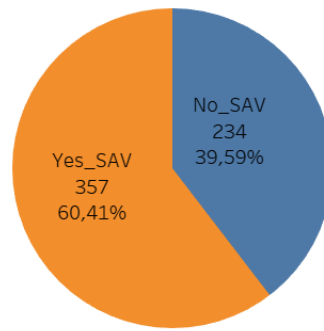
The real use of AVs cannot be tested as long as the AVs are not publicly available, which is why we have tested the intention to use AVs instead of the actual use. Moreover, as long as the same conditions surround the participants, the intention to use should be a good reflection of future use unless changes are made to the factors that affect the intention; an increase in the accident rates of AVs that affect trust and perceived usefulness at the same time, for example.

The intention to use AVs was studied as the intention to use private autonomous vehicles (PAV) and shared autonomous vehicles (SAV). Figures: 3.10-(a)& 3.10-(b) show the distribution of the sample as users of PAV and users of SAV, figure 3.10-(c)

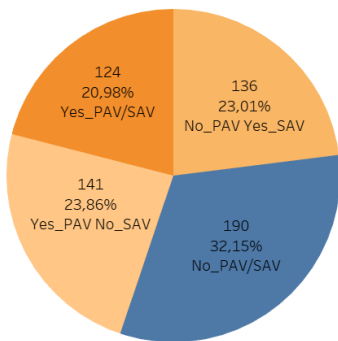
is a combination of both figures as one graph, it shows that 32.15% of those surveyed are totally against the use of AVs, they do not intend to use AVs neither as PAV nor as SAV. On the contrary, 20.98% of people are ready to use PAV and SAV. In addition, it should be noted that 23.01% of people who do not wish to use PAV are ready to use SAV and 23.86% are ready to use PAV but not SAV. Moreover, it can be noticed that there are more people interested in SAV (60.41%) than in acquiring personal autonomous vehicles (44.84%). The thing that highlights the trend in moving from personal to shared mobility. In general, 67.85% of respondents intend to use AVs as PAV or SAV while only 32.15% do not, that shows a general positive intention to use AVs as shown in figure 3.10-(d).



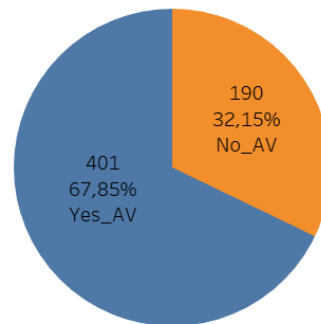
(a) Participants intention to use PAV



(b) Participants intention to use SAV



(c) Participants intention to use PAV, SAV, both or non of them



(d) Participants intention to use AV whether SAV or PAV

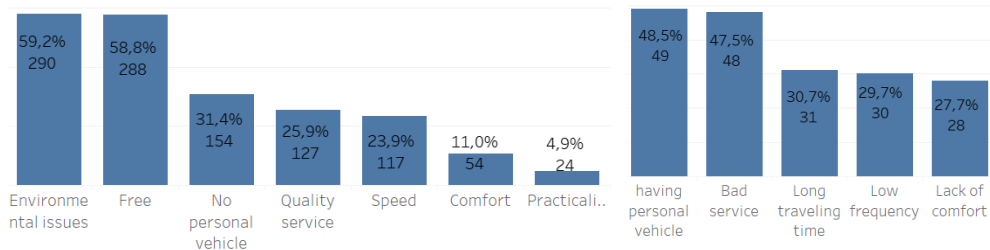
Figure 3.10: Participants intention to use PAV and SAV

3.1.2.7 The transition from public transport to public autonomous transport

To build a sustainable mobility system, it is important to improve mass mobility not only small scale shared mobility that serves a small group of people at the same time, but also public transport (PT) on its large scale. To this end, it was important to study people's use of PT, encouraging factors for the PT use and the dissuading factors and the expected changes automation will bring to PT; the frequency distribution of such questions are presented in figure 3.11.

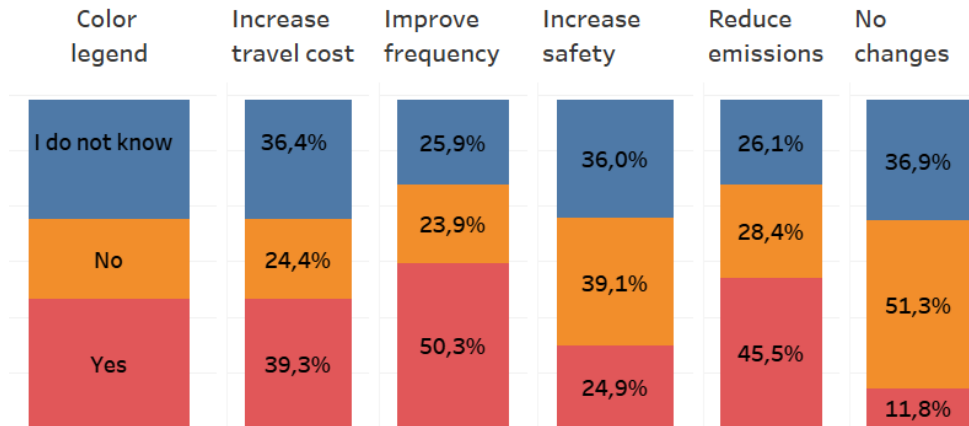


(a) The participants frequencies of using PT per week



(b) Reasons for using PT

(c) Reasons for not using PT



(d) The benefits of using public autonomous transport

Figure 3.11: The percentages of participants who use PT, the reasons for using or not using PT and the benefits automation will bring to PT

As is evident from figure 3.11-(a), the studied sample is not a PT lover, where 17.09% of the sample stated that they never use PT and 65.65% use PT rarely as once or twice per week, It is likely that they have another mode of transport for their daily travels, while only 17.26% of the respondents use PT more than twice per week. The sample was then divided into two sub-samples: the PT-users (at least used PT once per week) and the PT-non-users, to inspect the reasons for using or not the PT. As demonstrated in figures: 3.11-(a) & 3.11-(b), the most important reasons

for using PT in addition to not having a personal vehicle are environmental issues (reducing the use of PV thus reducing energy consumption, hence reducing emissions of air pollutants and greenhouse gases) and being free in the ARC area. On the other hand, people who do not use PT declared that they prefer other modes since PT is of bad services (47.5%), long travelling time (30.7%) and low frequency (29.7%).

Asking people about their perception of the impacts of automation on the PT, we found that 50.3% of the people believe that automation will improve PT frequency which could encourage non-users to become users as this was of their important dissuading factors. Moreover, 45.5% of participants think that public autonomous transport (PAT) will reduce emissions and are more eco-friendly than PT, the thing that enhances PT-users to be more looking for PAT. Whilst, 39.3% of the participants believe that PAT will increase travel cost that most probably will make PT not free and will affect PAT attraction for PT-users.

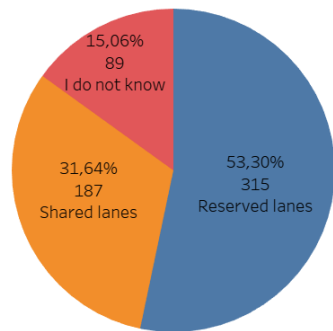
3.1.2.8 The effects of autonomous vehicles on urban areas

The effects of the AVs on the urban area and urban system are as presented in section 1.2.1, mainly based on the mode of autonomous transport to be used, which is an important question of this study. However, there are many other aspects that play an important role in predicting AVs impacts, some cannot be tested in this study like legislation and policies while others like people's intention to change their living location and their perception of how AVs will operate were tested in this study.

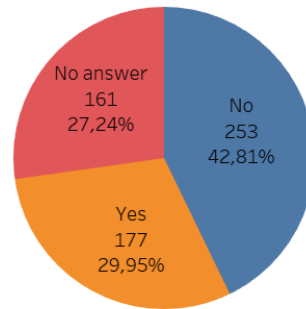
As shown in figure 3.12, a high percentage (42.81%) of respondents are not willing to change their living location if they had the chance to use autonomous transport, while only 29.95% of the participants state that they would change their location and the others could not choose or decide. If, as presented in this study, more than a quarter of the population changed their living location, the impacts will be enormous including changing land prices, taxes, crowding, services needs, traffic conditions, etc.

The respondents who stated to like to change their location were asked also to say what they expect to do in an AV, especially if changing location and increasing the commuting time that increases the time in the vehicle. As a result, 45.43% of the sample seems to prefer having fun the vehicle whether by listening to music, reading a book, watching movies, chatting, surfing the net or playing a game, 35.60% would do working tasks and 16.62% would regard the street and stay focus and ready to take control at any minute.

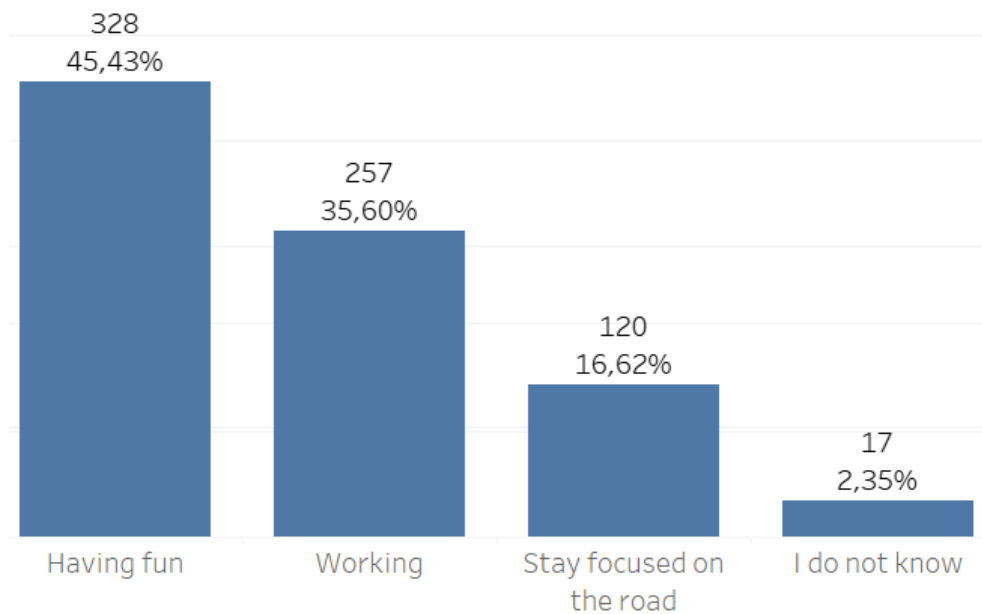
When it comes to deciding how AVs should operate whether on reserved lanes or on same lanes as other conventional vehicles, almost 53% of the questioned people prefer that AVs operate on reserved lanes which shows high concerns towards the integration of AVs in the traffic system, 32% voted for sharing lanes with conventional vehicles, while the others did not choose; refer to figure 3.12.



(a) Participants who prefer that AVs operate on reserved lanes or on shared lanes with traditional traffic



(b) Participants who would change their living location if autonomous vehicles became real



(c) The tasks that participants prefer to do while travelling

Figure 3.12: Participants perceptions about traffic lanes, changing living location and tasks to do in an autonomous vehicle

The descriptive analysis shows that the majority of respondents are familiar with the concept of AVs and their operation. It also shows that almost half of the sample are PV users and almost 40% are SM users while the few rests are PT users when asking about the most repeated trip that is in most of the answers less than 15 minutes the thing that encourages SM use. When considering the public perception towards

the impacts of AVs, we find that a relatively high percentage of the participants believes that AVs will enhance traveling conditions and security on roads, but still, the concerns related to collecting personal data and losing jobs are high. Trust in AVs technologies as compared to other studies is somehow high, where the majority of respondents trust ADAS, navigation applications and driverless metros and trams, as well as, a fifth of the sample believe that cybersecurity will prevent hacking the vehicle. Moreover, almost 70% of respondents intend to use AVs as PAV or SAV which reflects a high intention to adopt AVs. Thus, raising the question of how AVs will affect the transport system, especially that half of the sample want AVs to operate on reserved lanes that will affect the transport as well as the urban system.

3.1.3 Crosstab analysis

In order to build a first view on the relation between the defined independent variables (socio-demographic status, familiarity, past mobility behaviour, perceived usefulness, driving pleasure and trust) and the dependent variable (intention to use AVs), we had performed a crosstab analysis followed by a chi-square test. Crosstab can be considered as a branch of descriptive analysis where more than one variable is studied at the same time. The results of crosstab are highly biased by sample size and sample distribution, they are based mainly on the researcher intuition, that is why a test to validate the results is necessary which is the chi-square test in this study.

Therefore, we started by studying the relation between socio-demographic status and acceptance of AVs. Table 3.3, presents the distribution of socio-demographic variables (gender, age, professional activity, household size and number of owned vehicles per household) in two categories: people who intend to use AVs (as PAV or SAV) and people who do not. As presents in the table, males seem more willing to use AVs than females with a ratio 77.66% to 59.00%, which was confirmed by previous studies as in Konig and Neumayr (2017), Zwerver (2016), Piao et al. (2016) and Hulse et al. (2018); as men by nature have a greater love for new technologies and

adventures than women (He and Freeman, 2019).

Table 3.3: Contingency table of socio-demographic status and willingness to use AVs

Variable	Value	No AV		Yes AV	
Gender	Female	123	41.00%	177	59.00%
	Male	64	22.38%	222	77.62%
Age	Less than 17	3	50.00%	3	50.00%
	[18-24]	89	28.25%	226	71.29%
	[25-39]	23	27.71%	60	72.29%
	[40-54]	26	33.33%	52	66.67%
	[55-64]	13	31.71%	28	68.29%
	[65-79]	11	39.29%	17	60.71%
	More than 80	5	55.56%	4	44.44%
Professional activity	Executive/higher intellectual	30	25.42%	88	74.58%
	Student	100	30.77%	225	69.23%
	Craftsman/trader/entrepreneur	2	13.33%	13	86.67%
	Employee	21	45.65%	25	54.35%
	Worker	4	44.44%	5	55.56%
	Intermediate profession	7	30.43%	16	69.57%
	Retired	19	48.72%	20	51.28%
	Without professional activity	4	36.36%	7	63.64%
Household Size	1	68	34.34%	130	65.66%
	2	49	32.45%	102	67.55%
	3	20	24.69%	61	75.31%
	More than 3	50	32.05%	106	67.95%
Number of vehicles	0	48	30.00%	112	70.00%
	1	66	33.33%	132	66.67%
	2 or more	73	32.02%	155	67.98%

Similarly, it can be noticed that age intervals 18 to 24 and 25 to 39 embrace the peo-

ple that are most looking for AVs with percentages 71.29% and 72.29% respectively. Whereas older people are less likely for AVs adoption with percentages between 60% and 67%. Nevertheless, no conclusions can be drawn for people less than 17 as only six persons in the sample belong to this group age.

Professional activity has eight groups, as seen in table 3.3, they can be grouped into three groups. The first group including executive/ higher intellectual profession and craftsman/trader/entrepreneur with the highest percentages of people willing to use AVs (75% and 86%), the second group includes intermediate profession and students with percentages around 69% and the third group including employees, workers, retired and those without professional activity with the lowest willingness to use AVs (between 54% and 63%).

For household size and vehicles owned not much can be concluded as different groups have similar distributions between AVs potential users and non-users, for household size the percentages of potential users for different groups range between 65% to 75% and for vehicles owned the range is narrower (between 67% and 70%).

However, in order to confirm the relations that we build, a chi-square test was performed for each relation and their results are reported in table 3.4. Considering gender, "H0" is the hypothesis that gender and acceptance of AVs are independent, in other words, there are no differences between choosing to use AV (Yes AV) or not to use AV (No AV) with respect to the individual's gender. While "Ha" that is the alternative hypothesis states that an individual's gender and his/her intention to use AVs are related. As can be noticed from table 3.4, the test of chi-square is significant at 99.9% (p-value <0.01) in this case. However, as the chi-square depends on the size of the sample and the degree of freedom, the Cramer test is provided too, which gives information on the strength of the relation between two variables. The closer the Cramer index is to 1 the stronger the relation, however, a value bigger than 0.25 is considered as a very strong relation (Akoglu, 2018). According to Cramer index, the relation between gender and intention to use an AV is very strong. Similarly, it can

be found that professional activity has a strong relation with AVs acceptance, while, age, household and number of owned vehicles seem not to affect the acceptance of AVs.

Table 3.4: Hypothesis test result for socio-demographic status

Variable	Chi-square	p-value	Cramer's V	Result
Gender	23.63181	0.00002	0.2	Reject H0; very strong relation
Age	6.2875	0,3918	0,1031	Accept H0
Profession	14,6209	0,0412	0,1573	Reject H0; strong relation
Household size	2.5307	0.4698	0.0654	Accept H0
Vehicles owned	0,3843	0,8252	0,0255	Accept H0

The relation between familiarity and acceptance of AVs was studied based on two questions, whether the respondents know what AVs are and whether they had used some of the ADAS functions before. The majority of the respondents (92.83%) stated that they know AVs, and out of those who know AVs almost 70% intend to use AVs as reported in table 3.5, even people who do not know AVs show a relatively high intention to use AVs (61.9%) which make it hard to draw conclusions.

On the other hand, when it comes to the ADAS functions used, the number of functions used are counted and presented in table 3.5. It can be seen that the more ADAS functions an individual uses, the more likely he intends to use AVs. Only those who do not use any ADAS functions are mostly not ready to use AV. Hence, we can conclude that testing and using some of the ADAS functions encourage individuals to use AV in the future.

Table 3.5: Contingency table of familiarity variables and willingness to use AVs

Variable	Value	No AV		Yes AV	
		Know AV	No	16	38.10%	26	61.90%
	Yes	171	31.43%	373	68.57%
Number of ADAS functions used	0	48	36.46%	83	63.36%
	1	31	31.63%	67	68.37%
	2	25	34.25%	48	65.75%
	3	7	22.58%	24	77.47%
	4	4	23.53%	13	76.47%
	5	0	0%	3	100%
	6	0	0%	8	100%

However, according to the chi-squared test, both variables are not linked to AVs acceptance as shown in table 3.6. However, even though they seem not related to AVs acceptance but in the later sections, they will be studied for different sub-sample groups (potential users of PAV, of SAV and of PAT), which could draw relation in certain groups and not all as here.

Table 3.6: Hypothesis test result for familiarity variables

Variable	Chi-square	p-value	Cramer's V	Result
Know AV	0.7329	0.3919	0.0352	Accept H0
Number of used ADAS	8.8334	0.2648	0.1223	Accept H0

The relation between past mobility behaviour and acceptance of AVs was then studied based on the mobility for the most important trip per week including the trip frequency, the trip duration and the travel mode for this trip. According to the contingency table 3.7, individuals who repeated their trip more than twice per week are more likely to adopt AVs (about 70%), whereas, individuals with less mobility, as the frequency of their most important and repeated trip, are once or twice per week

are less likely to adopt AVs (60%), but, they still show a high positive intention to use AVs.

Table 3.7: Contingency table of past mobility behaviour variables and willingness to use AVs

Variable	Value	No AV		Yes AV	
Most important trip frequency	[1,2]	23	40.35%	34	59.65%
	[3,4]	14	29.17%	34	70.83%
	[5,6]	43	33.86%	84	66.14%
	[7,+]	107	30.23%	247	69.77%
Most important trip duration	]00,05]	12	25.53%	35	74.47%
	]05,15]	116	32.58%	240	67.42%
	]15,30]	42	34.15%	81	65.85%
	]30,45]	11	40.74%	16	59.26%
	]45,60]	4	23.53%	13	76.47%
	]60,++]	2	12.50%	14	87.50%
Travel mode for the most important trip	PT	24	28.24%	61	71.76%
	PV	92	33.33%	184	66.67%
	SM	71	31.56%	154	68.44%

The relation between the duration of the most important trip and the intention to use AVs is not so clear in the table, as people making short trips and people making the longest trips, more than 45 minutes, are more likely to use AVs than participants that make trips with duration from 15 to 30 minutes. Moreover, the travel mode used seems not to be related to the intention to use AVs as the three modes register similar percentages for AVs-users (around 68%). The results of the chi-square tests come in line with our conclusions as to that related to trip duration and travel mode that are not related to AVs adoption, but unlike our expectations, even for trip frequency, the test found no relation as presented in table 3.8.

Table 3.8: Hypothesis test result for past mobility behaviour variables

Variable	Chi-square	p-value	Cramer's V	Result
Trip duration	6.6369	0.2491	0.1060	Accept H0
Trip frequency	2.5078	0.4739	0.0651	Accept H0
Trip mode	0.7744	0.6790	0.0362	Accept H0

The relation between perceived usefulness and acceptance of AVs was also tested. It is expected that people who think AVs will bring benefits for them and for the universe should be more open for AVs than people who think the contrary. The thing that was confirmed in this study too, as people who think AVs will improve route navigation (78.69%), improve security (88.04%), reduce travel time (86.05%), improve trip comfort (80.97%), reduce the need for driving license (76.81%) and reduce accidents(88.89%) are more looking for AVs than people who do not think so. Whereas, people who believe that AVs will affect negatively privacy (64.80%) and accidents (43.43%) are less looking for AVs (refer to table 3.9). As can be noticed, improvements in security and accidents are the most affecting variables with the highest percentages around 88%. These relations were also confirmed by the chi-square tests (see table 3.10), where most of these factors showed strong relations with AVs acceptance.

Table 3.9: Contingency table of advantages of AVs and the willingness to use them

Variable	Value	No AV		Yes AV	
AVs will improve route navigation	No	125	42.37%	170	57.63%
	Yes	62	21.31%	229	78.69%
AVs will improve security	No	165	41.04%	237	58.96%
	Yes	22	11.96%	162	88.04%
AVs will reduce travel time	No	157	42.32%	214	57.68%
	Yes	30	13.95%	185	86.05%
AVs will improve trip comfort	No	136	42.77%	182	57.23%
	Yes	51	19.03%	217	80.97%
AVs will reduce privacy	No	74	27.92%	191	72.08%
	Yes	113	35.20%	208	64.80%
AVs will eliminate the need for driving license	No	155	34.60%	293	65.40%
	Yes	32	23.19%	106	76.81%
AVs will affect accidents	increase	56	56.57%	43	43.43%
	not affect	41	33.88%	80	66.12%
	reduce	23	11.11%	184	88.89%

Table 3.10: Hypothesis test result for usefulness of AVs

Variable	Chi-square	p-value	Cramer's V	Result
Improve navigation	30.1986	0.0000	0.2260	Reject H0; strong relation
Improve security	50.6595	0.0000	0.2928	Reject H0; strong relation
Reduce travel-time	52.0342	0.0000	0.2967	Reject H0; strong relation
Improve trip-comfort	37.1881	0.0000	0.2508	Reject H0; strong relation
Reduce privacy	3.6785	0.0551	0.0789	Reject H0; weak relation
Eliminate licenses	6.4917	0.0108	0.1048	Reject H0; moderate relation
Affect accidents	77.4302	0.0000	0.3620	Reject H0; strong relation

Unlike previous studies that highlighted the need to study driving pleasure in forecasting AVs' acceptance, in this study, the effect of reducing driving pleasure was not found to be an important factor. In fact, both groups of individuals who believe that AVs will reduce driving pleasure and those who do not believe that, have an approximately equal percentage of those who would like to use AVs (68%) and those who would not use; as reported in table 3.11. The same result was confirmed in table 3.12 by the chi-square test result for this factor.

Table 3.11: Contingency table of driving pleasure and willingness to use AVs

Variable	Value	No AV		Yes AV	
		Driving pleasure	will not be affected	83	31.56%	180	68.44%
	will be reduced	104	32.20%	219	67.80%

Table 3.12: Hypothesis test result for driving pleasure

Variable	Chi-square	p-value	Cramer's V	Result
Driving pleasure	0.0220	0.8822	0.0061	Accept H0

Finally, the relation between trust and acceptance of AVs was tested. Table 3.13 reports the distribution of the sample percentage between five variables testing trust and the intention to use AVs. It is easy to see that participants who declared that they trust ADAS and cybersecurity in AVs are more looking for AVs (76.90% & 81.30%) than those who do not trust them (51.71% & 64.58%). It is worth to note that the latter group is also in favour of AVs but with less intention than the former.

However, trust in driverless metros/trams and trust in new technology seems to be more crucial variables. Individuals who trust these variables are more willing to use AVs, whereas, individuals who do not trust them are most probably not going to use AVs. Therefore, they can be very essential in determining AVs-users and AVs-non-users. This is to be expected given that they form the cornerstone of trust in

AVs, as, people who are sceptical about new technologies are not expected to easily accept advanced technologies and automation. Moreover, people who do not trust driverless metro and trams running on reserved lanes and tested by many people, are not expected to trust AVs as well.

Table 3.13: Contingency table of trust measures and willingness to use AVs

Variable	Value	No AV		Yes AV	
Trust in ADAS	Yes	88	23.10%	293	76.90%
	No	99	48.29%	106	51.71%
Trust in driverless metros and trams	Yes	107	23.88%	341	76.12%
	No	80	57.97%	58	42.03%
Trust in GPS and navigation applications	Yes	127	30.24%	293	69.76%
	No	60	36.14%	106	63.86%
Trust in new technologies	Yes	170	30.36%	390	69.64%
	No	17	65.38%	9	34.62%
Trust in cybersecurity in AVs	Yes	23	18.70%	100	81.30%
	No	164	35.42%	299	64.58%

Participants were also asked to state whether they trust GPS and mobile navigation applications as AVs are expected to rely on similar technology to navigate without a human driver. As presented in table 3.13, individuals who answered "yes" and those who answered "no" for this question have almost equal probabilities for accepting AVs (69.76% and 63.86%). Thus, this variable seems not to be important as expected. The same result was confirmed by the chi-square test in table 3.14, by accepting the null hypothesis with a p-value greater than 0.5.

Table 3.14 also reveals that trust in ADAS, driverless metro/trams, new technology and cybersecurity have strong relations with accepting AVs.

Table 3.14: Hypothesis test result for trust variables

Variable	Chi-square	p-value	Cramer's V	Result
Trust in ADAS	36.6924	0.00001	0.2492	Reject H0; very strong relation
Trust in driverless metros and trams	55.0337	0.0000	0.3052	Reject H0; very strong relation
Trust in GPS and navigation applications	2.4338	0.1187	0.0642	Accept H0
Trust in new technologies	13.7721	0.0002	0.1527	Reject H0; strong relation
Trust in cybersecurity in AVs	13.3070	0.0003	0.1501	Reject H0; strong relation

To summarize the results of the crosstab analysis shows that the factors socio-demographic status, perceived usefulness and trust in automation are effective when studying intention to use AVs. Although not all measures of socio-demographic status were effective as only gender and professional activity showed strong relations with acceptance but, they were sufficient for accepting the overall relation. Whereas, familiarity, past mobility habits and driving pleasure were found in all their scale items not to affect the acceptance of the AVs. The effect of these factors will be investigated again when the sample is clustered into different groups of autonomous transport mode users, in order to understand if they affect the groups differently. The point is to check if the relation between these factors and the acceptance of PAV, SAV or PAT separately can be generalized from their relation with the acceptance of AVs in general.

3.2 Survey data: underlying structures

As can be noticed, from the crosstab analysis, several questions were used in the survey to investigate the same variable, thus we decided to use MCA to lower the dimensionality and reduce the data we are dealing with, to facilitate later analysis. Moreover, MCA was also used to draw a general view of the profiles of the respondents and their AVs related preferences. Hierarchical cluster analysis was then performed to cluster the sample into different autonomous transport modes users.

3.2.1 Dimension reduction

As can be seen in section 3.1.3, five of the six acceptance influencing factors are tested through a list of questions since they cannot be measured directly. Thus, the aim of this section is to create fewer dimensions that can reflect individuals respond to each of socio-demographic, familiarity, past mobility behaviour, perceived usefulness and trust variables. Driving pleasure is studied with only one question, so it will be used later as a stand-alone variable.

The MCA was performed on data containing 25 columns (variables) and 591 rows (individuals). Only the first four dimensions were considered in the interpretation. These dimensions present an amount of inertia greater than those obtained by the 0.95-quantile of random distributions (28.5% against 27.32%), which suggests that only these dimensions are carrying real information. The thing that was also suggested by Bendixen (1995), who stated that only dimensions with contribution more than the average inertia of each variable (AIV) should be considered important and included in the solution for the interpretation of the data; the AIV is the maximum of the rows and columns expected eigenvalues that are $1/(\text{number of rows} - 1) \cdot 100$ and $1/(\text{number of columns} - 1) \cdot 100$ respectively. In this case, the AIV is equal to 4.17% and as presented on figure 3.13, it is just below the fourth dimension (presented as a

red line), thus, the interpretation will only include the first four dimensions.

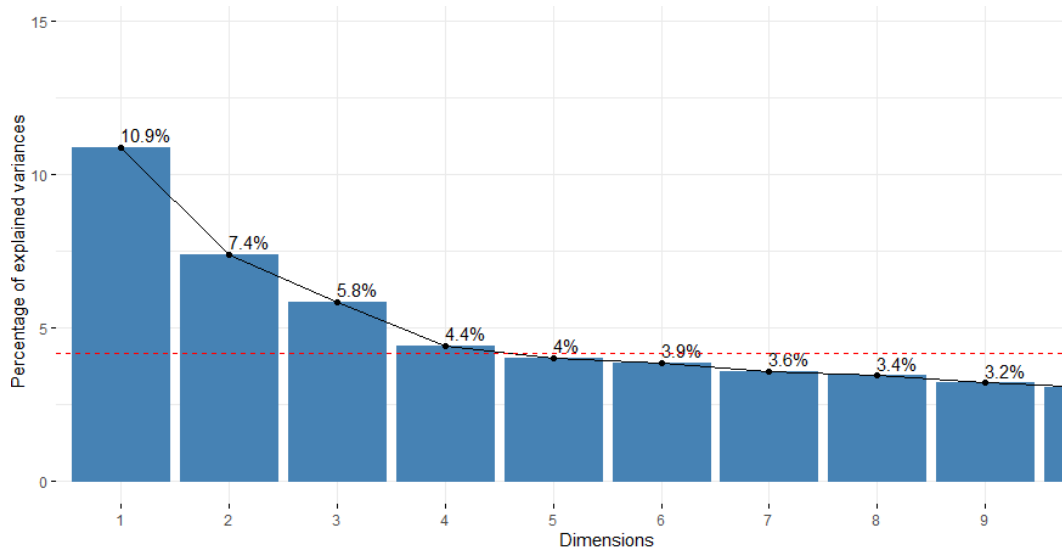


Figure 3.13: The scree plot of the MCA dimensions variances

The first four dimensions of MCA express 28.5% of the total dataset inertia; that means that 28.5% of the variables cloud total variability is explained by these planes. The factor loading for the first four dimensions are presented in Appendix C. The first dimension has the highest contribution for professional activity, age, number of vehicles owned, a regular driver or not and the household size with contributions 0.703,0.671,0.632,0.527 and 0.375 respectively. This dimension counts mainly on socio-demographic status (SDS) except that gender was not highlighted here. Therefore, this dimension was called SDS or D1 in the later analysis. The variables distribution on this dimension are presented in figure 3.14-a, where students of age range 17 to 24, living alone, non-drivers and non-owners of vehicles are at the negative side of this axis while the other professional categories are distributed on the positive side of this axis along with ages between 25 and above, owning more than a vehicle, drive regularly and with household size more than 1.

The second dimension has the highest contribution for trust in ADAS, trust in driverless metros and trams, the effect of AVs on accidents rate, the effect of AVs on security, trust in new technology and trust in cybersecurity, with contributions 0.429,

0.408, 0.399, 0.342, 0.257 and 0.138 respectively. This dimension counts mainly on trust variables (TST) even variables that were not considered in section 3.1.3 as trust variables, that are: the effect of AVs on accident rate and security, in this analysis they showed high correlation with trust variables thus they are included in the same dimension, which makes sense since they also affect the trust in AVs safety and security. Therefore, this dimension was called TST or D2 in the later analysis. The variables distribution on this dimension are presented in figure 3.14-b, where individuals trusting the different factors are placed on the negative side of the axis where individuals not trusting these factors are on the positive side.

The third dimension has the highest contribution for trip frequency, trip travelling mode and trip duration with contributions 0.208, 0.193 and 0.290 respectively. These variables are placed under the past mobility behaviour (PMB) umbrella as they test the individuals' mobility in a standard week. Subsequently, this dimension is called PMB or D3. On the negative side of D3, one can find high trip frequency (seven and more times), the used mode is the soft mode and the trip duration varies from 0 to 15 minutes, which represent short trips that are repeated more than once per day. On the contrary, long trips are less repeated and usually done using private vehicles or public transport, these trips can be found on the positive side of D3. the distribution of the variables is illustrated in figure 3.14-c.

Finally, the fourth dimension has the highest contribution for increasing comfort, increasing route optimization, eliminating the need for driving license and saving travelling time with contributions 0.182, 0.262, 0.174 and 0.235 respectively. This dimension can be considered as the perceived usefulness (PU) or expected advantages of using AVs, Thus, it will be named PU or D4. For this axis, the positive opinions were found on the right side (positive) while the negative thoughts were found on the left side (negative); see figure 3.14-d.

a	D1: Socio-demographic variables(SDS)	
	D1<0	D1>0
	Profession	
	Student	Executive and higher intellectual profession Employee or worker Retired or without activity Entrepreneur or intermediate Profession
	Age	
	[17-24]	[25-39] [40-54] [55-64] [65,++]
	Vehicles	
	[0]	[2++]
	Driver	
	No	Yes
Household size		
1	2, 3, 4+	
b	D2: Trust (TST)	
	D2<0	D2>0
	Trust ADAS	
	Yes	No
	Trust driverless metros and trams	
	Yes	No
	AV will affect accidents	
	Reduce accidents	Not affect accidents I do not know Increase accidents
AVs will increase security		
Yes	No	
Trust new technology		
Yes	No	
Trust cybersecurity		
Yes	No	
c	D3: Past mobility behaviour (PMB)	
	D3<0	D3>0
	Trip frequency	
	[7,+]	[1,2] [3,4] [5,6]
	Trip travelling mode	
SM	PT PV	
Trip duration		
]00,05]]05,15]	]15,30]]30,45]]45,++]	
d	D4: Perceived usefulness (PU)	
	D4<0	D4>0
	AVs will increase comfort	
	No	Yes
	AVs will increase route optimization	
No	Yes	
AVs will eliminate the need for a license		
No	Yes	
AVs will save travelling time		
No	Yes	

Figure 3.14: distribution of the variables on the first four dimensions of the MCA

As can be noticed, familiarity variables including knowing AVs, using ADAS and the number of ADAS used were not highlighted in any of the dimensions. Thus, they

will not be reduced to fewer dimensions.

After understanding what each dimension represents and giving them appropriate titles, the new dimensions were added to the data as new columns that will be used in studying if they along with familiarity with AVs and driving pleasure will affect the acceptance of AVs. Thus, these four new variables will be used instead of the 22 variables that were put forward in the survey while the latter two variables will be studied as they were presented in the survey.

3.2.2 Similarities between individuals profiles

In order to build a general view of the respondents' profiles and their association with their intention towards the use of AVs, a MCA was carried out. In this analysis, two sets of variables were used the active variables that contribute to the formation of the dimensions and supplementary variables that despite having no role in the construction of the dimensions, they are useful for the interpretation. Hereby, in this study, the active variables were chosen as the variables related to the individual's characteristics and profile such as socio-demographic status and travel behaviour profile such as age, gender, regular driver, number of people in the household, number of the owned vehicles, professional activity category, traveling mode, trip frequency and trip duration. While the supplementary variables were chosen as the individual perception towards variables related to AVs integration that are: intention to use PAV, SAV, living far when AVs become available and the preferences about the lanes on which AVs can operate whether reserved lanes for AVs only or lanes shared with traditional vehicles.

A two-dimension MCA solution was considered in the analysis, where the first and second dimensions have inertia 0.162 and 0.095 respectively (see figure 3.15). These dimensions present an amount of inertia greater than those obtained by the 0.95-quantile of random distributions (25.7 % against 22.74 %), which suggests that only

these dimensions are carrying real information. The thing that was also confirmed by calculating the AIV that is 8.3%. The scree-plot for the dimensions contribution percentage together with a red dotted line representing $y=8.3\%$ are presented in figure 3.15, which shows that only dimensions one and two are above this threshold. As a consequence, the description will stand to the first two dimensions representing a total of 25.7% of the inertia.

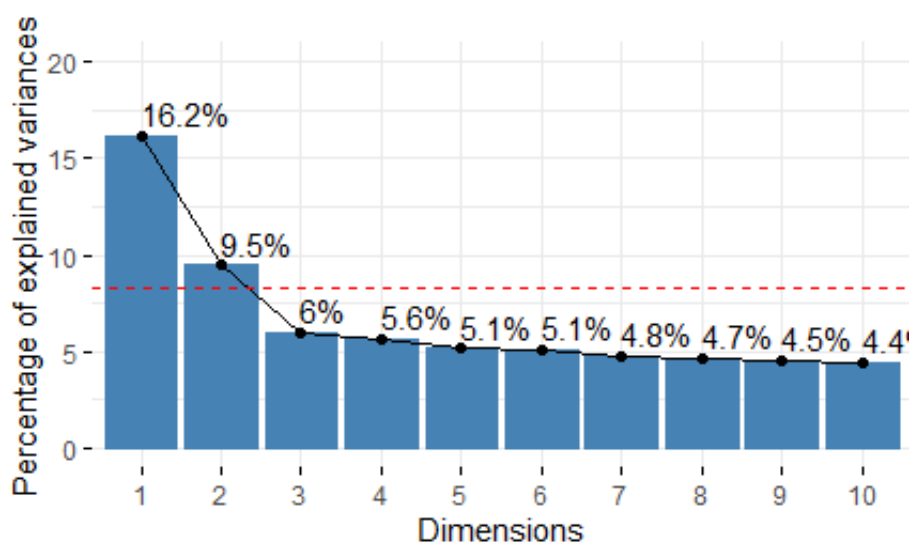


Figure 3.15: The scree plot of the MCA dimensions variances

As a result, thanks to the MCA, we obtain a representation of the individuals surveyed in a plane composed of 2 factorial dimensions. For dimension 1, the variables: number of owned vehicles, trip travelling mode, regular driver and trip frequency are the most contributing variables with contribution 0.627, 0.626, 0.557 and 0.291 respectively. While for dimension 2, individuals' age, professional activity and household size, have the highest representation with contributions 0.741, 0.757 and 0.264 respectively. Thus, dimension 1 summarizes the mobility behaviour of individuals while dimension 2 summarizes the socio-demographic profiles of the individuals.

The scatter plot representing the distribution of socio-demographic and mobility variables are presented in figure 3.16 and in a bigger format in Appendix D. As can be shown, three profiles can be drawn from these graphs based mainly on the professional

activity of the individuals, the groups can be deduced by placing the graphs above each other, where the intersection of variables' ellipses makes it easy to predict the characteristics of the different groups. The groups are as follow:

1. Students are more for public transport and soft mobility with a frequent trip repeated seven or more times a week, less likely to own a vehicle and to drive, with the majority living alone and are mostly of ages between 17 and 24 years old.
2. Retired or without professional activity are mostly private vehicles users and little are soft mode users, their most important trip is repeated 3 to 6 times per week, they have at least one vehicle per household, thus the majority are drivers, they are living in households of two persons and are mostly above 64 years old.
3. The other three professional activity categories (employee or worker, executive or higher intellectual profession and trader or entrepreneur or intermediate profession) can be combined to form one group (the active group), as their individuals representing points are mixed in all the graphs of figure 3.16, which make it hard to distinguish differences between them. For the three categories, the majority of respondents are private vehicle users, drivers with at least one vehicle and most probably two vehicles per household, repeating their frequent trip more than 3 times per week, with household sizes more than 3 and ages between 25 and 64 years old.

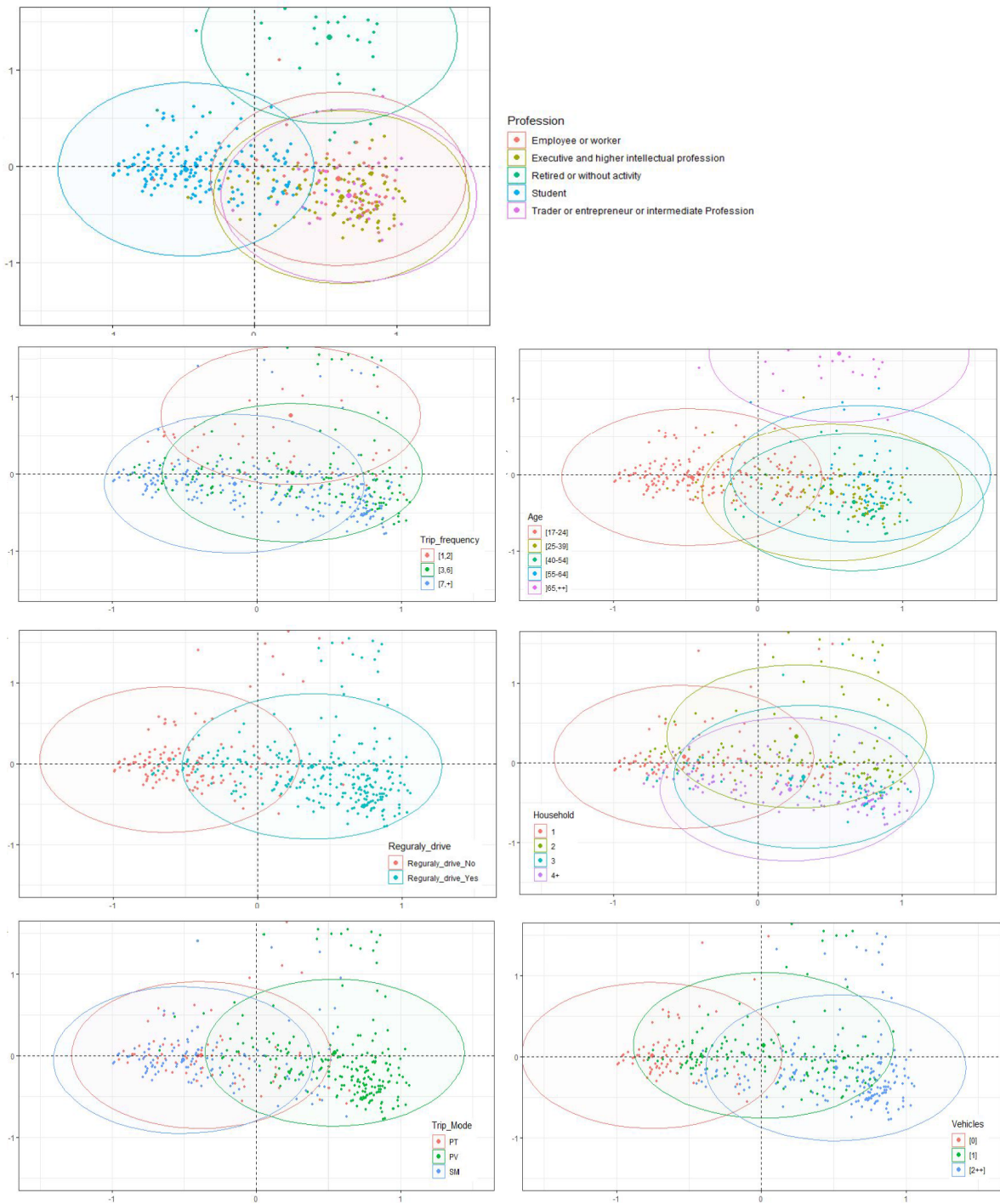


Figure 3.16: The MCA factor map for active variables

These three groups are also studied against the intention to use private autonomous vehicles (PAV), shared autonomous vehicles (SAV), changing living location to live

far from the city (live_far) and the preferred integration of AVs in the streets whether the individuals prefer that AVs use reserved lanes, use lanes shared with other kinds of vehicles or they do not know (AV_lanes). The results of these variables that were studied as supplementary variables are presented in figure 3.17, As can be noticed the ellipses are close to each other, thus no significant distinction between different groups are found on these four variables. Therefore, no conclusion can be raised at this stage concerning the association between these variables and the groups of similar individuals profiles.

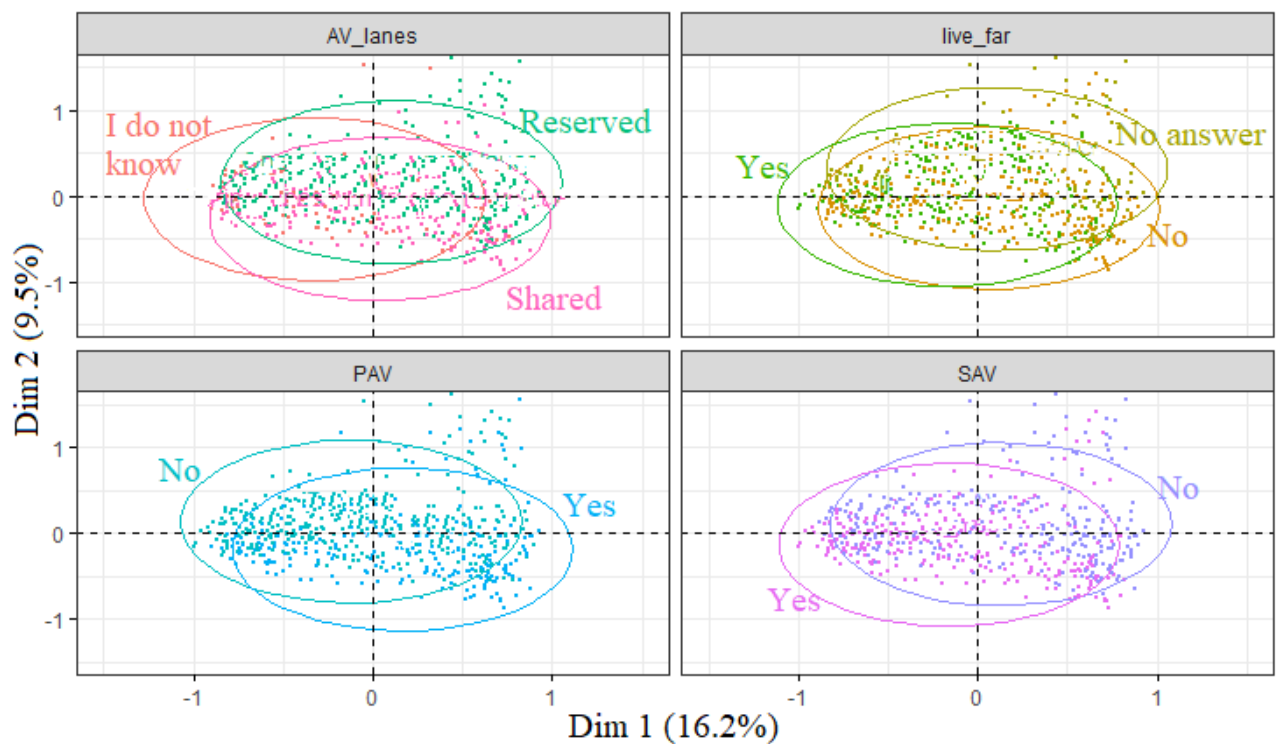


Figure 3.17: The MCA factor map for supplementary variables (PAV,SAV, AV_lanes and live_far)

The results of this section are to be used when interpreting the hierarchical cluster analysis as the clusters to be formed are supposed to have similar profiles to these groups. The hierarchical cluster analysis results are presented in the next section.

3.2.3 Four groups of potential AVs users

From MCA we succeeded to predict three groups of the respondents based on similarities between their socio-demographic and past travel trip variables. However, these groups of profiles are not enough to understand which mode of AVs will be used by each individual. To this end, the hierarchical agglomerative cluster analysis was performed on the survey data including the new dimensions of the MCA to build clusters of AVs potential users.

As previously mentioned, the first step and the backbone in any clustering problem is building the dissimilarity Matrix (DM). However, as most of the survey data are categorical, the distances will be calculated using the Gower Distance, which is used to find the similarity between two rows of a dataset whose attribute has a mixed of categorical and numerical values (Gower, 1971). It uses the concept of Manhattan distance for continuous variables and dice distance for categorical variables. Suppose we have two individuals responding to a certain variable as $X1$ and $X2$ respectively.

- Manhattan distance= $|X1 - X2|$
- Dice distance= 0 if $(X1 = X2)$ and 1 if $(X1 \neq X2)$

Using the Gower distance the DM was built, which was used in calculating the Cophenetic Correlation Coefficient for the different linkage methods: ward(0.621), complete (0.529), average(0.546) and single (0.156). As the ward linkage has the highest coefficient, then it was chosen.

After building the DM and defining the most suitable linkage method, the HCA algorithm was run. The algorithm follows several steps: starting by treating each data point as one cluster, thus, the number of clusters at the beginning is 591. Next, the two closest data points are joined to form a new cluster, resulting in 590 clusters. Then, more clusters are formed by joining the two closest clusters, resulting in 589

clusters. Finally, the previous steps are repeated until one big cluster is formed; as presented in figure 3.18. Once this big cluster is formed, the dendrogram is drawn and it is used to split the cluster into multiple clusters of related data points. Once this big cluster is formed, the dendrogram is drawn and it is used to split the cluster into multiple clusters of related data points.

Figure 3.18, presents the hierarchical clustering dendrogram of the survey data starting with 591 clusters and ending with one cluster. However, since this graph is too condensed, the upper part of it presenting the last clusters and their merging distances is truncated and zoomed in figure 3.19. As these figures show, the largest merging-distance jump is between 12.2 and 18.9, thus, the cutting threshold could be any value between these two values (15 for example).

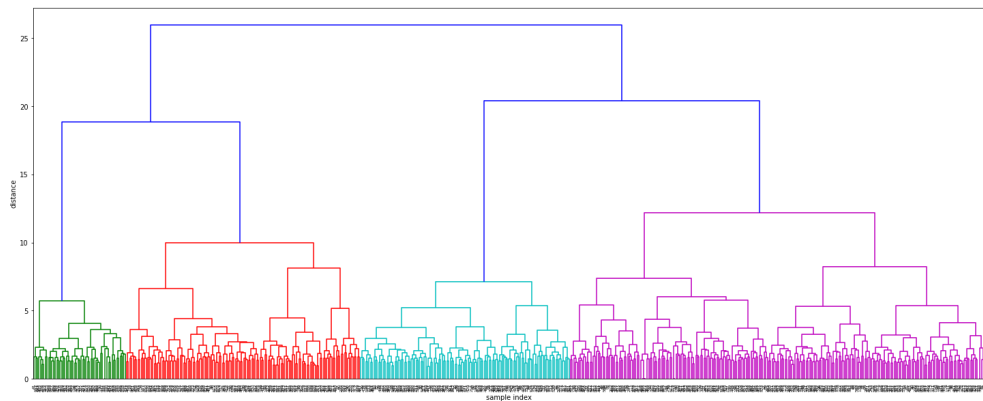


Figure 3.18: Hierarchical Clustering Dendrogram

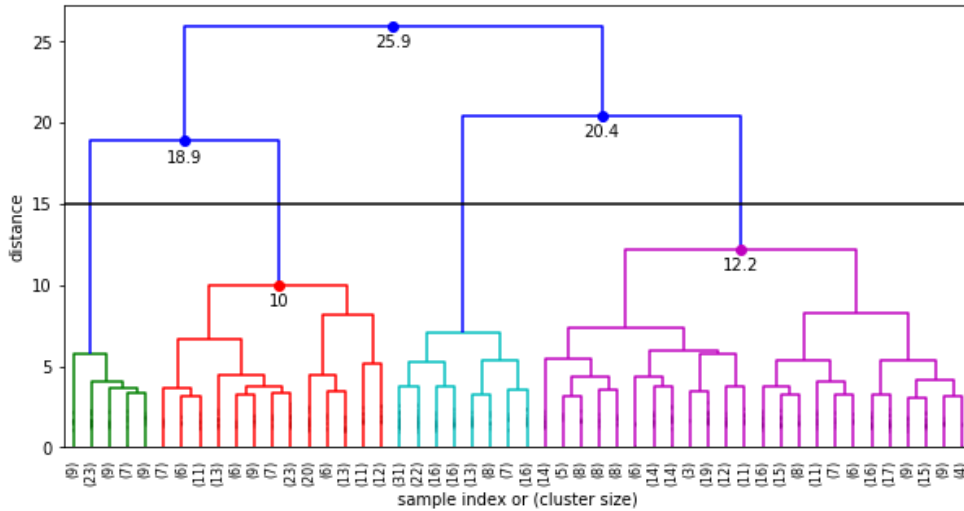


Figure 3.19: Hierarchical Clustering Dendrogram (truncated)

Cutting the dendrogram at distance = 15 reveals 4 clusters. The clusters together with the percentage of individuals distribution on variables related to socio-demographic, travel behaviour and willingness to use AVs are tabulated in Appendix E, this help in understanding the characteristics of each cluster (group) by associating it with the categories of the variables with the highest percentages. Following are summaries of the characteristics of each cluster:

- **Cluster 1:** composed of 258 individuals with high frequencies of being drivers, private vehicles users, with executive and higher intellectual professions, potential users of AV and PAV, planning to take advantages of time in AV, owners of two vehicles or more and they believe in the positive impacts of AVs. On the contrary, they have low frequencies of being non-drivers, not owning a vehicle, not potential users of PAV, soft mode users, being students of ages between 17 and 24, public transport users and with no answer for their preferences concerning changing living location.

=> Individuals in this group are mainly from the executive and higher intellectual professions, they are open for AVs and are more looking to use PAV than other modes. Thus, they are considered as potential **PAV-users**.

- **Cluster 2:** composed of 145 individuals sharing high frequencies of being public transport users, caring for trip cost, not caring for trip independence, non-drivers, willing to increase their use of public transport, students of age range (17-24) and they trust driverless metros and trams. While sharing low frequencies of being private vehicles or soft mode users, caring for trip independence, drivers and having two driving licenses in their household.

=> Individuals in this group are mainly students, public transport lovers, believing in AVs advantages and trusting public autonomous transport which is supposed to be similar to driverless metros and trams. Therefore, they are referred to as potential **PAT-users**.

- **Cluster 3:** including 130 individuals sharing high frequencies of being soft mode users, students, aged between 17 and 24, ready for using AVs and SAVs, non-drivers, not owning vehicles, environmentally friendly and they prefer to use public transport over private vehicles to reduce emissions. On the contrary, they have low frequencies of being private vehicles or public transport users, drivers, not caring for the environment, owning two or more vehicles, with executive and higher intellectual professions, public transport users and aged between 40 and 54.

=> Individuals in this group are mainly students of age between 17 and 24, soft mode users, caring for the environment, ready for AVs as PAV or SAV but, more willing for using AVs as SAV. Thus, they are considered as potential **SAV-users**.

- **Cluster 4:** including 58 individuals sharing high frequencies of being private vehicles users, not willing to use AVs, not believing in AVs advantages, not trusting driverless metros and trams, not expecting advantages of time in AVs, retired or without activity and drivers. On the contrary, they have low frequencies of being students, aged 17 and 24 years, trusting new technology, not owning vehicles, soft mode users and non-drivers.

=> Individuals in this group are mainly retired or without activity, not trusting

new technology, not believing in AVs advantages and not willing to use AVs. Thus, they are considered as **AV-non-users**.

In summary, the hierarchical cluster analysis revealed four groups: potential PAV-users (n = 258), potential PAT-users (n = 145), potential SAV-users (n = 130) and AV-non-users (n = 58). This shows a relatively high positive adoption perception toward AVs as only 58 individuals are counted as non-AV users, i.e. approximately 10% of the total sample, while the others are ready to use at least one autonomous transport mode. Moreover, to draw a better picture of these groups, we will study the factors that influence the belonging of individuals to each group that in the next section using logistic regression.

3.3 Influence of the predefined variables on the acceptance of AVs

Multinomial logistic regression is used to test the significance of the predictors/ predefined variables: socio-demographic status (SDS), familiarity with AVs tested by whether the respondents know AVs before the survey or not (KAV), past behaviour or more specifically past mobility behaviour (PMB), perceived usefulness (PU), affect toward use or simply driving pleasure (DP) and trust (TST) on predicting the cluster (PAV-users, PAT-users, SAV-users or AV-non-users) to which each individual belongs. In other words, it is used to test the effect of these variables on the users' intention to use AVs in different modes.

The AV-non-users cluster was chosen as a baseline or reference category cluster. Thus, the analysis was performed based on the differences between PAT-users and AV-non-users, PAV-users and AV-non-users, as well as the difference between SAV-users and AV-non-users. After the data was screened and no problems appeared to be present, the predictors were entered to the equation at the same time as there is

no theory about their order, thus, direct logistic regression was performed.

Overall, the model was predictive of clusters classification with $X^2(21) = 832.99$, $p < 0.001$ and McFadden $R^2 = 0.56$. The model correctly classified 77.78% of participants, with 88.63% of the PAV-users being classified correctly, 72.87% of the SAV-users, 70.83% of the PAT-users, and 57.90% of the AV-non-users (the low percentage is mainly due to the low number of participants in this cluster).

The results of the logistic regression analysis are presented in table 3.15, containing the parameters estimates for the three equations and the odds ratio ($\exp(b)$) that represents the constant effect of the predictor on the likelihood of falling in a certain cluster. In the case of PAT users, TST (which represent not trusting in AVs) has an odd ratio of 0.19 whose inverse is 5, thus, TST is 5 times less likely to play on the choice of PAT users. However, as it is not easy to imagine trust quantitatively, as well as other predictors in this study, we decided to explain the predictors' effects on the clusters as relations, whether they have significant relations (positive or negative) with falling in one cluster rather than the other. The effects of the predictors on falling in one cluster vs. the other are tabulated in table 3.16, the relations are reported with significance level 99.9% except for the influence of PU on SAV-users that is 90% significant (represented as marginal).

The first conclusion to be drawn is that KAV and DP are not significant in predicting an individual to belong to any cluster. Which comes in-line with the results of the cross-tab in section 3.1.3.

Aside from KAV and DP, the other predictors seem to be significant in classifying the difference between the clusters. PAT, PAV and SAV-users, all have a significant positive relationship with the variable PU, where individuals that believe in AVs advantages and benefits are more looking for AVs than others. Whereas, they have negative significant relationships with the variables TST and PMB. That is expected as both variables are negatively scaled, and these negative relations represent that individuals that trust low in AVs have a higher probability of being AV-non-users and

Table 3.15: Estimated effects of selected predictors on the clusters using multinomial logistic regression

Cluster	Predictors	Constant	Std. Error	t	Sig.	Odds ratio
PAT users	Intercept	3.14	0.61	5.16	<0.01	
	KAV	-0.51	0.96	-0.54	0.59	-
	DP	-0.74	0.51	-1.45	0.15	-
	SDS	-7.10	0.88	-8.09	<0.01	0.0008
	TST	-1.61	0.61	-2.64	<0.01	0.1998
	PMB	-4.21	0.74	-5.73	<0.01	0.0148
	PU	3.06	0.69	0.09	<0.01	21.3275
PAV users	Intercept	3.49	0.57	6.15	<0.01	
	KAV	0.19	0.52	0.36	0.72	-
	DP	0.44	0.40	1.12	0.26	-
	SDS	-0.80	0.71	-1.13	0.26	-
	TST	-2.86	0.50	-5.71	<0.01	0.0572
	PMB	-3.38	0.62	-5.45	<0.01	0.0340
	PU	1.87	0.60	3.13	<0.01	6.4882
SAV users	Intercept	1.90	0.67	2.83	<0.01	
	KAV	-1.16	1.26	-0.92	0.36	-
	DP	0.10	0.54	0.18	0.86	-
	SDS	-6.57	0.91	-7.19	<0.01	0.0014
	TST	-4.97	0.71	-6.98	<0.01	0.0069
	PMB	-7.08	0.83	-8.53	<0.01	0.0008
	PU	1.31	0.70	1.86	0.06	3.70617

Note. AV-non-users is the reference category

individuals with low trip frequency, long trips and are private vehicles users have a higher probability of being AV-non-users.

Considering SDS, only PAT and SAV users showed a significant relation; a negative one. Individuals with more family members, vehicles owned, non-students, drivers and bigger in age have higher prob of being AV-non-users than being PAT or SAV users. The significant relationships between these variables and the clusters classification or AVs acceptance, are expected as they were found in the cross-tabulation analysis, see section 3.1.3.

Table 3.16: Interpretation of predictors significance and effect on the clusters

	PAT-users Vs. AV-non-users	PAV-users Vs. AV-non-users	SAV-users Vs. AV-non-users
KAV	Non significant	Non significant	Non significant
DP	Non significant	Non significant	Non significant
SDS	More SDS (more family members, vehicles owned, non-students, drivers, older) → higher prob of being AV-non-users	Non significant	More SDS (more family members, vehicles owned, non-students, drivers, older)→ higher prob of being AV-non-users
TST	More TST (less trustful) → higher prob of being AV-non-users	More TST (less trustful) → higher prob of being AV-non-users	More TST (less trustful) → higher prob of being AV-non-users
PMB	More PMB (lower trip frequency, using PV, and longer trips) → higher prob of being AV-non-users	more PMB (lower trip frequency, using PV, and longer trips) → higher prob of being AV-non-users	more PMB (lower trip frequency, using PV, and longer trips) → higher prob of being AV-non-users
PU	More PU (more believing in AVs advantages) → higher prob of being PAT-users	More PU (more believing in AVs advantages) → higher prob of being PAV-users	More PU (more believing in AVs advantages) → higher prob of being SAV-users (marginal)

To this end, four of the study hypotheses set in section 2.1.2, H1: SDS has a significant effect on the users' intention to use AVs, H3: PB has a significant effect on the users' intention to use AVs, H4: PU has a significant positive effect on the users' intention to use AVs and H6:TST has a significant positive effect on the users' intention to use AVs, are validated and accepted. Whilst, the other two hypotheses H2: F has a significant positive effect on the users' intention to use AVs and H5: DP

has a significant effect on the users' intention to use AVs, are rejected. Therefore, socio-demographic status, past mobility behaviour, perceived usefulness, and trust positively influence the acceptability of AVs while familiarity with AVs and affect toward use were shown not to influence acceptance, at least in this study.

This chapter has made it possible to highlight some perception of the potential integration of AVs in urban spaces. Through the survey carried out in the area of the ARC, we can arrive at several observations on the potential uses of AVs and their integration. The integration can be of two forms (if both CVs and AVs are allowed on the roads) and the potential adoption can be of three forms other than not using AVs, the percentage distribution of the total sample with respect to these scenarios are presented in table 3.17. As can be noticed, the most rated scenario is private AVs in reserved lanes.

Table 3.17: The potential scenarios of AVs integration

Scenarios	Reserved lanes (AVs only)	Shared lanes (AVs and CVs)
PAV users	21%	18%
PAT users	15%	3%
SAV users	9%	10%

Besides the scenarios, another important aspect has been highlighted in the analysis that is the link between different preferences regarding AVs and professional groups. All the results show that executives, retirees and the students do not have the same approach to the AVs adoption. Therefore, the AV is today a subject that divides, even among a single age-category of individuals such as students and executives; categories which one might have thought to be the most inclined to accept this type of vehicle in a similar manner.

It must be taken into account that the AV is still a very theoretical technology from the point of usage. In fact, for the majority of people surveyed, it was difficult to predict the impact of AVs on safety, the environment or their modes of life when

they have never experienced it before. Therefore, the objective of this survey was to anticipate this transition from theory to practice.

It is interesting to note that part of the population states that they ready to accept the AV in one of its forms. In fact, 80% of respondents think that AV could bring improvements in their daily life. Although this technology is not unanimous, it still has a definite potential for insertion. Therefore, We can assume that it is now up to the manufacturers of this type of vehicle to prove themselves, both from the point of view of safety and service efficiency, to comfort those who have confidence in this technology and convince those who still have reservations.

Discussion and conclusions

"Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less."

*Marie Curie
(Benarde, 1973)*

The aim of this study is to pave the way for the good implementation of the AVs in the ARC area as well as the medium-sized cities by giving the potential for the insertion of AVs in the urban areas, through understanding the factors influencing the adoption of AVs in different modes based on technology acceptance theories and previous studies, as well as the characteristics of their potential users, and thereafter predicting the impacts of AVs on the urban system. This chapter discusses the outcomes related to the three research questions followed by research implications, research limitations and research future direction.

The profiles of different autonomous transport modes users

Research question : *Which mode of autonomous transport (private, shared or public) is preferred by the participants and what are the profiles of the users of each mode?*

The hierarchical cluster analysis (HCA) performed indicates that the sample can be divided into four groups. The dominant group with 43.7% of the sample are potential PAV-users, then 24.5% are potential PAT-users, followed by 22% representing potential SAV-users and the smallest group are AV-non-users (9.8%). The profiles of these groups are as follow:

- PAV-users are the working unit in the society mostly with executive and higher intellectual professions, they live in families with at least two members and they are owners of more than one vehicle.
- PAT-users are students aged between 17 and 24 years, living alone and they are the most careful about the trip cost.
- SAV-users are also students, young people, living alone, not owning vehicles and they care about environmental issues.
- AV-non-users are mainly old retired or without professional activity people, living with a partner and not believing in AVs advantages.

By comparing the clusters resulting from HCA and the profiles drawn from the MCA, we find that:

- PAV-users are mainly of the active group, they prefer that AVs share the lanes with traditional vehicles and they are less willing to change their living location. Which indicates that they are willing to change the type of vehicle (traditional to autonomous) without any changes that could affect their life routine.
- SAV and PAT users are without a decision when it comes to AVs' operating lanes and with a positive intention to change their living location. They are the impulsive young group looking for a change with less concern for safety and security
- AV-non-users are with the policy of making AVs operating on reserved lanes and mostly with no answer for changing their living location. They are more

attentive for safety and at the same time, skeptical about AVs good performance to overcome the current traffic safety.

Seeking to implement AVs in a way that encourages sustainable mobility, stakeholders and policymakers should promote the use of AVs as shared mobility (PAT and/or SAV). They should note that PAT-users have shown significant concerns when considering the cost of the trip which must be carefully considered before introducing automation into PT, in order to be a reason to encourage current PT users as well as other mode users to choose PAT. Whereas, to encourage people more to use SAV, the environmental improvements that AVs can bring must be studied well and shared with the public, as the environmental benefits are at the forefront of SAV-users interests.

In order to help stakeholders and governments build implementation plans for AVs, the population can be clustered in a more general way according to their generations. In other words, Baby Boomers (born between 1946 and 1964) are mostly retired and skeptical about AVs, they are AV-non-users, Generation X and Y (born between 1965 and 1994) are the active groups, they represent the people who have money but less time and looking for AVs as PAV, and the Generation Z (born between 1996 and 2015) who are young mostly students and familiar with technology, they are looking for AVs as PAT or SAV. This aggregation can help build a preconceived notion of population preferences when considering AVs in cities with similar characteristics, and thus help build appropriate future plans that respond to population mobility needs.

The expected impacts of AVs on the urban system

Research question : *What are the potential impacts of AVs on the urban system? that are mainly affected by the travel behavioural changes, the used mode of transport, and the expected changes in living locations.*

As can be noticed, most of the PAV-users are owners of two or more vehicles, which

could be replaced by one vehicle if using autonomous one as an AV can drive the first person for his/her destination then return to take the second to another destination. Then, a reduction in vehicle ownership of this group is expected.

Moreover, changing the living location to a further place with respect to the frequent trip destination could result in increasing the need for owning a vehicle. But, fortunately, individuals who would do this change are those who would use SAV or PAV. Thus, no private vehicles are needed and subsequently, no increase in vehicles ownership is expected. However, as this group forms the largest group of the studied sample, the change in their living location is expected to affect the entire spatial and demographic distribution, which will have huge impacts on the transport, social and economic systems.

If vehicles ownership is to be reduced with the insertion of AVs, then the other expected benefits are most probably to happen. In fact, AVs are programmed to use streets more efficiently and to drive more safely and in narrower space which should lead to a reduction in congestion and accidents; if there is no inflation in the number of vehicles that make these benefits doubtful. Furthermore, as AVs are designed to use clean energy and use it more efficiently without losses, and as most of the individuals were found to prefer shared mobility (SAV and PAT) over private one, thus, the impact of the transport sector on the environment should become less severe.

It is good to know that only one cluster of the sample - the one with a few individuals - is found to be strict about AVs operating in reserved lanes, and its individuals are basically the naysayers who oppose using AVs in all modes. Consequently, less effort (labour and money) should be made for building new vehicles lanes and more for convincing this group of people to use the AVs. While improving the existing infrastructure to respond to the AVs operating requirements.

Finally, it can be noticed that there is a relatively higher percentage of people interested in using SAV and PAT (46.5%) than in acquiring personal AVs (43.7%). The thing that highlights the trend in moving from personal to shared mobility.

Therefore, we can conclude that AVs will enhance shared mobility and thus, the number of vehicles roving our streets should decrease, leaving large empty spaces on the roads that facilitate the movement of other vehicles which result in less congestion.

The factors that influence the acceptance of AVs

Research question : *What are the factors that influence people's acceptance of AVs?*

Answering this question has started by reviewing acceptance models used in the transport sector especially when considering advanced driving systems and automation. Followed by a literature review of research and experimental studies carried on AVs. Together, they served to limit the independent variables (IVs) that are expected to influence the intention to use AVs to six variables: familiarity, trust (TST), affect toward use considered as driving pleasure (DP), perceived usefulness (PU), past behaviour integrated in this study as past mobility behaviours (PMB) and socio-demographic status (SDS).

To test the relation between the IVs and the intention to use the AVs two analyses were performed; the crosstab analysis (CT) and multinomial logistic regression analysis (MLR) . CT was used to test if the IVs influence the acceptance of AVs in general regardless of the mode used, while, MLR was used to study the relation of the IVs on the individuals falling in one of four categories SAV-users, PAV-users, PAT-users or AV-non-users (resulted from HCA).

Familiarity was studied in the CT analysis as a scale of two; 1) whether people know what AVs are (KAV) and 2) the used ADAS functions. Both scales were found not to be affecting the participants intention to use AVs. For MLR, only KAV was tested, and it confirmed the same result as for CT. Therefore, familiarity was concluded not to affect AVs acceptance. This result contradicts most of previous studies that state that people with a higher level of awareness of automated features have a stronger

intention to use AVs (Sanbonmatsu et al., 2018; Menon, 2015; Gabrhel, 2018). This contradiction could be due to the high percentage of participants that stated they are familiar with AVs (92.83%), thus, people who do not know AVs were not represented. On the other hand, DP was found not to affect AVs' acceptance in both analyses, which comes inline with Kelkel (2015a) study where DP was found not significant on behavioural intention to purchase an AV.

At the same time, TST, PU and SDS were found effective in predicting AVs acceptance in both analyses. It was found that the more the individuals trust ADAS, driverless metros and trams, new technology, cybersecurity and that AVs will reduce accidents and increase security, the more they are looking to use AVs. Likewise, the more the individuals believe that AVs will increase comfort, increase rout optimization, eliminate the need for a driving license and save traveling time, the more they are looking to use AVs. TST and PU have proven to be effective in predicting public acceptance in several studies (Kelkel, 2015a; Osswald et al., 2012; Zmud and Sener, 2017a; Ilias and George, 2018a; Piao et al., 2016; Degenhart, 2015; Benleulmi and Blecker, 2017). According to Choi and Ji (2015a) study, TST and PU are the major important determinants of intention to use AVs .

However, when studying SDS influence, In the MLR analysis SDS were found significant when studying the difference between PAT-users and AV-non-users and SAV-users and AV-non-users, while being non significant for when studying the difference between PAV-users and AV-non-users. Consequently, individuals that belong to families of few members and few vehicles owned, that are students, non drivers and young are more probably to become PAT or SAV users than being non users. Young people were also found more fervent about AVs than elderly in previous studies (Nielsen and Haustein, 2018; Becker and Axhausen, 2017; Prateek et al., 2016; Konig and Neumayr, 2017; Hawes, 2017; Abraham et al., 2017; Zwerver, 2016).

Nevertheless, PMB was found ineffective in the CT analysis while it was effective in the MLR analysis for the three accepting groups (SAV, PAV and PAT) with $p < 0.01$.

According to MLR results, individuals with high trip frequency, non PV users and performing short trips are more likely to adopt AVs in any of their modes than others. Whereas, other studies found that as the daily traveling distance increases people will be more willing to adapt AVs (Shabanpour et al., 2017; Menon, 2015; Kyriakidis et al., 2015; Clerkin, 2017; Shabanpour et al., 2017).

In general, trust, perceived usefulness and past mobility behaviour were found effective in studying AVs acceptance with no specifications for the three different modes even if they have different weights for each mode. Whilst, socio-demographic status was found significant when studying the adoption of PAT and SAV, but not significant for studying the difference between PAV-users and AV-non-users. Finally, familiarity and driving pleasure were found not significant for all modes' adoption intentions.

Research implications

The research findings presented here have several academic, urban and industrial implications. The integration of AVs in the urban transport system is of interest and concerns of several parties including the potential users themselves, researchers, transport planners, urban planners and AVs business developers.

This study brings a review of the benefits that the inclusion of AVs in the mobility system could produce. Therefore, it should be of interest to the general public as it can provide them with the knowledge of this new technology, their advantages and potential users' perceptions. Besides, It provides information on the factors that influence the acceptance of AVs and how they differ between potential users' groups, that could be used in future research dealing with acceptance or development of AVs.

In addition, getting a view of the potential AVs users as well as the percentage of users for each mode (PAV, SAV, and PAT) provides transport planners with a

foundation for building their transport plans that can respond to the new modal change. Moreover, this information can help them direct their resources to prepare the infrastructure to accommodate new mobility requirements. Furthermore, introducing new technologies to the world is not an easy task, especially for governments and policymakers who will be at the forefront of those responsible if there is a mistake. This is why most governments are reluctant to allow the roving of AVs on their streets, especially the residential ones. However, knowing the potential changes that will happen to the urban system if using AVs, can ensure AVs safe integration into the system as well as anticipating the required changes to travelling laws and rules.

Last but not least, AVs developers and stakeholders should be interested in this research as it helps them understand their future users' preferences. AVs potential users have requirements and concerns that must be taken into account when developing AVs solutions. Identifying barriers or factors that prevent a group of people from adopting these vehicles should be beneficial to overcome these barriers by adapting the information and solutions targeting that group. This research provides vital information related to AVs users' acceptance and preferences, thus will enable them to incorporate these factors in the design and implementation of AVs.

Research limitations

This study examines the factors that affect AVs' acceptance and the profile of users of different AVs' modes that together predict the changes that the AVs will bring to the urban system. Despite the pleasant results found, which answer the research questions, the results of this study should be considered with some caution as they mainly depend on the participants' intentions and past behaviours that will change over time; even before AVs become available in the market. Moreover, in the true integration of AVs in the transport system, a wide range of external factors may influence the results that could be a new innovation in automation technology, a

failure of the operation of AVs while testing, and much more.

Furthermore, other issues related to the study design and analysis should be also considered carefully before any attempt to generalize the results, such as:

1. The study area is a small city (Compiègne) and its surrounding cities which together represent less than 0.04% of the french territory. The thing that makes it hard to generalize the results to other areas for two main reasons. First, populations in other cities and countries might have dissimilar socio-demographic and economic characteristics, that are more or less affecting the study results. Second, the results are based on the mobility behaviour of the respondents that are affected directly by the geographical, spatial and economic characteristics of the study area.
2. The research was limited in terms of its target group, where it does not include experts in the automobile sector which could enrich the study from a different perspective. In addition, most of the sample contacted and responded to the survey are mainly students (55,2% of the total sample), as this study was conducted in a university research project and contacting students is easy in this case.
3. The study was constrained by the limitation of the survey questions. As this study was not financially supported by research companies or projects, the survey was conducted without financial help that would encourage respondents to answer. Therefore, we were restricted by the response time of the survey not to exceed 10 minutes in order not to take the risk of losing the attention of the respondents. Accordingly, the number of questions was considered carefully.
4. The survey was poor at representing and examining familiarity and perceived usefulness, as they were scaled by a phrase or two that is insufficient to cover all their aspects. To this end, the conclusions related to these two factors are highly doubtful.

Aware of these limitations, this research provides an effective comprehension of the acceptability of the AVs and their implications; At least in the ARC area. The study sheds light on how stakeholders and governments can benefit from integrating automation technology into the transport system to enhance the urban system sustainability, as well as helping automakers develop their business in this area by providing them with a study of the needs and perceptions of their potential customers.

Research future directions

This thesis was designed to investigate the acceptance and use of AVs by the ARC inhabitants. The findings and conclusions from this study can be enhanced by further research that paves the way for various directions including:

1. Expanding the items used in the research study. Indeed, the economic and educational status of the potential users could play an important role in driving them towards using AVs, as they are essential in building decisions and perceptions. Moreover, it is important to implement more reliable scales of familiarity and driving pleasure so that their impacts can be studied more precisely.
2. Comparing the study results with studies in areas with different demographic characteristics. That can help understand how changes in participants profiles can influence the development of AVs and to validate the current results.
3. Examining the participants' intent to use AVs before and after testing them in different modes. Testing can be at test sites where prototypes of AVs are available or by simulations using virtual reality that can place participants in environments similar to reality. This approach can help participants build their decisions based on experience that may be more similar to what they would do when AVs became available for their use.
4. Focusing on the current traffic situation and how AVs can be integrated with it

so that we end up with a system relies on both types of vehicles (autonomous and traditional) at the same time. Consequently, as AVs are introduced to the current transport system, longitudinal studies might produce some interesting insights on how users' perception and intention changes with time and experience with these vehicles.

5. Shedding light on the possibility of including AVs in the mobility as a service system especially for the disabled and residents of areas with a low population where public transport is ineffective. This is interesting, as it provides mobility at reasonable costs and flexibility while respecting users' independence.

The growing study of AVs in academic and industrial research is critical for the development of their safe and effective integration in the future transport system. To this end, any new approach and future research directions are appreciated where they can arise new challenges and directions for their development.

General conclusion

Automation is a recent revolution in the transport sector and nowadays, it is at the top of future mobility issues. It can be a heaven or a hell for the transport system as stated by Creger et al. (2019). Therefore there is a real need for the assessment of their impacts and their acceptance rate; after all, if AVs are not adopted by people then they will always rest as ideas to be developed in research and innovation centers. This thesis was set to assess users acceptance of AVs in different modes (shared, private and public transport), to draw the profiles of the users of the different modes and to predict the impacts of AVs on the urban system.

The study was designed to rely on previously conducted research to extract an idea about the expected impacts of AVs and the factors that can influence their acceptability. The result of the literature review was then used to build a survey able to

test the different reviewed aspects, which was disseminated between the agglomeration of Compiègne region inhabitants. The study collected 591 adequate answers on which cross-tabulation analysis, multiple correspondence analysis, hierarchical cluster analysis and multinomial logistic regression were performed.

The analysis results showed that there are four typologies of people: people who would like to use AVs as PAV, those who prefer SAV, others who prefer PAT and those who do not accept AVs at all. PAV users are mostly with a professional activity other than being students, do not live alone and they are drivers. SAV users have high probabilities of being students, males, not owning a vehicle, current users of soft mode or public transport for their daily travel and they usually perform short trips. PAT users profiles are similar to SAV users however, they differ by being against private vehicles use and are most probably females. Finally, The AVs non-users are mostly the elderly, those without professional activity, with a low repeating frequency for their important trip and they are users of private vehicles.

The results also showed that four factors influence individuals' intention to use the AVs in the future. The four factors are the socio-demographic status of individuals inspired by the "Unified Theory of Acceptance and Use of Technology" that tested the influence of gender and age on acceptance, trust in automation and technology that was pre-tested and validated through the "Model of Acceptance of Driver Assistance Systems", and perceived usefulness and past habits studied in many acceptance theories, for example, the Theory of Interpersonal Behaviour. On the other hand, the familiarity and driving pleasure highlighted in previous studies (refer to section: 2.1.1) were found unimportant in this study.

Concerning the changes in the current location, car ownership, modal shift, they seem to be made by the student group who are also affected by their parents and surrounding people, thus making it difficult to build discrete conclusions. As long as people did not really experience AVs and did not count on them in their daily trips, it is difficult to forecast basic change in their lives. However, the results showed that

in addition to the ability of AVs to positively affect the transport system by reducing congestion, perform driving task more efficiently, reduce accidents, reduce emissions, provide mobility for disabled and elderly, etc., they were found to reduce vehicles ownership, improve shared mobility services and free urban areas from population overload.

One should keep in mind that until AVs become available for the public, their impacts cannot be confirmed. Moreover, this study along with other studies reviewed in this research had studied the acceptance of AVs (the fully autonomous vehicles) and not semi-autonomous vehicles or vehicles with lower automation level. While in reality, the latter will have radical impacts on people's perception of AVs and AVs' overall implementation. Therefore, the results of this research are effective and useful for building development plans and recommendations before having AVs on the roadside to ensure the best implementation strategy that leads to the most beneficial outcomes.

Furthermore, the work presented in this thesis resulted in four recommendations to policymakers, automakers, governments and urban planners.

1. Use the benefits of automation to support and promote shared autonomous mobility (SAV and PAT).
2. Provide affordable and challenging travelling fares for SAV and PAT as most of their users are students with low income and their cost is of their main concerns.
3. Promote the environmental improvements that AVs can provide (reduce CO2 emissions, use renewable energy, reduce congestion, etc.) to encourage the public towards the shift to automation in shared modes.
4. Focus on the elderly population and how to convince them with AVs and how to make them trust this new technology as they are the main opposers for this technology while being among the most in need for this technology. Driving for the elderly is considered a hard task, for some, it becomes physically hard

to turn their head to look back or to quickly turn the steering wheel or brake, their reflexes might get slower, their eyesight and hearing become worse which make the driving task harder and unsafe.

In conclusion, it appears that a relatively high percentage (67.85%) of people accept the idea of autonomous vehicles that could drive them anywhere. However, they are concerned about their safety and the data that can be collected without permission. Nonetheless, some aspects still need to be considered before the real implementation of AVs such as regulations to guide the integration of AVs with conventional vehicles under the current transport system conditions and legal liability in the event of accidents and other troubles.

Appendix A: Summary of Reviewed Studies on Autonomous Vehicles

Table A.1: Summary of Reviewed Studies

Sample	design and administration	year	Country	Reference	Factors
Acceptance of AVs					
1,001 Public	Interviews	2014	UK	(Missel, 2014)	Socio-demographic
32 Drivers owning a vehicle	10 focus-group	2013	USA	(Silberg, 2013)	Socio-demographic
1,603 Public	Online Survey	2014	Germany	(Hohenberger et al., 2016)	Socio-demographic
63 Drivers	Online survey and two focus groups	2016	UK	(Politis et al., 2017)	Driving pleasure
483 Public	Online Survey, technology acceptance model	2017	-	(Ilias and George, 2018b)	Behavioural intention
101 Public	Online survey	2017	USA	(Orfield et al., 2018)	Familiarity, Perception of benefits
201 Public	Online survey	2016	Germany	(Pakusch and Bossauer, 2017)	Familiarity, Behavioural intention

Continued on next page

Sample	design and administration	year	Country	Reference	Factors
99 Public	-	-	Pakistan	(Sanaullah et al., 2017)	Familiarity, Behavioural intention
2,036 Public	Online Survey	2017	Finland	(Liljamo et al., 2018)	Socio-demographic, Current travel situation
467 Worcester Polytechnic Institute and Public	Online and printed surveys	2013	USA	(Casley et al., 2013)	Socio-demographic, Willingness to Pay
421 Drivers	Online survey and interviewed, questions from interviews results and previous studies	2013	France	(Payre et al., 2014)	Driving pleasure, Behavioural intention
21,549 experts and Public	Transport Online survey and interviews	2018	28 countries	(IPSOS, 2018)	Perception of benefits, Trust
4,100 owners and transport experts	Vehicles' Online survey and focus groups	2014	USA, Germany, Japan, China	(Degenhart, 2015)	Perception of benefits, T

Continued on next page

Sample	design and administration	year	Country	Reference	Factors
2,167 Public	Online survey	2015	USA	(Bansal and Kockel- man, 2017)	Trust, Willingness to Pay
1,102 Technology elites and Public	Online survey	-	USA	(Intel, 2018)	Trust, Behavioural intention
101 Students and university staff	Online Survey, technology adoption and driverless cars theories	2017	Australia	(Kaur and Ramper- sad, 2018)	Trust, Behavioural intention
1,013 Public	Online survey, stated preference survey, best-worst analysis	2016	USA	(Shabanpour et al., 2018)	Trust, Behavioural intention
22,000	Online survey	2016	17 countries	(Giffi et al., 2017)	Willingness to Pay, Behavioural intention
452 Public	Interviews	2017	China	(Liu et al., 2018)	Willingness to Pay, Behavioural intention
12,000	Online survey and 6 focus groups (48participants), transit state survey	2016	11 European countries	(Tennant et al., 2016)	Familiarity, Trust, Behavioural intention

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Sample	design and administration	year	Country	Reference	Factors
233 University students and Public	Online survey	2017	worldwide	(Hyde et al., 2017)	Socio-demographic, Trust, Behavioural intention
2,976 Vehicles' owners	Online survey	2017	-	(Abraham et al., 2017)	Socio-demographic, Trust, Behavioural intention
22,177 Public	Online Survey	2018	15 countries	(Giffi et al., 2018)	Current travel situation, Trust, Willingness to Pay
7,755 Public	Online survey, questions from prior surveys	2015	116 countries	(Nordhoff et al., 2018)	Familiarity, Socio-demographic, Current travel situation, Driving pleasure
Drivers and transport experts	Online survey, focus groups and expert interviews	2013	Germany, China, Japan, USA	(Klaus, 2013)	F, Socio-demographic, Current travel situation, Trust
2,850 Public	Online survey	2016	UK	(UKAutodrive)	Familiarity, Perception of benefits, Trust, Behavioural intention
1,088 Public	Online survey	2015	USA	(Bansal and Kockelman, 2018)	Socio-demographic, Trust, Willingness to Pay, Behavioural intention
Trust in AVs					
<i>Continued on next page</i>					

Sample	design and administration	year	Country	Reference	Factors
1,048 Public sample	Online Survey, questions from prior studies	2016	UK	(Hulse et al., 2018)	Socio-demographic, Trust
114 Turk workers	Mechanical Online Survey	2017	USA	(Sanbonmatsu et al., 2018)	Familiarity
8,000 Public	Online Survey	-	Australia, France, Germany, Japan, USA, UK, Netherlands	(Kürpick, 2018)	Trust
107 Visitors of Lawrence Hall of Science	-	2013	USA	(Howard and Dai, 2014)	Trust
238 recruited via Reddit	Online survey	2017	USA	(Bloom et al., 2017)	Trust

Continued on next page

Sample	design and administration	year	Country	Reference	Factors
30 a valid driver's license	Owners of Simulation with driving - videos and autopilot visualizations (chauffeur, world in miniature and indicators), questions from prior surveys	-	Germany	(Hauslschmid et al., 2017)	Trust
3,500 Transport experts	Online Survey	2012	UK	(Begg, 2014)	Trust
217 experts	Online Survey	2014	USA	(Underwood et al., 2014)	Trust
552 Drivers	Online Survey, technology acceptance model	2015	South Korea	(Choi and Ji, 2015b)	Trust
2,202		2017	USA	(Gerzema, 2018)	Trust, Behavioural intention
2,000 Drivers	Online survey	2014	USA	(Vallet, 2014)	Trust, Behavioural intention
126 University students	Online survey	-	Greece	(Ilias and George, 2018a)	Familiarity, Perception of benefits, Trust

Continued on next page

Sample	design and administration	year	Country	Reference	Factors
485	-	-	Canada	(Clerkin, 2017)	Socio-demographic, Current travel situation, Trust
Changes in travel behaviour and user preferences					
40 Public	Online survey using 10 different predicted scenarios	-	-	(Zwerver, 2016)	Socio-demographic,
556 Public	Online survey and interviews, car technology acceptance model	2015	USA	(Zmud and Sener, 2017b)	Current travel situation
302 Public	Online Survey, theory of travel mode choice and random utility	2017	Germany	(Pakusch et al., 2018)	Current travel situation
761 Public	Online Survey	2015	Netherlands	(Yap et al., 2015)	Current travel situation
435 Public	Online Survey, stated choice survey	2015	Australia	(Krueger et al., 2016)	Current travel situation
23,000 Public	Online Survey	2014	19 countries	(Brown et al., 2014)	Current travel situation

Continued on next page

Sample	design and administration	year	Country	Reference	Factors
633 Public	Online Survey and inter-views, stated preference survey	2012	South Korea	(Shin et al., 2015)	Socio-demographic, Current travel situation
14000 Public	Online Survey	2018	10 European countries	(Servodidio, 2018)	Socio-demographic, Behavioural intention
2,591 members American mobile association members	Online survey, tailor-made and stated preference	2015	USA ,Canada	(Menon, 2015)	Socio-demographic, Current travel situation, Behavioural intention
327 University employees	Online Survey, diffusion of innovations and agent-based modeling	2018	USA	(Talebian and Mishra, 2018)	Socio-demographic, Trust, Behavioural intention
425 Public	Online survey and telephone interview after automated buses demonstration	2015	France	(Piao et al., 2016)	Familiarity, Socio-demographic, Current travel situation, Perception of benefits, Behavioural intention

Continued on next page

Sample	design and administration	year	Country	Reference	Factors
Perception of benefits of AVs					
1,253 Public	Online Survey, multiple stated choice experiments	2016	USA	(Shabanpour et al., 2017)	Current travel situation
115 Public	Online survey, model of acceptance of driver assistance systems	2014	Germany	(Kelkel, 2015b)	Perception of benefits
516 Owners of a driver's license	Online Survey and focus groups N=17	2017	Germany	(Teresa et al., 2018)	Perception of benefits
3,040 Public	Online Survey	2016	Denmark	(Nielsen and Hausteine, 2018)	Socio-demographic, Current travel situation
3,116 Drivers from Klashwerks company	Online Survey	2017	-	(Brown, 2017)	Socio-demographic, Behavioural intention
505 Motorists	Online survey	2014	USA	(Schoettle and Sivak, 2015)	Socio-demographic, Behavioural intention
<i>Continued on next page</i>					

Sample	design and administration	year	Country	Reference	Factors
250 Senior business and decision makers	-	2018	UK	(Living-Lab, 2018)	Perception of benefits, Trust
347 Public	Online survey	2014	USA	(Prateek et al., 2016)	Socio-demographic, Trust, Willingness to Pay
489 Public skewed towards educated people	Online Survey	2015	33 countries	(Konig and Neumayr, 2017)	Familiarity, Socio-demographic, Current travel situation, Willingness to Pay
3,641	Online survey	-	UK	(Hawes, 2017)	Familiarity, Socio-demographic, Perception of benefits, Behavioural intention
1,065 Public	Computer assisted personal interviewing	2017	Czech Republic	(Gabrihel, 2018)	Familiarity, Socio-demographic, Trust, Willingness to Pay
Willingness to pay for AVs					
<i>Continued on next page</i>					

Sample	design and administration	year	Country	Reference	Factors
17,400 owners	Online survey	2012	USA	(Power, 2012)	Socio-demographic
1,260 Adults with a driving license	Online survey, purchase dis- crete choice experiment	2014	USA	(Daziano et al., 2017)	Willingness to Pay
1,002 vehicles own- ers	Online Survey, stated pref- erence survey	2016	Japan	(Jiang et al., 2018)	Willingness to Pay
1,722 database	Online survey	2014	China, India, Japan, USA, UK, Australia	(Schoettle and Sivak, 2014a)	Current travel situation, Trust, Willingness to Pay
5,000 Public	Online survey	2014	109 countries	(Kyriakidis et al., 2015)	Current travel situation, Driving pleasure, Trust, Willingness to Pay, Behavioural intention

Appendix B: Survey: Integration of Autonomous Vehicles in the Urban Space of the Agglomeration of Compiègne Region

Insertion des véhicules autonomes dans l'espace urbain de l'Agglomération de la Région de Compiègne

Madame, Monsieur,

Dans le cadre de notre projet pédagogique en Génie Urbain à l'Université de Technologie de Compiègne, nous réalisons une enquête exploratoire sur les véhicules autonomes en milieu urbain.

Ce questionnaire a pour objectif de :

- Cerner les habitudes de mobilité de la population de l'agglomération de Compiègne
- Étudier l'acceptabilité de l'insertion des véhicules totalement autonomes par la population de l'agglomération de Compiègne
- Connaître les conséquences de l'insertion des véhicules autonomes sur le paysage urbain

Merci de nous consacrer une dizaine de minutes pour répondre à ce questionnaire, dont les résultats resteront strictement anonymes*.

* Conformément à la loi informatique et liberté n°78-17 du 6 janvier 1978, les réponses aux sondages n'étant pas obligatoires, vous avez le droit de ne pas répondre à tout ou partie de ce questionnaire. Conformément à l'article 27 de la même loi, aucune information directement ou indirectement nominative ne sera communiquée.

***Obligatoire**

1. Habitez-vous l'agglomération de Compiègne? *

Une seule réponse possible.

- Oui
- Non

2. Quel(s) est/sont le(s) motif(s) de votre déplacement le plus fréquent ? (plusieurs choix possibles) *

Plusieurs réponses possibles.

- Travail / Études
- Accompagnement (enfants, personnes âgées...)
- Commerces (achats alimentaires)
- Loisirs (cinéma, shopping, sport, etc.)
- Je ne me déplace pas
- Autre :

3. À quelle fréquence effectuez-vous ce déplacement ? (nombre d'allers/retours) *

Une seule réponse possible.

- Uniquement le week-end
- 1 à 2 fois par semaine
- 3 à 4 fois par semaines
- 5 à 6 fois par semaine
- Tous les jours Plusieurs
- fois par jour

4. Quel est votre mode de transport principal pour ce trajet ? Précisez le mode le plus important (par exem : vélo-train-vélo → choisissez le train) *

Une seule réponse possible.

- Véhicule particulier
- Véhicule professionnel
- Co-voiturage
- Transports en commun urbains
- Train interurbain (TGV, TER)
- Deux-roues motorisés
- Vélo
- Marche à pied
- Taxi, VTC
- Autre :

5. Pour quelle(s) raison(s) choisissez-vous ce mode de transport ? (3 choix maximum) *

Plusieurs réponses possibles.

- Confort
- Sécurité
- Temps de trajet
- Coût
- Respect de l'environnement
- Indépendance
- Habitude
- Praticité
- Pas d'alternative
- Autre :

6. Combien de temps mettez-vous en moyenne pour effectuer ce trajet ? *
Une seule réponse possible.

- Moins de 5 minutes
 De 5 à 15 minutes
 De 15 à 30 minutes
 De 30 à 45 minutes
 De 45 minutes à 1
 heure Plus d'1 heure

7. Conduisez-vous régulièrement une voiture ? *
Une seule réponse possible.

- Oui
 Non *Passer à la question 9*

8. Quels assistants à la conduite utilisez-vous ? (plusieurs choix possibles) *

Plusieurs réponses possibles.

- Régulateur de vitesse
 Régulateur de vitesse adaptatif
 Freinage d'urgence
 Radar/Caméra de recul
 Assistance maintien de voies
 Détecteur d'angle mort
 Aucune assistance disponible sur mon véhicule
 Je n'en utilise jamais

9. Avez-vous déjà entendu parler de véhicule autonome ? *

Une seule réponse possible.

- Oui
 Non

Confiance
et sécurité
de
l'utilisateur pour le
véhicule
autonome

Dans le cadre de notre enquête, nous considérerons comme autonomes les véhicules déléguant totalement toutes les opérations liées à la conduite pendant toute la durée de leur parcours. Ces véhicules prennent les décisions liées à la circulation sans aucune intervention humaine. Ces véhicules ne transportent donc que des passagers passifs. Le véhicule autonome est totalement électrique. L'intérieur de la voiture serait du type TGV "4 places et une table centrale" (voir l'image ci-dessous). Nous nous plaçons dans une situation où les véhicules autonomes circulent sur les mêmes voies que les autres véhicules traditionnels.



10. Parmi les affirmations suivantes, veuillez cocher la ou les réponses qui vous correspondent le mieux :

Plusieurs réponses possibles.

- Je fais confiance aux dispositifs d'aide à la conduite (régulateur adaptatif de vitesse, freinage d'urgence, assistance au parking)
- Je fais confiance aux métro/tramway sans conducteur
- Je fais confiance à la cybersécurité pour prévenir le piratage du véhicule (cybersécurité : protection des données et de l'intégrité des ressources informatiques connectées ou installées sur un dispositif)
- Je fais confiance au GPS et aux applications mobiles d'aide au déplacement (Waze...)
- Je ne fais confiance à aucune de ces nouvelles technologies
- Je ne me prononce pas

**Véhicule
personnel**

Imaginez-vous que dans quelques années, les véhicules autonomes soient accessibles aux particuliers, et que vous puissiez vous-même utiliser un véhicule autonome à titre individuel et collectif...

11. Seriez-vous prêt(e) à posséder un véhicule autonome à titre personnel ? *

Une seule réponse possible.

- Oui
- Non

12. Seriez-vous prêt(e) à utiliser un véhicule autonome en libre-service ou en autopartage (ex : autolib) ? *

Une seule réponse possible.

- Oui
- Non

13. Pensez vous qu'il serait possible de mettre à profit le temps de trajet dans un véhicule autonome person? *

Une seule réponse possible.

- Oui
- Non

Passer à la question 16

14. Que penserez-vous faire à bord d'un véhicule autonome personnel?(plusieurs choix possibles)*

Plusieurs réponses possibles.

- Se divertir (détente, musique, qlms, vidéo, internet, lecture...)
- Travailler (études ou activité professionnelle)
- Je resterais concentré(e) sur la route
- Je ne sais pas

15. En mettant à profit votre temps de trajet pour une autre activité, seriez-vous prêt(e) à habiter plus loin votre destination la plus fréquente? *

Une seule réponse possible

Oui

Non

Du véhicule personnel vers les transports en commun

Imaginez-vous pouvoir utiliser les services Uber ou taxi au sein d'un véhicule autonome...

16. Seriez-vous prêt(e) à partager ce type véhicule autonome ? (plusieurs choix possibles) *

Plusieurs réponses possibles.

Oui

Non, car il peut y avoir des problèmes de sécurité entre les usagers (agression)

Non, car il peut y avoir des problèmes d'incivilité de la part de certains usagers (non respect du matériel)

Non, j'ai envie de tranquillité et préfère être seul(e)

Non, pour une autre raison

Transport en commun

Imaginez-vous que les transports en commun, comme les bus, deviennent autonomes et circulent sans chauffeur...

17. Au quotidien, essayez-vous de réduire l'utilisation de votre véhicule personnel au profit des transports commun ? *

Une seule réponse possible.

Oui

Non

Non, je n'en ai pas la possibilité

18. En dehors de votre déplacement principal, utilisez-vous les transports en commun pour vous déplacer

Une seule réponse possible.

Ponctuellement

Uniquement le week-end

1 à 2 fois par semaine

3 à 4 fois par semaine

5 à 6 fois par semaine

Tous les jours

Je n'utilise les transports en commun que pour mon déplacement principal

Passer à la question 20

19. Qu'est-ce qui vous incite aujourd'hui à utiliser les transports en commun plutôt qu'un autre mode de transport ? (plusieurs choix possibles) *

Plusieurs réponses possibles.

- Pour des questions environnementales
- Service de qualité (desserte et fréquence)
- Gratuité
- Pas de véhicule personnel Rapidité
- Confort (place assise, sécurité)
- Autre :

Passer à la question 21

20. Qu'est-ce qui vous incite aujourd'hui à ne pas utiliser les transports en commun plutôt qu'un autre mod de transport ? (plusieurs choix possibles) *

Plusieurs réponses possibles.

- Mauvaise desserte
- Fréquence trop faible
- Abonnement coûteux
- J'ai un véhicule personnel
- Temps de trajet trop long
- Manque de confort (place assise, sécurité, distance sociale...)

Autre :

21. En imaginant que les transports en commun de demain deviennent autonomes, qu'est-ce que cela changerait selon vous ? *

Une seule réponse possible par ligne.

	Oui	Non	Ne sais pas
Meilleure fréquence			
Réduction des gaz à effet de serre			
Trajet plus sûr			
Coût plus cher			
Pas de changement			

**Questions
bilan**

Nous revenons maintenant sur l'ensemble des types de véhicules autonomes qui pourront exister, que ce soit le véhicule personnel autonome ou le transport en commun autonome.

22. Selon vous, l'arrivée des véhicules autonomes sur les mêmes voies de circulation que les véhicules traditionnels aura pour conséquence de : *

Une seule réponse possible.

- Réduire le nombre d'accidents
 Augmenter le nombre d'accidents
 Ne changera rien au nombre d'accidents
 Je ne sais pas

23. Dans le cas où les véhicules autonomes arrivent demain sur le marché, préféreriez-vous que : *

Une seule réponse possible.

- Ces véhicules circulent sur les mêmes voies de circulation que les véhicules traditionnels
 Ces véhicules circulent sur des voies de circulation réservées
 Je ne sais pas

24. Quelles améliorations pourrait apporter le véhicule autonome dans votre vie quotidienne ? (plusieurs choix possibles) *

Plusieurs réponses possibles.

- Sécurité
 Gain de temps
 Optimisation du trajet
 Confort
 Permis de conduire non nécessaire
 Pas d'amélioration
 Je ne sais pas

25. Quels seraient les points négatifs engendrés par les véhicules autonomes ? (plusieurs choix possibles) *

Plusieurs réponses possibles.

- Perte du plaisir de conduire
 Collecte des données personnelles sans consentement préalable
 Perte d'emplois
 Insécurité sur les routes
 Pas de point négatif

26. Vous êtes ? *

Une seule réponse possible.

Un homme

Une femme

27. Quel âge avez-vous ? *

Une seule réponse possible.

Moins de 17 ans

18 à 24 ans

25 à 39 ans

40 à 54 ans

55 à 64 ans

65 à 79 ans

80 ans ou plus

28. Quelle est votre commune de résidence ? *

29. Veuillez préciser le code postal : *

30. Quelle est votre catégorie socio-professionnelle ou profession ? *

Une seule réponse possible.

Agriculteur exploitant

Cadre et profession intellectuelle

supérieure Artisan, commerçant et chef

d'entreprise Profession intermédiaire

Employés

Ouvriers

Élèves / Étudiant / Apprenti

Retraité

Sans activité professionnelle

Autre :

31. De combien de personnes est composé votre ménage ? *

Une seule réponse possible.

1 2 3 4 5 6 7 8 9 10

32. Combien de véhicules motorisés dispose votre ménage ? *

1 2 3 4 5 6 7 8 9 10

33. Dans votre ménage, combien de personnes sont titulaires du permis de conduire ? *

Une seule réponse possible.

0 1 2 3 4 5 6 7 8 9 10

34. Indiquez ci-dessous tout commentaire ou proposition qui vous paraîtrait utile pour notre enquête :

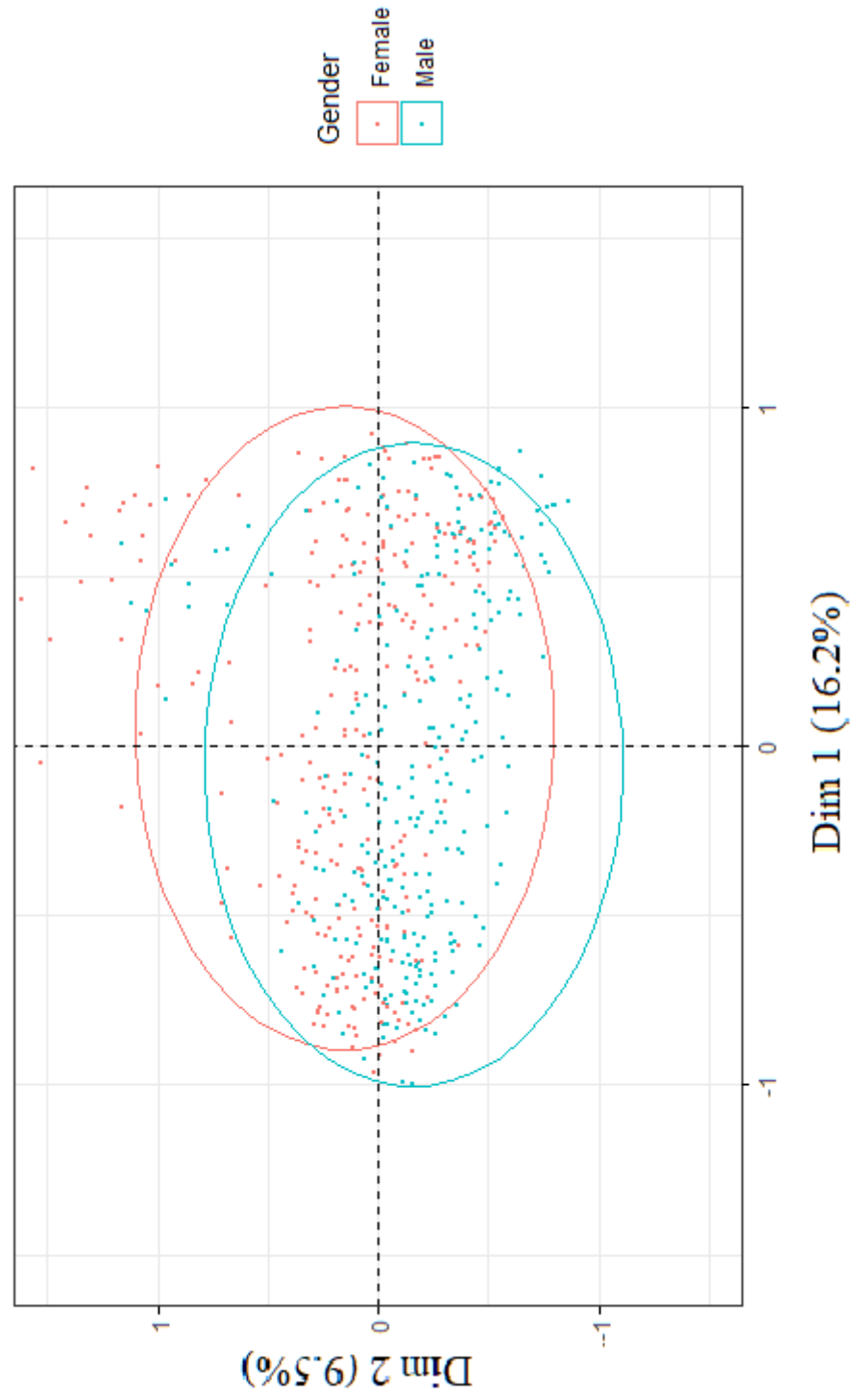
Appendix C: The MCA Factor Loading on the First Four Dimensions

The MCA Factor Loading on the First Four Dimensions

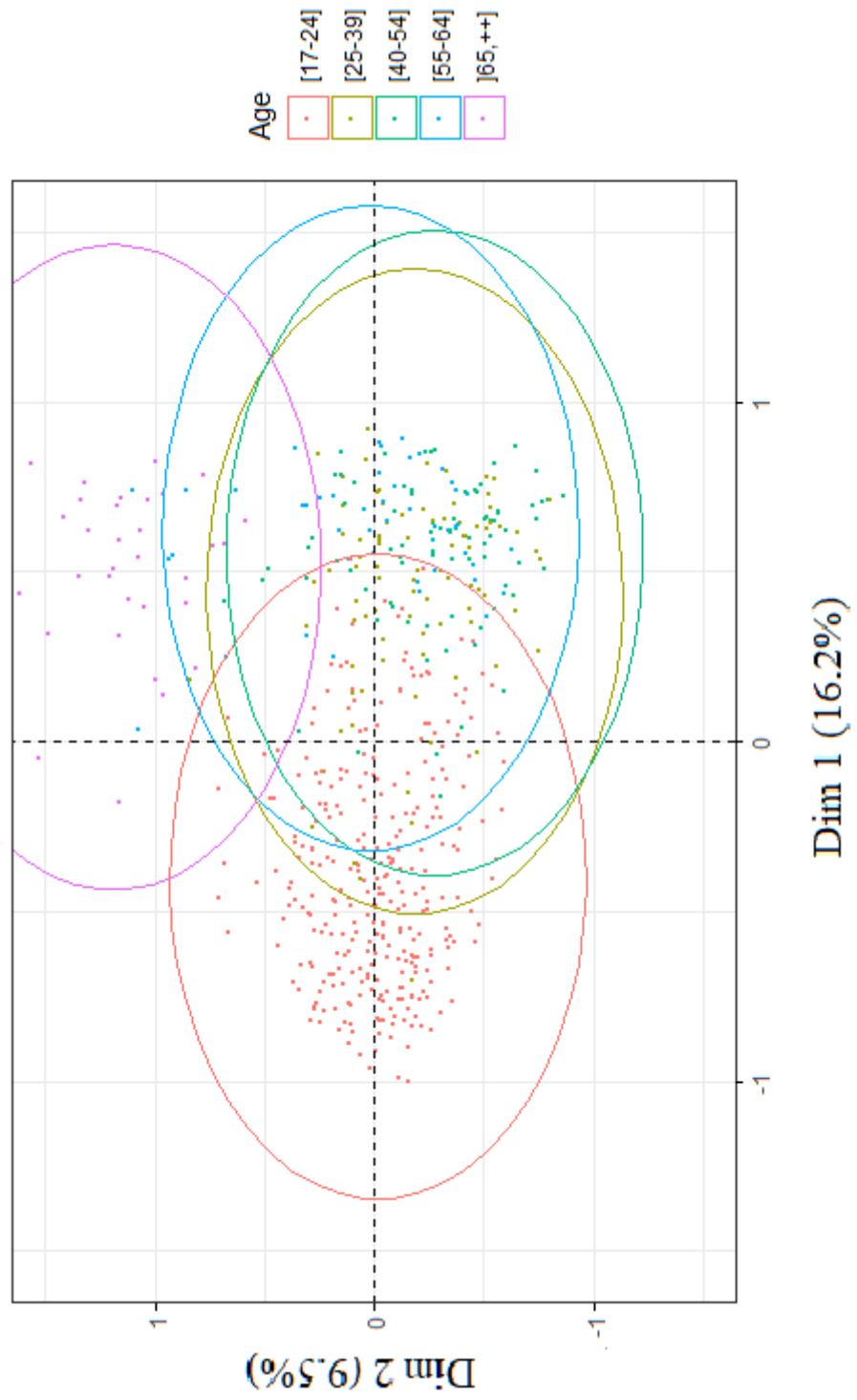
Variable	Dim1	Dim2	Dim3	Dim4
Profession	0.703	0.106	0.144	0.058
Age	0.671	0.060	0.130	0.080
Vehicles	0.632	0.010	0.055	0.149
Reguraly_drive	0.527	0.011	0.010	0.105
Household	0.375	0.035	0.122	0.052
trust_ADAS	0.000	0.429	0.014	0.007
trust_driverless_metro_tram	0.051	0.408	0.036	0.017
AV_advantages_same_lanes	0.010	0.399	0.049	0.050
AV-_Insecurity	0.008	0.342	0.017	0.001
trust_new_technology	0.001	0.257	0.048	0.009
trust_cybersecurity	0.017	0.138	0.040	0.016
Trip_duration	0.100	0.009	0.290	0.155
Trip_frequency	0.090	0.022	0.208	0.021
Trip_Mode	0.007	0.002	0.193	0.050
AV_Route_optimization	0.030	0.107	0.007	0.262
AV_Time_saving	0.008	0.112	0.002	0.235
AV_Comfort	0.000	0.014	0.000	0.182
AV_No_license	0.006	0.001	0.003	0.174
AV_loss_driving_pleasure	0.000	0.024	0.030	0.112
ADAS	0.069	0.007	0.016	0.043
Know_AV	0.066	0.056	0.016	0.036
PAV	0.065	0.107	0.003	0.018
AV_collecting_data	0.119	0.002	0.005	0.007
Gender	0.006	0.102	0.006	0.001
SAV	0.061	0.113	0.002	0.000

Appendix D: The MCA Factor Maps for Each Active Variable

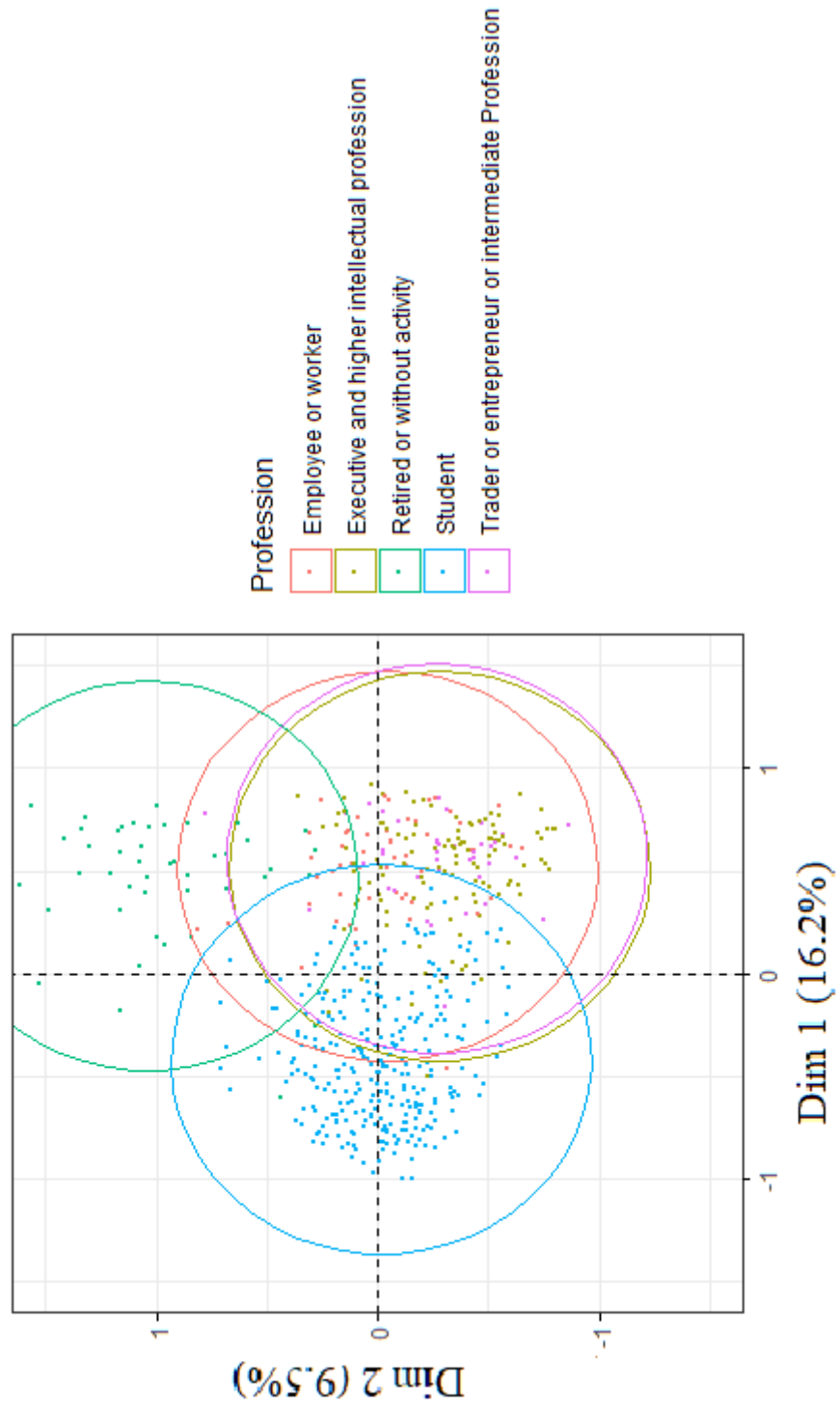
The MCA factor map for gender



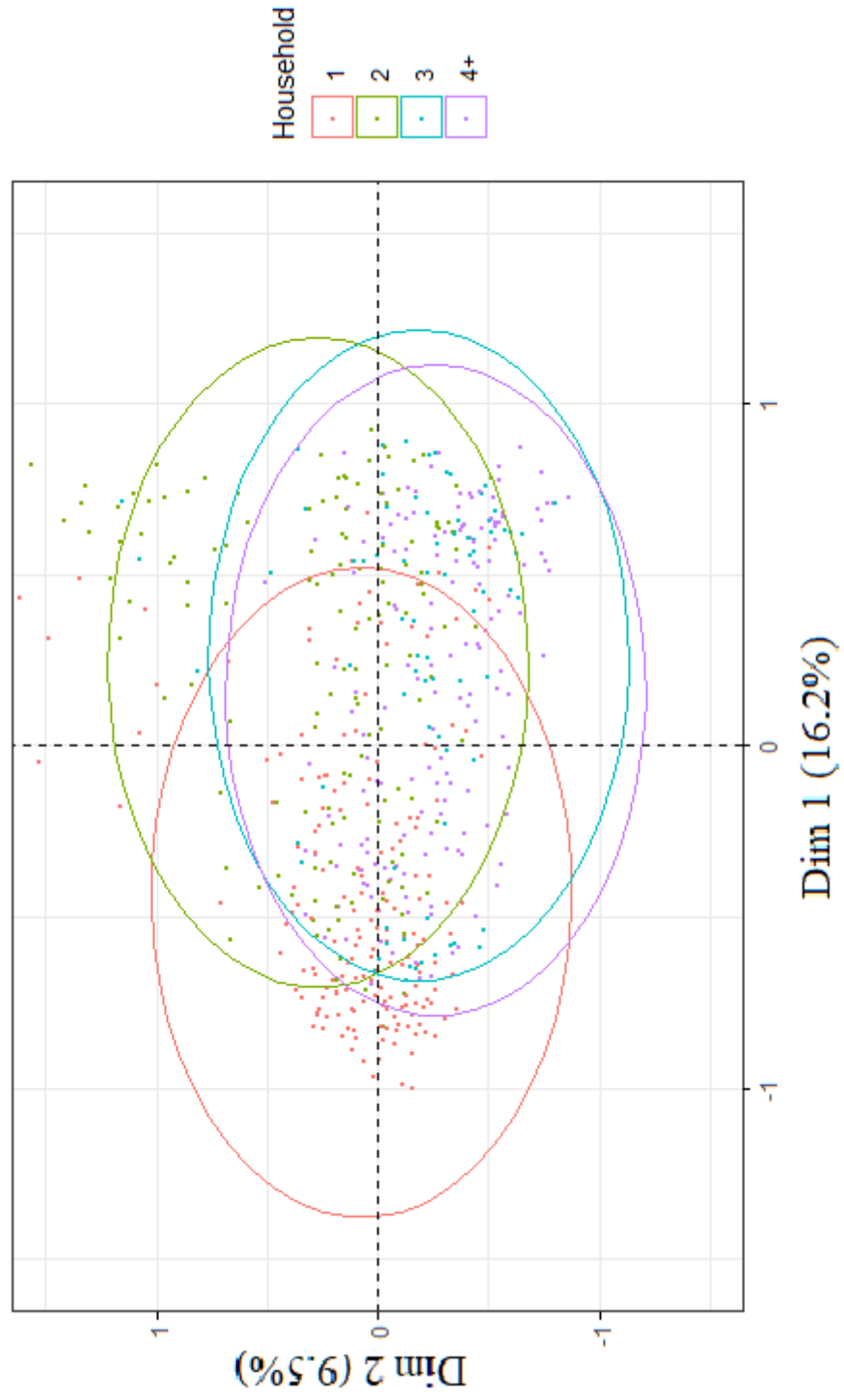
The MCA factor map for age groups



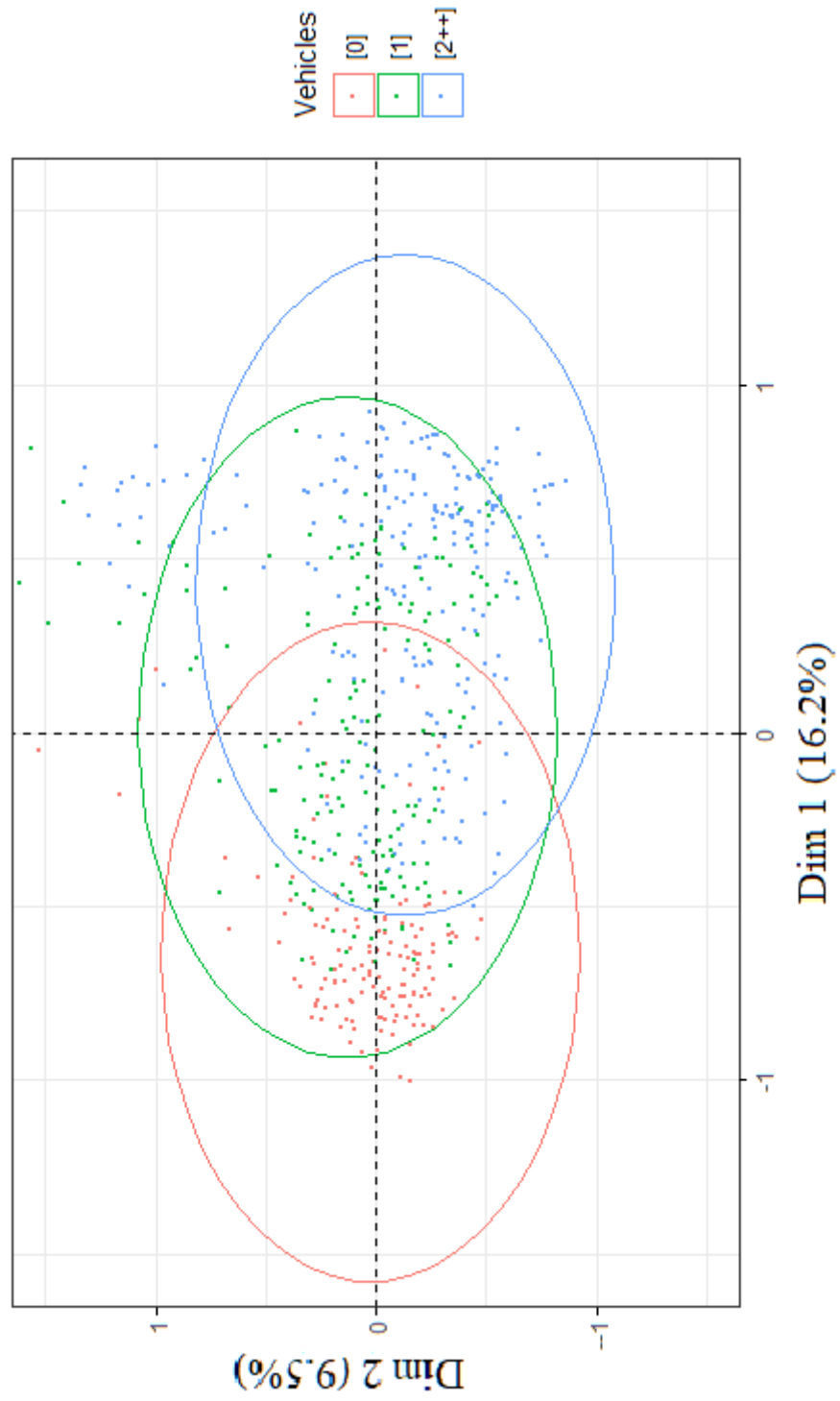
The MCA factor map for profession



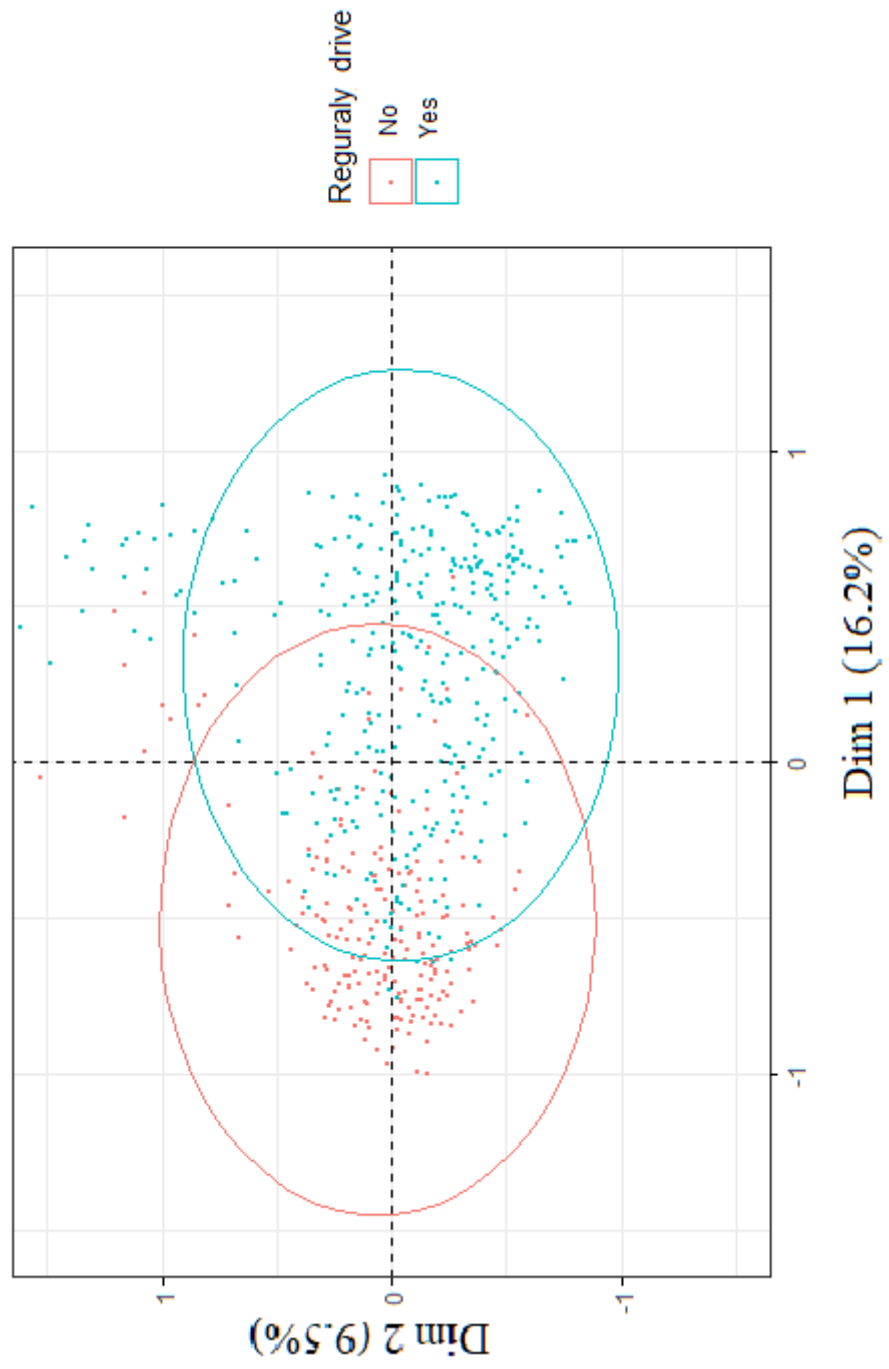
The MCA factor map for household size



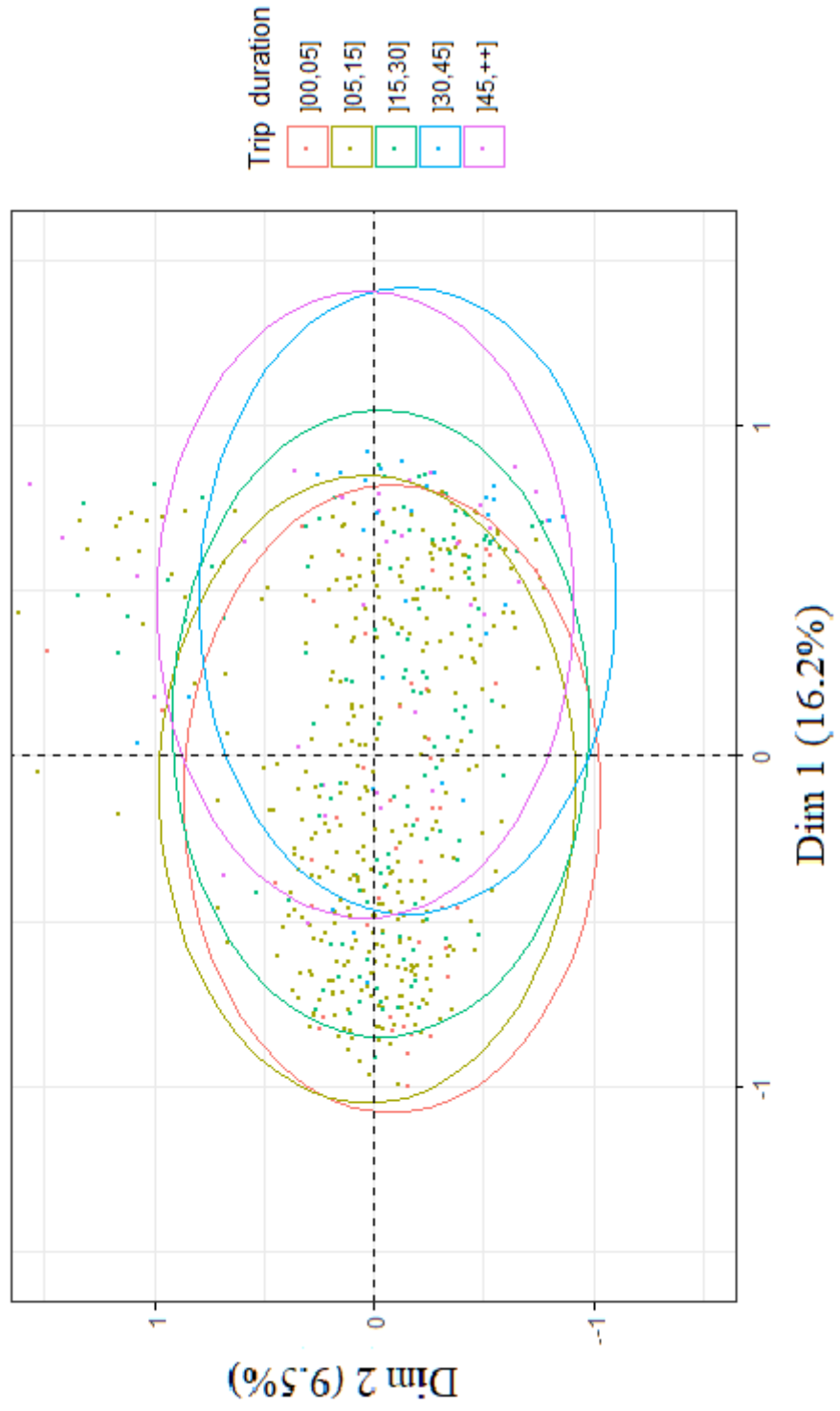
The MCA factor map for vehicles owned



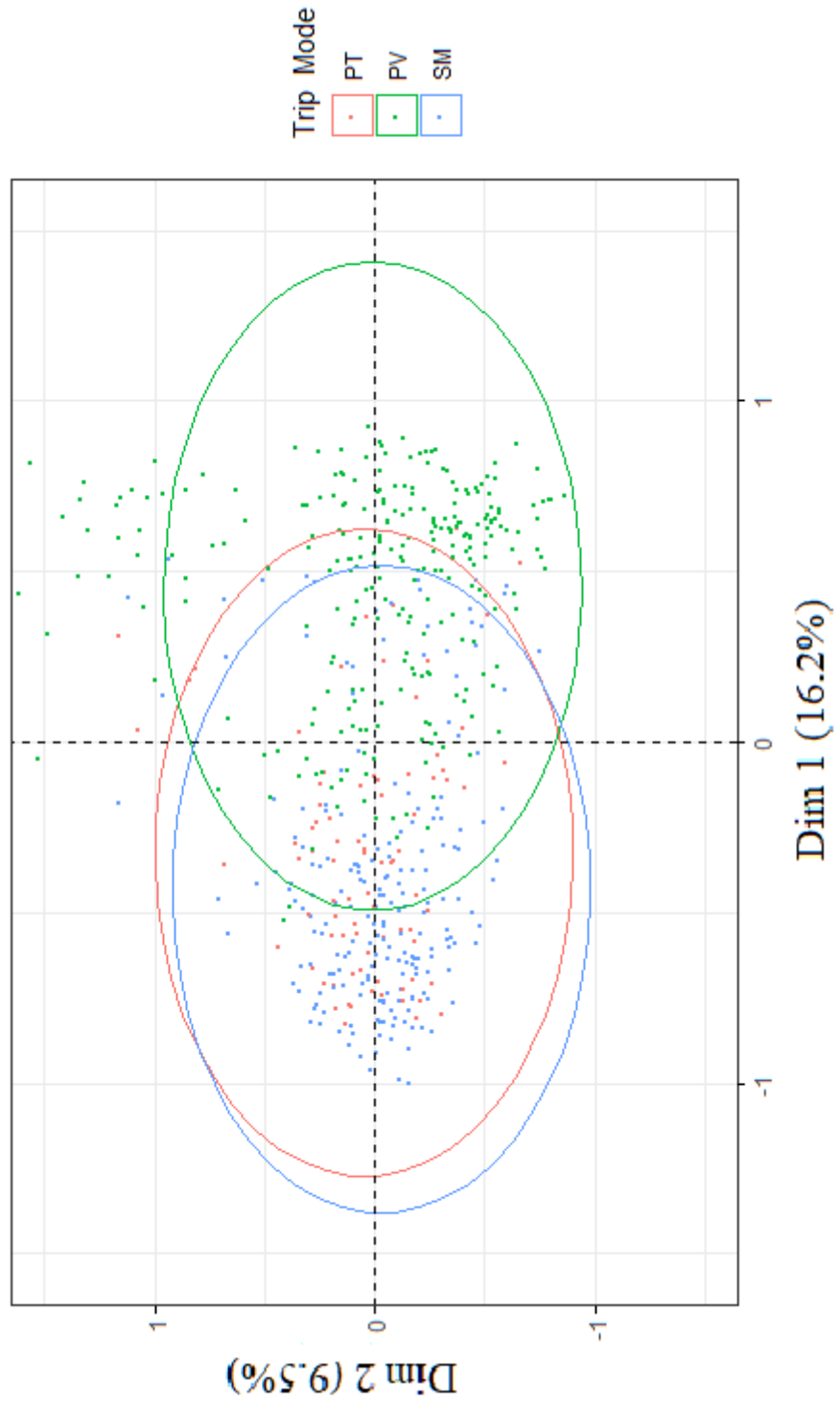
The MCA factor map for drivers



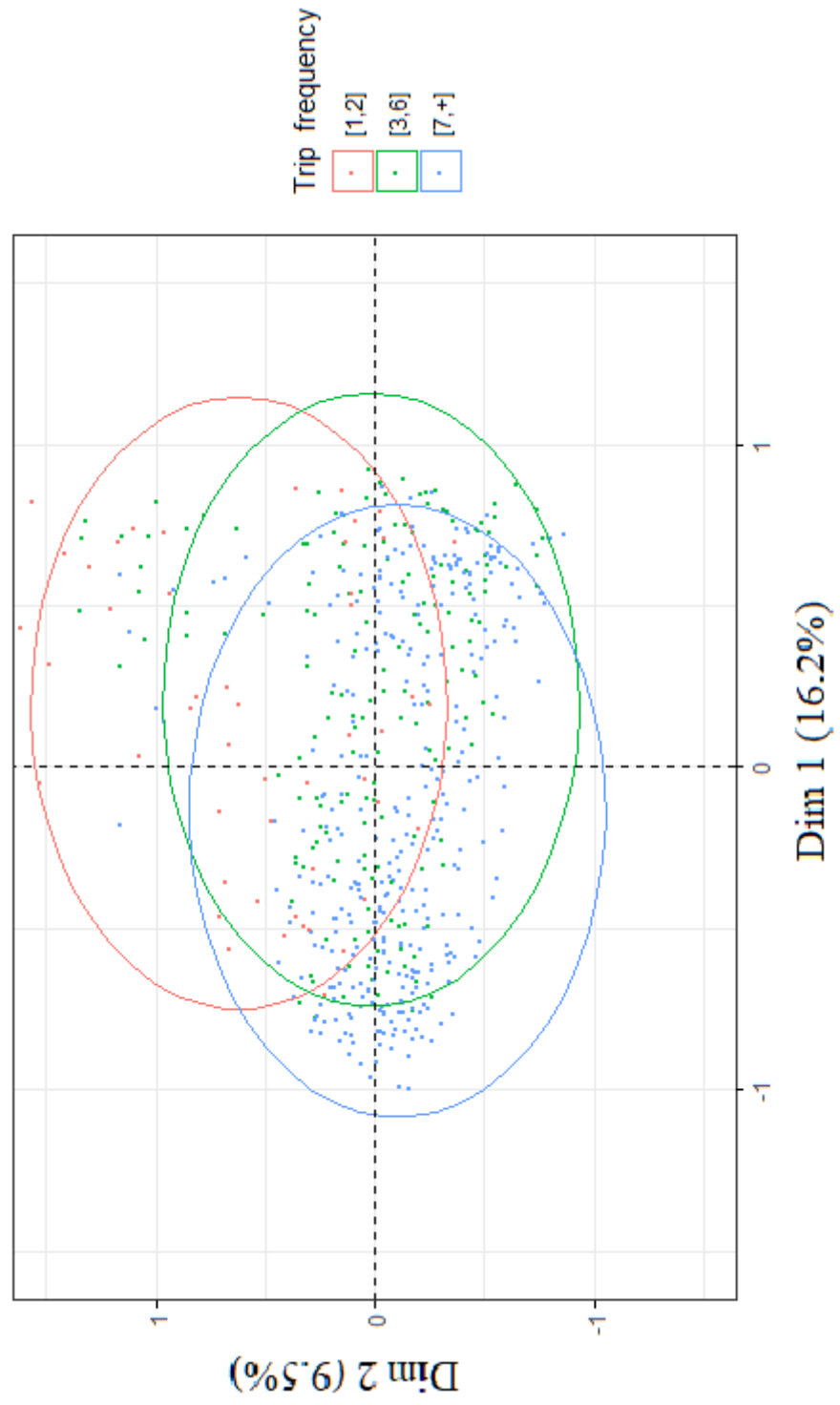
The MCA factor map for trip duration



The MCA factor map for trip mode



The MCA factor map for trip frequency



**Appendix E: The Distribution Frequency
of Different Variables on the
Four Clusters**

Table B.1: The distribution frequency of different variables on the four clusters

	Clusters distribution				Clusters distribution (%)				Sample distribution	Sample percentage (%)
	C 1	C 2	C 3	C 4	C 1	C 2	C 3	C 4		
size	258	145	130	58	100	100	100	100	591	100
Trip_frequenc y	[7,+]	135	103	102	18	52	71	78	31	358
	[3,6]	100	30	23	25	39	21	18	43	178
	[1,2]	23	12	5	15	9	8	4	26	55
Trip_Mode	PV	214	7	3	52	83	5	2	90	276
	SM	30	99	95	6	12	68	73	10	230
	PT	14	39	32	0	5	27	25	0	85
Trip_duration	]00,05]	18	8	15	4	7	6	12	7	45
	]05,15]	147	99	91	24	57	68	70	41	361
	]15,30]	55	26	23	19	21	18	18	33	123
	]30,45]	16	6	1	6	6	4	1	10	29
	]45,++]	22	6	0	5	9	4	0	9	33
Drive	Driver	236	32	40	54	91	22	31	93	362
	Non-driver	19	112	89	3	7	77	68	5	223
Gender	Female	128	88	47	40	50	61	36	69	303
	Male	130	57	83	18	50	39	64	31	288
Age	]17-24]	77	129	125	4	30	89	96	7	335
	]25-39]	69	5	4	10	27	3	3	17	88
	]40-54]	62	7	1	12	24	5	1	21	82
	]55-64]	31	1	0	15	12	1	0	26	47
	]65,++]	19	3	0	17	7	2	0	29	39
Profession	Executive/higher intellectual	99	6	1	14	38	4	1	24	120
	Student	69	128	126	3	27	88	97	5	326
	Trader/entrepreneur/intermediate	30	2	1	5	12	1	1	9	38
	Employee/worker	35	5	1	14	14	3	1	24	55
Retired/without activity	25	4	1	22	10	3	1	38	52	

Table B.1: The distribution frequency of different variables on the four clusters

	Clusters distribution				Clusters distribution (%)				Sample distribution	Sample percentage (%)
	C 1	C 2	C 3	C 4	C 1	C 2	C 3	C 4		
size	258	145	130	58	100	100	100	100	591	100
Household										
H_1	44	80	68	8	17	55	52	14	200	34
H_2	77	23	23	29	30	16	18	50	152	26
H_3	50	10	12	10	19	7	9	17	83	14
H_4+	86	32	27	11	33	22	21	19	156	26
V_0	4	84	72	1	2	58	55	2	161	27
V_1	99	44	37	20	38	30	28	34	200	34
V_2+	155	17	21	37	60	12	16	64	230	39
Driving_licens										
D_0	0	20	9	1	0	14	7	2	30	5
D_1	58	76	67	11	22	52	52	19	212	36
D_2+	200	49	54	46	78	34	42	79	349	59
Yes	139	90	121	7	54	62	93	12	357	60
No	119	55	9	51	46	38	7	88	234	40
PAV										
Yes	156	35	70	4	60	24	54	7	265	45
No	102	110	60	54	40	76	46	93	326	55
Yes	202	83	110	6	78	57	85	10	401	68
No	56	62	20	52	22	43	15	90	190	32
increase_PT_u										
Yes	105	126	111	17	41	87	85	29	359	61
No	84	9	12	22	33	6	9	38	127	21
Use_PT_apart										
Not possible	69	10	7	19	27	7	5	33	105	18
I do not use PT	65	3	4	31	25	2	3	53	103	17
1 to 2 times	171	99	93	23	66	68	72	40	386	65
3 to 4 times	4	19	19	3	2	13	15	5	45	8
5 + times	18	24	14	1	7	17	11	2	57	10

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