EXAMINING THE EFFICIENCY OF AUTONOMOUS VEHICLES IN HIGHWAY TRANSPORT

Mohammadamin Rezaei

A dissertation submitted to the University of Dublin for the partial fulfilment of the requirements for the degree of Doctor of Philosophy

May 2020

Department of Civil, Structural & Environmental Engineering

Trinity College Dublin

DECLARATION

I declare that this thesis has not been submitted as an exercise for a degree at this or any other university and it is entirely my own work.

I agree to deposit this thesis in the University's open access institutional repository or allow the Library to do so on my behalf, subject to Irish Copyright Legislation and Trinity College Library conditions of use and acknowledgement.

May 2020

____

Mohammadamin Rezaei

SUMMARY

This thesis reports on a research project which examined the efficiency of Autonomous Vehicles (AVs) in highway transport, and experts' and other people's perceptions and acceptance of these vehicles.

This research aimed to address the benefits and risks of the application of AVs using the results of past studies in this context. The study focused on the effects that AVs might have on factors associated with the adoption of AVs such as safety, traffic, cost, the environment and some other parameters. Then, it identified some gaps in the technology and research in this field, which need to be filled before the exploitation of AVs on public roads.

In order to address the research gaps on AVs, this study assessed public perception and acceptance of these vehicles through a national survey in Ireland with 474 participants. The results of this study addressed people's concerns regarding the adoption of AVs and their willingness to adopt an AV in their life. Then the study conducted a survey amongst 301 international experts in related fields to gather their comments and thoughts on the substantial risks and advantages of the application of AVs in highway traffic from an expert point of view. The results of these two surveys found that, despite the many benefits of switching to AVs, security concerns, legal liability, and safety concerns are the most substantial concerns of the experts and road users with regard to adopting AVs. Additionally, experts demonstrated that a lot more investigation, research, and technology development required before the adoption of AVs on public roads along with improvement in juridical issues and legal liabilities related to the use of the AVs.

After addressing different benefits and risks in the application of AVs, the study aimed to evaluate the impact of the adoption of these vehicles by modelling them in a real road network. The purpose of this modelling was to attain a clear understanding of the effects of AVs on some of the characteristics of the road trip assessed in the first step of the research. However, since the technologies used in AVs are new, and there is no previous experience of the application of AVs in highway transport, there is no information about the driving behaviours of these vehicles; this, therefore, is an essential aspect of the modelling. So, the study optimised the parameters of human driving behaviours to find out what would happen if AVs could drive with modified human behaviours. The optimisation, along with a few model configurations for AVs, was conducted over 86 simulation scenarios (1,003 hours' simulation) in a conceptual model of the M50 motorway in Dublin using the microsimulation software PTV-VISSIM (PTV, 2017). Then, the study acquired the optimised driving behaviours to evaluate how efficient AVs can be within the context of the anticipated driving behaviours.

The modelling for this study was conducted over 180 simulation scenarios under various traffic conditions of the year 2017, with 3,150 hours of traffic simulation to make sure the results are internally consistent. The simulation results addressed the impacts of adopting AVs in a diverse range of peak, normal and off-peak traffic conditions in 2017 on the M50 motorway. Also, the shared road of AVs and Traditional Vehicles (TVs) was tested under 11 simulation scenarios for each traffic condition where the proportion of the AVs increased by 10% from an entirely traditional network to a network fully occupied by AVs. In total, the simulation for the shared road was conducted over 33 simulation scenarios for all traffic conditions with 576 hours of simulation. Such an assessment of the mixed traffic represents the transition periods between TVs and AVs in highway transport. The results of the simulations showed that AVs could be efficient in all types of traffic conditions. However, AVs showed to be more efficient in the normal traffic condition when the network was not saturated in terms of traffic flow. Also, the results showed that AVs and TVs could share the network efficiently, and the smoothness of traffic flow increased with the increase in penetration of AVs. However, the results from the peak and normal traffic conditions in this evaluation showed that a road with a 60% share of AVs can improve traffic quality as much as a road entirely populated by AVs. Likewise, a 30% share of AVs on the road in off-peak traffic conditions provides approximately the same improvement as a 100% share of AVs.

Additionally, AVs were shown to be most effective in reducing the number of stops, stop delay, queue length and queue delay. In general, the assessments conducted for this study showed that AVs could improve the quality of highway trip characteristics by an overall average of 62% in all types of traffic conditions.

Finally, the study adopted driving behaviours recently (in 2018) suggested by PTV for the simulation of AVs over 41 simulation scenarios with 717 hours of simulation, and the results were compared to those of this study. The comparison of results from the simulation of the AVs of this study and those of PTV validated the optimisation and simulation of this study. The simulation of AVs using the optimised driving behaviours of this study obtained an overall improvement of 67.4% in traffic quality, which is in line with simulated 69.4% and 73.0% improvement from the PTV's normal and aggressive driving behaviours, respectively. Moreover, the simulation of the shared road of PTV returned results similar to those of this study. Additionally, the shared road of both studies (this study and PTV) showed no substantial improvement in the quality of traffic once the AV share of the road rose above 60%.

ACKNOWLEDGEMENTS

The past three years has been a period of intense learning for me, not only in the scientific arena but also on a personal level. Writing this dissertation has had a substantial impact on me and I would not have been able to complete this challenging journey without the help and support of certain people throughout this period.

Firstly, I would like to express my sincere gratitude to my supervisor Dr Brian Caulfield for his time, energy and continuous support of my PhD study, and for helping me to become a researcher. His patience and guidance played a major role throughout my study, especially during the writing of this doctoral thesis. Without his guidance and constant feedback, this PhD would not have been achievable.

I would also like to thank Dr Bidisha Ghosh and Dr Alexandros Nikitas for their insightful comments, which helped me to widen my research from various perspectives.

This research would have been impossible without the financial support of the Department of Civil, Structural, and Environmental Engineering. I would like to thank the members of the department committee for providing me with the opportunity to do my research with the department's financial support. Also, I would like to express my gratitude to all the other professors and staffs of the department, in particular for their expert advice and support.

I would also like to take this opportunity to thank my friend Hashem Zarafat for his consultations and support through the steps of my research.

Finally, but by no means least, my deep and sincere gratitude to my lovely family for their continuous and unconditional love, help and support throughout my PhD research and my life. They have selflessly encouraged me to explore new directions in life and to seek my own destiny. This journey would not have been possible without them. I dedicate this milestone to my parents, Mahmoud and Sedigh; my brothers, Masoud, Moein, and Mehdei; my sisters-in-law, Saeedeh, Parisa, and Nafiseh; and the sweeties of our family, Maneli, Maya, Vihan, and Helsa.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF STATISTICAL MODELS

ABBREVIATIONS

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AI	Artificial Intelligence
AIMSUN	Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks
ANOVA	Analysis of Variance
AV	Autonomous Vehicle
BPK	Billion Passenger-Kilometre
CAV	Connected and Automated Vehicle
CO	Carbon Monoxide
CORMAK	CORridor MACro-simulation software
CORSIM	CORridor SIMulation. A Micro-simulation software for signal, highway, and freeway systems
CSO	Central Statistics Office of Ireland
CV	Coefficient of Variation
DMV	Department of Motor Vehicle
EA	Evolutionary Algorithm
EXP	Exponential
FHA	Federal Highway Administration
GA	Genetic Algorithm
GHG	Greenhouse Gas
Hailo	A platform that connected taxi drivers and passengers through a mobile phone application. Hailo had become mytaxi in 2017
ITS	Intelligent Transportation System
LIDAR	Light Detection and Ranging
LOS	Level of Service
Lyft	A transportation network company that offers car rides, scooters, and a bicycle-sharing system
MNL	Multinomial Logistic
MRA	Multiple Responses Allowed
MSE	Mean Squared Error

MSR	Mean Squared of Rows (of data)
NGSIM	Next Generation SIMulation. A micro-simulation software developed by FHA
NHTSA	National Highway Traffic Safety Administration
O–D	Origin to Destination
OECD	Organisation for Economic Co-Operation and Development
OR	Odds Ratio
PARAMICS	Parallel Microscopic Simulation. A micro-simulation software developed by Quadstone PARAMICS in the UK
PennDOT	Pennsylvania Department of Transport
PTV	English: Planning Transport and Traffic
R&D	Research and Development
RSA	Road Safety Authority of Ireland
SA	Sensitivity Analysis
SAE	Society of Automotive Engineers
Sig.	Significance
SPSS	Statistical Package for Social Sciences. A software package used for statistical analysis
SUMO	Simulation of Urban MObility. A microscopic traffic simulation package, developed by German Aerospace Centre
TAM	Technology Acceptance Moel
TII	Transport Infrastructure Ireland
TPB	Theory of Planned Behaviour
TV	Traditional Vehicle
Uber	A transportation network company that offers ridesharing services, bicycle-sharing systems, and food delivery
UK	United Kingdom
US	United States
USD	United States Dollar
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VISSIM	Verkehr In Städten SIMulationsmodell. German for "Simulation Model for Traffic in Cities". A micro-simulation software developed by PTV
VMT	Vehicle-Mile-Travelled
W99	Wiedemann 99
WA	Weighted Average

WAYMO	A self-driving technology development company which was as a project of Google before becoming stand-alone. It is also called Google's AV
Word Cloud	A visual representation of text data and keywords to get free from texts.
WTA	Willingness to Adopt
WTP	Willingness to Pay

1. INTRODUCTION

1.1. Introduction

Over the past decade, there has been a sharp rise in the addition of vehicle sensors and technologies to cars to make them safer and more efficient (Greenough, 2016; Bell, 2015). More recently, there has been a strong focus on a new generation of Autonomous Vehicles (AVs), which are capable of driving without human intervention (Fagnant and Kockelman, 2015). AVs which are also known as self-driving cars or driverless cars are vehicles that can guide themselves with little or no human conduction (Taeihagh and Lim, 2019). Aside from the impact of AVs on the car industry, they may also play an essential role in transportation science. It is foreseen that they may have direct and positive implications for safety, traffic flow, fuel consumption, the environment, and the privacy of road users, which may impact upon users' acceptance. Therefore, it is essential to develop an understanding of the extent to which the awareness and acceptance of such technology among individuals is necessary and important. Moreover, it is also crucial to understand how AVs can behave in highway traffic.

Before describing the problems in the field and research objectives, it is essential to review various levels of vehicle automation and indicate which level is going to be studied in this research. In this context, the Society of Automotive Engineers (SAE) defined six levels of automation for AVs, which is also adopted by the National Highway Traffic Safety Administration (NHTSA). Table 1.1 represents the levels of automation defined by SAE (2016) and adopted by NHTSA (2019). It is worth noting that the names and definitions provided in Table 1.1 are generic and internationally developed by SAE, NHTSA, and the researchers in the field. Therefore, the terms in

Table 1.1 is adopted in this research without a substantial change in their definition.

Table 1.1. Levels of vehicle automation defined for AVs (NHTSA, 2019; SAE, 2016)

Level	Name	Definition
0	No Automation	The driver performs all the driving tasks
1	Driver Assistance	The driver controls the vehicle, but some Advanced Driving Assistance Systems (ADAS) may be included in the vehicle design
2	Partial Automation	An ADAS system can perform **some driving tasks** such as steering, acceleration, and braking under **some circumstances.** However, the human driver must pay full attention to the vehicle's driving operation at all times and remain engaged with the rest of the driving task.
3	Conditional Automation	An Automated Driving System (ADS) can perform **all aspects of the driving task** under **some circumstances**, while the presence of a driver is necessary**. The driver must be ready to take back control of the AV in those circumstances** when the ADS system requests the human driver to do so. In all the rest of the driving circumstances, the human driver should perform the driving task.
4	High Automation	An ADS system can perform **all driving tasks** in **certain circumstances,** and the **human driver does not need to pay attention to driving duties in those circumstances.** However, the driver may have the option to control the AV.
5	Full Automation	The vehicle (ADS system) can perform **all driving tasks** in **all circumstances,** and the **human driver does not need to get involved in driving.** The human driver is just a passenger of the AV.

Source: National Highway Traffic Safety Administration (2019) & Society of Automotive Engineers (2016)

Based on the information provided in Table 1.1, this study aims to evaluate the efficiency of AVs in the ultimate level of automation (i.e., level 5 which is also referred as full automation) in highway transport. Therefore, the abbreviation of the term AV throughout this thesis is adopted to represent a fully automated AV or level 5 AV. It is also worth noting that the term 'traffic efficiency' throughout this thesis points to an average of the followings:

- A decrease in travel time
- An increase in the number of vehicles from origin to destination of a trip
- An increase in the total number of vehicles in the network
- A decrease in queue length and queue delay
- A decrease in vehicle delay
- A decrease in the number of stops and stop delay
- A decrease in fuel consumption and CO emission
- Promotion in the Level of Service (LOS)

1.2. Problem Statement

Autonomous Vehicles may change travel behaviours as they will have direct impacts on the modes of travel (LaMondia et al. 2015). Various studies have pointed to AVs for their traffic and environmental benefits, reduction of human errors in driving, increase of vehicle safety, reduction of the severity of accidents, reduction of traffic congestion and their possibility of providing mobility for young, old and disabled people (Bansal et al., 2016; Krueger et al., 2016; PennDOT, 2016; Fagnant and Kockelman, 2015; NHTSA, 2015; Howard and Dai, 2014; Schoettle and Sivak, 2014b, 2014c; Casley et al., 2013). Some studies have also estimated a possible timeframe (2040 – 2075) in which AVs will become a reality and achieve a (5%) market share (Litman, 2016; Kyriakidis et al. 2015; Underwood, 2014).

On the one hand, it is likely that the transition and societal changes resulting from the adoption of AVs are extensive and so AVs might be required to operate and share the road with TVs for some decades (Hancock et al., 2019; Laan and Sadabadi, 2017). On the other hand, there has not yet been an official adoption of AVs on highways to address the exact outcomes of their adoption for long-distance travel. Therefore, it is unclear what exactly will happen to road trips in terms of characteristics such as safety, traffic, privacy and security, the environment and some others. Such characteristics impact on the transport industry, the car industry and road users. Addressing the possible outcomes of the adoption of AVs before their emergence on public roads will help different groups of experts who are dealing with the production and deployment of AVs in the road network. The related groups are including, but not limited to, transport scientists, car manufacturers, environmental protection agencies, road users, legislators, insurance companies, and all groups which might be relevant to mobility services. For this reason, the current research aims to address the benefits and risks of the different effects of AVs on users' acceptance, experts' perceptions of the adoption of AVs for highway trips, and the impact of AVs on the trip characteristics mentioned above. More details on the objectives of the thesis and the methodology for dealing with such concerns are presented in the following sections.

1.3. Research Objectives

The research aim is to find out whether AVs are efficient in highway transport or not and, if so, how efficient they are and how much ready are the people, governments, and industries and the transport network. Such an objective can be presented as follows:

i. To analyse road users' perceptions, concerns, and acceptance of automated driving;

ii. To explore the main concerns of the transportation experts regarding the application of AVs in highway transport;

iii. To help the human driving behaviours model for the representation of intelligent driving behaviours;

iv. To explore which parameters of driving behaviour model must change to attain the desired improvements on specific characteristics of highway trip;

v. To identify the possible outcomes of replacing human drivers with machines on the environment, travel time, queues, delays, the level of service (LOS); and

vi. To assess if AVs could be utilised in the current transport infrastructure in mixed traffic with TVs or if they would need a dedicated lane and evaluate the change in traffic flow by increasing the proportion of AVs in the highway.

1.4. Resolved Concerns regarding the adoption of AVs

Previous studies (see Chapter 2) contributed to some findings regarding users' perception and acceptance of AVs. However, several concerns and questions were remained unanswered regarding the adoption of AVs which are addressed in this study as follows:

- Would public individuals be interested to adopt AVs?
- What would be individuals' main reasons for adopting AVs?
- How much would public individuals be willing to pay for AVs?
- Would academia, industry and government experts support the adoption of AVs in public roads?
- Would Ridesharing AVs be more efficient than the private AVs in providing an efficient traffic flow?
- What would be the most valuable outcomes of adopting AVs?
- What would be the most substantial concern of adopting AVs?
- What would be the most significant technical concern of adopting AVs?
- Would AVs be safe and secure? What do people and experts believe considering the latest improvements in the technology of these vehicles?
- Would AVs be safer and more secure than human-driven vehicles?
- Who should have access to the travel data stored in AVs?
- Which group or agency should take the highest responsibility of AVs in case of an accident?
- Would AVs be helpful in increasing road throughput and improving the level of service? If yes, by how much?
- Would AVs be able to reduce fuel consumption and vehicle emissions? If yes, by how much?
- Would AVs be able to reduce travel time? If yes, by how much?
- Would AVs be able to reduce vehicle stops, queue length, and delay time? If yes, by how much?

- Would traditional driving behaviour models be adopted for replicating autonomous behaviours?
- What parameters of the traditional driving behaviour model (Wiedemann-99) should be changed (and by how much) in order to achieve the lowest travel time, queue length, delay time, fuel consumption, vehicle emission, and the highest LOS?
- Would AVs be able to operate in mixed traffic with traditional vehicles (TVs) or a dedicated lane is required for AVs' adoption in highway transport?
- Could statistical reliability tests such as Cronbach's alpha be used in traffic simulation studies?
- What proportion of AVs would be required in mixed traffic with TVs (if possible) to achieve the most efficient traffic quality?
- Would the recent autonomous driving behaviours defined by PTV be able to properly replicate autonomous behaviours?

1.5. Thesis Layout

The organisation of the rest of the thesis is as follows:

Chapter 2 reviews the relevant studies on the benefits and concerns relating to the adoption of AVs in highway transport. The results of past studies provide for a better understanding of the possible outcomes of the application of AVs and highlight gaps in the knowledge. Also, a review of the studies related to microsimulation of traffic flow and some previously performed analysis of the parameters of driving behaviours is conducted. The results of this section also highlight the gaps, concerns and risks of AVs in highway transport.

Chapter 3 deals with the research methodology. It explains the procedure of the surveys of this research, and the data collection procedures of the surveys. Since driving behaviours are an essential aspect of simulation modelling in this field, they define the logic behind the operations of the vehicles in the model. Therefore, it is crucial to have an understanding of driving behaviours. In this context, Chapter 3 conducts a review of the Wiedemann-99 Car-Following Model and its respective parameters. This chapter describes and adopts different parameters of driving behaviours which are used for optimisation. Then, it makes use of the organised driving behaviours and optimises them to simulate AVs. In this chapter, a detailed explanation is provided about the step by step process of optimisation. Additionally, chapter 3 provides a detailed explanation about the structure of simulations of TVs and AVs in single-mode occupancy and shared road with various proportions of these vehicles.

The findings of Chapter 2 reveal substantial concerns regarding the application of AVs. Since AVs directly impact on users' lives, **Chapter 4** presents the results of a national public survey conducted in Ireland. This chapter assesses users' perceptions and opinions of adopting AVs in their daily lives, their willingness to adopt AVs, their willingness to pay (WTP) and many other factors which impact on the viability of AVs.

Based on the insights gained from Chapters 2 and 4, it seemed necessary to estimate the possible outcomes of the application of AVs from an expert point of view. In this context, **Chapter 5** describes the expert survey conducted in this research with the help of specialists in fields relevant to AVs. The results from this chapter address the possible risks of AVs in terms of traffic, the environment, safety, and some other associated elements.

The findings from Chapters 4 and 5 answer a diverse range of questions regarding the application of AVs. However, it seemed necessary to carry out some experiments to find out the extent to which the results are in line with public and experts' perceptions in this matter. Therefore, the study proceeded to simulate AVs in a case study on the M50 motorway in Dublin. However, since no driving behaviours have been defined for AVs, the study optimised a human driving behaviour model to explore what would happen if AVs could drive with modified human driving behaviour model. For this, **Chapter 6** deals with the results of optimisation using Tables and graphs. This chapter presents the simulation results related to the optimisation of driving behaviours and provides the optimised values for the simulation of AVs. Additionally, the chapter represents the results of assessments on the impact of each driving behaviour on specific characteristics of a highway trip evaluated in this study.

Chapter 7 contains all the findings from the simulations of TVs and AVs in single occupancy and mixed traffic. Additionally, the chapter provides results of the simulations conducted using the parameters defined by PTV and compares them with the simulation results of this study.

Chapter 8 represents the conclusions of this thesis using a summary of the findings of the research. This chapter also describes the main contributions of the study and discusses the extent to which AVs could be useful in highway transport, and under what conditions. Then it provides some suggestions to direct future research in this context. Additionally, this chapter provides a brief discussion of all findings followed by an overall conclusion of the research.

1.6. Disseminations from Thesis

The contributions of this research have been published in the following journals and conferences:

1. Rezaei, A. & Caulfield, B. (2020). Simulating a Transition to Autonomous Mobility. *Simulation Modelling Practice and Theory*. (Under review)
2. Rezaei, A. & Caulfield, B. (2020). Autonomous Mobility from a Public Perspective. *Travel Behaviour and Society*. (Under review)
3. Rezaei, A. & Caulfield, B. (2020). Transition to Autonomous Mobility: A Study with 5,446 Hours of Simulation. Accepted for Presentation at *Transport Research Arena Conference (TRA VISION 2020)*. Helsinki, Finland.
4. Rezaei, A. & Caulfield, B. (2019). Public Survey on the Application of Autonomous Vehicles. Presented at the *47th European Transport Conference (ETC 2019).* Dublin Castle. Dublin, Ireland.
5. Rezaei, A. & Caulfield, B. (2019). Expert Survey on the Application of Autonomous Vehicles. Presented at the *47th European Transport Conference (ETC 2019).* Dublin Castle. Dublin, Ireland.
6. Rezaei, A. & Caulfield, B. (2018). Analysis of the Traffic Flow for Autonomous Vehicles in Freeway Transport: Optimisation and Simulation. Presented at the *46th European Transport Conference (ETC 2018)*. Dublin Castle. Dublin, Ireland.
7. Rezaei, A. & Caulfield, B. (2018). The Efficiency of Fully Autonomous Vehicles in Motorway Trips: A Case Study in Dublin – The M50 Motorway. *Civil Engineering Research in Ireland (CERI) in association with Irish Transportation Research Network (ITRN 2018).* Dublin, Ireland.
8. Rezaei, A. & Caulfield, B. (2017). Examining Users' Opinion and Acceptance of Fully Autonomous Vehicles (a review study). *Irish Transport Research Network (ITRN 2017).* University College Dublin (UCD). Dublin, Ireland.

2. LITERATURE REVIEW

2.1. Introduction

The acceptance of emerging technologies or a modal shift in the transport system has previously been studied using Technology Acceptance Models (TAM) and Theory of Planned Behaviours (TPB). Both of these models argue individuals' psychological behaviours, attitudes, and intentions towards a mode choice and how they come to accept and use a technology (Chen and Chao, 2010). For example, Chen et al. (2006) studied 300 highway motorists in Taiwan for their acceptance of electronic toll collection service (ETCS). Chen et al. (2006) used empirical data from motorists to examine the effects of TAM and TPB models on road users' intention towards the electronic toll collection service. The results of their study revealed that the perceived ease of use and usefulness of the ETCS service positively influence the users' attitude towards the adoption of it. Also, Jiang et al. (2017) examined 242 drivers with poor sleep quality adopting TPB models investigating why do drivers continue driving while they are fatigued. The drivers were investigated for their attitudes, subjective norms, perceived behavioural controls, fatigued driving information, and fatigued driving behaviours. The results of their study showed that drivers' intention, subjective norms and the rest of the evaluated behaviours impact drivers' decision to continue driving while fatigued. Moreover, Osswald et al. (2012) proposed a TAM model for predicting information technology (IT) acceptance in an automotive context. They considered perceived safety and anxiety as the model determinants to investigate the decision process towards the acceptance of in-vehicle IT systems as well as users' behaviour prediction. The result of Osswald et al. (2012)'s study revealed that participants were aware of the influence of anxiety and safety while they were using in-vehicle IT systems. Table 2.1 demonstrates studies which adopted TPB and TAM models for the evaluation of user acceptance of the emerging technologies or a modal shift in the transport-related system.

Table 2.1. Studies which adopted behavioral models for examining the acceptance of emerging technologies

Author(s)	Study Location	Purpose	Study method	Assessment model	Finding
Bohran et al. (2019)	Libya	Predicting the intention to accept the new high-speed rail	Surveying 338 individuals	TPB	Attitude and perceived behaviour controls affect car users' behavioural intention to take the new high-speed rail service
Adnan et al. (2018)	-	Identifying user acceptance for in-vehicle technologies of AVs	Literature review	TAM, TAB, and UTAUT*	TAM and TAP are the most performing model to explain the behavioural intention of AVs acceptance
Potard et al. (2018)	France	Testing the relationship between alcohol usage and the user's perceived invulnerability	Surveying 368 driving licence holder – young adults	TPB	The intention to drink and drive was predicted using the TPM model determinants. Psychological invulnerability had a significant impact on users' subjective norms, past behaviours and attitudes.
Yuen et al. (2017)	Singapore	Analysing companies' stakeholder pressure on the intensions to adopt sustainable shipping methods	Surveying 186 companies	TPB	Using planned behaviours, stakeholders can impact the intentions to use sustainable shipping practices

Chen and Chen (2011)	Taiwan	Evaluating factors affecting travellers' intention to use in-vehicle GPS devices	Surveying 251 drivers	TAM	Perceived ease of use and enjoyment have a substantial impact on users' intention to adopt an in-vehicle GPS device

* Unified Theory of Acceptance and Use of Technology

The studies – so far – presented in this Section focused on the reasons to "why" would drivers or road users chose a specific system or device and how those behaviours could be altered. However, the current study is going to focus on "what" would drivers or road users chose if they were given the opportunity of adopting an emerging technology like AVs and CAVs. For this, the current chapter is going to investigate previous studies on the benefits and risks of adopting AVs and people's behaviours and perceptions of this technology.

It is mindful to say why the current study is focusing on the user acceptance and efficiency of AVs, not CAVs. In this regard, an investigation on the number of publications related to the topic of autonomous mobility showed substantial growth in the research of AVs during the past years. Figure 2.1 validates such an argument by illustrating in the number of published papers related to AVs and CAVs in Elsevier between the years 2012 and 2019. However, Figure 2.1 indicates that fewer number of studies have focused on CAVs, which are the next generation of AVs. Also, due to the technological restrictions in the field of CAVs, the current study could not focus on this topic. Figure 2.1 also demonstrates that such restrictions persist in the current time (in 2019).

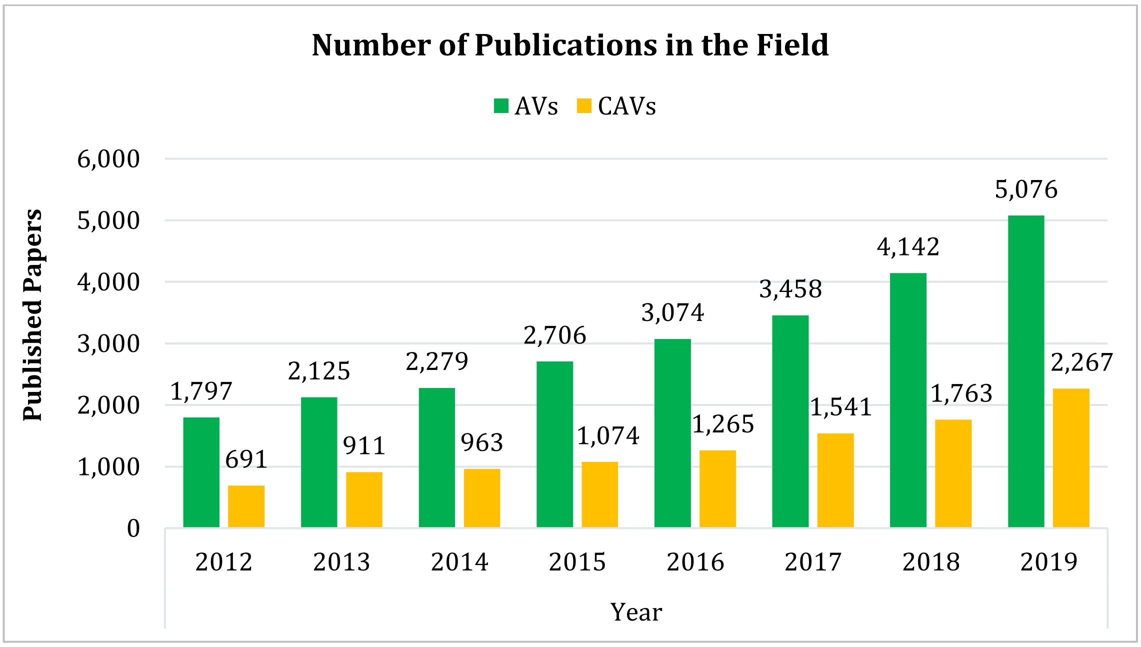


Figure 2.1. Number of Published Papers about AVs and CAVs

The investigation in the topic of autonomous mobility revealed that various studies have assessed users' acceptance and their perceptions regarding the adoption of AVs (Bansal et al., 2016; Kyriakidis et al., 2015; Howard and Dai, 2014; Underwood, 2014; Payre et al., 2014; Schoettle and Sivak, 2014b, 2014c; Casley et al., 2013). Those studies have examined the possible outcomes of adopting AVs by concentrating on safety, costs, and legal liability. They have also provided several insights on the efficiency of AVs and discussed some available technology and research gaps based on individuals' opinions.

The research for this study has identified several important factors, which impact on the feasibility of the application of AVs. Some factors might directly affect individuals' decisions to use AVs such as costs and safety, whereas some might have an indirect effect, like production issues. The factors are briefly classified in Figure 2.2. Then, they are explored in Section 2.2 of this Chapter.

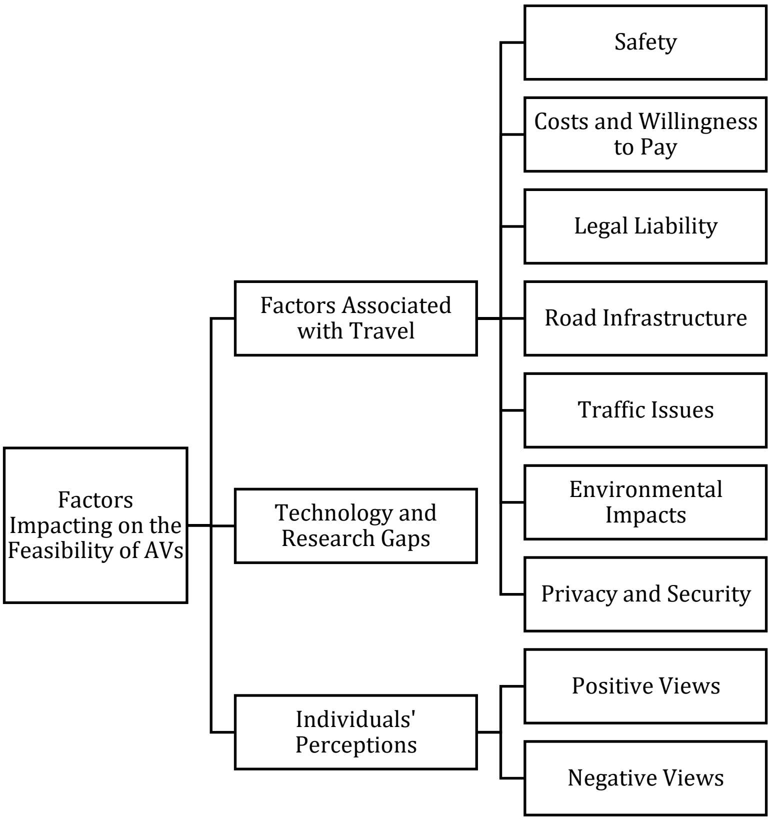


Figure 2.2. Classification tree for the factors impacting on the feasibility of AVs

It is worth noting that the materials in this Chapter were reviewed in May 2019 and supported by the results of the recent studies to make sure the literature is up to date.

2.2. The Interaction of Trip Characteristics with AV Viability

2.2.1. Safety

Safety is often cited as the number one concern relating to AVs but also the main reason for users to adopt AVs (Chan, 2017). The Organisation for Economic Co-Operation and Development (OECD) has estimated that the total motorised mobility in cities will have risen by 94% in 2050 reaching 34.9 billion passenger-kilometres (BPK), compared with 18 BPK in 2015 (OECD, 2017). As a result of the rise in demand for mobility, road safety has become a global public health issue since road crashes are estimated to be the number one cause of death among young people aged 15 – 29, and the data show that more than 1.2 million people die in global road crashes each year (OECD, 2017). Accidents related to passenger cars are mostly the result of driver errors relating to problems such as alcohol, distraction, drug involvement, fatigue, speeding and drowsiness, which are all human behaviours and which would all be eliminated in AVs (Fagnant and Kockelman, 2015). Hence, some survey investigations have been conducted to assess people's perceptions of the safety benefits of AVs, which encourage them to adopt an AV.

Table 2.2 shows the results of surveys about the main safety benefits of AVs.

Table 2.2. Summary of the (online) survey studies reviewed concerning the safety of AVs

Author(s)	Study Location	Survey Type	Number of Participants	Response Rate (%)	Evaluation Method	Main Benefit
Hulse et l. (2018)	UK	Public	925	46	MNL and ANOVA	Low risk of accidents
Bansal et al. (2016)	US	Public	347	80	Probit	Reduction of accidents
Continental (2015)	US and Germany	Public and Experts	4,100	53	*	Preventing serious accidents
Howard and Dai (2014)	US	Public	107	73	Logit	Increase in safety
Underwood (2014)	US	Expert – Delphi Survey	217	75	*	Reduction of accidents and fatality
Schoettle and Sivak (2014a)	Multiple Countries	Public	1,596	62	ANOVA	Fewer accidents with less severity and quicker response
Schoettle and Sivak (2014b)	Multiple Countries	Public	1,533	70	ANOVA	Increase in safety and reduction in accidents
Casley et al. (2013)	US	Public	450	82	ANOVA	Individuals' safety

* Not available

The studies reviewed in this section show that the first and maybe the most crucial aspect of using an AV in the view of potential users is safety, and it has direct effects on both the transportation network and road users.

In general, the safety benefits of the application of AVs can be summarised by the following factors:

- Safer driving than human drivers (Papadoulis et al., 2019)
- Capability to deliver freight and unlicensed drivers (Beirigo et al., 2018)
- Making informed decisions about the upcoming traffic (Noy et al., 2018)
- Acquiring smart sensors to avoid collisions with pedestrians (Tabitha et al., 2018; Matsumi et al., 2013)
- Quicker reaction times than human drivers (Laan and Sadabadi, 2017)
- Reduction in accidents resulting from errors in human driving operations due to problems such as drinking, using drugs, distraction, and fatigue behaviours (Howard and Dai, 2014).

2.2.2. Costs and Willingness to Pay

As with all car purchases, AVs need to be affordable for users. After safety, the cost would be considered another essential factor in influencing individuals to think more about the appeal of adopting an AV (Kyriakidis et al., 2015; Schoettle and Sivak, 2014b; Underwood, 2014). In this context, Liu et al. (2019) evaluated WTP for AVs through a public survey of 1,355 participants in China. The results of their study revealed that around 26% of participants would be unwilling to pay extra for AVs, and approximately 40% would be willing to spend more than USD 2900. Also, in another study conducted by Howard and Dai (2014), on the public perception of using AVs, with 107 respondents in Berkeley, California, over 65% of the respondents considered the cost to be a substantial concern regarding the adoption of an AV.

It is also worth mentioning that people with a higher income, highly educated people and young people are more willing to pay for AVs (Liu et al., 2019). Additionally, the results of the study by Liu et al. (2019) revealed that those who had previous information about AVs had more trust and WTP for these vehicles. So, this could indicate that WTP might be affected by people's perceptions of the AV technologies with those who are more informed about the benefits of AVs and those who have had an experience of using intelligent vehicle technologies more interested in paying for them.

One of the most substantial costs of AVs is the equipment and infrastructure. For example, a LIDAR system used in the Google car costs USD 70,000, and the total price of an AV was estimated at around USD 150,000 in 2012 (Howard and Dai, 2014; KPMG, 2012b; Priddle and Woodyard, 2012). Neiger (2016) found that adding autonomous technology to a vehicle could increase the cost of the vehicle to the USD 70,000-100,000 price range, based on the price of the LIDAR technology in 2014. However, according to Bosch et al. (2018), the operating cost of AVs will be lower due to lower insurance fees and lower fuel and maintenance costs.

Given the high price of AV technologies, it is essential to understand customers' WTP. In this context, a few studies have surveyed individuals' perceptions about the costs and WTP for AVs; these are summarised in Table 2.3.

Table 2.3. Summary of the (online) survey studies reviewed for WTP for AVs

Author(s)	Location	Survey Type	Number of Participants	Response Rate (%)	Evaluation Method	Average WTP for Adding Full Automation Technology (USD)
Liu et al. (2019)	China	Public	1,355	34	Partial / Ordinary least squares & Tobit	2,900
Bansal et al. (2016)	US	Public	347	81	Probit	7,300
Kyriakidis et al. (2015)	109 Countries	Public	5,000	78	Spearman Correlation	10,500
Schoettle and Sivak (2014b)	US, UK, Australia	Public	1,533	43	ANOVA	4,400
Schoettle and Sivak (2014c)	China, India, Japan, US, UK, Australia	Public	3,255	45	ANOVA	2,400
Casley et al. (2013)	US	Public – Online	450	100	ANOVA	5,500

In brief, the reviewed studies show that the average WTP to add full self-driving automation is around USD 5,500, which is far below the estimated price of an AV (USD 150,000) in 2012

(Howard and Dai, 2014; KPMG, 2012b; Priddle and Woodyard, 2012). Therefore, this could be a substantial problem in the future adoption of AVs.

2.2.3. Legal Liability

Just as for safety and costs, legal liability is another key issue when examining the introduction of AVs. Bartolini et al. (2017) classify legal liability relating to AVs into three main types: civil, criminal, and administrative liability. Civil liability deals with the value of property damage caused to third parties, criminal liability relates to the injury or death of a person in an accident with an AV, and administrative liability is related to driving incidents in the absence of the required authorisation (Bartolini et al., 2017). So, several concerns over these three types of liability must be resolved before introducing AVs to individuals as the tort liability allocated by law will have a substantial impact on consumers' acceptance of AVs. For instance, concerns about the responsibility of the AV in the case of an accident revolve around the fact that the driver is no longer in charge of the driving operations or control of the AV (Howard and Dai, 2014).

Regarding the public's concerns about AVs' legal liability, several studies (Continental, 2015; Howard and Dai, 2014; Schoettle and Sivak, 2014b; Underwood, 2014) have examined responses from potential users. The results of those studies have shown that users are not sure about the responsible person and or agency in the case of accidents involved in future AVs. Users considered the legal liability to be one of the most critical barriers to the adoption of AVs. In addition, legal liability has been found to be one of the most common gaps in all the investigated studies to date as there is not yet an official framework or policy to test this area of concern in the adoption of AVs, or to take account of the type of data and the sharing of information they record (Bansal and Kockelman, 2016; Bansal et al., 2016; NCSL, 2016; NHTSA, 2016; PennDOT, 2016; Fagnant and Kockelman, 2015; Kyriakidis et al., 2015; Anderson et al., 2014; Fagnant, 2014; Howard and Dai, 2014; Schoettle and Sivak, 2014a, 2014b, 2014c; Xavier Rhodes, 2014; Casley et al., 2013; KPMG, 2012b). Such concern about AVs' liability leads to security concerns. For example, AVs might be victims of hackers and unauthorised tracking by individuals who might have access to tracking data, which could lead to severe collisions, disruption of the traffic network, car hijacking, and even kidnapping of important individuals (Fagnant and Kockelman, 2015).

The rules related to legal liability could also impact on automobile liability insurance costs in jurisdictions in which AVs operate (NHTSA, 2016). Policymakers have yet to determine who must carry motor vehicle insurance. Being an AV user does not necessarily assign the entire legal liability to the user for an accident involving that vehicle. Therefore, lawmakers should determine in which circumstances the legal responsibility for an accident should be assigned to the driver and in which circumstances to the manufacturer of the AV or other groups and agencies (NHTSA, 2016).

Many attempts have been made to put together frameworks for the assignment of liability where AVs are involved, though they have not been completely successful in achieving the satisfaction of the authorities (Collingwood, 2017; Bansal and Kockelman, 2016; Bansal et al., 2016; Kyriakidis et al., 2015; Anderson et al., 2014; Howard and Dai, 2014). For instance, individual US states have been advancing AV legislation through incremental measures, but federal guidance has not yet officially been issued for testing purposes on public roads (Fagnant and Kockelman, 2015). However, Nevada and Arizona authorised testing and operation of AVs on public roads in 2011 and 2015, respectively. Also, the Governor of Massachusetts signed an executive order in October 2016 to promote the testing and deployment of automated driving technologies (NCSL, 2016). Also, the US Department of Motor Vehicle (DMV) released a draft of deployment regulations for review purposes in December 2015 (DMV, 2016).

In 2016, NHTSA issued updated guidance for the safe development of AVs (NHTSA, 2016). The policy confirms that the US states the need to retain its traditional responsibilities for vehicle licensing, traffic laws, enforcement, insurance and vehicle's liability framework. Hence, the designated agencies should take the necessary steps regarding legal liability issues such as regulations for using AVs, licensing, driver education, insurance, enforcement of traffic regulations and administration of motor vehicle inspections to address barriers to the safe testing and operation of AVs (NHTSA, 2016). Also, recently, there have been some advances in AV legislation and testing operations, and research and deployment policies which are helping the practical functionality of AVs on public roads and their possible impact on traffic and other vital aspects of highway transportation to be understood (Bruyne and Werbrouck, 2018; SAE, 2016).

2.2.4. Infrastructure

When a new generation of a vehicle or new technology comes to the market, it may need its own rules and terms of operation. For example, when electric cars were introduced, they needed and still need new charging infrastructure. Likewise, AVs might require changes in the transportation network as the current driving infrastructure in the transportation network is designed for vehicles with human drivers (Eldredge, 2016).

After evaluations on safety, costs, legal liability, user acceptance, and before introducing AVs to public roads, the infrastructure needs to be prepared. The road infrastructure plays an essential role in the performance quality of AVs as all trips will be undertaken within the framework of the road infrastructure. Therefore, it is crucial to assess whether current road networks can efficiently interact with AVs or not. For example, AVs may provide mobility for those who are too young to drive, the elderly and the disabled. Such an increase in mobility would add user groups to the road network who have not been able to operate in it before, and the consequences would be increased demands on the road network in terms of traffic and congestion. Therefore, new lanes or changes in road infrastructure and facilities might be needed to support such an increase in traffic. However, the Fagnant and Kockelman's (2015) study shows that the existing infrastructure capacity of roadways should be adequate to accommodate the added demands imposed by AVs.

Also, AVs might be able to communicate with each other when they emerge in which case; the infrastructure must meet new requirements to support vehicle connection technologies. KPMG (2012b) has indicated that connected and automated vehicles (CAVs) use wireless technologies to facilitate communication from Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), and Vehicle to Everything (V2X). Also, Rakotonirainy et al. (2014) assert that future cars will utilise V2V technology to support and enhance the ability of the driver to make more reasonable decisions. Therefore, new infrastructure facilities need to be installed, and it may be that changes are required on some sections of roads. In this context, Weiss (2011) indicates that vehicle communication inevitably needs a communication partner; it could be a V2V system or a form of V2I such as a cellular tool to support the infrastructure of the V2I application. Weiss (2011) also explains that infrastructure networks require ITS roadside stations, Geoserver[1], and test management centres.

Also, the need for dedicated lanes for AVs and CAVs is another issue which needs special consideration and assessment. In this context, Yea and Yamamoto (2018) studied the impact of dedicated lanes for AVs and CAVs on traffic flow throughput. The result of their study showed that dedicated lanes for CAVs could be beneficial but only for medium traffic densities. Yea and Yamamoto (2018) recommend defining a higher speed flow for AVs in dedicated lanes than TVs in order to help to achieve higher performance in dedicated lanes. Therefore, infrastructure changes such as devoting dedicated lanes to AVs might increase the performance of AVs, which must be further evaluated.

[1] GeoServer is a software map-server that allows users to handle and share geospatial data.

In general, the studies reviewed in this section show that special equipment and facilities might not be necessary for AVs, but they are needed for CAVs so that they can interact with other vehicles and the infrastructure.

2.2.5. Traffic

AVs may have a substantial effect on traffic flows. Fagnant and Kockelman (2015) indicate this by reference to the adoption of autonomous technology like Adaptive Cruise Control (ACC) and traffic monitoring operations; there would be smoother traffic flow through the application of automated braking and acceleration systems. This adoption would result in a gap reduction with a constant average speed, which in turn would lead to more reliable travel time in the fleet.

In addition, AVs may be more alert in comparison with human drivers (Howard and Dai, 2014). Bansal et al. (2016) found that the ability to forecast the movements of vehicles in the fleet provides safer and smarter mobility due to more efficient connection with other cars. Besides this, better enforcement of the law could be applied to speed limits as AVs adhere to driving rules and do not violate them (Howard and Dai, 2014). So, the result would be a more sustainable transport system, which leads to more logical and desirable traffic behaviour. However, Smith's (2013) study shows that the introduction of AVs to the network may have adverse effects on traffic patterns due to a dramatic increase in highway trips and an increase in traffic congestion.

In the study by Fagnant and Kockelman (2015), the results showed AVs could anticipate other vehicles' reactions like any unexpected braking or any decision to accelerate. As AVs have better route choice capability, they can use the road lanes more efficiently. Subsequently, they can operate with shorter gaps with other vehicles in the platoon, and this ability provides better control of the vehicle for smoother braking operation and better adjustment of vehicle speed in the platoon (Fagnant and Kockelman, 2015).

Also, investigations regarding parking areas and possible concerns around this issue show that AVs can implicitly reduce the cost of parking and they can better manage the free spaces in the city to use as parking spaces (Millard-Ball, 2019).

In general, AVs could bring the following benefits to road traffic:

- Help to catch the green time at intersections and make more informed decisions using the data from infrastructure facilities (V2X) (Briscoe, 2019)
- Smooth traffic with near-constant velocities and reduction of gaps with other cars (Cui et al., 2018; Fagnant and Kockelman, 2015)

- Recognition of traffic conditions and upstream incidents using smart sensors (Li et al., 2018)
- Efficient route choices using the data from LIDAR and the data from other vehicles and infrastructure facilities (Levin, 2017; Fagnant and Kockelman, 2015)
- Enforcement of speed limits in a more efficient way than TVs (Gerdes and Thornton, 2016; NHTSA, 2016; Bansal et al., 2016)
- Efficient use of parking spaces with parking assist technologies and smaller standstill distances with other vehicles (Millard-Ball, 2019; Li and Shao, 2015)
- Coordinating and connecting with other cars in platoons (Fagnant and Kockelman 2015)
- Efficient use of existing lanes and intersections with shorter headways (Awal et al., 2015; Fagnant and Kockelman, 2015).

2.2.6. Environment

Environmental issues such as air pollution and quality have always been an important issue in transportation as they originate from fuel consumption and vehicle emissions. The amount of global CO_2 emissions from road transport was 6 billion tons in 2015 which, it is estimated, will increase to 7.5 and 10 billion tons of CO_2 emissions by 2030 and 2050 respectively (OECD, 2017). Such environmental problems in transportation have forced policymakers to concentrate more on alternative fuels and vehicles (Browne et al., 2012). In this context, Anderson et al. (2014) suggest AVs might be a helpful solution in attempting to reduce pollution since they can use alternative fuel systems.

Smith (2013) shows while there might be a decrease in the emissions produced by AVs, the total emissions, from gasoline and dependence on other oil in vehicles might increase. Such an increase in fuel consumption might be as a result of an increase in Vehicle-Mile-Travelled (VMT) by adding new road users such as the elderly and those who were not able to drive before which leads to an increase in traffic congestion (Fagnant and Kockelman, 2015). Such an increase in VMT has been highlighted as an ironic effect of adopting AVs since it is in contradiction with reducing traffic congestion (Smith, 2013). However, Schoettle and Sivak (2014b, 2014c) show that AVs will reduce emissions by an average of 65%-70%. Also, Fagnant and Kockelman (2015) verify the results of Schoettle and Sivak (2014b, 2014c) and add that although the total VMT might increase through the use of AVs, the amount of emissions per mile will reduce. In this context, Bansal et al. (2016) assessed 347 road users' opinions about the environmental impact of AVs in Austin, Texas. The study showed a positive response about the reduction in emissions and about improved fuel economy from 88% and 60% of participants respectively.

2.2.7. Privacy and Security

Despite the efforts to assess the different characteristics of AVs and probable outcomes of adopting them on public roads, there are still some unanswered questions regarding the privacy and security of AVs. For example, issues related to the types of data which might be stored by AVs, availability of the stored data, the security of AVs against hacking and privacy of AV users (Fagnant and Kockelman, 2015). Also, the results of a study conducted by Kyriakidis et al. (2015) on 5,000 individuals showed that participants were most concerned about security issues like hacking and misuse of their vehicles by hackers. In this context, Rakotonirainy et al. (2014) indicate that a weak security system in AVs could lead to serious crimes, as human users are the weakest elements in the security chain in an AV network. Stolen data could be misused for unauthorised surveillance of important individuals (Fagnant and Kockelman, 2015).

According to Rizvi et al. (2017), in order to design a robust security system for AVs, a clear understanding of the potential threats and vulnerabilities is needed. In this context, Macher et al. (2016) classified many cyber-security issues related to AVs, which could help identify countermeasures and proactive defence systems.

Note that the installed sensors on AVs will always collect information about the vehicle and the incidents involved in vehicles' surroundings (Rakotonirainy et al., 2014). However, the positive outcome of such data collection is that transport planners could use them for a better understanding of the real-time interaction of AVs and the traffic flow and use them in future planning. Additionally, car manufacturers can use the stored data from AVs to monitor the vehicles' responses in the case of possible incidents and use those data for future retrofitting and fill technology gaps in AV security systems and measures to ensure the safety of users.

2.3. Benefits of Adopting AVs

Section 2.1 has already discussed the interaction of AVs with trip characteristics. Some areas of interest and concern in the adoption of AVs have also been presented, and the results of studies and some surveys have been discussed to facilitate an understanding of the impact of AVs on each characteristic of a road trip.

This section classifies the main advantages of the adoption of AVs, which are known to date. The benefits summarised in Table 2.4 are excerpts of previously reviewed studies in addition to the results of certain other studies.

Table 2.4. Summary of studies about the benefits of AVs

Criteria	Study	Benefits
Safety	Papadoulis et al. (2019)	Safe driving
	Noy et al. (2018)	Making informed decisions
	Beirigo et al. (2018)	Useful in transporting freight
	Laan and Sadabadi (2017)	Quick reaction time
	Chan (2017)	Providing safe mobility for the elderly and disabled people
	Kyriakidis et al. (2015)	Removing human errors
	Katrakazas et al. (2015)	Safe identifying of surrounding objects (human, animals, etc.)
	Howard and Dai (2014)	Reduction in accidents
	Matsumi et al. (2013)	Avoiding collisions with pedestrians
Cost and WTP	Liu et al. (2019)	More WTP in young people, educated individuals, and people with higher income Note: Previous information about AVs increases WTP and trust in AVs
	Bosch et al. (2018)	Cheaper than private vehicles Lower costs of maintenance, insurance and fuel
Legal liability	Bruyne and Werbrouck (2018); SAE (2016);	Recent advancements in terms of use of AVs on public roads and some rules for deployment and research in this area
Infrastructure	Brummelen et al. (2018)	Some technologies are available right now; however, they need improvement
	Fagnant and Kockelman (2015)	Existing infrastructure capacity might be adequate
Traffic	Briscoe (2019)	Help to catch green lights at intersections
	Millard-Ball (2019); Li and Shao (2015)	Efficient parking management

	Schwarting et al. (2018)	Making informed decisions using approaches combining decision-making, control, and perception
	Cui et al. (2018)	Stabilised traffic flow
	Li et al. (2018)	Recognition and balance of the upstream traffic in the platoon
	Levin (2017)	Efficient route choice
	Igliński and Babiak (2017); Howard and Dai (2014)	Not violating traffic regulations
	Gerdes and Thornton (2016); NHTSA, 2016; Bansal et al. (2016)	Enforcement and management of the speed limits
	Fagnant and Kockelman (2015)	Coordinating with other vehicles in platoons
	Awal et al. (2015)	Efficient use of the lanes and reducing lane-changing bottlenecks
Environment	Iglinski and Babiak (2017)	Reducing emissions of GHG
	Moriarty and Wang (2017)	Reducing fuel consumption and emissions
	Ross and Guhathakurta (2017)	Saving energy by smoothing traffic flow, platooning, and eco-driving
	Mersky and Samaras (2016)	Improving fuel economy
Privacy	Sheehan et al. (2018)	Predicting cyber-attacks using new methods and technologies
	Rizvi et al. (2017)	Acquiring a hybrid security system to fight proactively against cyber-attacks
	Macher et al. (2016)	Many cyber-security threats to AVs are identified, and countermeasures are being considered

2.4. Concerns about Adopting AVs

Sections 2.2 and 2.3 have addressed the potential implications of the adoption of AVs on transport safety, costs, the environment, and some other factors. It is also imperative to identify the main concerns regarding the application of AVs as they might impact individuals' acceptance.

Fagnant and Kockelman (2015) highlight that intelligent technologies can provide high perception for AVs about their surroundings by utilising image processing tools. Such smart technologies help the vehicle make informed decisions in the case of unexpected incidents, and this represents one of the most substantial advantages of using AVs. However, Rakotonirainy et al. (2014) indicate that the information recorded by such smart sensor technologies might be used against the owner of the vehicle in the case of an accident when the owner is no longer in control of the car. Besides this, Rakotonirainy et al. (2014) found that AV sensors will have limited coverage, which might lead to incomplete decisions, resulting in an ambiguous understanding of their surrounding objects. However, Katrakazas et al. (2015) say that by using thermal cameras, objects such as pedestrians, cyclists, animals, and vehicles can be identified through the classification of their thermal energy. Such a tool will also work correctly in low light conditions during night trips.

Also, Browne et al. (2012) indicate that lack of professional technicians and the need for spare parts in the case of a machine failure might lead to range anxiety for consumers in relation to the reliability of new high-tech vehicles. Such a concern could also be considered a technology concern for AVs.

There are also some concerns regarding the cost of technologies in AVs. The cost of new sensor technologies, such as LIDAR, is currently high, which substantially increases the price of an AV; this could also be of substantial concern to users (Fagnant and Kockelman, 2015). The findings from Bansal et al.'s (2016) study show that some users have greater trust in traditional car companies such as Ford and Toyota instead of newcomers like Google; this could represent an obstacle for manufacturers.

Table 2.5 summarises the main concerns in the adoption of AVs on public roads; the summary includes concerns reviewed before in this study.

Table 2.5. Summary of studies about concerns relating to adopting AVs

Criteria	Study	Concerns
Safety	Noy et al. (2018)	Software failures and operation failures due to a mix of AVs and TVs
	Rakotonirainy et al. (2014)	Obscure understanding of humans, animals, and other objects
	Schoettle and Sivak (2014c)	Not being as good as human drivers at quick driving reactions
Cost and WTP	Liu et al. (2019)	The high price of the vehicle
	Liu et al. (2019); Schoettle and Sivak (2014c)	Low average WTP (USD 2,500-4,500)
Legal liability	NHTSA (2016); DMV (2016); Underwood (2014)	Need for completed regulatory frameworks
	Kyriakidis et al. (2015); Underwood (2014); Schoettle and Sivak (2014a); Schoettle and Sivak (2014b); Howard and Dai (2014); KPMG (2012a)	One of the main concerns in many public surveys
	Continental (2015); Howard and Dai (2014); Schoettle and Sivak (2014b); Underwood (2014)	Uncertainty about who will be responsible for AVs' accidents and to what extent
Infrastructure	Nikitas et al. (2019)	Infrastructure changes could be expensive
	Sappin (2018)	Need for large investments by automaker and risks of financial loses
	Yea and Yamamoto (2018); Laan and Sadabadi (2017)	The need for special considerations in terms of dedicated lanes for AVs
	Muoio (2016)	Performance struggle on roads without clear lane markings
	Eldredge (2016); Rakotonirainy et al. (2014); KPMG (2012b); Weiss (2011)	Need for new installations of infrastructure sensor technologies
Traffic	Nikitas et al. (2019)	The mixed traffic could create safety problems in the first few years of the adoption of AVs

	Martinez and Viegas (2017)	Increase in VMT by adopting shared AVs
	Fagnant and Kockelman (2015) Smith (2013);	Increase in unnecessary trips, VMT, traffic volume and congestion
Environment	Fox-Penner et al. (2018); Schwartz et al. (2017);	Increasing air pollution due to increase in demand, ride services, and VMT
	Rojas-Rueda et al. (2017)	An increase in air pollution and noise emissions from AVs burning fossil fuel
Privacy	Nikitas et al. (2019)	Increases in the exposure of potential vulnerabilities, unauthorised private data sharing, hacking, and cyber-terrorism
	Sheehan et al. (2018); Kyriakidis et al. (2015); Curtis (2015); Payre et al. (2014)	Security breaches and hacking
	Faife (2017)	Risk of car hijacking and kidnapping
	Fagnant and Kockelman (2015)	Risk of disruption in traffic networks and catastrophic collisions
	Rose (2017); Heaps (2016); Fagnant and Kockelman (2015)	Concerns about data privacy: type of stored data, availability of data, tracking individuals' locations, access and use of data by third-parties

2.5. Users' Perceptions of AVs

The improvements regarding safety, security, costs and other assessed factors related to AVs will not be successful if individuals do not trust these vehicles. So, for a better understanding of individuals' perceptions about adopting AVs, people's interests and concerns are presented in this section.

Kaur and Rampersad (2018) studied users' trust of AVs over 101 staff and students of the Flinders University in Australia. The participants in the survey were most likely to adopt AVs in closed-environments for finding a car park. Also, respondents indicated they might be happy to adopt AVs on highways if they could take the full control of the AV whenever they wanted to.

Schoettle and Sivak's (2014b) study found that some groups of people are more interested in adopting AVs than others, namely: those who had an experience of using current semi-autonomous technologies, people with a higher level of education, those who could not drive, young individuals, and full-time employed individuals and students. In this context, the results of the studies by Kyriakidis et al. (2015) and Schoettle and Sivak (2014b) showed that individuals, on average, would be more willing to pay for fully automated vehicles because of amenities such as sleeping, reading, watching movies, talking, playing games, and working. Also, Kyriakidis et al. (2015) found that individuals who spent more time on driving and individuals who used intelligent sensor technologies like ACC are more willing to adopt AVs.

Regarding public WTP for the adoption of AVs, Bansal et al. (2016) found the following groups of people have higher WTP: those who travel long distances more frequently; those who live farther from their work location; those who drive alone to work, and male drivers with a higher income who had been in an accident before.

In general, despite several benefits of using AVs, there are still some gaps in the research and the technology for AVs. Such discrepancies should be resolved before the exploitation of AVs on public roads as, otherwise, the gaps in knowledge and technology might affect user acceptance. As an example, Howard and Dai (2014) showed that individuals are most concerned about losing control of their vehicle due to a security breach to their AVs. Some people also drew distinctions between the road network for AVs and airway networks, indicating that although there might be a lower number of accidents, the accidents would be more severe. Table 2.6 represents a summary of studies that have investigated individuals' interests and concerns regarding the application AVs.

Table 2.6. Summary of studies about individuals' interests and concerns relating to using AVs

Author(s)	Location	Survey Type	Number of Participants	Avg. User Acceptance of AVs (%)	Evaluation Method	Interest	Concern
Kaur and Rampersad (2018)	Australia	Public	101	NA	Confirmatory Factor Analysis	Finding parking in a closed environment	Privacy and Security
Habouch a et al. (2017)	Israel and North America	Public	721	56	Random Utility Models, Factor Analysis, Logit	No need for parking; environmental benefits	Manual driving is fun; being expensive
Bansal et al. (2016)	US	Public	347	80	Probit	Fewer accidents	Equipment failure

Continental (2015)	US, Germany	Public and expert	4,100	58	*	Relief of stressful driving; reduction in the severity of accidents	Not being as fun as manual driving; being expensive, scary, and not reliable
Kyriakidis et al. (2015)	109 Countries	Public	4,886	74	Spearman Correlation	Being fascinating and more comfortable than manual driving	Not being as fun as manual driving; getting hacked; legal liability; safety concerns
Underwood (2014)	US	Expert	217	75	*	Reduction in accidents and fatalities	Legal liability; regulations; technology concerns; costs
Payre et al. (2014)	France	Drivers	421	71	Exploratory Factor Analysis, Linear Regression, ANOVA	Help in impaired conditions like alcohol, drugs and medications	Losing control and misuse by hackers
Schoettle and Sivak (2014a)	US, UK, Australia	Public	1,596	62	ANOVA	Fewer crashes; reduction in the severity of accidents; improvement of emergency response	Legal liability; equipment failure; interacting with non-AVs and pedestrians
Schoettle and Sivak (2014b)	US, UK, Australia	Public	1,533	70	ANOVA	Safety; less traffic congestion; fewer crashes	Equipment failures; legal liability; privacy and

							security; not being able to drive as well as human drivers
Schoettle and Sivak (2014c)	China, India, Japan, US, UK, Australia	Public	3,255	54	ANOVA	Reduction in the severity of accidents	Equipment failures; not as good as human drivers
Howard and Dai (2014)	US	Public	107	86	Logit	Increase in safety; the convenience of not having to find parking	Vehicle's liability; losing control of the vehicle
Casley et al. (2013)	US	Public	450	82	ANOVA	Passengers' safety	Malfunction; poor awareness of the surroundings
Vallet (2013)	US	Public (drivers)	2000	20	*	80% discount on car insurance	Costs; security; not as safe as human drivers
KPMG (2012a)	US	Public	32	80	*	50% reduction in travel time	Liability; security; malfunction

* Not available

2.6. Microscopic Simulation

As the technology of AVs is relatively new and there is not yet a vast experience of their application in the transport system, simulation of vehicles with intelligent behaviours would provide some insights into the possible outcomes of using AVs. However, before conducting assessments on the microsimulation of AVs, it is useful to review the past studies focused on microsimulation modelling in traffic studies. Section 2.6.1 provides some information about previous studies on microsimulation of traffic flow and the applied method of analysis. Then, Section 2.6.2 reviews some simulation studies for the calibration of Wiedemann-99, which is a car-following model that is known for its extensive use in microsimulation software VISSIM (Higgs et al., 2011). Additionally, the Chapter reviews the recent studies on the microsimulation of AVs and their evaluation methods in Section 2.6.3.

2.6.1. Simulations in Traffic Studies

Kesting et al. (2008) proposed a microscopic simulation model for a traffic assistance system using ACC and a jam avoidance strategy. The ACC vehicles in their model detected the traffic state based on the actual traffic situation and local information. The vehicles utilised variable driving strategies and adapted themselves to the traffic by choosing the procedure, which was more suitable for the actual traffic conditions. Results of the study showed that vehicles equipped with ACC could substantially reduce the travel time and improve the smoothness of traffic flow.

In another study by Ma et al. (2017), a two-dimensional model was developed to simulate turning behaviours in the conflict area of an intersection with mixed traffic flow. The model adopted a social force model for behaviour decisions and movement constraints to recreate one-dimensional turning behaviours. The model could provide a more realistic simulation compared to previous methods which only used one-dimensional simulations. Moreover, the model offered satisfactory results on the spatial distribution of simulated trajectories. Table 2.7 shows a list of studies with a focus on microsimulation modelling in traffic studies.

Table 2.7. Summary of studies focused on microsimulation modelling of traffic flow

Study	Year	Location	Study Type	Assessment Method	Evaluation Tool
Gallelli et al.	2018	Italy	Suburban network	Genetic Algorithm (GA)	VISSIM
Yu and Fan	2017	US	Freeway	GA and Tabu Search*	VISSIM
Rhoades et al.	2016	US	Urban Network	Maximum Likelihood Estimation and GA	NGSIM
Paz et al.	2015	US	Freeway	GA and a Simulated Annealing Approach	CORSIM
Vasconcelos et al.	2014	Portugal	Urban Network	Adopting Trajectory Data and GA	MATLAB
Siddharth and Ramadurai	2013	India	Urban Network	Sensitivity Analysis, GA, and Programming	VISSIM
Treiber and Kesting	2013	Germany	Urban Network	Local Maximum-Likelihood and Global Least-Squared Errors Technique	NGSIM

* Tabu search is a metaheuristic search method to resolve combinatorial optimisation problems

Also, regarding the application of Sensitivity Analysis (SA) and microsimulation modelling, Marczak et al. (2015) proposed a microscopic model to analyse waving sections on freeways. Their model represented the relationship between the microscopic interactions of weaving movements and their impact on capacity. The model incorporated parameters such as free-flow speed relations, jam density, wave speed in congestion, and vehicles' acceleration and relaxation factors. In this context, the result of the SA in the study by Marczak et al. (2015) revealed that acceleration and relaxation of the weaving vehicles create voids in a traffic jam, which reduce the capacity of the weaving section. The results of the SA were later verified by microsimulation modelling and the collected empirical data in the weaving section.

In general, the studies reviewed in this section show that microsimulation approaches could be efficient in estimating the possible outcomes of adopting emerging technologies. Therefore, microsimulation modelling would be a beneficial tool for assessing the impact of the adoption of AVs on highway traffic. Section 2.6.3 reviews studies in this context.

2.6.2. Simulations for the Calibration of Wiedemann-99

As previously mentioned, there is a lack of information about the driving behaviours of AVs to date, nor is it clear what specific type of driving behaviours they will adopt. However, Hawkins (2018) says Artificial Intelligence (AI) such as machine learning methods are being used by Google's AV (WAYMO) to train driving behaviours to the vehicle. However, Bartolini et al. (2017) specify some major obstacles in adopting AI techniques such as the connection between the defined input parameters and the output driving behaviours from machine learning. The lack of such a stable connection raises concerns for backtracking to the exact reasons for possible errors in driving behaviours. Therefore, the current study decided to simulate AVs using the traditional human driving behaviours defined in Wiedemann-99 to find out how efficiently AVs might behave if they drive with optimised human driving behaviours. The advantage of applying Wiedemann-99 is that the input parameters of the model are available and could be used for backtracking and modification of the false driving behaviours. This demonstrates the importance of understanding the literature on past experiments which applied microsimulation methods to optimise the human driving behaviour models for this study. Table 2.8 gives a list of studies with a focus on the optimisation of driving behaviour models and their acquired methods of assessment.

As an example of the car-following calibration methods, Lu et al. (2016) calibrated car following model parameters of VISSIM using video-based processing approach. For this, they processed the traffic videos and extracted the vehicle trajectories in the form of a time-series position. Then, they calculated the optimal value of the car following parameters using a golden section search algorithm and minimised the errors between the observed and simulation results in VISSIM. Lu et al. (2016) were able to calibrate VISSIM for speed, acceleration, and following distance.

Also, Chu et al. (2003) calibrated the car following parameters of Paramics for freeway traffic with consideration of the route choice model and OD estimation. For this, they adopted a mathematical method referred to as parameter fine-tuning method and GEH statistics to minimise the deviation between the observed data and simulation results in Paramics.

Table 2.8. Summary of studies with an emphasis on the evaluation of human driving behaviour models

Study	Year	Location	Study Type	Assessment Method	Evaluation Tool
Lu et al.	2016	Canada	Urban Network	Video Processing with SA	VISSIM
Durrani et al.	2016	US	Freeway	Analysing Vehicle Trajectories	VISSIM
Song et al.	2015	China	Freeway	Numerical Analysis of Vehicle Trajectories	MATLAB
Essa	2015	Canada	Urban Network	SA and GA	VISSIM and PARAMICS
Ge and Menendez	2014	Switzerland	Urban Network	SA	AIMSUN and VISSIM
Aghabayk et al.	2013	Australia	Freeway	EA	VISSIM
Menneni et al.	2008	US	Freeway	GA	VISSIM
Park and Schneeberger	2003	US	Freeway	SA	VISSIM
Chu et al.	2003	US	Freeway	SA	PARAMICS
Ma and Abdulhai	2002	Canada	Urban Network	GA	PARAMICS
Gardes et al.	2002	US	Freeway	SA	PARAMICS

2.6.3. Simulations of AVs

Bischoff and Maciejewski (2016) proposed a simulation model to assess the replacement of TVs with autonomous taxis in Berlin. They applied an algorithm to dispatch autonomous taxies to handle the demand for vehicles in the network. Results of their simulation showed that one autonomous taxi could provide the demand served by ten TVs. Also, Talebpour and Mahmassani (2016) presented a framework to simulate different car following models using stability analysis of traffic stream behaviour for different penetration rates of AVs. The results of their study revealed that AVs could be useful in preventing shockwave formation and propagation of traffic flow and improving the string stability of mixed traffic streams.

Besides, throughput showed a substantial potential to increase in some scenarios, where automation was incorporated.

Yea and Yamamoto (2018) developed a two-lane traffic flow model for the simulation of CAVs and measured their impact on road capacity. The results of their study indicated that road capacity increases with an increase in the penetration of CAVs. Also, Zhu and Ukkusuri (2018) adopted a cell-based simulation approach for modelling the proactive driving behaviours of connected vehicles. Their model identifies the trajectory of connected cars and simulates proactive driving behaviours by adjusting the exit flow of the model cells containing connected vehicles. The results of their simulation verify that the presence of connected vehicles on the network substantially impact on the smoothness of traffic flow and help to reduce emissions. Table 2.9 reviews studies with a focus on the simulation of AVs and the acquired methods.

Table 2.9. Summary of studies with a focus on the simulation of AVs

Study	Year	Location	Study Type	Assessment Method	Evaluation Tool
Alam and Habib	2018	Canada	Urban Network	Latin Hypercube Sampling Technique	VISSIM
Yea and Yamamoto	2017	US	Freeway	Cellular Automation	Two-state Safe-Speed Model and NGSIM
Zhu and Ukkusuri	2017	US	Urban Network	Mesoscopic Cell Transmission Model; Vehicle Trajectory Data	MATLAB
Laan and Sadabadi	2017	US	Freeway	Simultaneous Perturbation Stochastic Approximation Algorithm	Corridor Macro Simulation Software (CORMAK), developed in JAVA
Talebpour and Mahmassani	2016	US	Urban Network	String Stability Analysis and SA	Programming, Deterministic Acceleration Modelling
Gerado et al.	2015	Mexico	Urban Network	Proposed Parameter Estimator Algorithm	Unity, Programming, Parameter Estimator Algorithm (PEA)

As is discussed in this section, some recent studies have calibrated car following models for the analysis of traffic flow, vehicle trajectory, and road capacity for connected and automated vehicles. However, more research and analysis in this context would be helpful to assess a broader range of the impacts of AVs on highway transport. In this context, the experiment in the current research also provides a set of optimised driving behaviours, which could be used for the simulation of AVs in this study and any simulation software in future studies. Also, the optimisation in this study provided insights into the specific impacts of each parameter of Wiedemann-99 on the characteristics of highway trip such as travel time, queues, delays and some others. Such information provides a useful guideline about which driving behaviour must be targeted and the extent to which it must be changed to attain the desired improvement in each element of the highway trip. More information relating to this will be provided in Chapter 4 of this thesis.

2.7. Discussion

This Chapter presented a literature review of published research related to safety, costs, traffic and some other factors associated with the application of AVs in highway transport in line with research objective one. The previous studies focused on some of the different characteristics of highway trips while they lacked in covering a combination of effect on characteristics associated with highway trips. Therefore, this thesis is aiming to make a comprehensive study of different characteristics of highway trips. The first step of such a goal is conducted in the literature review where the associated elements are classified, and the gaps in the research and technology have been addressed in Tables with their references.

The results of previous studies showed that there are some questions regarding the application of AVs, which remained unanswered. For example, questions about how much people will accept AVs' liability if they know about recording data by AVs; who should have access to the recorded data by AVs; which group of agency should accept AVs' liability in case of an accident; how much people's interest in driving AVs might impact their decision about paying and adopting AVs, whether people prefer a ridesharing AV or a private AV and many other questions. Therefore, this thesis is aiming to assess the public's opinion and acceptance of the application of AVs in their daily transport trends and answer those questions. This assessment will be conducted by running a public survey in Ireland. The results of this survey are expected to reveal the public's interest, concern and their ultimate decision about adopting AVs. It is worthy to note that the public survey will answer the questions about AVs from a general point of view. However, there are some benefits and concerns on the aspect of the impact of AVs' on traffic flow and transport, which is not focused widely by the previous research. Therefore, this thesis aims to undertake an international survey of transportation experts in academia and industry to address experts concerns and thoughts regarding the adoption of AVs in highway transport (research objective two). The outcomes of the expert survey will be beneficial for transport researchers, car manufacturers, legislators, insurance companies, traffic and transport consultancies, and any other related groups with a focus on AVs.

Literature review on the simulation of AVs showed that there is a lack of information about the calibration of driving behaviours of AVs to date, nor is it clear what specific type of driving behaviours they will adopt. However, according to the literature review, some AV manufacturers like Google are using new methodologies such as deep learning and machine learning for training AVs how to drive (Hawkins, 2018). In this regard, there is a belief that machine learning techniques have some major problems for being used in training AVs that they cannot provide a stable connection between the input parameters and output driving behaviours (Bartolini et al., 2017). This brings the concern for tracking the exact reason for the possible errors in driving behaviours. Therefore, until further improvements in the application of deep learning, machine learning, and AI, in general, there is not a solid proof that these methods would be the best options for training AVs to drive safely. Hence, the current study decided to optimise a traditional human driving behaviour model (Wiedemann-99) for AVs and simulate AVs with it to find out how efficiently AVs might behave if they drive with optimised human driving behaviours. The advantage of applying Wiedemann-99 is that the input parameters of the model are available and could be used for backtracking and modification of the false driving behaviours. Therefore, this thesis is planning to propose a method for optimising human driving behaviours (research objective three). The driving behaviours are going get optimised for the modelling of AVs along with some configurations to replicate AV behaviours. Results of the simulations with optimised driving behaviours will provide a vision of what might happen if AVs can drive with optimised human driving behaviours and the extent to which they can improve the quality of trip characteristics. Besides, since no driving behaviours have been defined for AVs, there was a gap about the reason of how much, in any, the driving behaviours might impact upon the characteristics of highway trip evaluated in this study (travel time, queue length, delays, and some others). Therefore, this thesis is aiming to address the impact of each driving behaviour on specific characteristics of a highway trip evaluated in this study (research objective four). In this context - during the optimisation process - the study estimates how these characteristics are affected by changes in driving behaviours. The results of this evaluation provide a useful guideline to provide a target framework for driving behaviour and information on the extent to which driving behaviour must change to attain the desired improvements in travel time, queues, delays, and all the other assessed parameters.

The previous studies were mostly focused on theoretical aspects of the application of AVs such as price, interest, and some other factors, and there was a gap in understanding of what would practically happen to the highway traffic flow during long travel distances. Therefore, this thesis is aiming to examine the practical efficiency of AVs on long trips by modelling AVs in a case study in Dublin, Ireland (research objective five). The results of the simulation will assess travel time, queue length, delays, LOS, road throughput, fuel consumption and emissions.

The studies in the literature review represented a gap in the study of AVs about whether AVs will be able to cooperate with TVs in mixed traffic or AVs will need a dedicated lane. Therefore, this thesis is planning to examine the operability of TV and AVs in mixed traffic over 33 simulation scenarios (research objective six). For this part of the study, TVs and AVs will be designed to work in separate modes and then in mixed traffic situations with different penetration rates on the road. The results will show how flexibly TVs and AVs can interact with each other, and how much penetration of AVs is needed on a motorway to cause considerable reductions in queues, delays, fuel consumption, emissions and increases in the network throughput along with an improvement in LOS. Also, the literature showed that some previous studies made attempts to simulation AVs. However, no simulation has been done for AVs due to the gap in AVs' driving behaviours on highway transport. Such a gap is filled in this thesis. In 2018, PTV presented three sets of driving behaviours which are claimed to be capable of replicating autonomous and semi-connected behaviours, which there is no study with a focus on PTV's modified driving behaviours for AVs. For this purpose, this thesis is aiming to assess the new driving behaviours tuned by PTV for AVs, and the results will be compared to those of this study which is in line objective six of this thesis. Such an evaluation shows the extent to which the optimised parameters of the current research are in line with the tuned parameters recommended by PTV.

3. METHODOLOGY

3.1. Introduction

The following Chapter outlines the methodology adopted for the evaluations in this study. In this context, the Chapter explains how the study is constructed for finding the gap of the knowledge and what approaches are adopted for filling those gaps.

With the advent of new technologies in the Transport industry, new methodologies have been adopted in transport science to solve the research problems as of which the mixed methodology approach is one of them. Mixed methodology approach is a research method that integrates various types of quantitative and qualitative approaches in order for better utilisation of the research data (Wisdom and Creswell, 2013). Mixed methodology approach has been (limitedly) adopted in some areas of transport and health studies such as the transport policy investigations, built environment and health, and the analysis of travel behaviours by Moody et al. (2019), Steinmetz-Wood et al. (2019), and Mars et al. (2016), respectively. Mixed methodology approaches are also able to provide advantages such as comparing the research data using various research instruments, using qualitative data to explore the quantitative findings, collecting rich data, and validating the research results by the help of multiple research instruments (Wisdom and Creswell, 2013).

This research adopts a mixed methodology approach to investigate the efficiency of AVs in highway transport, which to the best of the author's knowledge, it has not been conducted before in this field. For this purpose, the study adopts qualitative and quantitative studies using past studies in the literature and conducts a national public survey and a global expert survey in the field. Then, the study simulates AVs and TVs in single occupancy and mixed traffic conditions. Each of these investigations is considered as research instruments which help the study evaluate the efficiency of AVs from its own perspectives. Finally, the study adopts a triangulation method to assess how successful the study was in evaluating the efficiency of AVs. The triangulation assessment is done by comparing the findings of the adopted research instruments against each other to identify which one those investigations confirm or reject the findings of the rest of the investigations. More information about the triangulation method of this study will be provided in Chapter 3, Section 3.7.3.3.

This Chapter provides an overview of the research structure in Section 3.2 and the connections between the chapters of the thesis. Sections 3.3 and 3.4 explain the framework acquired for the design and implementation of the public survey and expert survey in this study, respectively. Section 3.5 reviews multiple simulation software packages and represents the reason for choosing the software package of this study. Also, Section 3.6 describes the design of the simulation model of this study and the setting configurations applied for preparing the simulation model for optimisation and simulations of TVs and AVs in this study. Besides, an assessment is conducted in Section 3.6.7 to introduce the driving behaviours of this study. Furthermore, Section 3.7 describes the methodology of the simulations in this study; how the scenarios are defined for the simulation of TVs and AV in the single occupancy mode and the mixed traffic, reliability and validity of the simulation models. Besides, Section 3.7 describes the new driving behaviours of AVs defined by PTV, which are going to be simulated and compared with the simulation results of this study, later in Chapter 7.

3.2. Research Structure

In order to perform the required assessments for the research objectives, the study is organised as follows:

Chapter 2 of the research represents the review of past studies with a focus on classifying different factors associated with the application of AVs.

Chapter 3 shows gathering traffic data and preparing the model of this study for optimisation and simulation.

Chapter 4 deals with the conduct of the public survey in Ireland to assess people's acceptance and concerns regarding the adoption of AVs.

Chapter 5 deals with the conduct of the international expert survey to assess the technical concerns around the application of AVs and their potential impact on road transport.

Chapter 6 evaluates the driving behaviours required for modelling purposes.

Chapter 7 deals with the simulation of AVs using the optimised driving behaviours and comparing them with results of the simulation of TVs.

Chapter 8 reviews the discussion of all Chapters and represents the key findings of this study.

Figure 3.1 briefly illustrates the organisation of the thesis in four directions, which each direction deals with a specific type of study, namely, methodology, survey studies, optimisation and simulation, and overall evaluations. Also, Figure 3.2 depicts the organisation of the thesis steps and their chapters.

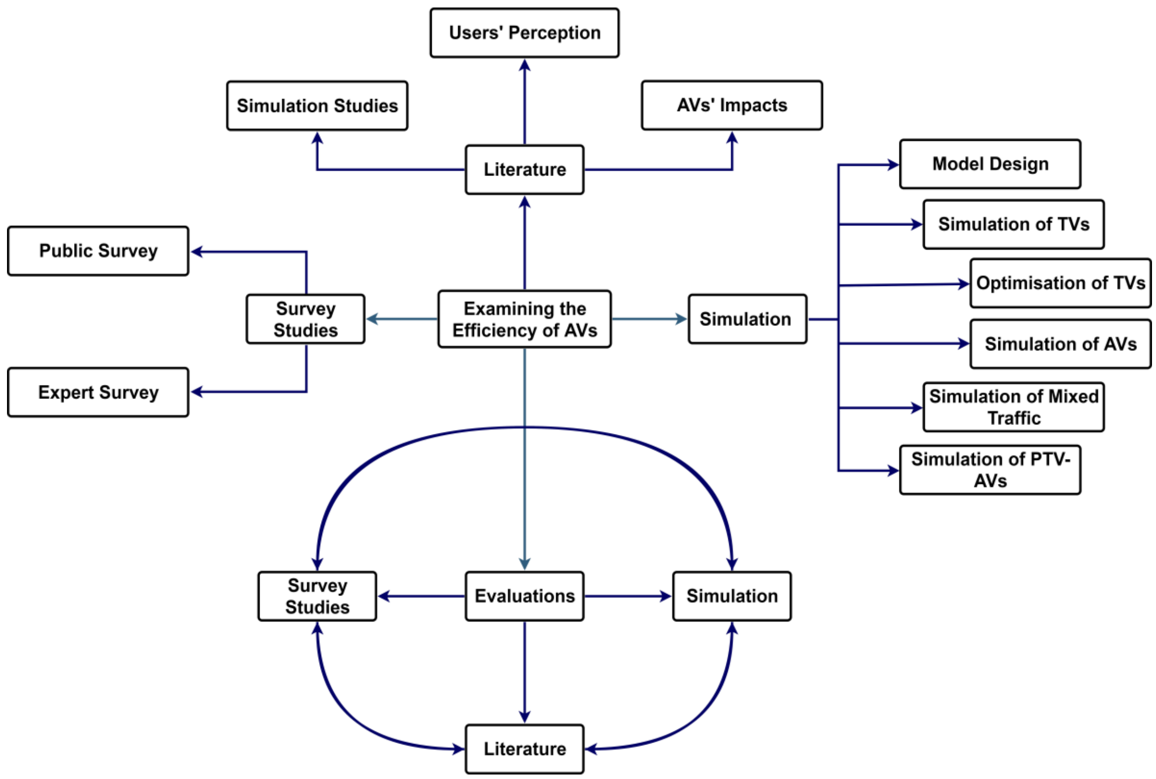


Figure 3.1. Research flowchart in brief

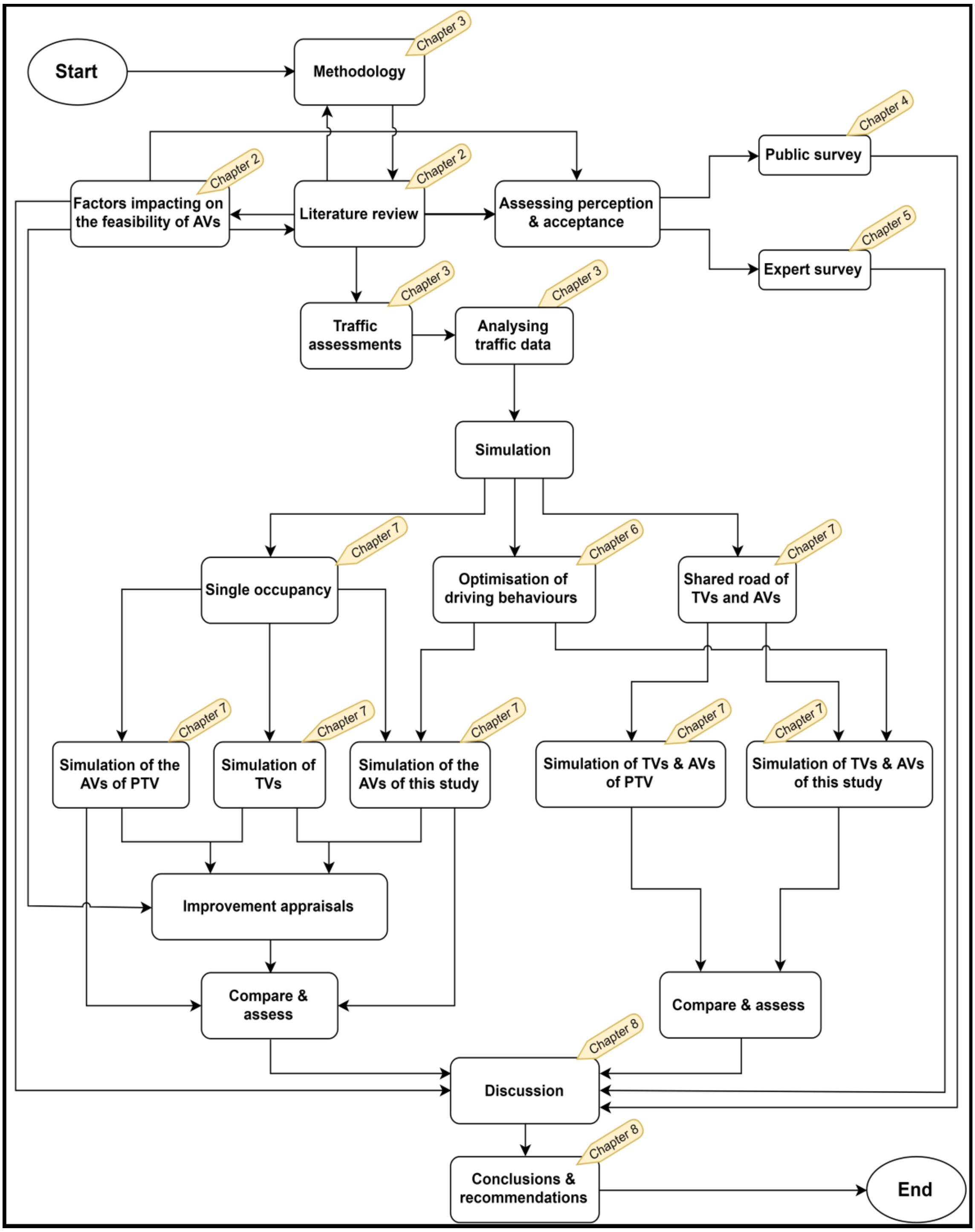


Figure 3.2. Breakdown of the research steps

3.3. Public Survey

3.3.1. Survey Sample

According to the Central Statistics Office of Ireland (CSO), Ireland had a population of 4,761,865 in 2016 (CSO, 2017). This was considered the population size of the study for purposes of calculating the sample size for the public survey. Also, a margin of error is deemed to represent the accuracy of the data and how much error is allowed in the study. A ±5% margin of error was calculated for the population size of this survey using the "margin of error calculator" of Survey Monkey (Survey Monkey, 2018). Also, a confidence level of 95% was considered for the research, which indicates that 95% of the results are expected to fall within the plus-minus confidence interval. Such a confidence level is also commonly set by researchers as it provides an acceptable accurately that reflects the attitudes of the total population (Survey Monkey, 2018). Using these figures, the sample size was determined using the following formula:

Equation 3.1

$$\text{Sample size} = \frac{\frac{z^2 * p(1-p)}{e^2}}{1+(\frac{z^2 * p(1-p)}{e^2 * N})}$$

where

N = population size: 4,761,865

E = margin of error: 0.05

P = standard deviation: 0.5

Z = z-score (the number of standard deviations a given proportion is away from the mean). The z-score value is 1.96 for a 95% confidence level.

Using Equation 3.1, the ideal sample size was computed as follows:

$$N = \frac{\frac{(1.96)^2 * 0.5(1-0.5)}{(0.05)^2}}{1+(\frac{(1.96)^2 * 0.5(1-0.5)}{(0.05)^2 * 4{,}761{,}865})} = 384.16.$$

Therefore, a total sample size of 400 was selected for the public survey to ensure that the survey sample size would be representative of the population of Ireland in 2019.

3.3.2. Design and Assessment

The public survey in this study was designed to assess road users' awareness and acceptance of AVs. Before running the main public survey; however, a pilot survey was distributed to make sure the questions of the main survey were fair, accurate, descriptive, comprehensive, and understandable to public users. For this purpose, the survey was distributed among some of the students at Trinity College Dublin. The pilot survey collected 20 valid responses which could be used for assessment. Also, participants of the pilot survey were then asked about the quality of the questions, whether they were easily understandable, and their relevance and consistency. The participants were also asked to share any other feedback and comments that could help to improve the survey.

The assessment of the pilot survey showed that nearly all participants were satisfied with the survey questions and declared they had no difficulties reading, understanding, and answering the survey questions. Also, the questions in the survey were ordered to analyse users' perceptions about the application of AVs, but the survey in general also provided information to participants to help increase public understanding of the possible pros and cons of the application of AVs. Respondents to the pilot survey were asked about their previous awareness of AVs and their interest in driving one. Also included in the survey were questions about people's concerns regarding the safety and security of those who use AVs, and the liability for the vehicle in case of an accident. In addition, people were asked about their overall interest in the vehicles and their WTP regarding buying an AV. Finally, some questions were asked to collect respondents' personal demographic information.

The evaluation of the feedback and comments of the pilot survey showed that some changes could increase the willingness to participate and help to avoid survey dropouts. The modifications implemented to the main public survey included the following:

- Reduced the total number of questions by merging some questions with similar contexts, where it was possible
- Merged some answer options in multiple-choice and checkbox questions to condense answers and reduce the number of answer options
- Reduced the number of answer options from a 5-point Likert scale to 3-point scales to make the question easier to answer, speeding up the survey response, and reducing the survey time
- Reduced the number of comparative questions designed to compare TVs and AVs, as some participants considered that section too long and boring

- Changed the structure of the survey interface, such as the progress bar and question number, and made some formatting changes.

In general, the valuation of the pilot survey and implementation of revisions (mentioned in this Section) helped to assure that the main public survey is reliable in the aspect of content and structure. Also, it is worth noting that the conclusion and internal validity of the responses were later evaluated using statistical methods, which are discussed in Chapter 4 of this study.

After the results from the pilot survey were assessed and necessary changes were made, the main survey was distributed (online) with the aid of Delve Research (2018), an independent Irish research agency, specialising in survey design, research and analysis. Delve Research (2018) operate on a panel of Irish residents who registered in this company to take part in the surveys in return of receiving monetary payments or cash prizes. The advantage of adopting an online research method using a research company is that the information of the survey panellists are available to the company. Therefore, panellists could be recruited for any required sample size without spending time on finding survey participants; this saves so much time and money. Another advantage is that the participants get paid in return of answering questions and (usually) cash prizes are considered as incentives, which attracts more participants in a shorter time (depending on the prize amount). For the survey of this research, the panellists were encouraged to take part in the survey for a chance to win one of the three cash prizes - first prize of €150 and two prizes of €50 each in exchange for fully completing the survey provided (Delve Research, 2018).

Despite that all participants were asked to complete the survey questionnaire, there were a few participants who didn't complete the survey or they had too many unanswered questions. Therefore, the survey responses should have been checked for completeness to make sure the results are valid for analysis. It is worth noting that the survey platform was designed to be used with devices with various screen sizes such as laptops, tablets, and mobile phones. The survey had 36 questions, which could have increased the chance of missing one or two questions for participants who were taking the survey in devices with small screens. Also, removing participants with only one or two missing response (missing values) could have increased the chance of losing many participants, which could have negatively affected the sample size. Therefore, the respondents who completed the survey to the end and answered more than 34 questions out of 36 were selected for analysis. The survey is available in Appendix B (B3) for review.

. In total, the research company collected 525 responses to provide a gender balance of 56% female and 44% male participants. Out of 525 collected responses, 475 were completed and usable for the analysis, which is greater than the minimum required sample size for the study. The extra responses increase the accuracy of the results and assessments. While efforts were made to contact a representative sample, it is mindful to consider that the survey was conducted online, and those who did not have access to the Internet were not covered in the survey. However, it is also noteworthy that 87% of Irish households had an Internet connection in 2016 (CSO, 2016).

It is imperative to say that the number of participants in the age ranges of 18-25 years was very few since there is less tendency for this age group to register at the survey companies than other age groups (Delve Research, 2018). Also, note that some questions in the public survey require some experiences of driving, for example, those which ask participants to compare AVs and TVs under some hypothetical driving scenarios. Hence, having higher participation from the older age groups would increase the chance of having more participants with driving licence and so driving experience.

Regarding the research ethics, all permissions were granted from the School of Engineering Research Ethics Committee of Trinity College Dublin. The survey participants were ensured that the survey is completely anonymous, and the results can only be accessed and disseminated by the scientific researcher of the study. Also, participants were told that their participation is completely voluntary, and a participant can drop out of the study at any time.

The survey covered a diverse range of questions regarding public interests and concerns about the adoption of AVs, and some of the associated parameters in the questionnaire were drawn from different behavioural contexts. Therefore, a variety of methods were required for the statistical assessment of the results. Linear regression was adopted for evaluation of the questions where there was a linear correlation between dependent and independent variables. In this context, the results of the study by McCarthy et al. (2016) showed that stepwise logistic regression is an effective method for analysing the effects of explanatory variables. Several studies recommend a backwards elimination using the likelihood ratio, as they acknowledge that such a method reduces the risk of omitting a variable that predicts the outcome (McCarthy et al. 2016; Field (2009) and Agresti (2013)). Equation (2), extracted from Agresti (2019) and which is also adopted by McCarthy et al. (2016), shows the function of the logistic regression model:

Equation 3.2

$$P(Y) = \frac{exp(\alpha + \beta x)}{1 + exp(\alpha + \beta x)}$$

where

$P(Y)$ is the probability of outcome Y occurring given x

Y is the dependent variable

x is a predictor variable

α is the intercept parameter

β is the odds (multiply by e^{β} for every 1-unit change in x)

Additionally, the odds ratio (OR) is used to estimate how strongly a variable is associated with the outcome of interest. In other words, it shows the probability that an event will occur versus the likelihood that the event will not occur. Equation (3) shows the function of the OR:

Equation 3.3

$$\mathrm{OR} = \frac{P(Y)}{1 - P(Y)}$$

where

P (Y) = the probability that an event will occur

Multinomial logistic (MNL) regression was used in the study as the results of initial assessments showed that people's awareness and acceptance originates from a diverse range of behaviours, and therefore, a simultaneous impact of different variables and covariates should be considered in assessments. Such a logistic regression can be extended to models with multiple explanatory variables (El-Habil, 2012). For this purpose, the study evaluated different variables which could be closely related to the dependent variables to find those variables with the highest correlation and statistical significance. Equations 4–7 show the elements of the MNL function that are extracted from El-Habil (2012) and McCarthy et al. (2016).

Equation 3.4

$$\text{Logit } [P(Y = 1)] = \alpha + \beta_1 x_1 + \cdots + \beta_n x_n$$

Equation 3.5

$$\pi(\mathrm{x}) = \frac{exp(\alpha + \beta_1 x_1 + \cdots + \beta_k x_{k)}}{1 + exp(\alpha + \beta_1 x_1 + \cdots + \beta_k x_{k)}}$$

where

β_i refers to the effect of x_i

K = number of predictors

Y = binary response $x_1, x_2, \ldots, x_k$

π_j = multinomial probability of an observation falling in the j_{th} category

Therefore, in a model with *n* independent variables, *p* explanatory variables, and *k* categories of the qualitative response variable, the regression model is

Equation 3.6

$$\text{Log}\left[\frac{\pi_j(x_i)}{\pi_k(x_i)}\right] = \alpha_{0i} + \beta_{1j}\,x_{1i} + \beta_{2j}\,x_{2i} + \cdots + \beta_{pj}\,x_{pi}$$

where

$i = 1, 2, \ldots, n$

$j = 1, 2, \ldots, (k\text{-}1)$

Therefore, the final form of the reduced model would be;

Equation 3.7

$$\text{Log}\,(\pi_j(x_i)) = \frac{\exp(\alpha_{0i} + \beta_{1j}\,x_{1i} + \beta_{2j}\,x_{2i} + \cdots + \beta_{pj}\,x_{pi})}{1 + \sum_{j=1}^{k-1} exp\,(\alpha_{0i} + \beta_{1j}\,x_{1i} + \beta_{2j}\,x_{2i} + \cdots + \beta_{pj}\,x_{pi})}$$

In this study, the assessments of the MNL models are conducted using the statistical software IBM SPSS Statistics 25. In order to perform evaluations of the survey in SPSS, the survey questions are defined as variables and the answer options are coded, which are available in Appendix A (A1).

3.4. Expert Survey

The expert survey was designed to assess the acceptance of AVs among experts; it was created and distributed among specialists in fields relevant to AVs. Based on the insights gained from the pilot study for the public survey, the questionnaire for the expert survey was designed with 12 questions eight of which dealt with technical issues regarding safety, security, liability, traffic issues and some other consequences of the adoption of AVs. Also, four questions were asked to gain an understanding of the participants' demographics. In this context, participants were assigned to one of four groups: academia, government, private sector and industry, and road authority agencies. The expert survey is available in Appendix C for review.

Despite that the two surveys (public survey and expert survey) designed with different purposes and targeted completely different groups of participants, three questions in these two surveys followed similar purposes. However, the questions varied between two surveys based on their target participants, their answer options, and the gaps in the relevant context they were trying to address. For instance, there was a question in both surveys asking about the responsible group who should accept the highest liability of the AVs in case of accidents. Also, public participants were asked about their preferences for adopting ridesharing AVs (if they are provided), while experts were asked about the efficiency of such services on improving the quality of transport. Furthermore, public participants were asked about the most interesting aspect of AVs which make people buy them. In this regard, a question with similar context was asked designed for the experts asking about the most valuable outcomes of the adoption of AVs in public roads. Such questions with similar contexts help to find the relation between people's concern and interest, and their relationship with the technical reasons (if any) behind them.

Mirabeau et al. (2013) explain the advantage of using media networks such as LinkedIn for data collection in survey research. Their study found that the upsides of using social media networks for data collection outweigh its risks. In this regard, LinkedIn was found a convenient tool for reaching the potential candidates in this study. Therefore, the current study used LinkedIn social media profiles for transportation groups as the primary source for selecting experts in this survey. The participants were selected based on their expertise in the field and their level of experience. For those experts who provided an email address, they were individually invited to take part in the survey by email, and a LinkedIn invitation was sent to those without a public email.

Regarding the sample size of the study, the idea was to collect as many responses as possible to achieve participation from a diverse range of experts in fields related to AVs. In total, 325 responses were collected through the online survey platform of Survey Monkey. Of 325 responses collected in this survey, 301 of them answered all (eight) technical questions, so they were considered complete and valid for evaluation. The reason for adopting such a completeness criteria was that the expert survey had only eight technical questions each dealt with an important concern regarding the adoption of AVs and none could be missed.

However, within some of the questions, there were a few missing responses from the expert, which was less than 5% of the total answers, which is negligible (Madley-dowd, 2016; Shafer, 1999). Therefore, the total answers in some evaluations round to 300, which is denoted as 300 "observations" as what was observed in that specific question. But, the total number of participants was 301 in total.

The successful conduct and operation of AVs will rest with experts in the field and how they embrace this new technology and adapt them to the current highway networks. For this reason, the design method of the expert survey was a little different from that of the public survey. The public survey was aiming to assess people's perception and acceptance of AVs, which was also one of the intentions of running the expert survey. What was new in the expert survey – which was not a case of the public survey – was the group analysis. Therefore, recognising the adoption aspects of AVs and their pros and cons on the transport network from the perspectives of various expert groups was of the most importance. Hence, it was deemed necessary to analyse the experts' responses within the total participants and their own group. In this way, it was possible to identify how much the opinions of the various expert groups (academia, private sector, road authority, and government) conform or they are in conflict with each other. For this purpose, the statistical assessments of the expert survey were conducted using the cross-tabulation tool of the statistical software IBM SPSS Statistics 25, which help to understand the correlation between two different variables. It also presents the results of the entire group of respondents as well as results from the sub-groups of survey respondents. Since cross-tabulation provided all the required information for the assessment of the expert survey groups, the use of other statistical evaluation models such as ANOVA, or MNL did not seem necessary. Note that the variable coding of the expert survey in SPSS is available in Appendix A (A2).

3.5. Microsimulation Software

Multiple studies such as Ronaldo (2012), Gao (2008), Byungkyu et al. (2006), and Jones et al. (2004) evaluated various micro-simulation software packages adopted for transportation and traffic simulations. Those studies applied appraisals to compare the results of the simulations obtained by various software packages. In this context, Saidallah et al. (2016) conducted one of the most comprehensive assessments of the various simulation software packages. Saidallah et al. (2016) studied 11 software packages based on eight criteria such as the simulation type (microscopic, mesoscopic, and macroscopic), visualisation (2D, 3D), software's capability for designing infrastructure, and some others.

Among the software packages adopted by past studies (reviewed in Chapter 2) and the studies introduced in this Section, AIMSUN, VISSIM, CORSIM, PARAMICS, and SUMO obtained the highest attraction of the researchers of those studies. Therefore, the current study chose these five software packages, to evaluate which one could be the best candidate for the simulation of the current study. Then, the results related to the following criteria were adopted for those five software packages from the study conducted by Saidallah et al. (2016). Such criteria are adopted according to the need of the current study and conformed to the evaluations in this Section:

- Availability of the software package (open-source, commercial)
- Visualisation mode (2D, 3D)
- Ease or difficulty of designing infrastructure elements (junction, etc.)
- Software flexibility in designing various road types (freeway, urban, etc.)
- Ability to define new vehicle types (TV, AV, etc.)
- Ability to define vehicle dimensions (for TVs and AVs).

Regarding the efficiency of the chosen software packages for the simulation in this study, a weighting method was proposed by the current study that helps to find which software package can ideally provide the needs of this study. The weighting of software packages was conducted using the results obtained from the study conducted by Saidallah et al. (2016). In this context, Table 3.1 represents the evaluation of the simulation software packages. For each software package presented in Table 3.1, there is an evaluation feature and its related weighting values.

The results of the evaluation in Table 3.1 demonstrate that CORSIM and SUMO cannot provide the requirements of the simulation model of the current study. Also, PARAMICS looks a capable software package in visualisation features and flexibility in designing infrastructure elements. However, the availability of PARAMICS and its weakness in defining micro-features disqualifies it for the simulation requirements of this study. Moreover, Table 3.1 shows that AIMSUN has good capabilities in visualisation features, defining micro features such as vehicle type and dimension, and flexibility in designing various road types. However, AIMSUN is a commercial software package, where the free trial license version of it expires 30 days after installation, and the saving feature of the software is disabled. Therefore, AIMSUN is not suitable for the evaluations in this study.

The results of the weighting assessment in Table 3.1 represents that VISSIM, by far, would be the most suitable software package for the simulation in this study. VISSIM represents extensive micro-features for designing many types of vehicles such as TVs and AVs in any required dimensions. Besides, the ranking system represents that VISSIM follows the most straightforward procedures for creating infrastructure elements such as junctions, and it is a flexible software in defining various road types such as freeways and urban roads. Such a feature is essential in designing the road sections of the freeway (M50) and the junctions (nodes) in this study. Moreover, VISSIM provides both 2D and 3D visualisation modes, which is favourable in traffic simulation studies both for evaluation and presentation purposes. Also, VISSIM is an available software for the simulation in this study. Therefore, VISSIM seems the most competent software package for the simulations of the current study; hence, it is adopted for the simulation of TVs and AVs in this study.

Table 3.1. Evaluation of the simulation software packages

Feature		**Weight**		**AIMSUN**	**CORSIM**	**PARAMICS**	**SUMO**	**VISSIM**
Availability of the simulator	Open-source, and available	Yes	1*	0	0	0	1	0
		No	0**					
	Commercial	Not Available	-1***	-1	-1	-1	0	0
		Available	1	0	0	0	0	1
Visualisation mode		2D	1	1	1	1	1	1
		3D	1	1	1	1	0	1
Infrastructure design	Difficulty in designing (intersection, roundabout, etc.)	Easy	1	-1	0	0	-1	1
		Medium	0					
		Difficult	-1					
	Flexibility in designing various road types (freeway, urban, etc.)	Flexible	1	1	-1	1	-1	1
		Limited	0					
		Very Limited	-1					
Micro features for creating vehicles	Defining new vehicle types	Yes	1	1	0	0	0	1
		No	0					
	Defining vehicle dimensions	Yes	1	1	0	0	0	1
		No	0					
Overall value				**3**	**0**	**2**	**0**	**7**

Note: the weighting values could be anything other than -1, 0, and 1 as long as they provide a fair distinction regarding the advantage, natural, and disadvantage impact of a software feature. The weights could be defined based on the requirements and goals of any specific project.
* 1: Representing an advantage regarding the adoption of the related software **in this research**
** 2: Representing a neutral impact regarding the adoption of the related software **in this research**
*** 3: Representing a disadvantage regarding the adoption of the related software **in this research**

3.6. VISSIM Model

3.6.1. Introduction

In order to evaluate the efficiency of AVs in motorway traffic flow, they are designed in a conceptual model of the M50 motorway in Dublin, Ireland. The reason for choosing M50 was that it is the busiest motorway in Ireland. Besides, M50 has substantial importance in controlling the traffic of the national routes radiating from Dublin, as they begin at their junctions with the M50 (Irish Times, 2017).

The simulation was (firstly) conducted for TVs using the microsimulation software PTV-VISSIM with traffic data extracted from the Transport Infrastructure Ireland (TII) traffic data site. Then the model was designed to simulate AVs using the same traffic data and road network.

3.6.2. Road Network

The road network for the simulation is designed according to the geometry of the M50 motorway. The road starts in the vicinity of Bray in Dublin (a commuter town south of Dublin City) and terminates at Dublin International Airport (on the north side of the city); it is a total length of 40 kilometres, and the distance involved in the simulation helps to address how efficiently AVs could perform on long trips. The model evaluates travel scenarios generated from Bray to Dublin Airport, including traffic from six merging roads, which are referred to as nodes hereafter. Figure 3.3 shows the model created in VISSIM.

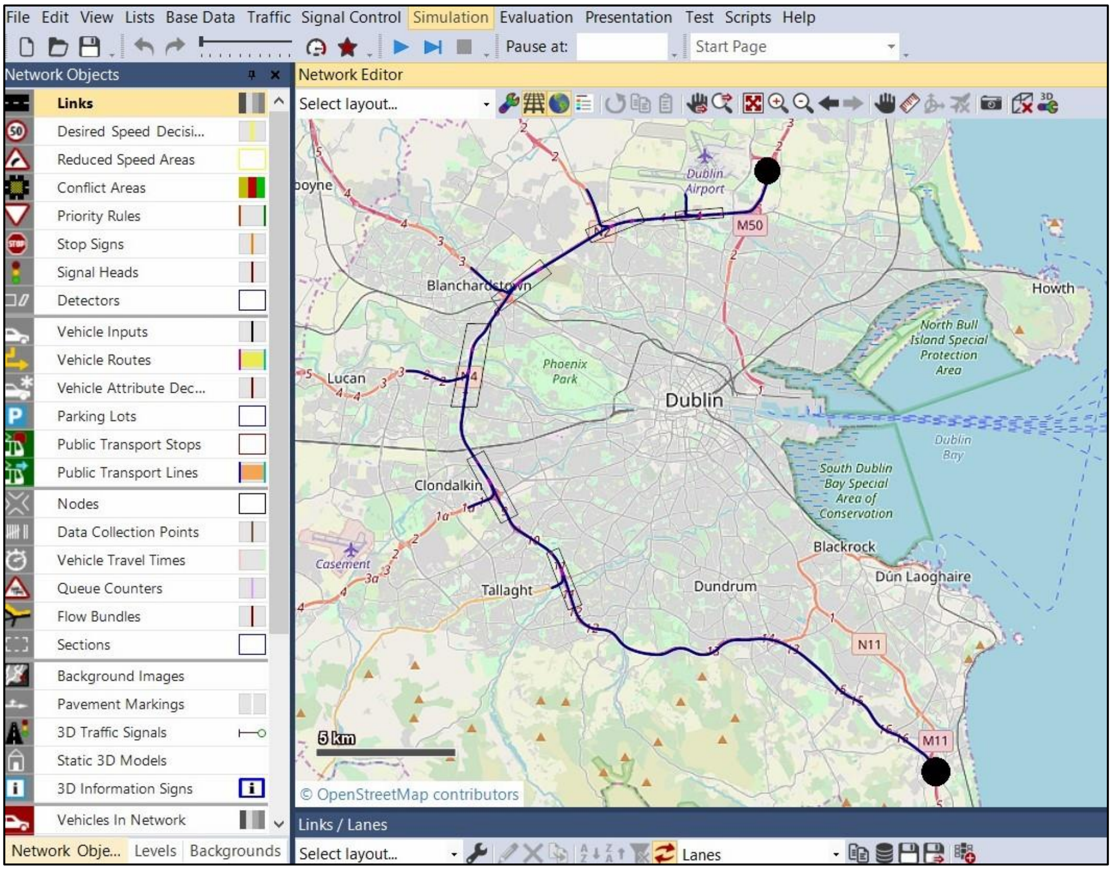


Figure 3.3. The road network for the simulation of TVs and AVs in VISSIM

As with all modelling tasks, certain assumptions are made for the VISSIM model in this study, as follow:

- **The VISSIM model is a conceptual model of the M50 motorway.** Therefore, the results do not represent the exact traffic stream of the M50 but describe a conceptual situation to compare the performance of TVs and AVs. However, all efforts have been made to make the model as realistic as possible such using the traffic data of the motorway
- **The motorway has four lanes (in one direction) across its entire length** except at nodes where one lane is added to lead the merging vehicles into the main traffic flow
- **The M50 has six nodes (junctions) in total**. Such an assumption was considered since there was a lack of sufficient traffic data for minor junctions at M50
- **Half of the traffic from the approaching roads to the M50 junctions (for example, N7) is heading towards the airport.** This assumption was made since there is no information about the percentage of traffic approaching the M50 that travels north, south or into the city. In this context, contact was made with TII to retrieve the exact traffic data for all junctions and their turning ratios. TII confirmed that they do not

have those turning proportions from the traffic count data, as they don't capture all movements entering and leaving the interchange (D. Kennan, D. Brennan, personal communication, Feb 12, 2019). However, the N7 interchange had a counter, and that provided more information about the traffic inside the junction. In this context, the peak traffic volume for N7 according to the data sent by TII was 2,103 for the traffic towards the airport, which was close to the assumption of this study (2,093). Therefore, the assumption for cutting the total approaching traffic in half seemed acceptable for the modelling of this study

- **All cars on the M50 move towards the airport and none leave the M50**. This assumption was made for a better evaluation of the travel time, the number of vehicles, and vehicle delay in a long highway trip between two destinations where no vehicles leave the trip

Due to the limitations regarding the data collection in this study, the model of this study was designed as a conceptual model of the M50. Also, other than some unofficial trials, there is no official experience of the application of AVs in highway transport, so there is no information about the impact of these vehicles on the evaluated parameters of this study such as fuel consumption and CO emission. As a result, validation of the simulation results with empirical results is not possible.

3.6.3. Link Behaviours

A discussion about driving behaviour is presented in Section 3.6.7, but a description of link behaviour types was required in this Section since such a feature is part of the model design. Therefore, a brief explanation of the link behaviours used in the study is presented in this Section.

In the modelling for this study, two types of link are created. One is the freeway (motorway) link referring to free lane selection behaviour, which is the behaviour on the main road from Bray to Dublin Airport. The second link type is urban road behaviour, which is applied to merging areas (nodes) to define how vehicles on the main road interact with joining traffic in terms of allowing them to blend into the main traffic on the M50. Table 3.2 shows these links and their behaviours:

Table 3.2. Link behaviour types

Type	Link section	Driving behaviour	Car-following model
1	Main links on M50	Traditional - Freeway	Wiedemann 99
		AV - Freeway	
2	Merging areas at nodes	Traditional - Urban	Wiedemann 74
		AV - Urban	

3.6.4. Vehicle Design

VISSIM uses a distribution of cars for a more realistic simulation of vehicles in highway transport. Table 3.3 shows the vehicle distribution for TVs in VISSIM with their proportions on the road (PTV, 2017). Table 3.3 represents the car models adopted (by VISSIM) with various model specification and proportions. Finding the exact proportion of the vehicles on the road could be substantial when the aim of the research is an evaluation of a specific car model. However, the study of this research aims to compare the performance of TVs and AVs in similar traffic conditions. Therefore, the proportion of cars is not a substantial issue as long as the same proportion is considered for both TVs and AVs. In this context, the current study adopted the default proportions defined by VISSIM for the simulation of TVs in this study.

Table 3.3. Vehicle distribution for TVs

Car Model	Proportions (%)	Model Specification				
		Length (m)	Width (m)	AxleFront (m)	AxleRear (m)	JointRear (m)
Car - Volkswagen Golf	24	4.211	2.004	0.901	3.478	4.211
Car - Audi A4	18	4.610	1.949	0.946	3.595	4.610
Car - Mercedes CLK	16	4.644	1.999	0.853	3.568	4.644
Car - Peugeot 607	16	4.760	2.069	0.944	3.743	4.761
Car - Volkswagen Beetle	14	4.012	1.852	0.783	3.298	4.012
Car - Porsche Cayman	2	4.359	1.970	1.041	3.456	4.359
Car - Toyota Yaris	10	3.749	1.987	0.749	3.209	3.749

For the model in this study, a new class of vehicles was created to represent AVs. Additionally, since the main differences between AVs and TVs in this study relate to their driving behaviours, all attempts have been made to ascertain that the model specifications and vehicle proportions are similarly configured for TVs and AVs except in terms of their driving behaviours and certain model configurations to define autonomous behaviours. In this context, a new class of cars has been created for AVs with similar physical car specifications as TVs of the model. However, some minor changes are implemented for visual aspects of AVs to better distinguish them from TVs in mixed traffic scenarios; this issue will be discussed in Chapter 7. Table 3.4 represents the distribution of AVs on VISSIM and Figure 3.4 illustrates the 3D model of the designed AVs in VISSIM.

Table 3.4. Vehicle distribution for AVs

Car Model	Proportions (%)	Model Specification				
		Length (m)	Width (m)	AxleFront (m)	AxleRear (m)	JointRear (m)
AV - Volkswagen Golf	24	4.211	2.004	0.901	3.478	4.211
AV - Audi A4	18	4.610	1.949	0.946	3.595	4.610
AV - Mercedes CLK	16	4.644	1.999	0.853	3.568	4.644
AV - Peugeot 607	16	4.760	2.069	0.944	3.743	4.761
AV - Volkswagen Beetle	14	4.012	1.852	0.783	3.298	4.012
AV - Porsche Cayman	2	4.359	1.970	1.041	3.456	4.359
AV - Toyota Yaris	10	3.749	1.987	0.749	3.209	3.749

Figure 3.4. AVs on the M50 in the VISSIM model of the study

3.6.5. Model Configuration

Generally, when a simulation aims to assess the changes in a real network, it needs comprehensive calibration to make sure that the model is representative of reality and the quality of the results is maximised for the experimental data (Trucano et al., 2006). In this context, the calibration refers to the adjustments of the simulation parameters to conform to the real model of the road so that the simulation model can represent realistic results (as much as possible) that comply with that of the actual condition. However, the purpose of the simulation in this study is to compare the efficiency of AVs with that of TVs in motorway transport and not to address the consequences of using AVs on traffic on the M50. So, as long as the model and traffic data are the same for both TVs and AVs, they can be compared. In light of this, the model for this study is a conceptual model of the M50, not an exact model. Besides, as explained in the assumptions, detailed information about the turning ratios at nodes was not available. Therefore, a comprehensive calibration of the model was not possible since the study had to make some assumptions about the traffic data and turning ratios at the merging areas.

Moreover, since AVs are not operating on the road network and their driving behaviours are not yet fully understood, and due to a lack of reliable reference points on this subject, the current study could not implement substantial changes to the model parameters to replicate AVs' driving behaviours more accurately. Yet, to fill some gaps of the knowledge in this regard, the current research has come up with a solution for adjusting some of the driving behaviours to represent what would happen if AVs could drive with some of the modified driving behaviours which are expected from human drivers. However, some configurations were applied to the VISSIM model for AVs based on the assumption that AVs will offer improvements compared to human behaviours. The following sub-sections present the model configurations used to demonstrate certain autonomous behaviours. Such settings will work in parallel with the optimised driving behaviours for the current study, which will be discussed later in Section 3.6.7.

3.6.5.1. Speed Distribution

The average speed limit of the M50 motorway is 100km/h, which is applied to the simulation model of this. It is worth noting that VISSIM applies a speed range of 80km/h – 120km/h for an ordinary speed of 100km/h (PTV, 2017). Such a speed distribution provides more realistic traffic flow of vehicles in the model. Therefore, for the modelling in this study, the 100 km/h speed of TVs is distributed in the range of 80–120 km/h to provide for the possibility of driving at any rate in this range similar to what VISSIM does for such speed (PTV, 2017). The speed distribution of TVs is presented in Appendix A (A3).

Also, PTV (2017) recommends removing the speed distribution of vehicles for AVs as these vehicles are expected to drive without such variation of speed. Therefore, for the modelling of AVs in this study - with respect to the average speed of the cars on the M50 - AVs are limited to driving at 100 km/h without distribution of their speed. It is worth noting that AVs of this study can reduce their speed when there is an object or vehicle in front of them, but they always drive at a constant speed and never exceed the speed limit of 100 km/h. The speed distribution of AVs is presented in Appendix A (A4).

3.6.5.2. Temporary Lack of Attention

Drivers experience distractions such as feeling drowsy which may lead to them closing their eyes for some seconds, losing control due to alcohol usage, using mobile phones or a combined effect of such distractions (Fagnant and Kockelman, 2015). However, AVs will not have any such distractions since AVs will adopt smart sensors and cameras such as LIDAR for navigation. In light of this, there is a driving behaviour in the model called "*temporary lack of attention"* to replicate such human distractions (PTV, 2017). For the simulation in this study, a distraction time of 5 seconds was built in for TVs, occurring for 5% of the total length of the driving period, while this value was considered zero for AVs.

3.6.5.3. Acceleration and Deceleration

The acceleration and deceleration boundaries for TVs and AVs were designed within the speed range of 0-250 km/h. The acceleration and deceleration for AVs were defined without distribution of values similar to that previously justified for speed distribution. The desired acceleration of TVs and AVs is presented in Appendix A (A5).

A TV can drive at any speed in the range of 80-120 km/h and the acceleration changes accordingly in the range of 0.42-2.29 m/s^2 (PTV, 2017). However, according to what explained about the speed of AVs in Section 3.6.5.1, an AV can only drive at 100 km/h without distribution of speed. Therefore, there will be no distribution in the desired acceleration of AVs; thus, a constant acceleration of 1.04 m/s^2 (as of TVs in such speed) is applied to AVs.

Regarding the maximum acceleration of cars in the model of this study (shown in Appendix A, A6), a TV can have a maximum acceleration of 3.5 m/s^2, which occurs at the speed of 0 km/h (PTV, 2017). The acceleration reduces with the increase in speed, reaching 0 m/s^2 at the speed of 250 km/h.

Additionally, PTV (2017) adopts a fixed desired deceleration for TVs at all speeds. In this context, the AVs of this study are defined with the mean desired deceleration of AVs, but without a distribution. Appendix A (A7) represents the desired deceleration for TVs and AVs.

It is also worth noting that PTV (2017) defines a distribution of speed and deceleration for TVs, while AVs are defined without such distributions in maximum deceleration. The maximum deceleration of TVs and AVs are presented in a Table in Appendix A (A8).

The application of such model configurations on speed, acceleration and deceleration for AVs means that they can run more smoothly in terms of acceleration and braking operations. Consequently, AVs might be able to offer continuous traffic flow with a nearly constant velocity, which might also increase the road capacity and reduce congestion.

In addition to the model settings explained in this Section, an optimisation of Wiedemann-99 was conducted and applied to the driving behaviours of AVs, which will be described in Chapter 6, Section 6.2.

3.6.6. Traffic Data

Traffic data was acquired from Transport Infrastructure Ireland (TII), which is the database of traffic data in Ireland (TII, 2017). Figure 3.5 shows the TII traffic data site with the location of data points acquired for the model design for this study. The data points are indicated by green circles and nodes are represented by black circles. The origin and endpoint for the model are indicated by black rectangles.

Figure 3.5. TII traffic data site

Figure 3.6 illustrates the site data for merging traffic at node 1 for the data month September 2017 (as an example). For each data point in the TII data site, there is a summary of data and complete traffic data which are accessible in the section named *Site Data*, which is shown in Figure 3.6.

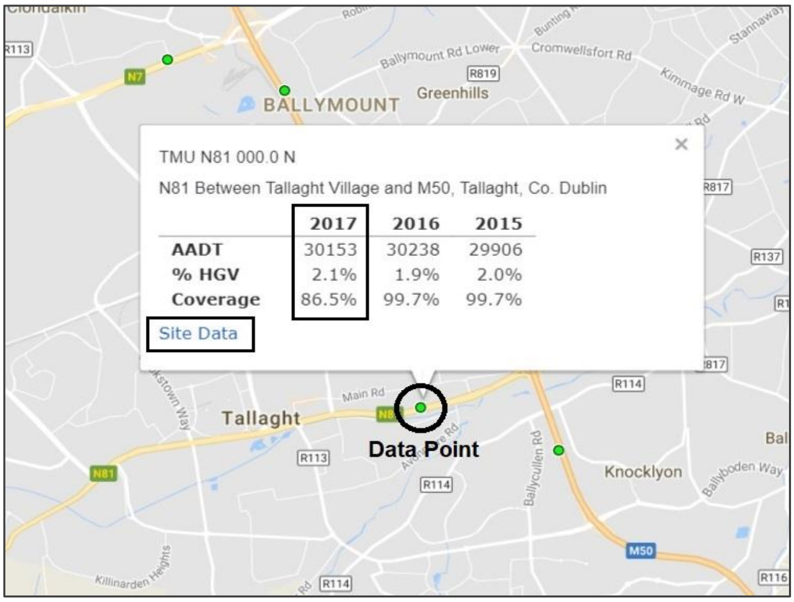


Figure 3.6. Example of site data for one of the data points (node 1)

The site data provides information about all directions of the traffic stream for the related data point. From the data available at each data point, only the traffic approaching M50 towards the airport was adopted as the input traffic to that junction. A sample page of the site data is available in Appendix A (A9). In the site data, traffic data is available for "all directions", "all eastbound", and "all westbound" traffic for node 1. Therefore, for the case of node 1, which is used as an example in this study, the information on eastbound traffic has been extracted. Note that the Figure presented in Appendix A (A9) only shows part of the data available.

In the next step, traffic data were assessed for all nodes, along with information on all the traffic originating from Bray for the whole data year 2017. The data were extracted from the related data points on the TII data site, then the cumulative volume for each month was calculated to find months with peak, normal and off-peak traffic conditions.

Table 3.5 shows the evaluated traffic data from TII for the whole data year 2017.

According to TII (2017) May, September and February experienced peak, normal, and off-peak traffic conditions, respectively. Therefore, these months were selected for further analysis and simulation. In this context, the traffic data were analysed in greater detail to find the peak, normal, and off-peak traffic conditions within each of these three months. Such an assessment covered a diverse range of traffic conditions with the minimum, average and maximum traffic conditions for the whole year included in the evaluation.

Table 3.5. Traffic Volume (Veh/h) at each data point for each month of the year 2017 (TII, 2017)

Month	**Traffic volume (vehicle/h)**							
	Origin	**Node 1**	**Node 2**	**Node 3**	**Node 4**	**Node 5**	**Node 6**	**Total**
	Data site 1	Data site 2	Data site 3	Data site 4	Data site 5	Data site 6	Data site 7	
Jan	1,125,968	451,359	1,463,279	1,436,308	1,141,295	535,563	234,042	6,387,814
Feb	1,067,638	436,842	1,418,848	1,392,433	1,105,306	519,935	225,758	**6,166,760**
Mar	1,233,190	492,986	1,597,094	1,571,852	1,244,545	591,863	259,726	6,991,256
Apr	1,201,310	452,179	1,534,849	1,498,097	1,180,427	546,957	258,334	6,672,153
May	1,287,254	496,855	1,662,277	1,627,478	1,286,058	608,954	280,804	**7,249,680**
Jun	1,231,291	461,010	1,594,936	1,557,649	1,233,810	576,554	280,482	6,935,732
Jul	1,289,729	450,729	1,633,137	1,585,320	1,220,319	575,278	281,388	7,035,900
Aug	1,293,855	450,869	1,657,952	1,597,677	1,234,272	590,786	283,136	7,108,547
Sep	1,205,815	467,307	1,595,776	1,575,862	1,227,316	581,786	277,504	**6,931,366**
Oct	1,203,539	468,021	1,572,276	1,562,638	1,237,222	585,991	270,952	6,900,639
Nov	1,203,069	477,573	1,595,394	1,564,769	1,217,837	607,787	258,041	6,924,470
Dec	1,126,774	451,154	1,443,018	1,475,689	1,178,114	525,740	222,935	6,423,424
Average	1,205,786	463,074	1,564,070	1,537,148	1,208,877	570,600	261,092	6,845,847
SD*	70,435	18,291	82,065	70,771	49,452	30,894	22,328	318,599
CV**	0.058	0.039	0.052	0.046	0.041	0.054	0.086	0.047

* Standard deviation
** Coefficient of variation

The breakdown of traffic data in February, May and September are represented in three Tables, which are available in Appendix A (A10 - A12). Each Table demonstrates ten peak traffic conditions, ten normal, and ten off-peak traffic conditions. The traffic volumes in those Tables were adopted for the simulation of TVs and AVs later in this study.

Note that the Road Safety Authority of Ireland (RSA) provides accident data for all roads in the country (RSA, 2017). However, the RSA database provided information up until the year 2016 and no accident data was available for the year 2017. Therefore, there was not sufficient information to check whether any of the days in the TII database had any form of a traffic accident or not. However, the SD and CV of the traffic data (presented in

Table 3.5) represents no severe incident has occurred on the M50 during the study period as otherwise there should have been an inconstancy in the traffic data of the various months (which was not).

3.6.7. Driving Behaviours

Car-following models define and control the driving behaviours of the "following" vehicles with regard to the leading vehicle's speed, acceleration, and decelerations (Olstam and Tapani, 2004). Car-following models vary based on their control logic and the way they define behaviours for the "following" vehicles. In this regard, some models work based on keeping a safe distance between the "following" and leading vehicles and some models adopts psycho-physical logics which use thresholds for controlling the "following" vehicles with respect to the leading one (Olstam and Tapani, 2004).

As previously explained (in Table 3.1), this study is using VISSIM for the simulation of TVs and AVs in this study. VISSIM uses the Wiedemann car-following model for the simulation of vehicles on the network which is psych-physical car following model (PTV, 2017). For this purpose, the current study acquired Wiedemann-99 (1999) for optimisation and adoption in AVs, as VISSIM does for the simulation of vehicles.

It is worth noting that there is not yet an official application of AVs on public roads and so there is not sufficient information about their driving behaviours. However, recent experiments show that WAYMO is using sophisticated artificial neural networks by implementing machine learning techniques to copy human driving behaviours in autonomous vehicles and train them how to drive (Hawkins, 2018; Quach, 2018). However, Bartolini et al. (2017) believe that adopting machine learning, and other AI techniques for training AVs in driving behaviours pose substantial challenges. For instance, Bartolini et al. (2017) demonstrate that training AVs involves settings for millions of connections in training phases where backtracking from the final decision, resulting in driving behaviours that have stimulated a specific set of driving inputs, is difficult. Therefore, it may not be possible to identify the precise causes of any false driving behaviour and the reason for such a type of reaction, since a connection between the exact inputs and output driving behaviours in machine learning techniques is not yet known. For this reason, the current research decided to simulate AVs by using traditional driving behaviours acquired in traffic simulations such as Wiedemann-99 since the exact input parameters for this model are available. Additionally, Wiedemann-99 is still being used by VISSIM (PTV, 2017) and was adopted by many studies, for example, Aghabayk et al. (2013), Higgs et al. (2011), and Menneni et al. (2008). Moreover, Zeidler et al. (2019) and PTV (2017) state that Wiedemann-99 could be used to replicate autonomous behaviours.

Regarding other methods for the simulation of autonomous behaviours in cars, and as previously indicated in the literature review, Hawkins (2018) indicates that Google is using machine learning methods to train autonomous driving behaviours to the vehicle. However, Bartolini et al. (2017) indicated some substantial obstacles to adopting such a means, citing the connection between the defined input parameters and the output driving behaviours from machine learning. The lack of such connection raises concerns for accurate retracing to the exact reasons for possible errors in driving behaviours.

Therefore, the study for this research represents what would happen if AVs could drive with the optimised driving behaviours expected from humans. The current study simulated AVs using traditional human driving behaviours defined in Wiedemann-99 to address how efficiently AVs might behave if they drive with optimised human driving behaviours. The advantage of applying Wiedemann-99 is that the input parameters for the model are available and can be used for retracing and modification of false driving behaviours.

The Wiedemann-99 in VISSIM relies on ten user-defined parameters to represent human driving behaviour in freeway traffic (PTV, 2017; Lowens and Machemehl, 2007). In addition to the parameters of Wiedemann-99, the study applied some additional configurations to better simulate autonomous behaviours, which will be discussed later in this Section.

Several previous studies such as Lu et al. (2016); Song et al. (2015); Aghabayk et al. (2013), Higgs et al. (2011), and have analysed the parameters of Wiedemann 99 in depth. Therefore, the equations for those parameters are not presented in this study, but the defined values for Wiedemann-99 are briefly presented in Table 3.6, and this is followed by a brief description of the parameters.

Table 3.6. Parameters of Wiedemann-99

Model Parameters	**Value**
CC0 (Standstill Distance) – m	1.50
CC1 (Headway Time) – s	0.9 ± 0.2
CC2 (“Following” Variation) – m	4.00
CC3 (The Threshold for Entering to “Following” Phase) – s	-8.00
CC4 (Negative “Following” Threshold) – m/s	-0.35
CC5 (Positive “Following” Threshold) – m/s	0.35
CC6 (Speed Dependency of Oscillation) – 10^{-4} rad/s	11.44
CC7 (Oscillation Acceleration) – m/s2	0.25
CC8 (Standstill Acceleration) – m/s2	3.50
CC9 (Acceleration at 80 km/h) – m/s2	1.50

- CC0: "*Standstill Distance*" is the desired rear-bumper to the front-bumper distance between two stationary vehicles
- CC1: "*Headway Time*" is a time-gap that provides the minimum safety distance that a driver needs to maintain at a certain speed. A higher value shows that the driver is more cautious. It is also worth noting that CC1 influences capacity in the case of high traffic volumes
- CC2: "*Following Variation*" refers to the longitudinal oscillation during the "following" phase. CC2 defines the additional distance to the desired safety distance that a driver can keep before he intentionally moves closer to the leading car
- CC3**:** this is the time (in seconds) before reaching the safety distance. CC3 controls the start of the deceleration phase when a driver recognises a slower vehicle in front
- CC4: this is the negative speed difference during the "following" phase. A lower value represents a more sensitive reaction of the driver to the acceleration or deceleration of the preceding vehicle
- CC5: this is the positive speed difference during the "following" phase. It is a positive value of CC4
- CC6: this shows the effect of distance on speed oscillation during the "following" phase. A greater value leads to a higher speed oscillation with increasing distance.
- CC7: this represents the oscillation during the "acceleration" phase
- CC8: this is the desired acceleration from a standstill situation. CC8 is controlled by the maximum acceleration
- CC9: this is the desired acceleration at the speed of 80km/h. CC9 is controlled by the maximum acceleration

In this study, an optimisation method was applied since the default values for driving behaviours might not represent the desired driving behaviours for AVs. The optimisation was conducted using the simulation model of the M50 in VISSIM. Detailed explanation about the optimisation method, model design, and results are presented in Chapter 6 of this thesis.

3.7. Simulation

3.7.1. Structure

In order to examine the likely impacts of AVs on road traffic, their performance was compared with the results from the simulation of TVs. In general, the simulation model aimed to address the following concerns:

- How are TVs performing on traditional motorways?
- How will AVs perform on traditional motorways?
- How will TVs and AVs interact in shared road traffic?

Figure 3.7 illustrates the overall steps for the simulation of this study. In addition, Figure 3.8 and Figure 3.9 show the breakdown of the simulation procedures for TVs and AVs in VISSIM, respectively.

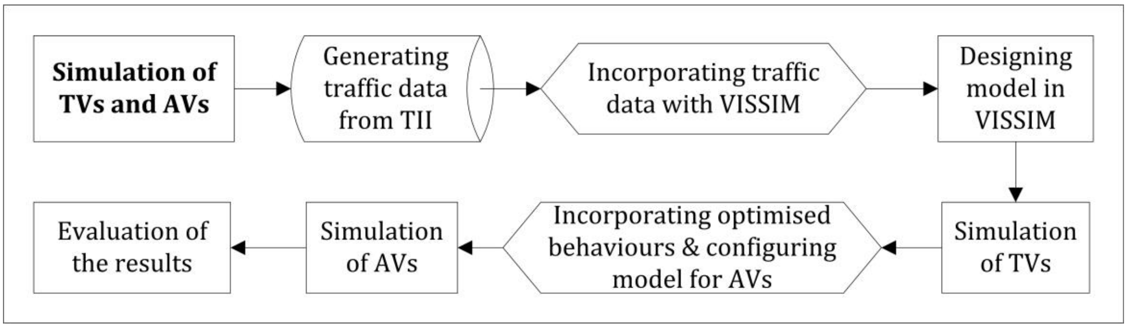


Figure 3.7. The overall workflow for the simulation of TVs and AVs

As shown in Figure 3.8, the traffic data were analysed to find the month with the heaviest traffic (May), the month with the closest to normal traffic (September) and the month with the lightest traffic (February). Then, the traffic data were reassessed to find the peak, the closest to normal, and off-peak traffic conditions within each of those three months to cover a diverse range of traffic conditions. For instance, in May, ten days with the heaviest traffic conditions were selected for the simulation of TVs. In this way, ten simulation scenarios were created where the average of those ten scenarios would represent the results related to heaviest traffic conditions within the peak month (May). Note that each simulation scenario was configured for 15 runs, and each took one hour of simulation plus an extra 10 minutes to fill up the model for ongoing traffic on the motorway. Therefore, the results represent the average for 150 hours of simulation for peak traffic conditions within May. Then, the same procedure was adopted for the simulation of TVs for the normal and off-peak traffic conditions within the same evaluation month (May). Likewise, the simulation was performed for traffic conditions in September and February. Such a framework of simulation represents reliable results for the simulation of all traffic conditions. In addition, the final values of the simulations in this step were subsequently compared with the results from the simulations of AVs. The simulation procedure, which is depicted in Figure 3.8, resulted in 90 scenarios with 1,350 hours of simulation. In the next step, the same simulation framework was adopted for AVs.

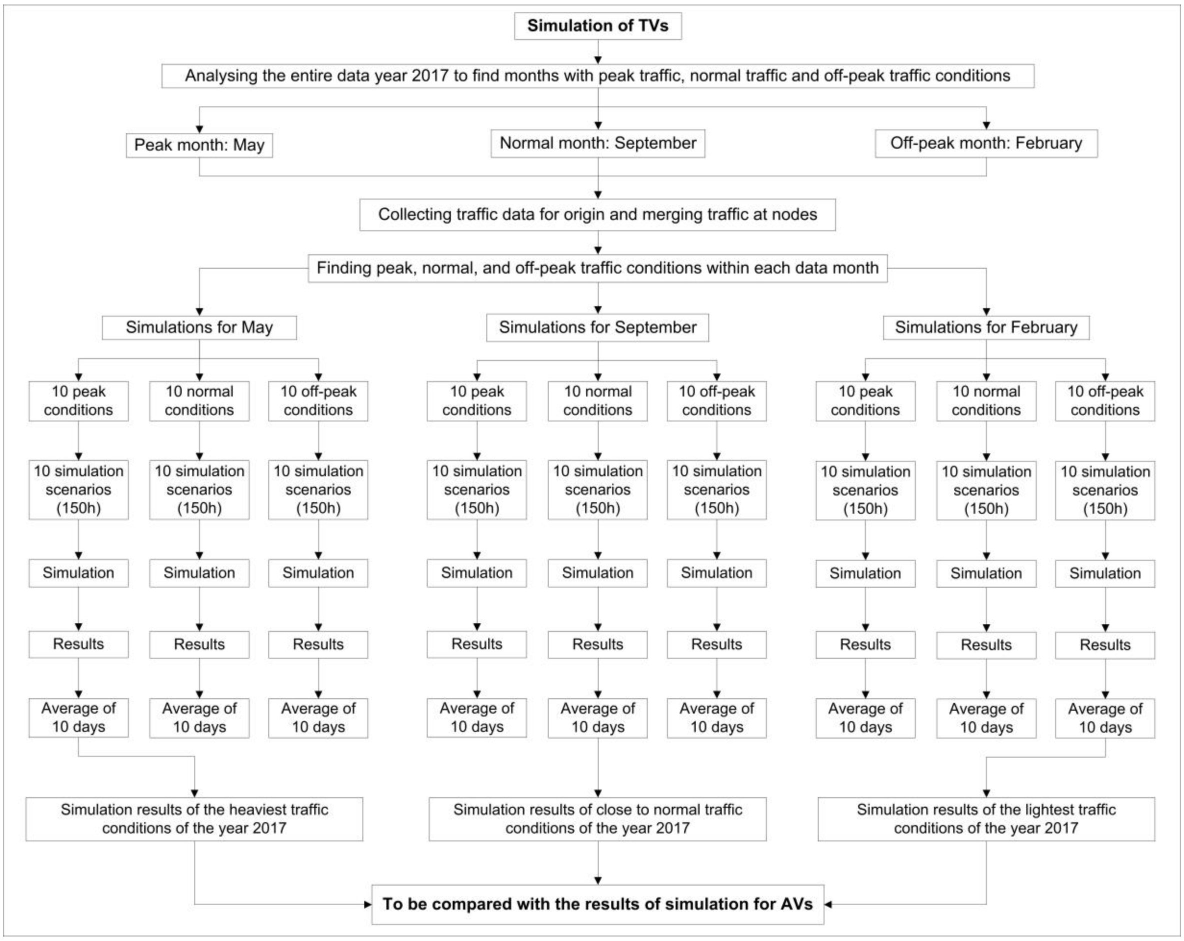


Figure 3.8. Flowchart for the simulation of TVs

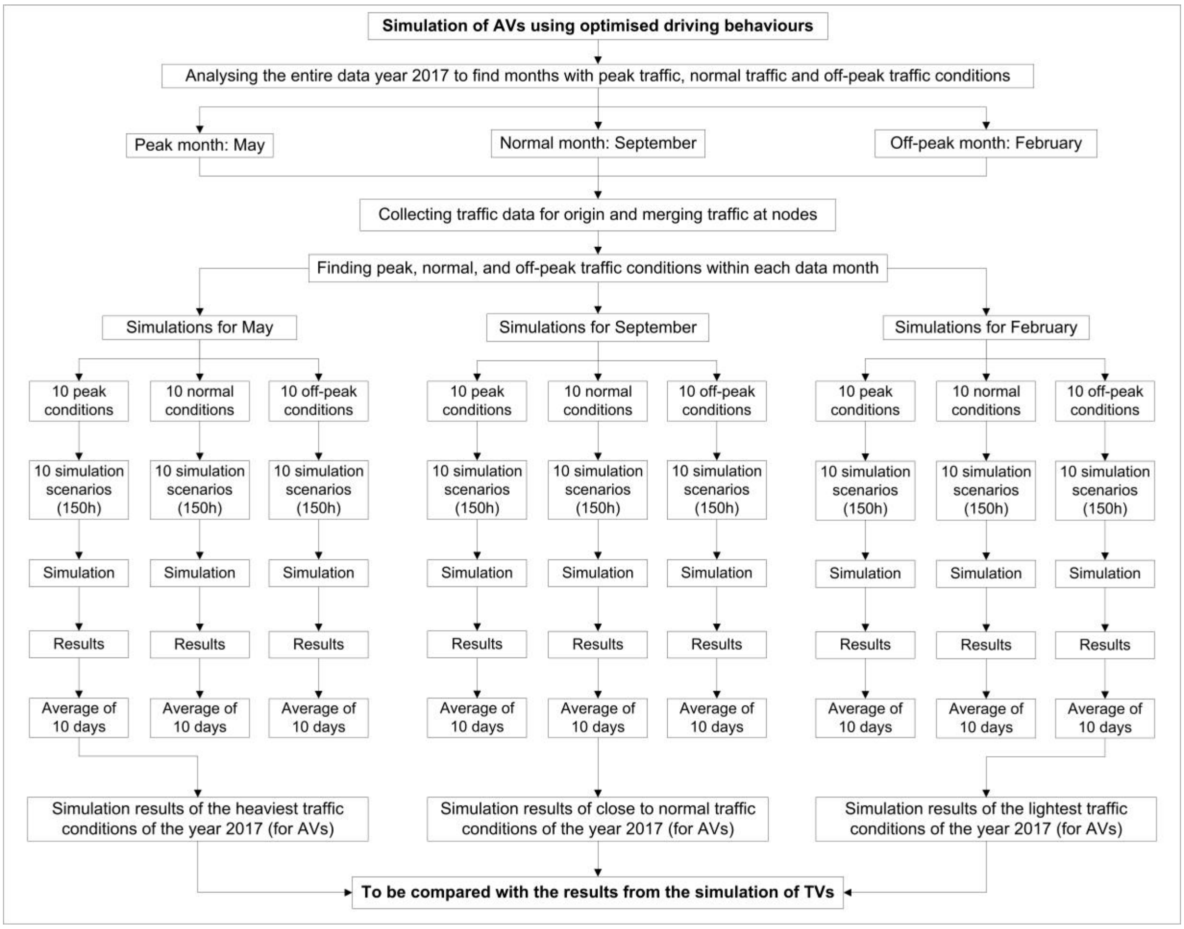


Figure 3.9. Flowchart for the simulation of AVs

In the next step, in order to simulate the transition period for adopting AVs and mixed traffic with TVs, 11 scenarios were defined for simulation. The simulation scenarios in this step represented different percentages of TVs and AVs for merged traffic. In this context, the network was designed to operate with TVs in scenario one. Then, AVs were added to the model, and their share of the traffic was increased by 10% for each scenario until AVs occupied the entire network in Scenario 11. The results of this evaluation offer an understanding of the quality of traffic flow with different proportions of TVs and AVs. Table 3.7 represents shared-mode scenarios with the percentages of TVs and AVs for each scenario. In addition, Figure 3.10 shows the flowchart for the shared-mode simulations.

Table 3.7. Scenarios for the simulation of TVs and AVs in mixed traffic

Scenario		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Proportions of TVs and AVs in percent	TVs	100	90	80	70	60	50	40	30	20	10	0
	AVs	0	10	20	30	40	50	60	70	80	90	100

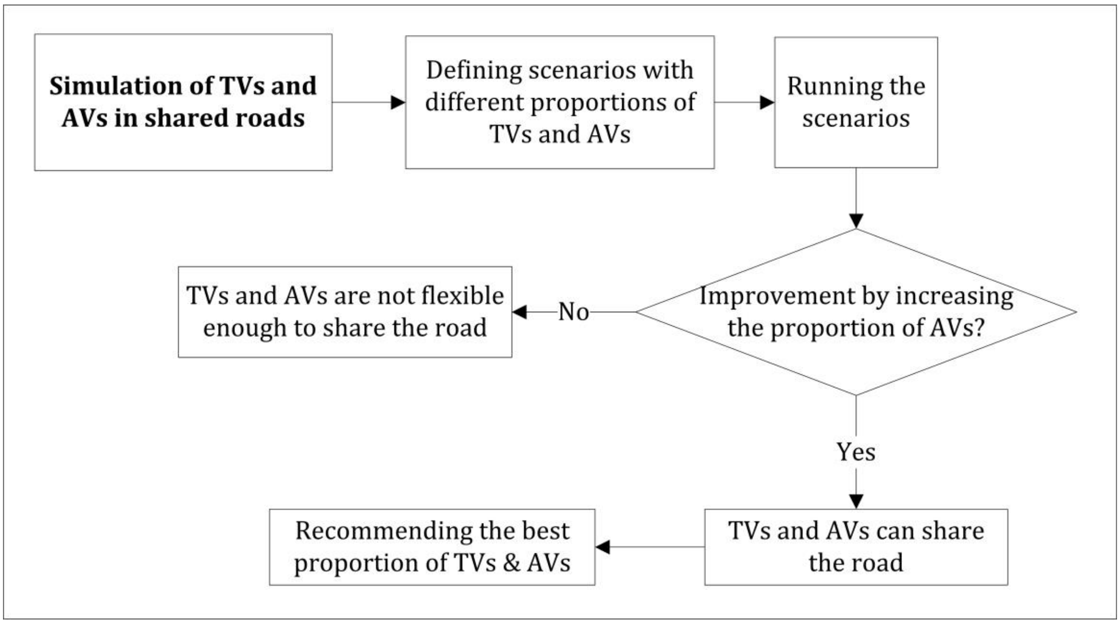


Figure 3.10. Flowchart for the simulation of TVs and AVs in shared roads

Furthermore, an assessment was conducted with the driving behaviours optimised by PTV for AVs.

Table 3.8 represents the driving behaviours defined by PTV[1] and those of this study and Wiedemann-99 (PTV, 2018). It is worth noting that PTV did not provide information about how they came up with these values. There is only a webinar on YouTube introducing the new features of VISSIM 11 along with the parameter values that PTV recommends for the simulation of AVs (Sukennik, 2018). In that video, Sukennik (2018) state that the driving behaviours of AVs are defined based on some empirical data and assessments PTV conducted in one of their projects.

As shown in

Table 3.8, PTV defined three sets of driving behaviours for AVs; AV aggressive, AV normal, and AV cautious (PTV, 2018). The aggressive mode of driving behaviours represents AVs in the minimal distances from each other, smaller thresholds, and higher acceleration and deceleration, whereas AV cautious represents an opposite mode of driving behaviours. Also, AV normal represents a normal mode of driving behaviours where all parameters have an average value in their range.

The driving behaviours suggested by PTV in

Table 3.8 were used for the simulation of AVs in normal traffic conditions. Then, the results were compared to those in this study. Such an evaluation shows the extent to which the

[1] PTV-driving behaviours for AVs were released on 02.07.2018 after that almost all the simulation modelling of this study was completed.

optimised parameters of the current study are in line with the tuned parameters recommended by PTV.

Table 3.8. Driving behaviour defined by PTV for AVs and those of this study

Model parameter	Wiedemann-99	Defined by PTV		
		AV Aggressive	AV Normal	AV Cautious
CC0 (Standstill Distance) – m	1.5	1.00	1.50	1.50
CC1 (Headway Time) – s	0.9	0.60	0.90	1.50
CC2 (“Following” Variation) – m	4.00	0.00	0.00	0.00
CC3 (The Threshold for Entering to “Following” Phase) – s	-8.00	-6.00	-8.00	-10.00
CC4 (Negative “Following” Threshold) – m/s	-0.35	-0.10	-0.10	-0.10
CC5 (Positive “Following” Threshold) – m/s	0.35	0.10	0.10	0.10
CC6 (Speed Dependency of Oscillation) – 10^{-4} rad/s	11.44	0.00	0.00	0.00
CC7 (Oscillation Acceleration) – m/s2	0.25	0.10	0.10	0.10
CC8 (Standstill Acceleration) – m/s2	3.50	4.00	3.50	3.00
CC9 (Acceleration at 80 km/h) – m/s2	1.50	2.00	1.50	1.20

In total, around 863 hours of simulation was conducted for optimisation purposes. Then, 2,715 hours of simulation were undertaken to assess the quality of traffic for TVs and AVs in their single mode of occupancy on the road. Also, 502 hours of simulation were undertaken on mixed traffic of transport between TVs and AVs providing an understanding of the transition periods when adopting AVs and what would ultimately happen to traffic streams when AVs occupy the entire road. Finally, 625 hours of simulation of AVs with the driving behaviours optimised by PTV were undertaken to represent the extent to which the optimisation in this study was in line with the results presented by PTV. Table 3.10 shows the structure of all the simulations conducted in this study.

Regarding the number of simulation runs, Byrne (2013) recommends 7 runs to achieve 0.05 confidence interval, and 0.05 coefficient of variation, and a 99% confidence level. However, Byrne (2013) indicates that more simulation runs might be required when more variables are associated with the simulation model. Therefore, a higher number of simulation run was adopted in this study to achieve a meaningful prediction of the impact of AVs in multiple characteristics (travel time, fuel consumption, and others). In this regard, 10 number of runs was defined for the optimisation process, and 15 runs for the simulation of TVs and AVs under various traffic conditions (scenarios).

Furthermore, for better assessment of the simulation results and monitoring the change of values through simulation, six time-intervals were defined for the simulation period (PTV, 2015). In this context, 10 minutes (600 seconds) time was considered as a model warm-up for filling up the road network followed by six other time intervals of each 10 minutes for the record of data. Table 3.9 represents simulation time intervals.

Table 3.9. Simulation time intervals

Interval	**Performance**	**Simulation time intervals (s)**	**Considered for evaluation**
1	Warm-up period for filling up the network	0 – 600	No
2	Simulation (recorded for assessments)	600 – 1200	Yes
3	Simulation (recorded for assessments)	1200 – 1800	Yes
4	Simulation (recorded for assessments)	1800 – 2400	Yes
5	Simulation (recorded for assessments)	2400 – 3000	Yes
6	Simulation (recorded for assessments)	3000 – 3600	Yes
7	Simulation (recorded for assessments)	3600 – 4200	Yes
Total Simulation		4200	
Recorded for evaluation		**3600**	

It is also worth noting that a simulation resolution[1] value of 10 time steps per simulation second and a (variable) random seed[2] of 42 was considered for the simulation of this study, suggested by PTV (2015).

Table 3.10 represents the structure of the simulation procedures in this study along with the number of scenarios, simulation time and some other attributes of the simulation settings in VISSIM.

[1] Simulation resolution: the number of times the vehicle's position will be calculated within one simulated second (range 1 to 20). A smoother simulation will be achieved by a higher value.
[2] Random seed creates random events in the simulation to replicate a more realistic simulation.

Table 3.10. Structure of the simulation procedures

Purpose of simulation	Description	# Scenarios	# Runs in each scenario	Simulation time (h)		
				Recorded for assessments	Warm-up	Total
Simulation for optimisation	CC0, CC1, and CC2	63	10	630	105	1,003
	CC3 to CC9	23	10	230	38	
Simulation of single modes of TVs and AVs	TVs in peak traffic (May)	30	15	450	75	3,150
	AVs in peak traffic (May)	30	15	450	75	
	TVs in normal traffic (Sep)	30	15	450	75	
	AVs in normal traffic (Sep)	30	15	450	75	
	TVs in off-peak (Feb)	30	15	450	75	
	AVs in off-peak traffic (Feb)	30	15	450	75	
Simulation of mixed traffic of TVs with AVs	Peak traffic (May)	11	15	165	27	576
	Normal traffic (Sep)	11	15	165	27	
	Off-peak traffic (Feb)	11	15	165	27	
Simulation with PTV values in normal traffic condition (Sep)	AVs with aggressive driving behaviours	10	15	150	25	717
	AVs with normal driving behaviours	10	15	150	25	
	AVs with cautious driving behaviours	10	15	150	25	
	Mixed traffic of PTV-AVs with TVs	11	15	165	27	
Total		**340**	**215**	**4,670**	**776**	**5,446**

Chapter 6 will represent the results gained during the optimisation of driving behaviours. The optimised values of driving behaviours will be presented, followed by different combinations of driving behaviours, which could be used to optimise each specific characteristic of the trip analysed in this study. For example, the results will show what parameters of driving behaviour must change to attain the lowest fuel consumption and level of emissions. Such findings will also be presented for some other characteristics in this study.

Furthermore, the results of the simulations undertaken for this study will be presented in Chapter 7. These results will demonstrate the likely impact of adopting AVs on public roads and their interaction with TVs. Also, the results will demonstrate the quality of traffic during the transition period for adopting AVs on public roads, where the share of AVs will increase gradually until they occupy the entire road.

3.7.2. Reliability

Reliability is the degree to which a simulation model of research produces consistent results when it is used under the same condition (Heale and Twycross, 2015). In this study, the simulation scenarios are tested over various simulation runs to make sure the results are internally consistent; then, the average values of the simulation runs are used as the overall results of the simulation scenario. In this regard, an internal constancy test named Cronbach's Alpha (α) is adopted to evaluate the consistency of the (initial) simulation runs, which is a common test for the internal consistency of an instrument (Heale and Twycross, 2015). Once the model tested for consistency, then it was adopted for the rest of the simulations. Equation 3.8 shows the mathematical function of Cronbach's α retrieved from the study conducted by Tavakol and Dennick (2011):

Equation 3.8

$$\alpha = \frac{N * \bar{C}}{\bar{V} + (N - 1) * \bar{C}}$$

where

N = the number of items

$\bar{C}$ = average covariance between item pairs

$\bar{V}$ = average variance

Also, there is another way to evaluation Cronbach's α, which is using "Two Factor ANOVA without Replication". This method acquires "Mean Squared Error (MSE)" and "Mean Squared Row (MSR)" of the data related to each sample (here, each characteristic such as the results of travel time). Equation 3.9 shows the mathematical function of Cronbach's α using MSE and MSR.

Equation 3.9

$$\alpha = 1 - \frac{MSE}{MSR}$$

where

MSE = mean squared error

MSR = mean square of the data rows in the sample (for example, the results of travel time in various time intervals defined in the simulation)

According to Siswaningsih et al. (2017), a Cronbach's α value of above 0.7 represents acceptable reliability of the model results, where α values of above 0.8 and 0.9 are considered a good and very good reliability, respectively. However, considering the stochastic nature of the simulations in traffic studies, and the result of a study by Taber (2016) an α value of above 0.64 is regarded adequate and satisfactory. Therefore, in this study, an α value of above 0.65 is also considered acceptable subject to the overall consistency of the simulation results under various traffic condition of the year, which is explained later in this Section.

In this study, the reliability assessments of Cronbach's α is conducted using SPSS. For this purpose, the results of the various simulation run for each characteristic evaluated in the simulation (travel time, LOS, and others) are analysed for consistency.

Additionally, the simulation results of the same traffic condition under various times of the year are compared to make sure the model results are reliable for other times of the year. For this, the simulation results of the AVs are compared for the peak traffic conditions of May, September, and February (as of shown in Chapter 7). The assessment criteria for this reliability is the Coefficient of Variance (CV), which represents the dispersion of a probability distribution, and it is the ratio of the standard deviation to mean of the data set (Zaiontz, 2019). A CV value of below 10% would represent a good consistency, whereas below 5% is regarded as excellent consistency (Zhichu, 1989). Equation 3.10 shows the calculation method of CV:

Equation 3.10

$$\text{CV} = \frac{\sigma}{\mu}$$

where

σ = standard deviation

μ = mean

3.7.3. Validity

3.7.3.1. External Validation

Validity in research is defined as a model accuracy in providing logically and sound results (Heale and Twycross, 2015). A typical method to evaluate the validity of the simulation results would be comparing them with empirical data (collected) from the street, which is a type of external validation. However, as previously discussed in Section 3.6.2, the limitations regarding the data collection in this study led to some assumptions in the model design and made the model of this study a conceptual model of M50. In addition, there is no experience of the official application of AVs in highway transport (other than small trials to date), so there is no information about the impact of these vehicles on travel time, queue length, and many other evaluated parameters of this study. As a result, external validation of the simulation results with empirical results is not possible.

3.7.3.2. Validation with PTV

In 2018, PTV presented three sets of driving behaviours (of AV-aggressive, AV-normal, and AV-cautious), which are claimed to be capable of replicating various types of autonomous behaviours. In this regards, three types of AVs are designed using these three sets of PTV-AV driving behaviours. Then, they are simulated (exactly) under the same traffic conditions as of the AVs of the current study. The overall improvements in traffic quality of the AVs of this study are compared to those of PTV's. Moreover, simulations models are designed for replicating the mixed traffic of PTV-AVs and TVs, and the results are compared to those of this study. The comparison of results between the AVs of this study and those of PTV under single occupancy mode and mixed traffic simulations represent the extent to which the current study's AV parameters are in line with those recommended by PTV. Such an evaluation represents the validation of the optimisation and simulation of this study.

3.7.3.3. Triangulation Validation

In addition to the validation of the simulation results with PTV driving behaviours in this study, another validation method is adopted which is called triangulation method. A triangulation method is a way of analysing the model results using multiple sources of assessment (Guion et al., 2011). Triangulation in research is done by comparing the findings of the research instruments (with similar research aim) against each other to identify how much those results are in line with each other.

As previously explained in Section 3.1, this research adopts a mixed methodology approach using a national public survey in Ireland and a global expert survey in the field. Also, the study conducts extensive simulations modelling of AVs and TVs over various traffic conditions. Therefore, using a triangulation method, the study can assess how successful it was in evaluating the efficiency of AVs using various research instruments.

In order to evaluate the validity of the surveys and simulations of this study, the overall simulation results of the various characteristics – such as the travel time – are compared against the reviewed studies in the literature, and the results of the public survey and expert survey. Figure 3.11 illustrates the triangulation of the various research instruments adopted in this study.

Note that the triangulation assessment is merged with the discussion of research (see Chapter 8, Section 8.3) in order to avoid repeating the results and discussion in this regard. Moreover, for a better assessment of the results in this context, a descriptive Table of the triangulation assessment has been provided in Section 8.4, which represents the main findings of the research instrument of this study (literature review, public survey, expert survey, and simulation). Such a Table of findings represents the extent to which the simulation results of this study are in line with the results obtained from the surveys and those in the literature, and how they oppose each other.

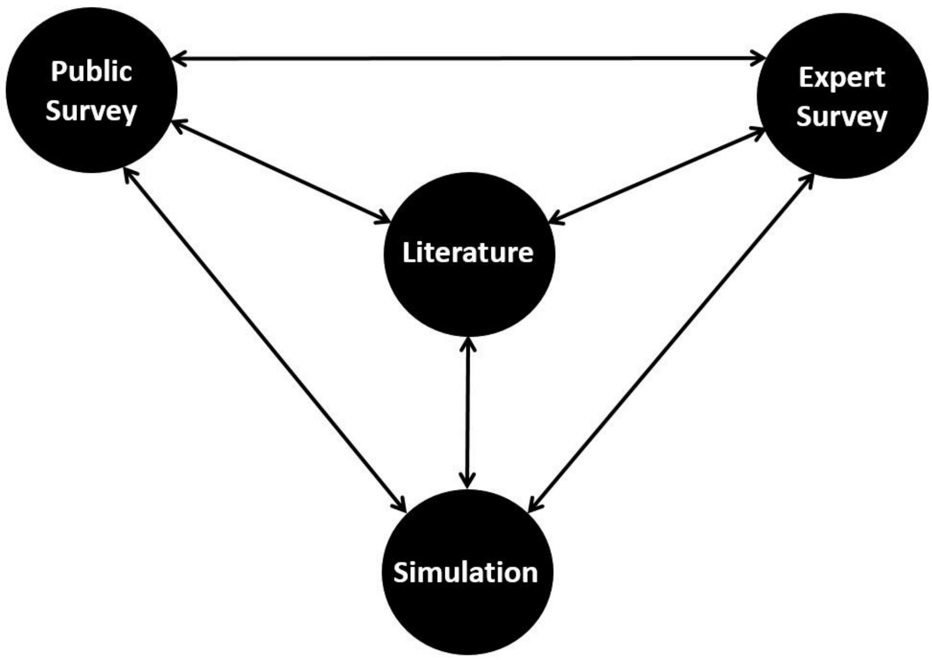


Figure 3.11. Triangulation of the Research Instruments

4. PUBLIC SURVEY

4.1. Introduction

The findings from the Literature Review in Chapter 2 (Section 2.4) revealed substantial concerns regarding the use of AV's on public roads. However, the rapid improvement of smart sensors and other technologies, specifically the application of AI in the transportation industry, may have more recently affected users' opinions about the adoption of these vehicles since the users in previous studies were surveyed. To examine this growing area a new assessment of people's perceptions and acceptance of AVs considering the latest improvements in the technology of these vehicles was conducted. A public survey was conducted in Ireland to assess the public's perception and acceptance of the application of AVs in their daily commute trends, their willingness to adopt (WTA) AVs, their WTP and many other factors which impact on the viability of AVs. This Chapter reports the results from this survey, which reveal public concerns regarding the application of AVs from a general viewpoint. The findings of this survey also show how much people are willing to pay for an AV and how willing they are to adopt an AV if the cost is not an issue for them.

4.2. Overview of the Socio-demographic Characteristics

Table 4.1 represents a summary of the socio-demographic characteristics of the sample of this study compared with those of Census 2016 data. Such an assessment was conducted to ensure that the sample was representative of the population of Ireland. For this purpose, the survey (demographic) questions were designed in the same classification as of the Census's and the smaller groups were not merged or changed so they can be comparable with the Census data. From this data, it can be seen that around 85.1% of the survey sample possessed a driving license which is 31.1% greater than the number of licensed drivers in 2016 (according to 2016 Census data). In this context, and looking at the number of cars in Table 4.1, the percentage of people who had one car in the survey was 29.9% higher than that of 2016 Census data. Therefore, such an increase in the percentage of licensed drivers and ownership of one car could be an indication of the improvement in mobility services and facilitation in this context. Although the overall car ownership did not change from 2016, there has been a change in the distribution of cars where more people owned at least one car compared to 2016.

It could also be observed from Table 4.1 that a greater percentage of the participants were aged between 36-50 years old (compared to 2016 Census data), where the participants' distribution in other age ranges was close to the recorded data of 2016 Census. Moreover, the gender split data shows that 55.4% of the sample were female, which reports a 4.79% increase from the 2016 Census data. Furthermore, Table 4.1 shows a 5.0% difference between the percentages of Male in the sample (44.4%) and Census data (49.4%). However, it is mindful to consider that this survey was conducted online, and those male participants aged 26-35 and 36-50 years old who might have been busy at work during the day were not represented as much in the survey. It is also worth noting that only one individual indicated "Other" in the question asking about participants' gender. Since the number of individuals in the "Other" gender group was not sufficient for statistical evaluations, it skewed the overall results; hence, it has not been considered for the assessments in this Chapter.

Table 4.1. Characteristics of the survey sample compared with the 2016 Census (CSO, 2016)

Variable	Survey Sample		Census (2016)		Difference
	N	%	N	%	%
Driving License					
Yes	400	85.1	2,820,528	59.2	25.9
No	70	14.9	1,941,337	40.8	25.9
Total	470	100.0	4,761,865	100.0	0.0
Car Ownership					
Yes	382	80.9	3,899,967	81.9	1.0
No	90	19.1	861,898	18.1	1.0
Total	472	100.0	4,761,865	100.0	0.0
Number of Cars					
0	90	18.9	737,094	18.9	0.0
1	283	59.8	1,743,285	44.7	15.1
2	88	18.5	1,212,890	31.1	15.3
3	10	2.1	183,298	4.7	2.6
4	0	0.0	0	0.0	0.0
5	3	0.6	23,400	0.6	0.0
Total	474	100.0	3,899,967	100.0	0.0
Age of car					
No car ownership	90	19.1	*	*	19.1
0 – 2 years old	49	10.4	*	*	10.4
2 – 5 years old	84	17.8	*	*	17.8
5 – 7 years old	52	11.0	*	*	11.0
7 – 10 years old	89	18.9	*	*	18.9
Above 10 years old	108	22.9	*	*	22.9
Total	472	100.0	*	*	100.0
Age (of participant)					
0-18 years old	*	*	1,128,514	23.7	23.7
18-25 years old	9	1.9	449,780	9.4	7.5
26-35 years old	87	18.4	683,677	14.4	4.0
36-50 years old	207	43.8	1,053,434	22.1	21.7
50+ years old	170	35.9	1,446,460	30.4	5.5
Total	473	100.0	4,761,865	100.0	0.0
Gender					
Male	210	44.4	2,354,428	49.4	5.0
Female	262	55.4	2,407,437	50.6	4.8
Other	1	0.2	*	*	0.2
Total	473	100.0	4,761,865	100.0	0.0

* Data was not collected

Additionally, Table 4.2 illustrates the county of residence of the participants. As shown in Table 4.2, the majority of the participants were from Dublin by 27.4% of the total participants (474 individuals). Then, Cork and Galway were the next counties with the highest participants after Dublin with 12.7% and 5.1%, respectively.

Table 4.2. County of residence (survey sample compared with 2016 census)

N = 474				
	Survey Sample		**Census 2016**	
County	**N**	**%**	**N**	**%**
Antrim	1	0.2	*	*
Armagh	0	0.0	*	*
Carlow	4	0.8	56,932	1.2
Cavan	6	1.3	76,176	1.6
Clare	8	1.7	118,817	2.5
Cork	60	12.7	542,868	11.4
Derry	1	0.2	*	*
Donegal	21	4.4	159,192	3.3
Down	0	0.0	*	*
Dublin	130	27.4	1,347,359	28.3
Fermanagh	0	0.0	*	*
Galway	24	5.1	258,058	5.4
Kerry	14	3.0	147,707	3.1
Kildare	14	3.0	222,504	4.7
Kilkenny	10	2.1	99,232	2.1
Laois	7	1.5	84,697	1.8
Leitrim	7	1.5	32,044	0.7
Limerick	21	4.4	194,899	4.1
Longford	3	0.6	40,873	0.9
Louth	16	3.4	128,884	2.7
Mayo	13	2.7	130,507	2.7
Meath	12	2.5	195,044	4.1
Monaghan	5	1.1	61,386	1.3
Offaly	10	2.1	77,961	1.6
Roscommon	8	1.7	64,544	1.4
Sligo	10	2.1	65,535	1.4
Tipperary	9	1.9	159,553	3.4
Tyrone	0	0.0	*	*
Waterford	8	1.7	116,176	2.4
Westmeath	14	3.0	88,770	1.9
Wexford	23	4.9	149,722	3.1
Wicklow	15	3.2	142,425	3.0
Total	**474**	**100.0**	**4,761,865**	**100.0**

* Data was not collected in the Census

In general, the county of residence, the number of cars, the overall rate of car ownership, and other statistics of the sample were found to be representative of the population of Ireland compared to 2016 Census data. Therefore, this verifies the authenticity of the sample recorded for the survey of the current study.

As explained in the methodology of survey result assessments (see Chapter 3, Section 3.3), the respondents who completed the survey to the end and answered more than 34 questions out of 36 were considered valid for evaluations. Despite that, there were some missing values within the responses, and they were left as they were. However, the survey results were checked for model fitting, standard deviation, and errors to make sure those missing values are not significant. The results of such evaluations are available within this Chapter when model fitting tests are conducted.

Section 4.3 explains the overall opinion and acceptance of the participant regarding the adoption of AVs and Section 4.4 presents the statistical assessments of the survey responses.

4.3. Overall Opinion and Acceptance

This Section represents an overview of the responses to the survey questions in order to conduct an overall assessment of participants' response.

4.3.1. Initial perception of AVs

Table 4.3 demonstrates the initial perception and interest of participants about AVs. The evaluation in this section shows how informed the participants were about AVs and how interested they were in such a vehicle. The results showed that 46.4% of the total participants (N = 466), in general, had not heard about AVs, and 31.3% had "somewhat" heard about it. Only 22.5% had a great deal of knowledge about AVs. A reason for such a low level of familiarity with AVs could be the lack of proper advertisements and informative programmes in this regard in Ireland.

Moreover, the assessment regarding the initial interest in driving AVs revealed that 41.2% of the participants who answered this question (N = 454)[1] were not interested in driving AVs and 30.4% were neutral about it. Only 28.4% stated a high interest in driving AVs. The breakdown of the responses for participants' gender, age, and car ownership for each of the questions is this evaluation is available in Appendix B (B4 and B5).

[1] The differences in the total number of participants (N) is due to the missing values.

Table 4.3. Initial perception of and interest in AVs

Variable	N	%
Heard about AV		
Nothing at all	216	46.4
Somewhat	145	31.3
A great deal	105	22.5
Total	466	100.0
Interest in driving AVs		
Not interested	187	41.2
Neither	138	30.4
Very interested	129	28.4
Total	454	100.0

4.3.2. Preference for Spending Time in an AV

Since AVs could perform all driving operations, the owners/drivers would be able to spend their time in other activities. In this regard, participants were asked how they would prefer to spend their time in an AV. A total of 474 observations were recorded in this investigation and they were allowed to select multiple responses. Table 4.4 represents the results of the preferred activities of participants while in an AV. The breakdown of the responses for participants' gender, age, and car ownership for each of the answer options is available in Appendix B (B6).

The results showed that 'enjoying the scenery' was the most favoured activity and was selected by 71.3% of those who answered this question. After that, 'sleeping/resting and reading' was the next most favoured activity, at 31.4%. The following most favoured levels of interest included social activities and working.

There were also 49 responses submitted for the answer option 'other', among which 'being worried', 'stressed' and 'keeping eyes on the road to make sure the vehicle is working properly' were the top answers. However, there were also some positive perceptions of AVs among the 'other' respondents, and interests in doing activities such as 'listening to podcasts, music, and audiobooks', 'playing with kids', and 'talking on the phone with friends and family' were the other answers. There were two disabled and epileptic respondents who declared they are not allowed to drive and so they would hugely enjoy the feeling of independence with AVs. Table 4.4 provides some of the most repeated quotes in this regard.

Table 4.4. Preference for spending time in AVs (MRA)

Variable	N	%
Enjoying the scenery	149	71.3
Sleeping, resting and reading	338	31.4
Any social activities (TV, games, internet)	133	28.1
Working	67	14.1
Other	49	10.3

Here are also people's direct quotes provided in the feedback and comments of the survey:

- "All of the above"
- "Checking that the car wasn't driving itself into something dangerous"
- "For the experience"
- "Getting the kids around"
- "I am an epileptic and therefore am legally unable to drive. I would hugely enjoy the independence"
- "I still would have to be aware of things around me"
- "I'd rather just drive"
- "Keeping my eye on the road"
- "Make sure that is driving properly"
- "Making sure everything was doing what it should"
- "Nervous. Still watching the road"
- "Observing traffic"
- "Prefer to drive it"
- "Talking on the phone"
- "Talking to friends or family"
- "Watching the road"
- "Will probably be worried about my safety each time I am in the vehicle"
- "Working on arts and crafts"
- "Would not be happy leaving the driving to a robot"
- "Wouldn't get in the car! Think it's a bad idea"

4.3.3. Overall Concerns about Safety and Security of AVs

This Section explains the overall perception of participants about the safety and security of AVs. In this context, questions were asked about AVs' safety and security compared with vehicles with human drivers, AV's safety and security with or without a steering wheel, AVs' quick driving reactions compared with human drivers and some others. The results from the survey questions in this Section would provide an understanding of how much such concerns might affect people's decision regarding the adoption of AVs. The overall results of the evaluations in this regard are presented in Table 4.5. Additionally, the breakdown of the responses for participants' gender, age, and car ownership for each of the questions in this evaluation is available in Appendix B (B7 – B11). As shown in Table 4.5, participants, in general, believed that AVs would be 'somewhat' safer and more secure than human drivers, which convey a neutral opinion in this regard. The results also revealed more concern when participants were asked how safe and secure they would feel if AVs had no steering wheel. In this vein, participants declared they would feel safer and more secure in an AV with a manual override control system than an AV without such a system.

Table 4.5 demonstrates that participants indicated they would feel ‘somewhat concerned’ about AV’s quick reaction in unexpected driving incidents. Also, the participants of the study were asked how much they would be interested in adopting AVs if AVs could only operate in some limited areas in the city and not everywhere around the country. People, in general, demonstrated a low tendency to adopt AVs in such a driving condition. In this context, participants indicated to ‘safety and security concerns of losing contact and control of the vehicle’, the need for purchasing an extra TV for their trips around the country, the cost of maintenance, insurance and some other issues as the reasons for their low interest in adopting AVs.

Table 4.5. The Overall Concerns about Safety and Security of AVs

Variable	N	%
AVs are safer and more secure than human drivers		
Not at all	205	44.0
Somewhat	145	31.1
Extremely	116	24.9
Total	466	100.0
Feeling safe and secure if AVs had no driving wheel		
Not at all	308	66.0
Somewhat	93	19.9
Extremely	66	14.1
Total	467	100.0
AVs with a manual override control system would be safer and more secure than an AV without such a system		
Not at all	83	17.8
Somewhat	111	23.8
Extremely	272	58.4
Total	466	100.0
Concern about AVs' quick driving reaction in unexpected driving incidents		
Not at all concerned	143	30.9
Somewhat concerned	144	31.0
Extremely concerned	177	38.1
Total	464	100.0
The tendency to adopt AVs if AVs could only operate in some limited areas in the city and not everywhere around the country		
Not at all likely	317	67.4
Somewhat likely	93	19.8
Extremely likely	93	19.8
Total	470	100.0

In addition, the assessment regarding the concerns about driving with TVs and AVs reveals that people, in general, were slightly more concerned about driving with AVs than TVs. Table 4.6 demonstrates the results of such evaluation.

Table 4.6. Passengers' concerns about operating with TVs and AVs

How much would you be concerned in the following situations?		**Driving Conditions**					
		You are travelling at night		**The road condition is slippery**		**The vehicle is moving at the speed limit**	
Answer Option	**Response**	**TV**	**AV**	**TV**	**AV**	**TV**	**AV**
Not at all concerned	Count	131	94	89	82	133	104
	%	27.6	20.1	18.7	17.6	28.1	22.3
Somewhat concerned	Count	141	102	118	83	139	104
	%	29.7	21.8	24.8	17.81	29.4	22.3
Extremely concerned	Count	202	272	267	301	201	258
	%	42.6	58.1	56.6	64.6	42.5	55.4
Total responses		474	468	474	466	473	466

4.3.4. Recording Travel Data by AVs

This Section presents the respondents' previous knowledge about and concerns regarding the record of data by AVs. The results from this Section would help to understand how much the record of data by AVs might impact upon user's acceptance of the adoption of AVs. As shown in Table 4.7, the majority of the participants (67.4%) did not know that AVs might record travel data, while 32.56% declared they were aware of such an issue. In this context, the evaluation regarding the concern about the privacy of AVs' travel data shows that participants, in general, were 'somewhat concerned' about the privacy of their travel data recorded by AVs. However, people were neutral (undecided) whether AVs should record travel data or not. The breakdown of the responses for participants' gender, age, and car ownership for each of the questions in Table 4.7 is available in Appendix B (B12 – B15).

In addition to the assessment regarding privacy concerns and the recording of data by AVs, participants were asked with whom they would prefer to share the recorded data if recording data was one of the mandatory rules and conditions for adopting AVs. According to the summary of responses in Table 4.7, local or national transport authorities and insurance companies are the two most trusted agencies that people would prefer to share their AV data with. After these, car manufacturers and traffic consultancies are in the next level of preferences. Also, around 8.2% of the participants submitted other answers, among which some participants believing no one should have access to the data recorded by AVs, and in case of mandatory access, the data should be accessible only by the owners. Some also said they might prefer to share it with police only in the case of an accident.

Table 4.7. Knowledge and concerns regarding the record of travel data by AVs

Variable	N	%
Previous knowledge that AVs might record travel data		
Yes	154	32.6
No	319	67.4
Total	473	100.0
Concern about the privacy of AVs' travel data		
Not at all concerned	131	27.6
Somewhat concerned	123	25.9
Extremely concerned	221	46.5
Total	475	100.0
Agree/disagreements about AVs to record travel data		
Disagree	153	32.9
Undecided	174	37.4
Agree	138	29.7
Total	465	100.0
Who should access to AVs' travel data (MRA)		
Local/national transport authorities	175	43.8
Insurance companies	207	41.4
Car manufacturers	88	37.0
Local/national transport consultant companies	196	18.6
Other	39	8.3

Here are also people’s direct quotes provided in the feedback and comments of the survey:

- “Don’t know”
- “Gardaí only”
- “I wouldn't want to share data with any company and would try to circumvent any data being shared”
- “Insurance companies if it benefits me”
- “Maybe police could access it if I needed to be found for some reason”
- “I could choose who to share this info with”
- “Myself only”
- “No one, not giving data”
- “Police”
- “Tax”.

4.3.5. AV's Legal Liability

This Section presents the overall results of the evaluations regarding participants' willingness to accept AVs' legal liability and the authorised agent or groups who should accept such responsibility. The results from this Section would impact upon user's acceptance of AVs. Table 4.8 represents the overall responses in this evaluation and the breakdown of the results for participants' gender, age, and car ownership for each of the questions in this evaluation is available in Appendix B (B16 and B17). The results represented that 57.2% of the total participants, were not willing to accept AVs' liability, and 28.9% had a neutral perception in this regard; only 13.9% showed a high willingness for accepting AVs' legal liability.

Additionally, participants were asked who should accept the highest responsibility for the AV in case of an accident, where the selection of multiple responses was allowed; Table 4.8 shows people's responses to this question. Among the survey responses, the AV manufacturer was selected by 70.7% of the people as the entity that should accept the highest level of liability for the AVs in case of accidents. By much lower percentage, insurance companies and AV owners were selected as the next most responsible groups, by 22.2% and 19.0% of respondents, respectively. Smaller numbers of participants submitted other responses that indicated they believed the assignment of responsibility for AVs depends on the circumstances and the nature of the incident. Note these three percentages total to well over 100% because respondents were allowed to select multiple answers.

Table 4.8. The overall responses regarding the acceptance of the AVs' legal liability in accidents

Variable	N	%
Willing to accept AV's legal liability in accidents		
Nothing at all	271	57.2
Somewhat	137	28.9
A great deal	66	13.9
Total	474	100.0
The group or agency which should accept the highest legal liability of AVs in accidents (MRA)*		
AV manufacturers	335	70.7
Insurance companies	105	22.2
AV owners	90	19.0
National Transport Authorities	66	13.9
Local traffic control centres	59	12.5
Other	14	3.0

* MRA: Multiple Responses Allowed

Here are also people's direct quotes provided in the feedback and comments of the survey:

- "Depends on circumstances"
- "Depends on the accident"
- "Don't know"
- "Government"
- "If the system fails it's the makers fault as long as not down to wear and tear"
- "The fault lies with whoever is responsible for the input system that is controlling the car"
- "The other driver"
- "Whoever owns and is responsible for maintenance".

4.3.6. Purchasing AVs

This Section presents the overall opinions regarding the purchase of AVs. Questions in this Section reveal whether people would wait to see the early adopters' opinion for buying AVs or not. Also, would people purchase AV once the technology is fully developed and tested and, if yes, what would be the most interesting aspects of the AVs which make participants buy them? The results from this Section would show how much AVs would be accepted by people which could also impact the market penetration of AVs. Table 4.9 represents the overall results of the evaluation in this regard, and the breakdown of the results are available in Appendix B (B18 – B20).

According to Table 4.9, results revealed that people, in general, were not likely to purchase AVs once the technology is fully developed and tested, and it is available in the market. In this regard, around 69.3% of the people would 'extremely likely' tend to wait to see the early adopters' opinion about the application of AVs. Approximately 17.8% were neutral on this, where only 12.9% of the participants stated they would be so interested to adopt AVs so they would not wait to see the early adopters' opinions. Additionally, around 50% of the total participants stated they would 'not at all likely' tend to purchase AVs once the technology is fully developed and tested and they would wait to see the early adopters' opinions in this regard.

In addition to the assessments of this study, and as a general evaluation of the main reason for adopting AVs, people were asked what their main reason for purchasing an AV would be if they were interested in making a purchase. Answers to this question suggested that safe driving was the main benefit people saw in buying AVs, a benefit identified by 48.41% of those polled. Next in line among mentioned reasons for purchasing an AV was the reduction of emissions and fuel consumption and the automatic guidance and navigation systems of

AVs. A group of participants submitted other answers as well, among which 'not interested in driving AVs' was the main response. The disabled respondents, however, did represent their interest in adopting AVs. Table 4.9 shows the main reasons respondents gave for purchasing an AV.

Table 4.9. The overall opinions regarding the purchase of AVs

Variable	**N**	**%**
Wait to see the early adopters' opinion for buying AVs		
Not at all likely	61	12.9
Somewhat likely	84	17.8
Extremely likely	327	69.3
Total	472	100.0
Purchasing AV once the technology is fully developed and tested		
Not at all likely	237	50.0
Somewhat likely	119	25.1
Extremely likely	118	24.9
Total	474	100.0
The most interesting aspects of the AVs which make participants buy them (MRA)		
Variable	N	%
Safe driving	228	48.4
Reduction of emissions and fuel consumption	181	42.9
Automatic guidance and navigation systems	138	38.4
Reduction of traffic congestion, queue, and delay	144	30.6
Being fun and enjoying the free time when not driving	202	29.3
Other	27	5.7

Here are also people's direct quotes provided in the feedback and comments of the survey:

- "As an epileptic I would greatly enjoy the independence which an autonomous vehicle would bring me"
- "Being able to drink"
- "I am not interested, driving is fun for me"
- "I can't drive so it would be good"
- "I would rather have to use an electric wheelchair or walk than buy or use an autonomous vehicle"
- "I'd rather not own one due to safety, cost and liability reasons"
- "I'm a nervous driver and get lost early. I would love if I could turn it off for areas I knew & turn it on for new areas"
- "I'm sorry, but nothing would interest me in them"
- "Low cost"
- "Not interested"
- "Would not buy one"

4.3.7. WTP for AVs

This Section presents the results of survey questions asking about people's WTP for AVs. The results of this evaluation address whether AVs would be affordable for people or not, which impacts upon people's final decision regarding the adoption of AVs. The overall results of this evaluation are available in Table 4.10. Additionally, the breakdown of the WTP for an AV in addition to the price of the same vehicle in the traditional mode and the question asking about purchasing AV if the cost was not an issue is available in Appendix B (B21 and B22).

The overall opinions regarding the WTP for AVs (shown in Table 4.10) represents that around 43.13% of the people indicated they would spend 'below 10%' for AVs in addition to the price of the same vehicle in the traditional model. Around 35.52% declared they would spend '10% - 20%' and about 21.35% showed a tendency to pay above 20%. Moreover, people were asked how likely they would purchase AVs if the cost was not an issue for them. The average responses in this evaluation indicated to 'somewhat likely' where people showed a neutral opinion in this regard.

Table 4.10. The overall opinions regarding the WTP for AVs

Variable	N	%
WTP for an AV in addition to the price of the same vehicle in the traditional mode		
Below 10%	204	43.1
10% - 20%	168	35.5
Above 20%	101	21.4
Total	473	100.0
Purchasing AV if the cost was not an issue		
Not at all likely	179	37.9
Somewhat likely	119	25.2
Extremely likely	174	36.9
Total	472	100.0

4.3.8. On-Demand Ridesharing AVs

This Section represents the overall results related to people's belief about adopting on-demand ridesharing service of AVs. The results from this Section reveal that tendencies regarding the adoption of AVs, if any, arise from people's interest in these vehicles or individuals' tendency toward contributing to more efficient traffic, or any other reason. Table 4.11 represents the results of such evaluation. In addition, the breakdown of the results for participants' gender, age, and car ownership for each of the questions in Table 4.11 is available in Appendix B (B23 and B24).

The assessment of ridesharing AV services revealed that people, in general, did not think that on-demand ridesharing services of AVs would be more efficient than owning private AVs. In this context, around 43.2% of the participants indicated they would purchase private AVs even if ridesharing services had been provided. Nevertheless, around 56.8% of the total participants in this survey did not represent a tendency to buy private AVs. Reasons for such a decision would be safety, security, privacy and some other concerns which discussed before.

Table 4.11. The tendency to adopt on-demand ridesharing service of AVs

Variable	N	%
An on-demand ridesharing service of AVs would be more efficient than owning an AV		
Not at all likely	206	44.1
Somewhat likely	144	30.8
Extremely likely	117	25.1
Total	467	100.0
Purchasing private AVs even if an on-demand ridesharing service of AVs had been provided		
Yes	204	43.2
No	268	56.8
Total	472	100.0

4.3.9. Interest in Technology

Within the survey, participants were asked about their interest in technology. For this, four questions were asked regarding mobile phone ownership, the time of purchasing their mobile phone, and the version of the mobile phone when participants were buying it. Finally, the participants were asked how much they would be interested in using smart technologies. The responses from these questions will reveal how participants' tendency to adopt new technologies such as those which are adopted in AVs. In this regard, an evaluation of the responses from this section and participants' interest in AVs will reveal how much interest in smart technologies could have affected participants' response about adopting AVs. The overall results of such evaluation are presented in Table 4.12, and the breakdown of the results for participants' gender, age, and car ownership for each of the questions in Table 4.12 is available in Appendix B (B25 – B28).

The evaluation of the interest in technology services revealed that around 99% of the participants owned a mobile phone, with above 75% of the purchasing their phone in the past two years. The mobile phone was not the latest version of its brand in the market for 53% of the participants when they were buying it, yet 55.9% of the total participants represented a high interest in the latest smart technologies.

Table 4.12. Overall results for the questions asking about participants' interest in technology

Variable	N	%
Mobile phone ownership		
Yes	468	98.9
No	5	1.1
Total	473	100.0
When buying the mobile phone, it was the latest version of its brand available in the market		
Yes	218	46.6
No	250	53.4
Total	468	100.0
Time of purchasing the mobile phone		
In the past 12 months	176	37.5
1-2 years ago	176	37.5
2-4 years ago	79	16.8
4-7 years ago	21	4.5
More than 7 years ago	17	3.7
Total	469	100.0
Interest in the latest smart technologies		
Nothing at all	56	11.8
Somewhat	153	32.3
A great deal	265	55.9
Total	474	100.0

4.4. Results Analysis

4.4.1. Introduction

Section 4.3 presented the overall opinions of participants regarding the adoption of AVs. This Section presents the results of statistical assessments on the survey responses. In this regard, Section 4.4.2 presents the results of the statistical evaluation of the survey responses related to the interest in driving AVs followed by the concerns about adopting AVs in Section 4.4.3. Then, Section 4.4.4 discusses the statistical evaluations regarding the public's reasons for purchasing AVs. Finally, Section 4.4.5 presents the results of assessments on people's WTP. The Sections (mentioned above) are classified, which each presents the impact of 'gender', 'age', and some other parameters on participant's perception and preferences about the adoption of AVs.

As previously explained in Chapter 3 (Section 3.3.2) people's awareness and acceptance originate from a diverse range of behaviours, and therefore, a simultaneous impact of various variables and covariates should be considered in assessments. Therefore, MNL[1] regression method was used for the assessments in this regard that could be extended to models with multiple explanatory variables (El-Habil, 2012). In this context, the study evaluated different variables which could be closely related to the dependent variables to find those variables with the highest correlation and statistical significance.

For the MNL model to be used, there are a few assumptions which must be passed. One is that the dependent variables should be nominal (Laerd, 2019). In the case of this study, despite that the dependent variables were (qualitatively) ordinal, they were converted to nominal values first, so an MNL model could be adopted. Another assumption of the MNL model is that one or more independent variables should be continuous, nominal, or ordinal (Laerd, 2019). However, ordinal variables should be treated as nominal, which is done in this research – ordinal independent variables were transformed to nominal variables and adopted in the MNL model. Moreover, the assessments revealed that the MNL model responded well with valid test results for model fit tests. Therefore, changing the evaluation method did not seem necessary.

Note that in some of the statistical assessments, the MNL model was also tested with the association of other variables to make a more comprehensive model that includes are variables. However, the Pearson *p*-value for some of the assessments crossed the significance level (>0.05), meaning that the model could not find a substantial impact of all incorporated variables. Also, big models would have been confusing and hard to interpret due to the high number of independent variables. Therefore, the study tried to make smaller models with the fewer number of independent variables which could be easily interpreted and do not confuse the readers of the research. Such an issue is explained within the model results when needed.

It is also worth noting that in the MNL model, one category of the dependent variable should be considered as the reference category, with the significance of the other categories assessed relative to the significance of this category. It is imperative to say that there is no specific rule with the selection of reference category and any of the independent variables within the model could be considered as the reference category since the results are relative

[1] Multinomial Logistic

to other groups; it merely depends on what groups are aimed for analysis. For this reason, in the current study, the groups with the fewest number of participants are considered as the reference categories so that the study can benefit from analysing the larger groups which could be better representatives of the sample size. Moreover, as previously explained (in Section 4.2), the smaller groups are kept in the survey analysis as they were collected (and they were not merged with other groups) in order to keep the consistency of the groups' analysis with the CSO (2016) database groups.

It is also worth noting that the models in this thesis are numbered so they can be easily addressed throughout the thesis. Moreover, a list of the models is available in the contents of the thesis.

4.4.2. Interest in Driving AVs

4.4.2.1. The Impact of Gender on Individuals' Interest in Driving AVs

This Section presents the results of statistical assessments on the impact of 'gender' on participants' interest in driving AVs using the MNL model. In this model, the 'interest in driving AVs' is the dependent variable meaning that any amount of participants' interest in AVs would be dependent on a feature of participants such as 'gender'. Therefore, 'gender' is the independent variable of the model in this Section. Additionally, an extra parameter was included in the assessment as a covariate to 'gender' to address what adoption impact of AVs might affect different gender's opinion regarding their interest in driving AVs. The covariate variable was the question from the survey 'How much would AVs be safer and more secure than human drivers?'.

According to the response summary (shown in Table 4.13), 445 observations recorded for this assessment, of whom 54.4% were female and 45.6% male. Out of 445 views, 41.3% stated they are 'not interested' in driving AVs, and 30.6% were neutral about this. Only 28.1% of the respondents showed a high interest in driving AVs.

Table 4.13. Case processing summary of the impact of 'gender' on 'individuals' interest in driving AVs

Variable		**N**	**%**
Interested in Driving AV	Not interested	184	41.3
	Neither	136	30.6
	Very interested	125	28.1
	Total	445	100
Gender	Female	242	54.4
	Male	203	45.6
	Total	445	100
AVs are Safer and More Secure than Human Drivers	Not at all	194	43.6
	Somewhat	141	31.7
	Extremely	110	24.7
	Total	445	100.0

The results of the MNL model with model fitting information is presented in Table 4.14. More details regarding the model fitting information and the MNL model parameter estimates are available in Appendix B (B29 and B30). The results were evaluated using the likelihood ratio tests with -2 log-likelihood criteria. The model fitting assessments showed that the results are statistically significant by providing p values below 0.05 for the independent variable. Also, the model showed 0.337 pseudo-R-squared for the Nagelkerke test.

Moreover, Table 4.14 presents the correlation between 'people's interest in driving AVs' as the dependent variable and 'gender' as an independent variable, including the covariate of the model. Also, the answer option 'not at all interested' is considered the reference category for the dependent variable 'interested in driving AV'. Of the two categories for 'gender', the 'male' group is considered the reference category, with a B-coefficient value of 0.

Looking at the MNL model results (shown in Table 4.14) related to the responses given to 'neither' relative to 'Interested in driving AV', where " gender (male)" is the reference category, the variable "gender (female)" has low model significance. However, considering the overall significance of the model, the positive coefficient of 0.367 for female shows that females are generally more likely than males to have a neutral interest in driving AVs. In this context, the exponential value of B, or Exp(β), represents the exact likelihood by presenting the odds ratios of the model. The odds ratio for "female" is 1.44, which is greater than 1, meaning that females are 44% more likely than men to have a neutral interest in driving AVs. Also, looking at the results related to respondents who indicated they were 'very interested in driving AVs', the negative value of -0.295 for B-coefficient and the odd-ratio of 0.745 in the corresponding cell, it is clear that females are 22.5% (1-0.745) less likely than male to be very interested in driving AVs. In general, the results show that females are more neutral and less likely to be interested in driving AVs than males.

Model 4.1. MNL
Table 4.14. Results of the MNL model for the impact of "gender" on individuals' interest in driving AVs

Variable	Model Coefficient: (β)	Odds Ratio: Exp (β)	Sig.
Interested in Driving AV[a]: Neither			
AVs are safer and more secure than human drivers	0.482	1.619	0.000
Gender (Female)	0.367	1.444	0.131
Gender (Male)	0[b]	.	.
Interested in Driving AV[a]: Very Interested			
AVs are safer and more secure than human drivers	1.041	2.831	0.000
Gender (Female)	-0.295	0.745	0.296
Gender (Male)	0[b]	.	.
Chi-Square: 157.632, **Degrees of freedom:** 4, **P-value:** 0.000, **Pseudo R-square:** 0.337			
Likelihood significance for "AVs are safer and more secure than human drivers"			0.000
Likelihood significance for "Gender"			0.041

a. The reference category is: Not at all.
b. This parameter is set to zero because it is redundant.

Note that the model was also tested with the association of 'age', 'driving license', 'car ownership', 'number of cars', and 'age of car' but the Pearson *p*-value for each assessment crossed the significance level (>0.05), meaning that the model could not find a substantial impact of these variables (in association with 'gender') on the interest in driving AVs. The model has also considered the possible impact of the variables 'mobile phone ownership', 'mobile phone purchasing time', and 'mobile phone version' in association with 'gender' on individual's interest in driving AVs. However, results showed below 10% Pseudo R-squared for each step of the regression model, meaning that the model's inputs could not explain above 10% of the observed variation. In other words, these variables did not have a substantial impact on the 'interest in driving AVs' when they were considered in association with 'gender' as the main dependent variable.

4.4.2.2. The Impact of Age on Individuals' Interest in Driving AVs

Section 4.4.2.1 explained that when the model considered the association of 'age' to the impact of 'gender' on individuals' interest in driving AVs, the MNL model resulted in a Pearson *p*-value (0.38) which crossed the significance level (>0.05). This means that there is no statistical proof that 'gender' and 'age' might simultaneously impact participants' interest in driving AVs. However, each of these two parameters could separately affect the user's interest in driving AVs. Section 4.4.2.1 argued the impact of 'gender' on the public's interest in driving AVs. This Section evaluates how much 'age' could affect users' interest in driving AVs. For this purpose, the independent variable was changed to 'age', and another covariate, measuring the safe and secure feeling about AVs' quick reaction in accidents, was added to the assessment model presented in Section 4.4.2.1. Table 4.15 represents the overall results of this evaluation. In total, 437 observations were recorded for this assessment, with the 36–50 age group having the highest participation at 45.3% of the total population. The next highest participation was 33.9% by the age group 50+, while the other two age groups of 26–35 and 18–25 had the participation of 19% and 1.8%, respectively. Note that the age groups on average showed 28.6% interest in driving AVs, with the rest neutral (30%) or not interested (41.4%).

Table 4.15. Case Processing Summary of the impact of 'age' on 'individuals' interest in driving AVs'

Variable		**N**	**%**
Interested in Driving AV	Not interested	181	41.4
	Neither	131	30.0
	Very interested	125	28.6
	Total	437	100
Age	18–25	8	1.8
	26–35	83	19.0
	36–50	198	45.3
	50+	148	33.9
	Total	437	100

Also, Table 4.16 presents the MNL model results of this evaluation. More details regarding the model fitting information and the MNL model parameter estimates are available in Appendix B (Tables B31 and B32). The model fitting and likelihood ratio tests with -2 log-likelihood criteria showed that results have a high statistical significance, with $p = 0.000$ (< 0.05) for 'AVs tend to be safer and more secure than human drivers'. Additionally, the model attained a 0.337 pseudo-R-squared value in the Nagelkerke test. However, 'age' and 'feeling safe and secure about AVs' quick reaction in accidents' showed relatively low likelihood values, which need further investigation. Therefore, the odds ratios and B-coefficients needs to be evaluated for more insight into the reasons for such inconsistency in the results.

Table 4.16 shows positive B-coefficients for 'AVs are safer and more secure than human drivers' and negative values for 'feeling safe and secure about AV's reaction in accidents' for both answer options 'neither' and 'very interested'. Therefore, it is very likely that respondents, in general, believed AVs are going to be safer and more secure than human drivers. However, respondents did not seem to support AVs for their quick reaction in accidents, which has also a low significance. The exact estimation values are provided by the odd ratios or Exp(β). Also, looking at the answer options 'very interested', the age groups

26–35 and 36–50 appear to be more interested in driving AVs than the other two age groups. The age group 26–35 were measured to be 80% more interested than the age group 36–50 in driving AVs. In general, the assessment reveals that the age range of 26–50-year-old people are more interested in driving AVs, as they believe AVs could be safer and more secure than human drivers. The other age groups seem to be less interested in driving AVs, as they do not feel safe and secure about AVs' quick reaction in accidents.

Model 4.2. MNL
Table 4.16. Results of the MNL model for the impact of "age" on individuals' interest in driving AVs

Variable	Model Coefficient: (β)	Odds Ratio: Exp (β)	Sig.
Interested in Driving AV[a]: Neither			
AVs are safer and more secure than human drivers	0.493	1.636	0.000
Feeling safe and secure about AVs quick reaction in accidents	-0.120	0.887	0.103
Age (18–25)	-0.494	0.610	0.595
Age (26–35)	0.045	1.047	0.898
Age (36–50)	-0.083	0.920	0.758
Age (50+)	0[b]	.	.
Interested in Driving AV[a]: Very Interested			
AVs are safer and more secure than human drivers	1.055	2.873	0.000
Feeling safe and secure about AVs quick reaction in accidents	-0.055	0.947	0.552
Age (18–25)	-0.242	0.785	0.826
Age (26–35)	0.590	1.803	0.141
Age (36–50)	0.078	1.082	0.808
Age (50+)	0[b]	.	.
Chi-Square: 154.792, **Degrees of freedom:** 10, **P-value:** 0.000, **Pseudo R-square:** 0.337			
Likelihood significance for "AVs are safer and more secure than human drivers"			0.000
Likelihood significance for "Feeling safe and secure about AVs quick reaction in accidents"			0.259
Likelihood significance for "Age"			0.778

a. The reference category is: Not at all.
b. This parameter is set to zero because it is redundant.

4.4.2.3. Preferred Activity for Spending Time in AVs

This Section measures how much 'gender' and 'age' could affect users' preferred activity for spending time in AVs. In this model, the 'spending time in AV: sleeping/resting, reading' is the dependent variable and 'gender' is the independent variable of the model. As shown in Table 4.17, 470 observations were recorded for this assessment, with the 36–50 age group having the highest participation at 44% of the total population. The next highest participation was 36% by the age group 50+, while the other two age groups of 26–35 and 18–25 had the participation of 18.3% and 1.7%, respectively. Note that the age groups on average showed 31.1% interest in 'sleeping, resting, and reading' in AVs, with the rest not interested (68.9%).

Table 4.17. Case Processing Summary for the preferred activity for spending time in AVs

Variable		N	%
Spending Time in AV: Sleeping/Resting, Reading	No	324	68.9
	Yes	146	31.1
	Total	470	100
Gender	Female	261	55.5
	Male	209	44.5
	Total	470	100
Age	18–25	8	1.7
	26–35	86	18.3
	36-50	207	44.0
	50+	169	36.0
	Total	470	100

The results of the MNL model with model fitting information is presented in Table 4.18. Additionally, more details regarding the model fitting information and the MNL model parameter estimates are available in Appendix B (B34 and B35). The model fitting and likelihood ratio tests with -2 log-likelihood criteria showed that results have a high statistical significance, with p = 0.000 (< 0.05) for 'age'. However, 'gender' showed relatively low likelihood values (p-value = 0.782 > 0.05), which means 'gender' does not correlate with 'sleeping, resting, and reading'. Note that the model was also tested for other preferred activities such as 'enjoying the scenery', and 'social activities' with the association of 'gender' and 'age'. However, the 'goodness of fits' test represented insignificant Pearson p values (>0.05) in each assessment. It means that 'gender' and 'age' did not shown to have (statistically) a substantial impact on 'enjoying the scenery', and 'social activities' as the preferred activity for spending time in AVs.

Since the MNL model showed positive B-coefficients for all 'age' groups (shown in Table 4.18), it is very likely that 'age' had an impact on respondents' opinion regarding 'sleeping, resting, and reading' as a preferred activity to spend time in AVs. The exact estimation values are provided by the odds ratios. The age group '18–25' showed the highest odds ratio, meaning they had more tendency to spend their time in AVs with 'sleeping, resting, and reading'. However, looking at the sig. column (or p values), the age group '36–50' had the highest model significance (p-value of 0.001) which means that the results to this age group are more significant of all other age groups. In this context, the age group '36–50' were measured to be 1.2 times more interested than the age group '50+' in spending their time in AVs with 'sleeping, resting, and reading'.

Model 4.3. MNL

Table 4.18. Results of the MNL model for individuals' preferred activity in AVs

Variable	Model Coefficient: (β)	Odds Ratio: Exp (β)	Sig.
Sleeping/Resting, Reading[a]: Yes			
Gender (Female)	0.058	1.060	0.782
Gender (Male)	0[b]	.	.
Age (18–25)	2.416	11.206	0.004
Age (26–35)	0.601	1.824	0.047
Age (36–50)	0.811	2.250	0.001
Age (50+)	0[b]	.	.
Chi-Square: 19.329, **Degrees of freedom:** 4, **P-value:** 0.001, **Pseudo R-square:** 0.057			
Likelihood significance for "Gender"			0.782
Likelihood significance for "Age"			0.000
Likelihood significance for "Sleeping/Resting, Reading"			0.000

a. The reference category is: No.
b. This parameter is set to zero because it is redundant.

For further evaluation in this regard, a cross-tabulation of the variables is conducted between 'sleeping, resting, and reading' and 'age' to address the correlation of the sub-groups between these two variables. Table 4.19 illustrates the result of the cross-tabulation in this assessment.

According to Table 4.19, 68.7% of the participants indicated they would not spend their time in an AV on 'sleeping, resting, and reading', where above 40% and 41.5% of them were from the age groups of '36–50' and '+50' years old, respectively. In this context, and from another perspective, around 62.8% and 79.4% of the participants from the age groups of 36–50 and +50 years old declared they would not spend their time in an AV with 'sleeping, resting, and reading' which shows the correlation of the variables from both sides. Furthermore, around 31.3% of the participants in this assessment indicated they would spend their time in an AV on 'sleeping, resting, and reading', where 52% of them being in the age group of 36–50 years old. In general, the assessment revealed that more than half of the participants would not be interested in spending their time in an AV on 'sleeping, resting, and reading'. However, the rest of the participants who are interested in 'sleeping, resting, and reading' in AVs are from the age group of 36–50 years old. The correlation of the parameters in this assessment is verified by the p-value of 0.000, which shows the results are statistically significant.

Model 4.4. Cross-tabulation

Table 4.19. Cross-tabulation of spending time in AV: sleeping, resting, and reading versus Age

			Age				Total
			18–35	26–35	36–50	50+	
Sleeping, resting, and reading	No	Count	2	58	130	135	325
		% within sleeping, resting, …	0.6	17.8	40.0	41.5	100.0
		% within Age	22.2	66.7	62.8	79.4	68.7
		% of total	0.4	12.3	27.5	28.5	68.7
	Yes	Count	7	29	77	35	148
		% within sleeping, resting, …	4.7	19.6	52.0	23.6	100.0
		% within age	77.8	33.3	37.2	20.6	31.3
		% of total	1.5	6.1	16.3	7.4	31.3
Total		Count	9	87	207	170	473
		% within sleeping, resting, …	1.9	18.4	43.8	35.9	100.0
		% within age	100.0	100.0	100.0	100.0	100.0
		% of total	1.9	18.4	43.8	35.9	100.0

χ^2 = 21.63, degrees of freedom= 3, p-value=0.000.

4.4.3. Concerns about Adopting AVs

Section 4.4.2 presented some results regarding the survey users' interest in driving AVs. This Section makes some assessments of respondents' concerns about adopting AVs. The results are provided in several sections, with each evaluating the AV concerns using different dependent and independent variables.

4.4.3.1. Impact of Gender, Age, and Number of Cars on Perceptions of AVs' Safe and Secure Operation Compared to Human Drivers

The study, in this Section, measures the effective factors that impacted users' perceptions regarding AVs' safe and secure operation. In this regard, the parameter 'AVs are safer and more secure than human drivers' is the dependent variable of the MNL model in this evaluation. The independent variables in the model are 'gender', 'age', and the 'number of cars' each user owns. Additionally, some covariates have been added to the model, which might have impacted participants' perception regarding AVs' safe and secure operations. The covariates of the MNL model in this assessment are 'feeling safe and secure about AVs' quick reaction in accidents', 'feeling safe and secure in an AV with manual control', and 'feeling safe and secure in an AV without a steering wheel'. Table 4.20 shows a summary of the descriptive statistics from this assessment. The response summary shows that 53.4% of the participants in this evaluation were female and that the highest responses came from the age group 36–50. Of the respondents, 73.4% had only one car, and 46.6% believed that AVs are 'not at all' safer and more secure than human drivers.

Table 4.20. Case processing of the AVs' safe and secure operation compared to human drivers

		N	%
AVs are safer and more secure than human drivers	1 = Not at all likely	165	46.6
	3 = Somewhat likely	104	29.4
	5 = Extremely likely	85	24.0
	Total	354	100
Gender	0 = Female	189	53.4
	1 = Male	165	46.6
	Total	354	100
Age	1= 18–25	2	0.6
	2 = 26–35	64	18.1
	3 = 36–50	163	46.0
	4 = 50+	125	35.3
	Total	290	100
Number of cars	1 = 1	260	73.4
	2 = 2	83	23.4
	3 = 3	8	2.3
	4 = 5+	3	0.9
	Total	354	100

The results of the MNL model are presented in Table 4.21. Additionally, more details regarding the model fitting information and the MNL model parameter estimates are available in Appendix B (B35 and B36). The model fitting tests presented *p* values below 0.05, meaning that the model results are statistically significant in general. The correlation between the model's predicted values and the actual values is also validated by 0.517 pseudo-R-squared value in the Nagelkerke test. The likelihood ratio test revealed that 'number of cars' and two of the model covariates are statically significant, as the *p* values are less than 0.05. However, 'gender', 'age', and the other model covariates do not provide appropriate correlation with some other data. Such a discrepancy in likelihood ratio tests requires further investigation.

Results of the MNL model show that feeling safe and secure about AVs' quick reaction attained statistical significance for the answer options 'somewhat' and 'extremely'; the positive B-coefficients and *p* values below 0.05 are the proof of model significance. Also, the higher odds ratio for 'extremely' indicates that feeling safe and secure about AVs' reaction had affected people's perceptions of AVs as being remarkably safer and more secure than human drivers. The negative B-coefficients for females show that they are less likely than males to be neutral or extremely positive about the statement that AVs are safer and more secure than human drivers. The age group results reveal that people from 36–50 years old are more likely to be neutral and extremely positive about AVs safe and secure operation compared to humans. Also, respondents with one car had the highest B-coefficient and odds ratio, meaning these people were more likely to believe that AVs are safer than humans. However, people with five cars and above were the group with the highest tendency to believe in AVs safe operation compared to human drivers.

Overall, the assessment in this Section finds that only a few percent of respondents believe in AVs' safe and secure operation when AVs are compared to human drivers. Also, the number of cars respondents own had an impact on their positive opinion such that people with five cars and above were more likely to believe in AVs' extreme capabilities, while people with one car were more neutral in this matter. Also, males, in general, were more likely than females to think that AVs will be safer and more secure than human drivers.

Model 4.5. MNL

Table 4.21. Results of the MNL model for AVs' safe and secure operation compared to human drivers

Variable	Model Coefficient: (β)	Odds Ratio: Exp (β)	Sig.
AVs are safer and more secure than human drivers[a]: Somewhat			
'Not at all' feeling safe and secure about AVs' quick reaction	-0.022	0.978	0.804
'Somewhat' feeling safe and secure about AVs' quick reaction	0.569	1.767	0.000
'Extremely' feeling safe and secure about AVs' quick reaction	1.081	2.948	0.000
Gender (Female)	-0.318	0.728	0.290
Gender (Male)	0[b]	.	.
Age (18–25)	-19.025	0.004	0.997
Age (26–35)	-0.600	0.549	0.163
Age (36–50)	-0.137	0.872	0.667
Age (50+)	0[b]	.	.
Number of cars (1)	1.182	3.261	0.001
Number of cars (2)	0.854	2.349	.
Number of cars (3)	-16.832	0.004	0.995
Number of cars (5+)	0[b]	.	.
AVs are safer and more secure than human drivers[a]: Extremely			
'Not at all' feeling safe and secure about AVs' quick reaction	0.219	1.244	0.083
'Somewhat' feeling safe and secure about AVs' quick reaction	0.700	2.014	0.000
'Extremely' feeling safe and secure about AVs' quick reaction	1.631	5.109	0.000
Gender (Female)	-0.610	0.543	0.119
Gender (Male)	0[b]	.	.
Age (18–25)	-2.545	0.078	0.136
Age (26–35)	-0.382	0.682	0.489
Age (36–50)	0.052	1.054	0.899
Age (50+)	0[b]	.	.
Number of cars (1)	-18.369	0.001	0.996
Number of cars (2)	-18.786	0.006	0.996
Number of cars (3)	-19.385	0.003	0.996
Number of cars (5+)	0[b]	.	.
'Not at all' feeling safe and secure about AVs' quick reaction	0.219	1.244	0.083
'Somewhat' feeling safe and secure about AVs' quick reaction	0.700	2.014	0.000
Chi-Square: 214.452, **Degrees of freedom:** 20, **P-value:** 0.000, **Pseudo R-square:** 0.517			
Likelihood significance for "Feeling safe and secure about AVs quick reaction in accidents"			0.119
Likelihood significance for "Feeling safe and secure in an AV with manual control"			0.000
Likelihood significance for "Feeling safe and secure in an AV without a steering wheel"			0.000
Likelihood significance for "Gender"			0.278
Likelihood significance for "Age"			0.402
Likelihood significance for "Number of cars"			0.020

a. The reference category is: Not at all.
b. This parameter is set to zero because it is redundant.

4.4.3.2. *Impact of the Advantages of Adopting AVs on How Safe and Secure Would AVs be Without a Steering wheel*

An AV with level 5 autonomy (SAE, 2016) will conduct all driving operations by itself; a steering wheel might or might not be in the vehicle. Therefore, it is crucial to understand how safe and secure the respondents would feel if their car had no steering wheel, which is considered as the dependent variable of the MNL model in this Section. Hence, the question in this Section evaluates such a perception, adopting three independent variables: 'AVs are safer and more secure than human drivers', 'feeling safe and secure about AVs quick reaction in accidents', and 'interested in driving AV'. Also, two covariates have been acquired, which help to correlate the answers with some other user perceptions about AVs. The covariates were 'agree that AVs should record data', and 'purchase AV when it is fully developed and tested'. Table 4.22 shows the answer summary for this assessment. Results show that 66% of the users (427 observations), in general, would not feel safe and secure in an AV without a steering wheel, while 20.8% were more neutral about it. Only 13.2% declared an extremely positive attitude about a fully driverless AV.

Table 4.22. Case processing summary of how safe and secure would AVs be without a steering wheel

Variable		N	%
Feeling safe and secure in an AV without a steering wheel	1 = Not at all likely	282	66.0
	3 = Somewhat likely	89	20.8
	5 = Extremely likely	56	13.2
	Total	427	100
AVs are safer and more secure than human drivers	1 = Not at all likely	186	43.6
	3 = Somewhat likely	135	31.6
	5 = Extremely likely	106	24.8
	Total	427	100
Feeling safe and secure about AVs quick reaction in accidents	1 = Not at all concerned	129	30.2
	3 = Somewhat concerned	134	31.4
	5 = Extremely concerned	164	38.4
	Total	427	100
Interested in driving AV	1 = Not interested	177	41.5
	3 = Neither	128	30.0
	5 = Very interested	122	28.5
	Total	427	100

Moreover, Table 4.23 shows the results of the MNL model and model fitting information of this evaluation. Detailed model fitting information and the MNL model parameter estimates are available in Appendix B (B37 and B38). The model fitting test of this assessment presented *p* values below 0.05, which indicates the results are statistically significant. Also, the likelihood ratio tests verify the significance of the correlation between answers by providing *p* values below 0.05 for all except one independent variable. However, the model in general looks valid, and the correlation between the model's predicted values and the actual values is also validated by the Nagelkerke R-squared value of 51.9%.

Viewing the B-coefficients and odds ratios in Table 4.23 with regard to the reference category, the analysis in this Section evaluates the results from respondents who said they would feel extremely safe and secure in driverless AVs. According to Table 4.23, respondents who believed in the safe operation of driverless AVs were 90% (Exp(β) = 1.9) more likely to agree that AVs should record data. Also, those who believed in the safe operation of driverless AVs were 43% (Exp(β) = 1.43) more likely to have an interest in purchasing AVs when they are fully developed than the people who would feel 'not at all' safe and secure in driverless AVs. Also, the results make clear that those who were not interested in driverless AVs believed AVs are 'not at all' safer and more secure than human drivers, and they did not feel safe and secure about AVs' quick reaction in accidents. The small values for the odds ratios for these independent variables are proof of such a declaration. For example, people who were extremely interested in driverless AVs were 97.7% less likely (1 – 0.023) to feel that AVs were 'not at all' safer and more secure than human drivers than the reference category. Therefore, in general, the assessment verifies that 66% of respondents lack interest (according to Table 4.22) in AVs without steering wheels. The reasons for such lack of interest could be concerns about recording data, not feeling safer and more secure in AVs than with human drivers, and concerns about AVs' quick reaction in accidents.

Model 4.6. MNL

Table 4.23. Results of the MNL model for how safe and secure would AVs be without a steering wheel

Variable	Model Coefficient: (β)	Odds Ratio: Exp (β)	Sig.
Feeling safe and secure in an AV without a steering wheel[a]: somewhat likely			
Agree that AVs should record data	0.271	1.311	0.033
Purchase AV when It is fully developed and tested	0.267	1.306	0.018
'Not at all' feeling that AVs are safer and more secure than humans	-2.385	0.092	0.000
'Somewhat' feeling that AVs are safer and more secure than humans	-0.833	0.435	0.022
'Extremely' feeling that AVs are safer and more secure than humans	0[b]	.	.
'Not at all concerned' about AVs' quick reaction in accidents	-0.526	0.591	0.216
'Somewhat concerned' about AVs' quick reaction in accidents	0.865	2.375	0.009
'Extremely concerned' about AVs' quick reaction in accidents	0[b]	.	.
'Not at all concerned' interested in driving AVs	0.620	1.859	0.185
'Neither' interested in driving AVs	0.458	1.581	0.248
'Very interested' interested in driving AVs	0[b]	.	.
Feeling safe and secure in an AV without a steering wheel[a]: Extremely likely			
Agree that AVs should record data	0.642	1.900	0.000
Purchase AV when It is fully developed and tested	0.363	1.438	0.019
'Not at all' feeling that AVs are safer and more secure than humans	-3.788	0.023	0.000
'Somewhat' feeling that AVs are safer and more secure than humans	-2.397	0.091	0.000
'Extremely' feeling that AVs are safer and more secure than humans	0[b]	.	.
'Not at all concerned' about AVs' quick reaction in accidents	-0.579	0.560	0.270
'Somewhat concerned' about AVs' quick reaction in accidents	-0.385	0.680	0.402
'Extremely concerned' about AVs' quick reaction in accidents	0[b]	.	.
'Not at all concerned' interested in driving AVs	-0.718	0.488	0.367
'Neither' interested in driving AVs	0.358	1.431	0.487
'Very interested' interested in driving AVs	0[b]	.	.
Chi-Square: 237.820, **Degrees of freedom:** 16, **P-value:** 0.000, **Pseudo R-square:** 0.519			
Likelihood significance for "Agree that AVs should record data"			0.000
Likelihood significance for "Purchase AV when It is fully developed and tested"			0.014
Likelihood significance for "AVs are safer and more secure than human Drivers"			0.000
Likelihood significance for "Feeling safe and secure about AVs quick reaction in accidents"			0.001
Likelihood significance for "Interested in driving AV"			0.344

a. The reference category is: Not at all likely.
b. This parameter is set to zero because it is redundant.

4.4.3.3. AVs' Safer and More Secure Operation Compared to Human Drivers Versus Feeling Safe and Secure About AVs' Quick Reaction in Accidents

Previously in the result analysis of this Chapter (Section 4.4), regression analysis was acquired to identify which independent variables have an impact on a specific dependent variable. In such a way, the regression method confidently determined which factors matter most, which factors could be ignored, and how those factors influenced each other. In this Section, cross-tabulation is acquired to understand the correlation between two variables**,** which shows whether there is a statistical relationship between two variables or not. Cross-tabulation also presents the results of the entire group of respondents as well as results from the sub-groups of survey respondents. For the sake of the assessment in this Section, cross-tabulation was acquired to make assessments regarding the impact of AVs' safe and secure operation on users' interest in AVs, which might consequently influence users' acceptance of them. Therefore, respondents' 'interest in driving AV' responses were correlated with responses to the question asking whether 'AVs would be safer and more secure than human drivers'. Table 4.24 shows the cross-tabulation of this correlation.

As shown in Table 4.24, a total of 447 observations recorded for this evaluation. 41.4% of the respondents were not interested in driving AVs, with nearly 70.3% of them believing that AVs are not at all safer and more secure than human drivers. In this regard, and from another perspective, results also show that 66.3% of the people who believed AVs are not safer and more secure than human drivers had no interest in driving AVs, which verifies the correlation of these variables from both sides. Within those 41.4% participants, around 22.7% had a neutral opinion about driving AVs, and only 7% indicated an extremely positive perception. On the other hand, 28.2% of the total participants in this assessment indicated a high interest in driving AVs, with 59.5% of them thinking AVs will be remarkably safer and more secure than human drivers. Also, 68.2% of respondents perceived AVs extremely safe and secure which verifies the correlation, meaning that interest in driving AVs and feeling safe and secure about their operation compared to human drivers are statistically related. The actual observed data are compared to the expected values using a Chi-square test (χ^2). Results of the evaluation showed a *p*-value of 0.000 for the Pearson test with 4 degrees of freedom, which represents statistical significance for the model.

Model 4.7. Cross-tabulation
Table 4.24. Cross-tabulation of interest in driving AV versus AVs' safe and secure operation

Variable			**AVs are safer and more secure than human drivers**			**Total**
			Not at all likely	Somewhat likely	Extremely likely	
Interested in driving AV	Not interested	Count	130	42	13	185
		% within interest	70.3	22.7	7.0	100.0
		% within safety	66.3	29.8	11.8	41.4
	Neither	Count	48	66	22	136
		% within interest	35.3	48.5	16.2	100.0
		% within safety	24.5	46.8	20.0	30.4
	Very interested	Count	18	33	75	126
		% within interest	14.3	26.2	59.5	100.0
		% within safety	9.2	23.4	68.2	28.2
Total		Count	196	141	110	447
		% within interest	43.8	31.5	24.6	100.0
		% within Safety	100.0	100.0	100.0	100.0

χ^2 = 164.59, degrees of freedom= 4, p-value= 0.000

4.4.3.4. Comparing Passengers' Concern about Operating with TVs Versus AVs

This Section presents the results of an assessment regarding the comparison of driving experience between TVs and hypothetical scenarios for AVs where people were told to assume if they were driving AVs under the same driving condition as TVs. In this assessment, the respondents were given three driving scenarios, and they were asked to rate their concern for each scenario. Table 4.25 summarises the driving conditions and responses to this assessment.

The results show that approximately 53% of respondents in this survey, on average, expressed extreme concern about driving TVs under the given conditions which could be due to the concerning nature of the conditions. However, people showed a higher concern for driving with AVs than with TVs in all three conditions. This observation is also supported by the results from the answer option 'not at all concerned', which was chosen more frequently for situations with TVs than it was for the same situations with AVs. Also, looking at the weighted concern for all three driving conditions reveals that people, in general, were slightly more concerned about driving with AVs than TVs. Using the weighted concern from Table 4.25, the weighted average concern can be calculated for each vehicle model as follows:

Weighted average concern for TVs: $\frac{2.15+2.38+2.14}{3}$ = 2.22 (out of 3) = 0.740 = 74.0%

Weighted average concern for AVs: $\frac{2.38+2.47+2.33}{3}$ = 2.39 (out of 3) = 0.796 = 79.6%

Therefore, the weighted average shows AVs brought 5.6% more concern than TVs for driving in the same conditions.

Furthermore, the weighted average values in Table 4.25 show that driving when the road condition is slippery is the most concerning driving condition of all provided in this question, for both TVs and AVs.

Table 4.25. Passengers' concerns about operating with TVs and AVs

			Driving Conditions					
			You are travelling at night		**The road condition is slippery**		**The vehicle is moving at the speed limit**	
Answer Option	Weight	Response	TV	AV	TV	AV	TV	AV
Not at all concerned	1	Count	131	94	89	82	133	104
		%	27.64	20.08	18.74	17.60	28.11	22.32
Somewhat concerned	2	Count	141	102	118	83	139	104
		%	29.75	21.79	24.84	17.81	29.39	22.32
Extremely concerned	3	Count	202	272	268	301	201	258
		%	42.62	58.12	56.43	64.59	42.50	55.37
Total responses			474	468	475	466	473	466
Weighted concern value (out of 3)			**2.15**	**2.38**	**2.38**	**2.47**	**2.14**	**2.33**

Moreover, Table 4.26 represents the breakdown of the weighted concerns (out of 3) about operating with TVs and AVs. In this Table, an increase or decrease of concern is shown with a positive or negative percentage, respectively. In this context, for example, in the assessments related to 'gender', female demonstrated a greater percentage of a concern than male about operating with AVs comparing to TVs on the same driving condition. Moreover, people in the age group of '50+' showed higher concern of all age groups for operating with AVs at night, and when the vehicle is at speed limit. However, some age groups represented a decrease of concern for operating with AVs in some driving conditions. In this context, participants aged 18–25 years old showed an 11% decrease of concern for driving AVs comparing with TVs when the road is slippery and when the vehicle is at speed limit. Furthermore, the assessment regarding the car ownership revealed that those who owned a car represented 13% and 23% more concern in driving AVs rather than TVs for the slippery road condition and driving at the speed limit.

Table 4.26. Breakdown of the weighted concerns (out of 3) about operating with TVs and AVs

		Driving Conditions								
		Travelling at night			**Road is slippery**			**Vehicle at speed limit**		
		TV	**AV**	**Concern**	**TV**	**AV**	**Concern**	**TV**	**AV**	**Concern**
Gender	Female	2.15	2.43	+28%	2.38	2.51	+13%	2.13	2.37	+24%
	Male	2.16	2.32	+16%	2.38	2.42	+4%	2.16	2.28	+12%
Age	18–35	2.22	2.44	+22%	2.67	2.56	-11%	2.22	2.11	-11%
	26–35	2.25	2.40	+15%	2.30	2.51	+21%	2.08	2.28	+20%
	36–50	2.15	2.33	+18%	2.43	2.41	-2%	2.17	2.32	+15%
	50+	2.10	2.43	+33%	2.34	2.52	+19%	2.14	2.39	+24%
Car Ownership	No	2.20	2.16	-4%	2.54	2.49	-5%	2.16	2.15	-1%
	Yes	2.14	2.14	0%	2.34	2.47	+13%	2.14	2.38	+23%

4.4.3.5. Correlation of Concerns about the Privacy of Data and Recording Data

The literature review (Chapter 2, Section 2.4) suggested that the confidentiality of data and concerns regarding the recording of data by AVs might reduce people's interest in adopting AVs. Therefore, the survey aimed to address how much worries about the privacy of data and user acceptance of the recording of data could be correlated. Table 4.27 shows the cross-tabulation of this assessment.

In total, 465 observations were recorded for this assessment, with 218 (46.9%) of the respondents expressing an utmost concern about the privacy of the recorded data in AVs. Out of 218 concerned respondents, 45.9% disagreed that AVs should record data, and 30.3% of them were neutral on the subject; only 23.9% of the respondents agreed that AVs should record data. The assessment within the 'recording of data' confirms a correlation between 'concerns about the privacy of data' and 'recording data' by representing 65.4% disagreement about the 'recording of data'.

Also, of the 129 respondents who were not at all concerned about the privacy of data, 39.5% agreed that AVs should record data, and 36.4% were neutral about it. The comparison of the expected values and the observed results in the survey is also verified by the Chi-square (χ^2) value of 37.66 and the Pearson p-value of less than 0.05.

In general, the assessment finds that 32.9% of all participants disagreed with the recording of data by AVs, and 37.4% were neutral; only 29.7% agreed that AVs should record data.

Therefore, the assessment implies that the recording of data by AVs is not acceptable to the majority of respondents because it raises concerns about data privacy. Such concerns could affect users' interest in and acceptance of AVs on public roads.

Model 4.8. Cross-tabulation

Table 4.27. Cross-tabulation of the privacy of recorded data in AV versus acceptance of recording of data by AV

Variable			**Agree that AVs should record data**			**Total**
			Disagree	Undecided	Agree	
Concerned about the privacy of recorded data in AV	Not at all concerned	Count	31	47	51	129
		% within privacy	24.0	36.4	39.5	100.0
		% within record data	20.3	27.0	37.0	27.7
	Somewhat concerned	Count	22	61	35	118
		% within privacy	18.6	51.7	29.7	100.0
		% within record data	14.4	35.1	25.4	25.4
	Extremely concerned	Count	100	66	52	218
		% within privacy	45.9	30.3	23.9	100.0
		% within record data	65.4	37.9	37.7	46.9
Total		Count	153	174	138	465
		% within privacy	32.9	37.4	29.7	100.0
		% within record data	100.0	100.0	100.0	100.0

χ^2 = 37.66, degrees of freedom= 4, p-value=0.000.

4.4.3.6. Correlation of Interest and Advantages of Adopting AVs Versus Willingness to Accept AV's Liability

As was seen in the literature review (Chapter 2, Section 2.4), legal liability has been considered as one of the barriers to adopting AVs in many surveys. Therefore, the study in this Section assesses potential interest and some other features that might affect users' willingness to accept AVs' liability.

First, the study asked about people's interest in driving AVs and correlated the results with the responses regarding liability acceptance for AVs. Out of 453 observations in this assessment, 187 participants (41.3%) were 'not interested' in driving AVs. Within those 187 respondents, 64.7% of them rated 'nothing at all' for liability acceptance. Among the 137 participants (30%) who had a neutral level of interest in driving AVs, 54.7% did not want to accept liability at all. The last group were those who showed a high interest in driving AVs, with 129 responses representing 28% of all participants. Out of 129 interested respondents, 48.1% declared they did not want to accept liability at all, and 31% were neutral about accepting liability. Only 20.9% showed a great deal of willingness to accept liability.

Model 4.9. Cross-tabulation

Table 4.28 shows the cross-tabulation of interest in driving AV and respondents' willingness to accept liability for AVs.

The analysis shows that people, in general, are not willing to accept AVs' liability, even the majority of those who are interested in driving an AV. The accuracy of the analysis and the statistical significance are confirmed with a Pearson *p*-value of 0.017 (< 0.05).

Model 4.9. Cross-tabulation
Table 4.28. Cross-tabulation of the interest in driving AVs versus the willingness to accept AVs' liability

Variable			**How much will you accept AVs' liability**			**Total**
			Nothing at all	Somewhat	A great deal	
Interested in driving AV	Not interested	Count	121	46	20	187
		% within interest	64.7	24.6	10.7	100.0
		% within liability	46.9	35.1	31.3	41.3
	Neither	Count	75	45	17	137
		% within interest	54.7	32.8	12.4	100.0
		% within liability	29.1	34.4	26.6	30.2
	Very interested	Count	62	40	27	129
		% within interest	48.1	31.0	20.9	100.0
		% within liability	24.0	30.5	42.2	28.5
Total		Count	258	131	64	453
		% within interest	57.0	28.9	14.1	100.0
		% within liability	100.0	100.0	100.0	100.0

χ^2 = 12.08, degrees of freedom= 4, p-value=0.017.

The study then investigated the impact of AVs' safe and secure operation compared to human drivers and the impact of such perception on respondents' willingness to accept AVs' liability. Table 4.29 displays the results.

Looking at the results from Table 4.29, 43.9% of the total (465) participants in this investigation believed that AVs are not at all safer and more secure than human drivers. Within those 43.9% respondents, 65.7% declared they do not want to accept AVs' liability under any conditions. The responses to the question about liability confirm the correlation by showing that 50.4% of people who are not willing to accept AVs' liability, do not believe that AVs might be safer and more secure than human drivers. Also, 31.2% of the total participants in this investigation were neutral as to whether AVs would be safer and more secure than human drivers. The other group in this investigation were those who believed AVs would be 'Extremely' safer and more secure than human drivers, which was the view of

24.9% of the total participants. However, 46.6% of this last group did not want to accept AVs' liability despite their belief in AVs' safe and secure operation. However, the results within liability show that the majority of the people in this group who are extremely or somewhat willing to accept AV's liability do believe that AVs are extremely safer and more secure than human drivers. Therefore, results overall suggest that the majority of participants are not willing to accept AVs' liability, not even those who believe in AVs' safe and secure operation, but those who are willing to accept liability have more trust in AVs' safe and secure operation.

Model 4.10. Cross-tabulation

Table 4.29. Cross-tabulation of AVs' safe and secure operation versus willingness to accept AV's liability

Variable			**How much will you accept AVs' liability**			**Total**
			Nothing at all	Somewhat	A great deal	
AVs are safer and more secure than human drivers	Not at all likely	Count	134	50	20	204
		% within safety	65.7	24.5	9.8	100.0
		% within liability	50.4	37.3	30.8	43.9
	Undecided	Count	78	46	21	145
		% within safety	53.8	31.7	14.5	100.0
		% within liability	29.3	34.3	32.3	31.2
	Extremely likely	Count	54	38	24	116
		% within safety	46.6	32.8	20.7	100.0
		% within liability	20.3	28.4	36.9	24.9
Total		Count	266	134	65	465
		% within safety	57.2	28.8	14.0	100.0
		% within liability	100.0	100.0	100.0	100.0

χ^2 = 13.83, degrees of freedom= 4, p-value=0.008.

The study then evaluated how much feeling safe and secure about AVs' quick reaction in accidents could be related to willingness to accept liability. Table 4.30 shows the cross-tabulation of this assessment.

Results from Table 4.30 show that 38.2% of all participants in this assessment were extremely concerned about AVs' quick reaction in accidents, of which 53.1% were not at all willing to accept liability and 24.9% were neutral about liability. Only 22% of those 38.2 % were willing to accept AVs' liability, and they had an extreme concern about AVs' quick reaction in accidents. The rest of the participants in the survey were evenly split between those who were somewhat concerned and those who were not at all concerned about AVs' quick reaction. Around 55.9% of the somewhat concerned people did not want to accept liability at all, while 65% of the people who were not at all concerned about AVs' quick reaction in accidents declared they also were not willing to accept liability. In general, 57.7% of all respondents were not willing to accept liability under any condition, 28.5% were somewhat willing, and only 13.8% showed a high willingness to accept AVs' liability. Therefore, the study finds that few people are willing to accept AVs' liability because of the concern about AVs' quick reaction.

Model 4.11. Cross-tabulation

Table 4.30. Cross-tabulation of feeling safe and secure about AVs' quick reaction in accidents versus willingness to accept AVs' liability

Variable			How much will you accept AVs' liability			Total
			Nothing at all	Somewhat	A great deal	
Feeling safe and secure about AVs quick reaction in accidents	Not at all concerned	Count	93	35	15	143
		% within safety	65.0	24.5	10.5	100.0
		% within liability	34.8	26.5	23.4	30.9
	Somewhat concerned	Count	80	53	10	143
		% within safety	55.9	37.1	7.0	100.0
		% within liability	30.0	40.2	15.6	30.9
	Extremely concerned	Count	94	44	39	177
		% within safety	53.1	24.9	22.0	100.0
		% within liability	35.2	33.3	60.9	38.2
Total		Count	267	132	64	463
		% within safety	57.7	28.5	13.8	100.0
		% within liability	100.0	100.0	100.0	100.0

χ^2 = 21.98, degrees of freedom= 4, p-value=0.000.

In order to evaluate participant's feedback and comments regarding their concerns about the adoption of AVs, a qualitative content analysis was adopted. Qualitative content analysis is an approach for interpreting the verbal data which could be used for the analysis of survey feedbacks (Shreier, 2012). Since the required software for applying this method was available online for free use, it has been used for the analysis of the survey feedback and responses in this study. For this, an internet-based software was adopted named as "word cloud", which filters the text (here as the people's feedback) based on the frequency of the words was used. Word cloud represents the keywords which were most adopted by the survey participants and, in general, the topics which were more discussed and focused. Figure 4.1 shows the word cloud of the concerning issues regarding the adoption of AVs. According to Figure 4.1, safety concerns were the biggest concern of participants overall with 16 frequency size, meaning that it has been used 16 times by participants in the feedback and comment. After that, stressful driving (9 frequency), the price of AVs and tax concerns (each, seven frequencies) were among those concerns at the next level of importance.

Figure 4.1. Word cloud of the concerning issues regarding the adoption of AVs.

Here are also people's direct quotes provided in the feedback and comments of the survey:

- "An autonomous vehicle has already killed a woman because it thought she was a plastic bag. This would make me think that the makers have made a conscious decision that killing someone is easier/cheaper than having the car stop whenever it senses a disruption that it thinks might be a plastic bag"
- "As an epileptic, autonomous vehicles represent independence and freedom to me. I had no real interest in driving before I developed epilepsy. I figured that I would get around to taking the driving test at some time. Then I developed epilepsy before I had a chance. People like me are particularly excited by the prospect of autonomous vehicles"
- "Autonomous car will be like robots, I prefer to have control of the car am driving and can be accountable if anything goes wrong"
- "Can't see how they will work in real world conditions, fly by wire planes operate in wide open spaces with ATC guiding them and watching for collisions, not so for cars etc."
- "Can't see this happening"
- "Cost of conventional cars is very expensive, being autonomous would be a wonderful compensation"
- "I am really fascinated by autonomous cars. As soon as they are reasonably priced I will get one - or use if part of fleet"
- "I can't see myself ever trusting them"
- "I completely absolutely and utterly would NEVER purchase or rent or be a passenger in any autonomous car or public service vehicle allowed on our roads to scourge my HUMAN RIGHTS!!"
- "I don't believe in the concept and would be nervous of these cars on the road"
- "I don't think they are safe - I heard bad feedback about them"

- “I have heard of a number of accidents involving autonomous vehicles. I believe it is in its infancy and needs further testing to ensure it has taken all conditions into account”
- “I just feel that they would never be 100% safe”
- “I like driving, parking, and using gears”
- “I like the idea of autonomous vehicles as it's a futuristic concept that's been talked about for many years. It's an exciting idea that could possibly revolutionise transport around the world. Because I'm interested in the concept”
- “I live in a rural area and I drive a 4wd. The places I go would be totally unsuited to Autonomous cars. It seems like a large town and city application and may work well in such places. In my area driving involves a lot of skill”
- “I love driving so I would not be interested in Autonomous Vehicles”
- “I question their safety after a pedestrian was hit in the States”
- “I Think autonomous vehicles will be available in ten to twenty years, if not before. They will improve road safety, help reduce congestion and improve the environment. They will also be downsides such of loss of employment which may cause social issues”
- “I think that there would need to be a lot of testing done and for there to be a proven track record that autonomous vehicles are safe and that they prevent accidents before they would be widely accepted by the general public. I think though once any flaws are ironed out, within 10 to 20 years, we could be seeing traditional vehicles being gradually phased out in favour of autonomous vehicles”
- “I think these cars are a great Idea BUT they would have to be an 'all or nothing' integration as we would still have people driving very fast and dangerously on the road!”
- “I was fully on board with them until learning that they all would record and share my travel data - if it's not possible to turn that off, I'd never consider buying one”
- “I would fear for safety to other drivers and pedestrians”
- “I would never trust one”
- “I would not trust one”
- “I would rather drive my own car and deal with every other driver driving theirs with all the inherent risks than turn control over to a machine, no matter what the risks"
- “If it’s going to happen I hope it’s 100% researched - safety is most important in new technology”
- “If the person using the said vehicle was classed as a passenger as they aren't in control of the vehicle what happens to car insurance/ liability/ road tax compared to being in a taxi as a passenger you wouldn't be liable for any accident/ tax or liability ..?”
- “If these vehicles where to come in with a built-in manual override would the driver/owner need a full licence?”
- “I'm 61 now and my driving license expires in about 6 years. I hope to live in a place by then where I won't need to drive, so will give up my car”
- “It is interesting to find out the attitudes of potential consumers of autonomous vehicles. I personally believe it will take time on the future development of this concept to ensure the general public is informed and comfortable. This survey definitely assists in information raising in relation to autonomous vehicles. Thank you.”
- “Liability in case of accident needs to be sorted”
- “Maybe it just seems to "Space Age". Too "Big Brother". With autonomous vehicles you don't seem to have much control of anything. If something technically went wrong then there could be some drastic incidents”
- “My concerns are outweighing the excitement to get behind the wheel of an autonomous vehicle at present”

- "My concerns are the transition period when driverless cars become available and human driven vehicles are both on the road. My other concern is the level of unemployment which will be caused following this advancement. Final concern would be due to the possibility of hacking"
- "Not really sure if they're a safer option"
- "Price must not be an inhibiting factor, as it is with electric cars now"
- "Properly safe and efficient they would be a great asset to the community"
- "Recent news of freak accidents and deaths caused by these cars make me extremely wary of their safety claims"
- "Regarding cost of tax and any incentives that might make me inclined to sway more to purchase an autonomous would be a good question"
- "Safety concerns as the vehicles have not been fully reliable/safe so far"
- "Safety"
- "Security of software in autonomous vehicles would be of concern"
- "Sooner the better"
- "The technology must be perfected before they are introduced"
- "To make people interested in buying them the cost should be near enough the same as a normal car to get people to switch"
- "Unfortunately it would take a lot for me to buy one. I wouldn't be comfortable from a safety point of view"
- "Unsure about vehicle technology"
- "What are the chances of the car being hacked or bugged?"
- "Who programs the morality of the vehicles decision making?"
- "Will there be a manual override?"
- "Wish they were available now - the technology is there it should be make available to the public"
- "Wondering how well tested they will be"
- "Would be extremely worried about getting into one of these vehicles. I think it's crazy. I prefer to be in control of my car. My stress levels would soar in one of these as a passenger or driver"
- "Would certainly need to a lot of testing on this type of transport before I would set foot in one"
- "Would like to see few adjustments to cars example self-alcohol limit cheek"
- "Would not feel safe"
- "Wouldn't feel safe at all in one or safe on the road"

A review of the analysis in this Section makes clear that even the majority of the people who had an interest in driving AV, those who believed AVs would be safer and more secure than human drivers, and those who believed in AVs' quick reaction in accidents still had a very low willingness to accept responsibility for the AV. Further investigation of people's willingness to adopt and willingness to pay for AVs might help reveal other practical factors which lead to such a low willingness to accept liability. Therefore, Section 4.4.4 focuses on the reasons people might have for purchasing AVs.

4.4.4. Reasons for Purchasing AVs

Section 4.4.2 presented some results regarding the survey users' interest in driving AVs, where the concerns about adopting AVs have been presented in Section 4.4.3. This Section presents the results of assessments related to respondents' reasons for purchasing AVs. In this regard, this Section addresses the relationships between some of the advantages of adopting AVs, participants' gender and some other parameters and people's decision regarding the adoption of AVs. The findings from this Section help to assess people's WTP for AVs, which will be discussed in Section 4.4.5.

4.4.4.1. Correlation of Interest and Some Advantages of Adopting AVs with Responses about Purchasing AV When it is Fully Developed and Tested

Section 4.4.2 evaluated the relationship between interest in driving AVs and some benefits of adopting AVs and willingness to accept liability, which might affect users' willingness to purchase AVs. In this Section, the same parameters are analysed to assess how they might affect users' perceptions and decisions about purchasing AVs when the technology is fully developed and tested. Such an evaluation provides insight into probable reasons for interest or concern when it comes to adopting AVs on public roads. Therefore, results from three survey questions are correlated with responses about purchasing AVs using cross-tabulation. Results of each evaluation are presented in Tables with the interpretation of the results.

The first analysis (shown in Table 4.31) correlated users' interest in driving AVs with their willingness to purchase AVs. Such an evaluation reveals to what extent interest could affect users' acceptance of and willingness to adopt AVs. In total, 453 individuals responded to this evaluation, with 41.3% of the individuals declaring they were not interested in driving AVs, and therefore, the majority of this group (82.9%) were not willing to purchase AVs. Also, 30.5% of the total participants were neutral about driving AVs, among which 39.1% and 21.7% were still somewhat likely or extremely likely to buy AVs, respectively. The last group of participants in this assessment were those who showed a high interest in driving AVs, with 28.3% of the total participants, of whom 62.5% were extremely likely to buy AVs when they are fully developed and tested. Also, 23.4% of the people in the last-mentioned group declared they might be somewhat likely to purchase AVs. The results of this assessment suggest that out of neutral and interested individuals, a considerable percentage looked very likely to actually buy and drive AVs. Therefore, the extreme interest in driving AVs affected the decisions regarding purchasing AVs, with 85.9% (23.4% and 62.5%) of the 128 total respondents who were interested in driving AVs indicating somewhat of a tendency or – for the majority – an extreme tendency to buy an AV. The statistical significance of the measurements and the results are provided in Table 4.31.

Model 4.12. Cross-Tabulation
Table 4.31. Cross-tabulation of the interest in driving AV versus purchasing AV when it's fully developed and tested

Variable			Purchase AV when it's fully developed and tested			Total
			Nothing at all likely	Somewhat likely	Extremely likely	
Interested in driving AV	Not interested	Count	155	30	2	187
		% within interest	82.9	16.0	1.1	100.0
		% within purchase	68.3	26.3	1.8	41.3
	Neither	Count	54	54	30	138
		% within interest	39.1	39.1	21.7	100.0
		% within purchase	23.8	47.4	26.8	30.5
	Very interested	Count	18	30	80	128
		% within interest	14.1	23.4	62.5	100.0
		% within purchase	7.9	26.3	71.4	28.3
Total		Count	227	114	112	453
		% within interest	50.1	25.2	24.7	100.0
		% within purchase	100.0	100.0	100.0	100.0

χ^2 = 210.332, degrees of freedom= 4, p-value=0.000.

In the next step, the responses indicating people's willingness to purchase AVs are correlated with their opinions about whether AVs would be safer and more secure than human drivers. Table 4.32 shows the cross-tabulation of two assessment criteria, namely the survey questions adopted for this assessment.

According to Table 4.32, around 43.9% believed that AVs are not at all safer and more secure than human drivers, and 77% in this group declared they are not at all likely to purchase AVs. So, these results reveal that concerns about the safe and secure operation of AVs could substantially affect decisions about buying AVs. Also, the assessment of results within the purchase category shows that 67.4% of the people who were not at all willing to purchase AVs also believed AVs are not at all safer and more secure than human drivers, which shows a correlation between these two variables. Approximately 31% of the total participants in the survey showed a somewhat positive perception of AVs as safer than human drivers, yet 62.1% (35.2%+26.9%) also showed a tendency to purchase AVs. Only 24.9% of all respondents believed AVs would be immensely safer and more secure than human drivers, and they mostly (81.9% = 22.4% + 59.5%) showed a high or moderate tendency to purchase AVs. The study showed that 77% of the people who had negative feelings about AVs' safe and secure operation were not willing to purchase AVs, whereas 59.5% of those who had a positive feeling about AVs' safe operation showed a high willingness to purchase. The *p*-value and Chi-square test result also validate the statistical significance of the model and the correlation between the model's predicted values and the actual values.

Model 4.13. Cross-tabulation
Table 4.32. Cross-tabulation of AVs' safe and secure operation versus purchasing AV when it's fully developed and tested

Variable			**Purchase AV when it's fully developed and tested**			**Total**
			Not at all likely	Somewhat likely	Extremely likely	
AVs are safer and more secure than human drivers	Not at all likely	Count	157	39	8	204
		% within safety	77.0	19.1	3.9	100.0
		% within purchase	67.4	33.6	6.9	43.9
	Somewhat likely	Count	55	51	39	145
		% within safety	37.9	35.2	26.9	100.0
		% within purchase	23.6	44.0	33.6	31.2
	Extremely likely	Count	21	26	69	116
		% within safety	18.1	22.4	59.5	100.0
		% within purchase	9.0	22.4	59.5	24.9
Total		Count	233	116	116	465
		% within Safety	50.1	24.9	24.9	100.0
		% within Purchase	100.0	100.0	100.0	100.0

χ^2 = 158.348, degrees of freedom= 4, p-value=0.000.

Finally, the study correlated the perceptions about AVs' quick reaction in accidents with the respondents' willingness to purchase AVs. Table 4.33 shows the cross-tabulation of this evaluation.

According to Table 4.33, around 38.2% of the total participants were extremely concerned about AVs' quick reaction in accidents, with 49.2% of them not at all likely to purchase AVs. The rest of the population was split almost equally between being somewhat worried and not at all worried about AVs' quick reaction in accidents. However, a considerable percentage of respondents (65.8) showed a tendency to purchase AVs. Of those who were not at all concerned about AVs' quick reaction, 66.4% indicated they were not at all likely to purchase AVs.

Model 4.14. Cross-tabulation

Table 4.33. Cross-tabulation of feeling safe and secure about AVs' quick reaction versus purchasing AV when it's fully developed and tested

Variable			**Purchase AV when it's fully developed and tested**			**Total**
			Nothing at all likely	Somewhat likely	Extremely likely	
Feeling safe and secure about AVs' quick reaction in accidents	Not at all concerned	Count	95	26	22	143
		% within safety	66.4	18.2	15.4	100.0
		% within purchase	41.1	22.2	19.1	30.9
	Somewhat concerned	Count	49	58	36	143
		% within safety	34.3	40.6	25.2	100.0
		% within purchase	21.2	49.6	31.3	30.9
	Extremely concerned	Count	87	33	57	177
		% within safety	49.2	18.6	32.2	100.0
		% within purchase	37.7	28.2	49.6	38.2
Total		Count	231	117	115	463
		% within Safety	49.9	25.3	24.8	100.0
		% within Purchase	100.0	100.0	100.0	100.0

χ^2 = 43.025, degrees of freedom= 4, p-value=0.000.

Therefore, the study shows that an extreme concern about AVs' quick reaction could reduce peoples' likelihood to purchase AVs. Also, results indicated people had negative perceptions about buying AVs even when they had no concern about AVs' safe and secure operation. However, there was still a high tendency to purchase AVs among those who were somewhat concerned and even among those who were extremely concerned about AVs' quick reaction. Such a willingness to purchase could also stem from other reasons, such as an interest in driving an AV.

4.4.4.2. Backward Stepwise Regression: Effects of the Advantages of Adopting AVs on Responses about Purchasing AV When it is Fully Developed

After running some analysis about the factors affecting users' willingness to purchase AVs in Section 4.4.4.1, it would be useful to gain more insight into the level of impact of each factor. In other words, the study in this Section seeks to identify which factors had the greatest influence on users' willingness to purchase. The result of such an evaluation could be useful for better understanding users' perceptions of and main reasons for adopting or rejecting AVs. Such results could be further used for market assessments. Hence, the study in this Section applies backwards linear regression. In this method, the study adds all independent variables into the model in the first step of analysis and correlates them with the dependent variable. Then, using the backward criterion, which is the probability of the

F-test to remove an independent variable from the model (*F*-to-remove <= 0.100), the model removes the variable whose loss gives the most statistically insignificant deterioration of the model fit. For the case of the assessment in this study, the model deletes independent variables which do not correlate with the dependent variable of the model. Therefore, what will be left in the model would be merely the independent variables which substantially affect the model results. Then, the model repeats the process until no further variables can be deleted without a statistically significant loss of fit. (Agresti, 2016; McCarthy et al., 2015). The dependent and independent variables of the model in this assessment are as follows:

Dependent Variable: Purchase AV when it is fully developed and tested
Independent Variables (model predictors):

- Whether AVs would be safer and more secure than human drivers
- Feeling safe and secure about AVs' quick reaction in accidents
- Purchasing AV if the cost is not an issue
- Interest in driving AVs
- Having heard about AVs.

The model summary of the assessment (shown in Table 4.34) represents around 60% R-squared for each step of the model, meaning that the model's inputs can explain 60% of the observed variation. Also, the analysis of variance in the model (ANOVA test) shows *p* values of 0.000 for all three steps, which are less than the 0.05 that verifies the model's goodness of fit. Table 4.34 displays the model summary and results of the ANOVA test.

Model 4.15. Stepwise Regression
Table 4.34. Model summary of the backward stepwise regression

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.777	**0.604**	0.600	1.048
2	.776	**0.603**	0.599	1.049
3	.775	**0.601**	0.598	1.050

ANOVA						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	716.995	5	143.399	130.506	**.000**
	Residual	469.185	427	1.099		
	Total	1186.18	432			
2	Regression	715.168	4	178.792	162.465	**.000**
	Residual	471.012	428	1.100		
	Total	1186.18	432			
3	Regression	712.815	3	237.605	215.336	**.000**
	Residual	473.365	429	1.103		
	Total	1186.18	432			

Also, an investigation of the model coefficients would provide more insights into which independent variables might have more impact on users' willingness to buy AVs. The result of such an investigation is provided in Table 4.35. According to Table 4.35, all of the independent variables are added to the model in step one with a constant predictor, which the model acquires to run the process. Looking at the variable significance values, the independent variable 'Heard about AV' had the *p*-value of 0.198, which is greater than 0.1, which is the criterion for removal, meaning this variable causes the greatest degradation of the model fit in step one. Therefore, it is removed from the model, and the rest of the variables enter the next step for another round of correlation. In step two, 'Feeling safe and secure about AVs' quick reaction in accidents' has a *p*-value of 0.144, which is greater than 0.1 and, for the same reason, it is removed from the model. Finally, the three independent variables left from step two enter the third step for another iteration of correlation. They are showing *p* values of 0.000, which are less than the removal criterion. This means that there is no other variable to make a statistically significant loss of fit to the model. Therefore, all three of them are considered valid and correlated to the dependent variable of the model. Out of the three remaining variables, the one with the greatest B-coefficients represents the variable with the greatest impact on the model significance. Therefore, 'purchase AV if the cost was not an issue', with a B-coefficient of 0.439, is the variable that most substantially affects users' decisions about purchasing an AV. After that, 'interested in driving AV', and 'AVs are safer and more secure than human drivers' are the next most important ones, with B-coefficients of 0.285 and 0.143, respectively.

Table 4.35. Model results of the backward stepwise regression

Step	Variable	B	Std. Error	Sig.
1	(Constant)	-0.169	0.146	0.249
	AVs are safer and more secure than human drivers	0.132	0.041	0.001
	Feeling safe and secure about AVs quick reaction in accidents	0.043	0.031	0.172
	Purchase AV if cost was not an issue	0.433	0.041	0.000
	Interested in driving AV	0.280	0.043	0.000
	Heard about AV	0.043	0.034	**0.198**
2	(Constant)	-0.111	0.140	0.426
	AVs are safer and more secure than human drivers	0.135	0.041	0.001
	Feeling safe and secure about AVs quick reaction in accidents	0.046	0.031	**0.144**
	Purchase AV if cost was not an issue	0.435	0.041	0.000
	Interested in driving AV	0.290	0.042	0.000
3	(Constant)	0.013	0.111	0.907
	AVs are safer and more secure than human drivers	0.143	0.041	**0.000**
	Purchase AV if cost was not an issue	0.439	0.041	**0.000**
	Interested in driving AV	0.285	0.042	**0.000**

4.4.4.3. The Impact of Gender on Responses about Purchasing Private AVs Even if Ridesharing AVs Are Provided

During the survey, respondents were asked whether they would purchase an AV if a ridesharing AV system had been provided to them. The result of such a question helps to understand whether adopting AVs is more rooted in people's interest in new technologies or is a result of peoples' concerns about the improvement in mobility services. In this assessment, an MNL method is adopted to investigate the possible impacts of various independent variables on the dependent variable of the model 'purchasing private AVs even if ridesharing AVs are provided'. Participants' gender has been considered as an independent variable to address how much the results are affected by the respondent's gender. Additionally, some other variables are acquired as covariates to the model to correlate people's perceptions about ridesharing AV with responses from some previous questions, which also help to increase the accuracy of the model results.

According to the results summary shown in Table 4.36, 439 observations were recorded for this assessment, with a gender share of 45.6% and 54.4% for males and females, respectively. Around 56.9% of the participants held a negative opinion toward purchasing private AVs when ridesharing AVs are provided. Before addressing the possible reasons for such a response, the response validity must be verified.

Table 4.36. Case processing summary of the impact of 'gender' on 'purchasing private AVs even if ridesharing AVs are provided

Variable		**N**	**%**
Purchase AV Even If Ridesharing AV Provided	No	250	56.9
	Yes	189	43.1
	Total	439	100
Gender	Female	239	54.4
	Male	200	45.6
	Total	439	100

Table 4.37 shows the results of the MNL model and model-fitting results of this assessment. More details regarding the model fitting information and the MNL model parameter estimates are available in Appendix B (B39 and B40). According to Table 4.37, the model, in general, had a valid p-value in the model fitting tests (Sig. = 0.000; < 0.05), which shows the model is statistically significant. The likelihood ratio tests reject two of the input covariates, one of which was gender, due to a p-value of 0.326 (> 0.05), meaning they do not adequately correlate to the model and so there is not a proper relation between those two variables and the responses. The other rejected variable was 'AVs are safer and more secure than human

drivers'. However, it is noteworthy that such rejection by the model does not mean that the rejected variables are not affecting people's response at all but only that the variables might not properly correlate with regard to the other covariates in this assessment. The rejected covariates could impact people's opinion indirectly, and that could be an indication of why the Nagelkerke pseudo-R-squared value is 0.289. This is not particularly high, but it is worthy of more assessment. The other two covariates, namely 'interested in driving AV', and 'feeling safe and secure in an AV without steering wheel', are statistically significant and are assessed below.

Looking at the *p* values (Sig.) and B-coefficients in Table 4.37, the model shows positive B-coefficients for 'interested in driving AV', and 'feeling safe and secure in an AV without steering wheel', and shows that these are statistically significant. This means that these two variables are more likely to occur when the answer to the question 'purchase AV even if ridesharing AV provided' is 'Yes'. The Exp(β) shows that it is 27.5% more likely than 'feeling safe and secure in an AV without steering wheel' to affect peoples' decisions about 'purchasing AV even if ridesharing AV provided'. In other words, those who feel safe and secure in an AV without a steering wheel are 27.5% more likely to purchase an AV even if ridesharing AV is provided. Therefore, feeling safe and secure substantially affected users' opinions about purchasing private AVs. Likewise, those who had an interest in driving AV were 57.1% more likely to buy private AVs even if ridesharing AV is provided. Also, the negative B-coefficient of -0.218 for females and the odds ratio of 0.804 show that females, in general, were 19.6% (1 – 0.804) less likely than men to purchase private AVs, and they seemed to be more interested in ridesharing services. Therefore, men were more interested in adopting private AVs even if ridesharing AVs are provided.

Model 4.16. MNL

Table 4.37. Results of the MNL model for purchasing private AVs even if ridesharing AVs are provided

Variable	Model Coefficient: (β)	Odds Ratio: Exp (β)	Sig.
Purchase AV even If ridesharing AV provided[a]: Yes			
AVs are safer and more secure than human drivers	0.128	1.137	0.145
Feeling safe and secure in an AV without a steering wheel	0.243	1.275	0.010
Interested in driving AV	0.452	1.571	0.000
Gender (Female)	-0.218	0.804	0.325
Gender (Male)	0[b]	.	.
Chi-Square: 106.589, **Degrees of freedom:** 4, **P-value:** 0.000, **Pseudo R-square:** 0.289			
Likelihood significance for “AVs are safer and more secure than human drivers”			0.146
Likelihood significance for “Feeling safe and secure in an AV without a steering wheel”			0.009
Likelihood significance for “Interested in driving AV”			0.000
Likelihood significance for “Gender”			0.326

a. The reference category is: No.
b. This parameter is set to zero because it is redundant.

All in all, it seems that people had a slightly greater preference for ridesharing AV as a solution to their mobility concerns. However, for men in general, and for those who were interested in driving AVs and those who felt safe and secure in driverless AVs, the private AV was preferred.

4.4.4.4. Correlation of Purchasing AVs Versus Mobile Phone Version

An investigation was conducted – using cross-tab evaluation – to learn to what extent an interest in technology could impact users’ opinions regarding the purchase of AVs. Hence, the survey asked respondents several questions about the version of their smartphone and whether respondents were interested in intelligent technologies.

The survey asked whether the user’s mobile phone was the latest version of its model on the market when they bought it. The results of this question were then correlated with the results from ‘purchase AV when it is fully developed and tested’. Table 4.38 shows the cross-tabulation of this assessment. According to Table 4.38, 467 valid responses were recorded for this assessment, with 250 respondents (53.5% of total participants) declaring their mobile phone was not the latest version. Out of those 250 users, 58.8% said they were not at all likely to purchase an AV. On the other hand, 40% of those whose mobile phones were the latest version when they were purchased were also not at all likely to purchase an AV. However, a total of 60% of the people in the latest mobile phone showed a moderate or extreme tendency to buy an AV. Looking at the question concerning the purchase of an AV, 65% of the people who said they were extremely likely to purchase an AV when it is developed had a mobile phone that was the latest version when purchased. Also, 62.8% of those who declared they were not at all likely to purchase an AV did not have a phone that was the latest version.

Model 4.17. Cross-tabulation

Table 4.38. Cross-tabulation of mobile phone version with purchasing AV when it is fully developed and tested

Variable			**Purchase AV when It is fully developed and tested**			**Total**
			Not at all likely	Somewhat likely	Extremely likely	
The mobile phone was the latest version	No	Count	147	63	40	250
		% within mobile phone version	58.8	25.2	16.0	100.0
		% within purchase AV	62.8	53.8	34.5	53.5
	Yes	Count	87	54	76	217
		% within mobile phone version	40.1	24.9	35.0	100.0
		% within purchase AV	37.2	46.2	65.5	46.5
Total		Count	234	117	116	467
		% within mobile phone version	50.1	25.1	24.8	100.0
		% within purchase AV	100.0	100.0	100.0	100.0

χ^2 = 25.04, degrees of freedom= 2, p-value=0.000.

In general, the assessment in this Section shows not all the people who had a mobile phone that was the latest version at the time of purchase were extremely likely to purchase an AV as well. However, it could be interpreted that people who were more likely to purchase an AV were also more likely to have the latest version of their mobile phone, which could be seen as an indication of interest in smart technologies. It is also worth noting that the cost of technology and people's budgets might also influence their decisions about buying the latest technologies. In order to widen the assessment in this matter, another correlation was conducted to evaluate how much people's interest in smart technology might have impacted their opinion regarding purchasing AVs. Table 4.39 shows the result of this correlation.

According to Table 4.39, a total of 265 individuals out of 473 participants (56%) liked smart technologies a great deal; 35% of these people professed an extreme tendency to purchase an AV when developed. Also, 23.8% declared they were somewhat likely to buy an AV. Looking at this assessment from another perspective shows that 78.8% of all those who had an extreme tendency to buy an AV had a high interest in smart technologies.

The other group of participants in this assessment included those who were somewhat interested in smart technologies, which was a group of 152 participants. Around 56.6% of these participants were not at all likely to purchase AVs. Finally, among the group of 56 individuals who were not at all interested in smart technologies, 73.2% also were not at all likely to purchase an AV.

Therefore, the study shows that 56% of participants liked smart technologies, and most of this group expressed at least a moderate tendency to buy an AV. Also, people who said they were highly likely to purchase an AV tended to have a high level of interest in smart technologies, meaning that interest in intelligent technology and a propensity to buy AVs are highly correlated. Finally, the results also support this finding by showing that those who did not have an interest in smart technology also tended to be unlikely to purchase an AV.

Model 4.18. Cross-tabulation
Table 4.39. Cross-tabulation of interest in smart technologies versus purchasing AV when it is fully developed and tested

Variable			Purchase AV when It is fully developed and tested			Total
			Not at all likely	Somewhat likely	Extremely likely	
Like smart technologies	Nothing at all	Count	41	11	4	56
		% within technologies	73.2	19.6	7.1	100.0
		% within purchase AV	17.4	9.2	3.4	11.8
	Somewhat	Count	86	45	21	152
		% within technologies	56.6	29.6	13.8	100.0
		% within purchase AV	36.4	37.8	17.8	32.1
	A great deal	Count	109	63	93	265
		% within technologies	41.1	23.8	35.1	100.0
		% within purchase AV	46.2	52.9	78.8	56.0
Total		Count	236	119	118	473
		% within technologies	49.9	25.2	24.9	100.0
		% within purchase AV	100.0	100.0	100.0	100.0

χ^2 = 39.21, degrees of freedom= 4, p-value=0.000.

4.4.5. Willingness to Pay for AVs

4.4.5.1. Introduction

After evaluating the desire to adopt AVs and addressing the possible reasons for purchasing, it is crucial to find out how much people would be willing to pay for these vehicles. The study in this Section assesses users' WTP for AVs, using variables such as 'interest in driving AVs', 'previous knowledge about AVs', and some demographic information.

The assessment of users' WTP in this study is measured in three ranges of below 10%, 10% - 20%, and above 20% over the base price of the same vehicle in the traditional model. Therefore, it is useful to have a view of the base price of traditional vehicles in Ireland. Table 4.40 shows Ireland's top 10 bestselling cars as of April 2019 (IrishTimes, 2019). The vehicles' price in Table 4.40 is extracted from the Irish Times newspaper and evaluated with Carzone Ireland[1], a famous car-selling company in Ireland.

Note that the studies in the literature (see Section 2.2.2) provided numerical price ranges for AVs and evaluated people's WTP accordingly. The author of the current research believes that providing a numerical value range for AVs which are not available in the market might lead to the anchoring bias[2] though negatively impact individuals' perception of their WTP for AVs.

Also, note that the WTP ranges were defined based on individuals' average WTP for AVs and the estimated price of AVs from the literature (see Section 2.2.2). For this purpose, an initial evaluation was made about the price of the traditional vehicles in Ireland (see Table 4.40); then, the average WTP from the literature was correlated with Ireland's vehicle prices. The ratio of the WTP from the literature to the average price of TVs in Ireland provided an estimation of the Irish people's WTP. In this way, the WTP ranges of the below and above the estimated value were considered for evaluations in the survey.

According to Table 4.40, the average price for a popular car in Ireland in 2019 is equivalent to USD 59,434 where 10% and 20% WTP for such a vehicle would be USD 5,943 and USD 11,887 respectively.

---

[1] www.carzone.ie

[2] Anchoring bias occurs during the decision making process when people are given an initial price of a device or tool. In this way, people might reply heavily on the given price and make a decision accordingly. For more information in this regard, please see Furnham and Boo (2011).

Table 4.40. Ireland's top 10 bestselling cars, 2019

Rank	Car	Price		10% WTP ($)		20% WTP ($) and above	
		Local (€)	Converted to USD ($)	10% Addition	Payable for AV	20% Addition	Payable for AV
1	Jaguar I-Pace SE	91,585	102,575	10,258	112,833	20,515	123,090
2	Audi E-Tron 55 Quattro	91,750	102,760	10,276	113,036	20,552	123,312
3	BMW 3 Series 320i	43,770	49,022	4,902	53,925	9,804	58,827
4	Peugeot 5008	35,255	39,486	3,949	43,434	7,897	47,383
5	Mercedes-Benz E-Class	55,420	62,070	6,207	68,277	12,414	74,484
6	Volkswagen Golf	27,000	30,240	3,024	33,264	6,048	36,288
7	Lexus UX	43,750	49,000	4,900	53,900	9,800	58,800
8	Mazda 6	31,945	35,778	3,578	39,356	7,156	42,934
9	Toyota Camry	39,750	44,520	4,452	48,972	8,904	53,424
10	Audi A6	70,430	78,882	7,888	86,770	15,776	94,658
Average Price		**53,066**	**59,434**	**5,943**	**65,377**	**11,887**	**71,321**

4.4.5.2. Interest in Driving AVs Versus WTP for AVs in Addition to the Price of TV

The correlation between users' interest in driving an AV and their WTP beyond the cost of the same vehicle in TV mode is assessed in this Section.

Table 4.41 shows the cross-tabulation for this assessment.

According to

Table 4.41, a total of 452 observations were recorded for this assessment, where 41.1% of the participants declared they were not interested in driving AVs. Of those 41.1% participants, 58.8% had a WTP of below 10% (USD 5,943) over the price of the same vehicle in the traditional model. In other words, they were not willing to pay for an AV if it cost more than 10% above the price of a comparable TV. Around 27.7% had a WTP of 10%–20% (USD 5,943 – USD 11,887), and 13.9% had a WTP above 20% (USD 11,887). Looking at the WTP results, approximately 56% of people who had a WTP of below 10% were not at all interested in driving an AV.

In another group, those who had an extreme interest in driving an AV, which comprised 128 individuals, around 29.7% had a WTP of above 20%. Another 35.9% had a WTP of 10%–20% and the rest of the group had a WTP of below 10%. Also, the results show that 68% of all those who had a WTP of greater than 10% also had a high interest in driving an AV.

Therefore, it could be interpreted that interest in driving an AV and a WTP for these vehicles could be related, as those with a higher interest in driving AVs had a higher WTP, and vice versa. Also, individuals with less interest in driving an AV tended to set a lower WTP. The goodness of fit of the model is confirmed by the *p*-value of 0.000 (< 0.05), which indicates the model is statistically significant.

Model 4.19. Cross-tabulation

Table 4.41. Cross-tabulation of the interest in driving AV versus WTP for AV in addition to the price of TV

Variable			WTP for AV in addition to the price of TV			Total
			Below 10% ($5,943)	10% - 20% ($5,943-$11,887)	Above 20% ($11,887)	
Interested in driving AV	Not interested	Count	110	51	26	187
		% within interest	58.8	27.3	13.9	100.0
		% within WTP	56.1	32.1	26.8	41.4
	Neither	Count	42	62	33	137
		% within interest	30.7	45.3	24.1	100.0
		% within WTP	21.4	39.0	34.0	30.3
	Very interested	Count	44	46	38	128
		% within interest	34.4	35.9	29.7	100.0
		% within WTP	22.4	28.9	39.2	28.3
Total		Count	196	159	97	452
		% within interest	43.4	35.2	21.5	100.0
		% within WTP	100.0	100.0	100.0	100.0

χ^2 = 34.54, degrees of freedom= 4, p-value=0.000.

4.4.5.3. Effects of Gender and Age on WTP for AVs

After assessing the impact of interest in driving an AV on WTP, it seemed necessary to have a more detailed look into some other factors which might impact the WTP for AVs. Therefore, this Section applied an MNL model to assess the correlation between 'gender' and 'age' as independent variables with 'WTP' as the dependent variable. Also, 'interest in driving AV' is adopted as a covariate to the model, along with people's response on how much they have heard about AVs. The response summary of this evaluation is shown in Table 4.42. In total 475 individuals responded to the question related to WTP for AV, with 43% of them having a WTP below 10%, 35.4% a WTP of 10%–20%, and 21.5% of them a WTP above 20%. Around 54.3% of the respondents were female, and the dominant age range was 36–50 at 44.8% of the population, followed by the age range of 50+ at 34.8% of the population.

Table 4.42. Case processing summary of the impact of 'gender' and 'age' on 'WTP' for AVs

Variable		**N**	**%**
WTP for AV in Addition to the Price of TV	Below 10%	192	43.0
	10% - 20%	158	35.5
	Above 20%	96	21.5
	Total	446	100.0
Gender	Female	242	54.3
	Male	204	45.7
	Total	446	100.0
Age	18-35	7	1.6
	26-35	84	18.8
	36-50	200	44.8
	50+	155	34.8
	Total	446	100.0

Table 4.43 shows the model-fitting information and the results of the MNL model of assessment. Detailed information regarding the model fitting tests and the MNL model parameter estimates are available in Appendix B (B41 and B42).

The model fitting information shows a *p*-value of 0.000, which is below 0.05, which means the model, in general, is statistically significant. The likelihood ratio tests prove the correlation of 'Interest in driving AV', and 'Age' with WTP, as both variables, have *p* values of 0.000 (< 0.05) and so are statistically significant. However, the variables 'Gender' and 'Heard about AV' present *p* values of greater than 0.1, which means they are not significant in this assessment. However, further investigation in this matter is required to see whether the values are meaningful or not.

According to the results related to age and WTP above 20%, and with regard to the reference category of the model, which is 'WTP below 10%', all age groups provided positive B-coefficients, meaning that these age groups were more likely to have a WTP above 20% than were those in the reference category. For more insight into this matter, odds ratios or Exp (β) values are presented in the model. For example, the odds ratio for the age group 18–25 is 8.897, meaning that people in that age range were 8.8 times more likely to have a 'WTP for AVs greater than 20%' than people in the age range 50+ compared to the reference category. The significance of the model is confirmed by the *p*-value of 0.000, which is below 0.05. Also, looking at 'gender' in this category shows that 'female' had a B-coefficient of 0.06 by the Exp(1.06), meaning females were 6% more likely to have a WTP above 20% than men with regard to the reference category.

Model 4.20. MNL
Table 4.43. Results of the MNL model for how safe and secure would AVs be without a steering wheel

Variable	Model Coefficient: (β)	Odds Ratio: Exp (β)	Sig.
WTP for AV in addition to the price of TV[a]: 10% - 20%			
Interested in driving AV	0.228	1.256	0.002
Heard about AV	0.094	1.098	0.228
Gender (Female)	0.373	1.452	0.122
Gender (Male)	0[b]	.	.
Age (18–25)	-0.563	.569	0.634
Age (26–35)	0.654	1.924	0.047
Age (36–50)	0.424	1.528	0.085
Age (50+)	0[b]	.	.
WTP for AV in addition to the price of TV[a]: Above 20%			
Interested in driving AV	0.374	1.454	0.000
Heard about AV	0.005	1.005	0.956
Gender (Female)	0.060	1.061	0.838
Gender (Male)	0[b]	.	.
Age (18–25)	2.186	8.897	0.016
Age (26–35)	1.953	7.051	0.000
Age (36–50)	1.613	5.018	0.000
Age (50+)	0[b]	.	.
Chi-Square: 63.908, **Degrees of freedom:** 12, **P-value:** 0.000, **Pseudo R-square:** 0.152			
Likelihood significance for “Interested in driving AV”			0.000
Likelihood significance for “Heard about AV”			0.425
Likelihood significance for “Gender”			0.267
Likelihood significance for “Age”			0.000

a. The reference category is: WTP Below 10%.
b. This parameter is set to zero because it is redundant.

For further evaluation of the correlation of age and WTP, a cross-tabulation was conducted to determine which age groups had greater WTP and by how much. Table 4.44 shows the results of this cross-tabulation. Results from Table 4.44 show the greatest number of people who had WTP above 20% were in the age range of 36–50, with 55 individuals. However, it is worthy to note that this age group had the greatest number of participants of all age groups, with 43.9% of the total population who took part in the survey. With respect to the number of participants in each age group, the highest WTP is related to the age group 18–25, in which 50% of the participants had a WTP above 20%. Next in line were the age ranges 26–30 at 31%, 36–50 at 26.6%, and finally, the age group of 50+, which had the lowest WTP above 20% rate at 8.9% of its group population. The study showed that with the increase in age, the WTP for AVs decreased, with the age range of 18–25 having the highest WTP with respect to the number of participants in its group. The WTP then reduced gradually as age increased. In general, around 42.9% had a WTP below 10%, 35.7% a WTP of 10%–20%, and only 21.4% of participants had a WTP above 20%.

Model 4.21. Cross-tabulation
Table 4.44. Cross-tabulation of the age ranges versus WTP for AVs in addition to the price of TV

Variable			**WTP for AV in addition to the price of TV**			**Total**
			Below 10% ($5,943)	10% – 20% ($5,943–$11,887)	Above 20% ($11,887)	
Age	18 - 25	Count	3	1	4	8
		% within age	37.5	12.5	50.0	100.0
		% within WTP	1.5	0.6	4.0	1.7
	26 - 35	Count	25	35	27	87
		% within age	28.7	40.2	31.0	100.0
		% within WTP	12.4	20.8	26.7	18.5
	36 - 50	Count	77	75	55	207
		% within age	37.2	36.2	26.6	100.0
		% within WTP	38.1	44.6	54.5	43.9
	50 +	Count	97	57	15	169
		% within age	57.4	33.7	8.9	100.0
		% within WTP	48.0	33.9	14.9	35.9
Total		Count	202	168	101	471
		% within age	42.9	35.7	21.4	100.0
		% within WTP	100.0	100.0	100.0	100.0

χ^2 = 37.64, degrees of freedom= 6, p-value = 0.000.

4.5. Discussion

The study analysed peoples' interest in, perception of, and acceptance of AVs along with their willingness to pay and willingness to adopt.

The results show that people, in general, were not very interested in driving AVs because of the concerns regarding safety, security and privacy; only one-fifth of the population expressed a high interest (Table 4.3, & Model 4.1) while studies such as Bansal et al. (2017), Kyriakidis et al. (2015), Howard and Dai (2014), Casley et al. (2013), and KPMG (2012a) recorded above 70% of users' interest and acceptance of AVs. Also, the correlation between gender and interest shows that females, in general, were more neutral and less likely to be interested in driving AVs than males (Model 4.1) and this is in line with the result of the study by Bansal et al. (2017). Also, people in the age range of 26–35 and 36–50 looked more interested in driving AVs, whereas the age group 26–35 appeared to be the most interested age range of all (Model 4.2). One reason for such high interest was that they believed AVs could be safer and more secure than cars driven by human drivers. The other age groups seemed to be less interested in driving AVs, as they did not feel safe and secure about AVs' abilities to react quickly in accident situations.

Only a small percentage of respondents believed that AVs would be much safer than cars with human drivers; people, in general, were mostly unsure or not likely to believe in AVs' safe and secure operation (Table 4.20, & Model 4.5). However, above 60% of the people in previous studies such as Bansal et al. (2018), Howard and Dai (2014), Schoettle and Sivak (2014a, b), and Casley et al. (2013) had a perception that AVs would be safer than human drivers. An important factor in the survey of this study, which influenced people's opinions about the matter was the number of cars they owned. Also, other results showed that feeling safe and secure about AVs' reaction in accidents affected people's perception of AVs' being safer and more secure than human drivers (Table 4.22). The survey of this study showed that male drivers and those who had five cars or more believed more in AVs' extreme capabilities to increase safety and security, while people with only one car were less sure in this matter (Model 4.5). In general, the male group had more trust that AVs were safer and more secure than human drivers. Also, Bansal et al. (2016) expressed that male drivers with higher income who had been in an accident before, have higher confidence in driving an AV.

The assessment of people's interest in driverless AVs shows that people, in general, were not interested in AVs without steering wheels (Model 4.6). The covariates of this assessment showed that concerns about AVs' safe and secure operation compared to human drivers, and concern about AVs' quick reaction in accidents reduced people's interest in driverless AVs. However, Laan and Sadabadi (2017) represent that AVs will have quicker reaction times than human drivers. Therefore, concerns about AVs' quick reaction might resolve if AVs can prove such capability. In general, interest in driving AVs and feeling safe and secure about AVs operation were statistically correlated (Model 4.7). Those who were not interested in driverless AVs believed AVs would not be safer and more secure than human drivers, and they did not feel safe and secure about AVs' quick reaction in accidents.

Also, concerns about recording data had an extreme and negative impact on interest, since the majority of respondents did not accept AVs' recording of data because of concerns about the privacy of data (Model 4.8). However, respondents who believed in the safe operation of driverless AVs were more likely to agree that AVs should record data, and so they were more likely to have an interest in purchasing AVs when the technology is fully developed than were the people who felt not at all safe and secure in driverless AVs. The correlation between the concern about the privacy of data and data recording is confirmed by the current study, as is the fact that privacy concerns have an impact on the agreement or disagreement with AV's recording data. Such concern about recording data could affect users' interest in and acceptance of AVs on public roads. The concerns about the recording data, type of stored data, availability of data and tracking individuals' locations were previously indicated by Rose (2017), Heaps (2016), and Fagnant and Kockelman (2015).

The evaluation of people's perceptions about driving with TVs and AVs under the same driving conditions showed that people, in general, were slightly more concerned about driving with AVs than TVs (Table 4.25). This statement validates the results of studies conducted by Schoettle and Sivak (2014c) and Vallet (2013) that AVs might not be as safe and secure as human-driven vehicles. However, since the focus of the current study was not on the evaluation of driving conditions, more investigation in this regard would be necessary to evaluate multiple driving scenarios.

The willingness to accept AVs' liability was assessed through three evaluations: interest in driving AVs (Model 4.9), trust in AVs to be safer and more secure than human drivers (Model 4.10) and feeling safe and secure about AVs' quick reaction in accidents (Model 4.11). In general, a review of all the analysis showed that 57.3% of people on average were not at all willing to accept liability for AVs. Even the majority of the people who had an interest in driving AVs, those who believed AVs would be safer and more secure than human drivers, and those who believed in AVs' quick reaction in accidents still had a very low willingness to accept the responsibility for the AV. Legal liability was also one of the main concerns in many public surveys such as Kyriakidis et al. (2015), Schoettle and Sivak (2014a, 2014b), Howard and Dai (2014) and KPMG (2012a). An average of 75% of the people in those studies were concerned about legal liability and that there is a need for completed regulatory frameworks in this matter.

The correlation between interest in driving AVs and in purchasing AVs (Model 4.12) shows that the extreme interest in driving AVs could affect decisions regarding purchasing AVs, with most of the respondents who were extremely interested in driving AVs having a tendency or – for the majority – an extreme tendency to purchase an AV. Also, the perception of users as to whether AVs are safer and more secure than human drivers could substantially impact users' decisions to purchase AVs (Model 4.13). People who were not at all willing to purchase AVs believed AVs are not at all safer and more secure than human drivers. Such an opinion was also verified from the other side, in that those who did not believe in AVs' safe and secure operation were not willing to purchase AVs, which shows the correlation of the two variables. Furthermore, the study shows that extreme concern about AVs' quick reaction can reduce likeliness to purchase an AV (Model 4.14).

Regarding the most important parameters that affect users' willingness to purchase AVs, a backward linear regression was conducted (Model 4.15). The results showed that 'purchasing AV if the cost is not an issue' is the variable that most substantially affected users' decisions about purchasing an AV. Also, 65% of the participants in the public survey conducted by Howard and Dai (2014) considered the cost to be a substantial concern regarding the adoption of an AV which verifies the results of this study in this regard. After cost, 'interest in driving AV', and 'AVs' safer and more secure operation comparing to human drivers' were the next two most essential parameters affecting the decision to purchase AVs.

The survey of this study showed that interest in driving AVs and WTP for these vehicles are related, as those with a higher interest in driving AVs had a higher WTP and vice versa (Model 4.19). Also, results indicated that nearly 43% of the participants had below USD 5,900 WTP in addition to the base price of the same vehicle in the traditional mode. Therefore, the average payable price for those 43% for one of the vehicles in Table 4.40 is around USD 65,377 which far below the estimated price of an AV (USD 150,000) in 2012 (Howard and Dai, 2014; KPMG, 2012b; Priddle and Woodyard, 2012). Also, the public survey by Liu et al. (2019) revealed that around 26% of the participants would be unwilling to pay extra for AVs and approximately 40% would be willing to spend more than USD 2,900. Additionally, the reviewed studies show that the average WTP to add full self-driving automation is around USD 5,500 which is far below the estimated price of an AV which is also in line with the results of the current study.

The study also showed that with an increase in age, the WTP for AVs shrank, with the age range of 18–25 having the highest WTP with respect to the number of participants in its group (Model 4.20). The WTP then decreased gradually as the age increased. Also, a gender evaluation showed that women, in general, had a slightly greater WTP above 20% over the base price of a traditional vehicle than did men in this regard (Model 4.20). However, the public survey conducted by Bansal et al. (2016) recorded a higher WTP for men than in.

The assessment of the purchase option between private AVs and ridesharing AVs (Model 4.16) showed that feeling safe and secure about AVs' operation substantially affected users' opinions about purchasing private AVs. Also, those who felt safe and secure in an AV without a steering wheel were more likely to purchase an AV even if ridesharing AVs are provided. In addition, level of interest had a substantial effect on the decision to purchase private AVs, as those who had an interest in driving AVs were more likely to buy private AVs even if ridesharing AVs were provided. Results indicated that women, in general, were less likely than men to purchase private AVs and that women seem to be more interested in ridesharing services (Model 4.16). In general, it seems that people had a slightly greater preference for ridesharing AVs as a solution to their mobility concerns. However, for men in general, and for those who were interested in driving AVs and those who felt safe and secure in driverless AVs, the private AV was a favourite choice.

The assessment relating the mobile phone version and interest in purchasing AVs (Model 4.17) showed that not all those who had a mobile phone that was the latest version at the time of purchase were extremely likely to purchase an AV as well. However, it could be interpreted that people who were more likely to purchase AV were also more likely to have the latest version of their mobile phone, which could be an indication of interest in smart technologies. However, it is worth noting that the cost of technology and people's budgets also influence their decisions about buying the latest technologies. Besides, participants on average liked smart technologies, and they showed a tendency to buy AVs (Model 4.18). People who had an excessive tendency to purchase AVs had a high interest in smart technologies, meaning that interest in intelligent technology and a propensity to buy AVs were highly correlated. Also, the results confirmed this by showing that those who did not have an interest in smart technology also did not tend to be interested in purchasing an AV.

The assessments in this Chapter revealed the source of many concerns of the public and their perception of AVs. Also, people's interest in driving AVs, their willingness to adopt these vehicles have been evaluated along with individuals WTP for AVs. However, some concerns regarding the technical impacts of the application of AVs on public roads' traffic, safety, security and some other aspects remained unanswered since they were out of the scope of the public knowledge. Therefore, Chapter 5 seeks to address the technical impacts of the adoption of AVs in such areas (traffic, environment, and some others) using an expert survey in this regard.

5. EXPERT SURVEY

5.1. Introduction

This Chapter presents an assessment of the technical concerns around the application of AVs and their potential impact on road transport from an expert point of view. In this context, this Chapter describes the expert survey conducted for this research with the help of specialists in fields relevant to AVs. A copy of the survey questionnaire is available in Appendix C (C2) for review. The results from this Chapter address the possible concerns related to AVs in terms of traffic, the environment, safety, security, technology, and some other associated elements. In this regard, Section 5.2 presents an overview of the socio-demographic characteristics of the survey. Section 5.3 presents the overall opinions regarding the adoption of AVs on public roads along with the feedback and comments recorded by the experts of this survey. In addition, Section 5.4 presents an analysis of the results of the survey including response summaries for each question, expert opinions from each group and some statistical analyses, which were conducted on SPSS to make sure the results were valid. Finally, Section 5.5 discusses the key findings of this Chapter.

5.2. Overview of the Socio-demographic Characteristics

In total, 325 responses were collected through the online survey platform of Survey Monkey. Table 5.1 demonstrates the characteristics of the survey sample. The responses in the survey were checked for completeness, and those participants who had not answered one of the technical questions of the survey were removed. Of 325 responses collected in this survey, 301 of them were completed all of the questions. Academia and private sectors having the highest participation rate of 44.5% and 43.9% of total answers, respectively. There were also participants from the government and road authority sections by 9.6% and 2%, respectively.

Furthermore, 72.1% of the total participants had expertise in one of the areas related to transportation sciences, including transport engineering, modelling, planning, environment, policy, economic, and other related fields. The other 27.9% were from the Behavioural and Social Sciences, Civil Engineering, Electronic, Mechanical, and Computer Engineering fields. Table 5.1 demonstrates more details in this regard.

Moreover, the demographics illustrate that around 56.6% of the total number of experts had above ten years' experience with 30.3% having above 20 years' experience. By far the highest number of participants were from Europe at 70.8%. Then, there were experts from North America, Asia, and Australia at 15.6%, 8.0%, and 4.3%, respectively.

Table 5.1. Characteristics of the expert survey sample

Characteristic	**%**	**N**
Segment of profession		
Academia	44.5	134
Private sector or Industry	43.9	132
Government	9.6	29
Road authority	2.0	6
Total	100.0	301
The main area of expertise		
Transportation (All fields)	72.1	217
Behavioural and Social Sciences	11.0	33
Civil Engineering	9.6	29
Electronic Engineering	3.3	10
Mechanical Engineering	2.3	7
Computer Engineering	1.7	5
Total	100.0	301
Experience in the field		
Above 20 years	30.3	91
10 – 20 years	26.3	79
5 – 10 years	24.7	74
3 – 5 years	11.3	34
1 – 3 years	7.3	22
Total	100.0	300
Continent of residence		
Europe	70.8	213
North America	15.6	47
Asia	8.0	24
Australia / Oceania	4.3	13
Other	1.3	4
Total	100.0	301

The groups for this survey aimed to address perceptions and acceptance of AVs from differing segments of the relevant professions, including designers, planners, policymakers and individuals working in any other business related to AVs.

5.3. Overall Opinion and Acceptance

The results in this Chapter have explained the concerns, perceived benefits and adoption impacts of AVs on public roads. The experts' views have been presented, and statistical assessments conducted to make sure the results are significant. This Section represents the overall opinions of the experts taking account of every relevant aspect and addressing their overall opinions based on their answers to the survey questions. The contents of this Section explain the overall results about:

- AV liability
- Experts' support for shared or private AVs
- Experts' opinions on the adoption of fully driverless AVs or AVs with a steering wheel and manual control
- Overall opinions about whether AVs should be adopted for highway transport and if yes, under what conditions

Moreover, a word cloud of the comments and feedback from the survey will be presented, addressing the topics highlighted by the experts in this survey.

5.3.1. Liability

This Section provides insights into the overall opinions on which group or agency should accept the highest liability in case of an accident involving an AV. The experts were allowed to choose multiple responses in this context.

As shown in Table 5.2, around 69% of the experts believed that 'AV manufacturers' should accept the highest liability for AVs in accidents. The second most popular answers were 'insurance company' and 'AV owners' at 24.7% and 19% of the participants, respectively.

Table 5.2. Overall opinions about the responsible agency, which should accept the highest liability in case of an accident involved with an AV (multiple responses allowed)

Variable	**%**	**N**
AV manufacturers	69.0	207
Insurance companies	24.7	74
AV owners	19.0	57
Legal authorities	12.3	37
Other responses	10.7	32
Local traffic control centres	8.0	24

Here are also the most common quotes provide in the "other" responses, which are the direct quotes from the experts:

- "This is highly dependent on the operational framework of AV. I would equate the responsibilities to those currently seen in the aviation industry - where accident investigation determines responsibility, especially when AV should have a vast amount of supporting evidence data."
- "Responsibility is an interesting word in this context. It MUST depend on circumstances and Case Law in the Courts"
- "Like discussed in UK single-organisation (e.g. by one and only one insurance company and not many)"
- "There may need to be a total rethink on how liability and recompense is handled"
- "Depends on the degree of control of the vehicle - if it's controlled as part of a fleet or under central Coop system"
- "The technology developers, those who invent this and propose that it works"
- "Depends whether the accident is with another AV vehicle or not. As is the case now, I think it will be for insurance companies to analyse data from the AV to understand where the fault lies (technical failure, user error, external factor that couldn't be forecast by software programmer) Unless the law changes with regard to AV and vehicles become truly AV without any driver intervention at all then I'd say it should be the AV owner as they will have responsibility for reacting to external factors or technical failures."
- "Depends on the nature of the accident as well as the main prevailing business model, which is still highly uncertain (Private vehicles? Corporate fleets? Taxi companies? State owned fleets?)"
- "Entirely depends on context"
- "This depends on the accident - if it was a total system failure then the manufacturer - if it is an issue where the 'driver' should be expected to take control, then the driver"
- "It would depend on how much control the owner had over the behaviour of the car. If they had the power to determine whether, for example, in a situation where the car has to choose between the safety of its occupant and a passerby, the car should choose the owner or not, then they should also carry greater liability. If not, then the manufacturer. Also, it should depend on the cause of the accident - if it was a mechanical issue, then obviously the manufacturer should carry the greatest liability."
- "How about the users? I suppose that AV manufacturers includes their contractors such as software writers"
- "Depends on the situation"
- "The 'driver' of the car responds of damage to human lives as it happens now (he can choose to intervene)"
- "Driver"
- "Depends on the accident"
- "Responsibility to the user, society, victim etc are all different and all need managed - insurance companies offer a promising business model to manage accountability involving all of the partners but would be mainly responsible for this management function rather than any actual liability"

- “Determining this in court will be expensive and difficult and I think we'll have to go towards a no-fault solution”
- “IT and Network connection supervisors”
- “Specifically in the case of Level 5 vehicles, the autonomy of the vehicle must be assured by the vendor (i.e. AV Manufacturers). You can't very well place the responsibility for a train derailment on the passengers”
- “Government will need to be involved initially, but ultimately the manufacturers should be responsible to the extent that "factory settings" cannot be changed. If owner can customize the settings (e.g. to prioritize safety of vehicle occupants over that of pedestrians/cyclists), then s/he should share liability.”
- “Impossible to answer. Owners need to maintain their vehicle, authorities need to have a certain standard of infrastructure deployed, vehicle needs to be fit for purpose, traffic systems need to be designed appropriately and insurance companies will ultimately foot the bill when something goes wrong (we assume they will). Too many variables so everyone is responsible at this time.”
- “Depends of the level of autonomy”.

Furthermore, an investigation was conducted on group opinions regarding the acceptance of AVs’ legal liability in accidents. In this context, around 75% of the experts from the academic sector believed that AV manufacturers should accept the highest liability. Then, the experts from the government and private sectors were the two next most likely groups to agree with academia in this context at 66% and 64%, respectively. The road authority group – at 33% - showed the least amount of agreement with this suggestion, but it is worth noting that the road authority group had the smallest number of participants. Regarding the results related to insurance companies, 28% of the experts from government, 26% from private sectors, and 24% from academia indicated that insurance companies should accept the second-highest liability for AVs after AV manufacturers. Table 5.3 illustrates the results of the group analysis with more information about group percentages and the number of experts in each group.

Table 5.3. Breakdown of the response regarding the agency, which should accept the highest liability for AVs

Group	Government		Road authority		Academia		Private Sector		Total	
Participants	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**
AV owners should accept the highest liability in case of an accident involved with an AV										
No	86.2	25	50.0	3	82.1	110	80.3	106	81.1	244
Yes	13.8	4	50.0	3	17.9	24	19.7	26	18.9	57
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Legal authorities should accept the highest liability in case of an accident involved with an AV										
No	96.5	28	83.0	5	86.6	116	87.1	115	87.7	264
Yes	3.5	1	16.7	1	13.4	18	12.9	17	12.3	37
Total	100.0	29	99.7	6	100.0	134	100.0	132	100.0	301
AV manufacturers should accept the highest liability in case of an accident involved with an AV										
No	34.5	10	66.7	4	24.6	33	35.6	47	31.2	94
Yes	65.5	19	33.3	2	75.4	101	64.4	85	68.8	207
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Insurance companies should accept the highest liability in case of an accident involved with an AV										
No	72.4	21	100.0	6	76.1	102	74.2	98	75.4	227
Yes	27.6	8	0.0	0	23.9	32	25.8	34	24.6	74
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Local traffic-control centres should accept the highest liability in case of an accident involved with an AV										
No	86.2	25	83.0	5	96.3	129	89.4	118	92.0	277
Yes	13.8	4	16.7	1	3.7	5	10.6	14	8.0	24
Total	100.0	29	99.7	6	100.0	134	100.0	132	100.0	301

As shown in Table 5.2, around 10.7% of the participants indicated ‘other responses’. For instance, a substantial number of participants declared that assigning legal liability for AVs in the case of accidents would depend on the nature of each accident and its situation. The experts believed an investigation would be required in each case into the vehicles, occupants of the AVs and non-AVs and other road users, if any, involved in those accidents. Some participants believed that AV manufacturers should accept liability, and some others believed the operator or whoever was driving the AV (not necessarily the owner) should accept liability. Figure 5.1 illustrates the word cloud for the ‘other’ responses in this assessment with the top five repeated keywords in the comments.

Figure 5.1. Other answers for the agency, which should accept the highest liability

5.3.2. On-demand Ridesharing for AVs

The experts in the survey were asked how likely they would be to support an on-demand ridesharing service for AVs such as an AV-Uber[1] rather than the application of private AVs. In total, 301 experts answered this question, with 54.2% of them declaring they would be 'extremely likely' to support such a ridesharing AV service. Around 24.3% declared they would be 'somewhat likely', and approximately 21.6% indicated that they would be 'not at all likely' to support such a service. Table 5.4 illustrates the results of this investigation.

Table 5.4. Overall opinions about supporting on-demand ridesharing AVs rather than the application of private AVs

Variable	%	N
Not at all likely	21.6	65
Somewhat likely	24.3	73
Extremely likely	54.2	163

Furthermore, the investigation into group opinions indicates that the highest support for an on-demand ride-sharing service was given by 25.6% of the total participants in this assessment who were from the private sector (58.3% within private sector). The second-highest amount of support was from experts from academia at 22.9% of the total

[1] AV-Uber could be a ridesharing service like what Uber provides but with AVs.

participants (51.5% within Academia) in this evaluation. The government sector was the next most likely group to supported ride-sharing AVs at 4.7% of the total participants (48.3% within the government sector), while only 1.0% of the total participants (50% within road authority) were 'extremely likely' to support such a service. In general, support for ridesharing AVs in the private sector was slightly higher than in academia. Nevertheless, the academic group had overall support of 44.5%, which is marginally higher than for the private sector at 43.9%. Therefore, it can be asserted that academia had the highest tendency to support on-demand ridesharing AVs. Table 5.5 demonstrates the results of the group analysis in this context.

Table 5.5. Breakdown of the opinions about supporting on-demand ridesharing AVs rather than the application of private AVs

Group		Government		Road authority		Academia		Private Sector		Total	
Participants		%	N	%	N	%	N	%	N	%	N
Not at all likely	WG*	34.5	10	33.3	2	18.7	25	21.2	28	21.6	65
	WT**	3.3		0.7		8.3		9.3		21.6	
Somewhat likely	WG*	17.2	5	16.7	1	29.9	40	20.5	27	24.3	73
	WT**	1.7		0.3		13.3		9.0		24.3	
Extremely likely	WG*	48.3	14	50.0	3	51.5	69	58.3	77	54.2	163
	WT**	4.7		1.0		22.9		25.6		54.2	
Total observations	WG*	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
	WT**	9.6		2.0		44.5		43.9		100.0	

* WG: Within Group
** WT: Within Total

5.3.3. Supporting AVs With or Without a Steering wheel

The experts in the survey were asked which type of AV they would recommend: 'an AV with a steering wheel and manual override control system' which allowed the driver to take over control of the vehicle at any time and in any condition or 'an AV without a steering wheel' – a fully driverless AV which conducts all the driving procedures by itself. It should be noted that, according to SAE (2016), both levels 4 and 5 AVs might be equipped with a steering wheel and therefore fully autonomous driving does not necessarily relate to the presence or absence of a steering wheel. However, the question in this survey aims to address the level of concern, which might be linked with AV drivers by removing the steering wheel from the vehicle. Moreover, it is essential to note that choosing multiple responses was allowed in this assessment.

The results, in general, revealed that around 56.3% of the experts would support 'AVs with a steering wheel and manual override control system'. The group assessment in this context represents that the experts from the road authority – at 67% – represented the most likely supporters of AVs with a steering wheel. Excluding the road authority group – as it had only six participants – the next most likely group to support AVs with a steering wheel was academia at 61%, followed by the government and private sector at 55% and 52%, respectively.

Furthermore, around 40.7% of the total participants supported 'AVs without a steering wheel'. The experts from the private sector represented a sizable number of supporters of such an AV type at 45.5% of the participants, followed by the government sector at 41.4%. The results revealed that academia was not a great supporter of AVs without a steering wheel. Table 5.6 illustrates a summary of the responses to this assessment. Additionally, Table 5.7 shows the results of group analysis for this evaluation.

Table 5.6. Overall opinions about the supported type of AVs (with or without a steering wheel)

Variable	%	N
An AV with a steering wheel and manual override control systems	56.3	169
An AV without a steering wheel	40.7	122
None	3.0	9

Table 5.7. Supporting AVs with or without a steering wheel

Group	Government		Road authority		Academia		Private Sector		Total	
Participants	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**
AV with steering wheel	55.2	16	66.7	4	60.9	81	51.5	68	56.3	169
AV without steering wheel	41.4	12	33.3	2	36.1	48	45.5	60	40.7	122
None	3.5	1	0.0	0	3.0	4	3.0	4	3.0	9
Total observations	100.0	29	100.0	6	100.0	133	100.0	132	100.0	300

5.3.4. Overall Opinion

Finally, in this survey on the future use of AVs on public roads, the experts were asked to indicate their ideal statement, to sum up their opinion regarding the application of AVs. The answer options provided (for the experts) in this assessment are defined based on the insights gained from the pilot survey (see Chapter 3, Section 3.3.2) and the researcher's personal experience. However, the survey question was designed as open-ended so the experts in order to provide the experts with the opportunity of adding any other options and overall opinion.

In total, 301 experts took part in this evaluation, with 53.8% of them indicating that 'a lot more investigation and preparation is needed before AVs' adoption on public roads'. Such an answer also demonstrates that the experts were not 'opposed to AVs ever being allowed on public roads', but they would not support the adoption of AVs until further investigations have demonstrated their safety, security and efficiency. The breakdown of the results reveals that the most substantial number of experts who supported this statement were from academia at 25.7% of the total number of participants. The next most likely group to support this statement was the private sector at 23.0%, while the government and road authority groups were the next most likely groups to declare 'more R&D [is] required' at 4.3% and 1.0%, respectively.

Furthermore, 25.3% of all the participants in the study declared that they were concerned about safety, security, and hacking threats, but they would like to try AVs. The results of the group analysis demonstrate that the experts from the private sector and academia were supporters of such an idea at 11.0% and 10.7% of all participants, respectively.

Table 5.8 illustrates a summary of the responses in this assessment and Table 5.9 provides a breakdown of the group responses in this regard. Additionally, Table 5.9 shows the results of group analysis in this evaluation.

Table 5.8. Overall opinion regarding the future use of AVs on public roads

Variable	%	N
A lot more investigation, research and development are needed before AVs' adoption on public roads. Therefore, I am not opposed to AVs, but I would not support their adoption without further investigations to approve their safety, security and efficiency.	53.8	162
I am concerned about safety, security and hacking threats but I would like to try AVs.	25.3	76
The science and industry of AVs are doing very well. Therefore, I have no concerns about adopting AVs.	10.3	31
Other	9.6	28
I am opposed to AVs ever being allowed on public roads in any condition.	1.0	3

Here are also the most common quotes provide in the "other" responses, which are the direct quotes from the experts:

- "A lot more investigations and preparation needed before AVs' adoption for public use. This might be on certain kinds of public roads, but I see the main application being in special environments"

- "AV-development is too much vehicle-driven, other modes of traffic (bikes, pedestrians) are considered too less"
- "AVs are the future. Delays in training and implementation of the AVs (due to political / societal reasons) will have a negative effect on safety and efficiency in the long run."
- "AVs require more research and testing, and they require more efficient road pricing so they do not increase urban traffic problems."
- "AVs should only be introduced in a proper thought out and tested regulatory framework"
- "AVs will be beneficial on multi-lane highways with no frontage interference. They could be severely counter-productive in an urban context (emissions, kilometrages, congestion, street-level ambience/ environment)"
- "Connected Vehicles at scale are needed before Automated Vehicles can gain wide adoption, public roads need to build out Connected Vehicle Infrastructure."
- "For technology to work - it must be fully understood by the user, poor handover to customers is legendary, and Jevons paradox shows this in abundance. Caution as the technology will NOT be adopted in the way that technologists expect."
- "Further investigations are definitely needed, especially with regard to safety, however there needs to be greater consideration of the operating environment and how AV will be integrated into the current (or then current) vehicle fleet"
- "Human has many degrees of freedom, how he/ she can do/ operate things/ car. Therefore a safe AV must understand human actions and human factors. However this is currently scarcely considered when developing such vehicles, as it is still technological. This needs to be solved, understood and applied first by system developers, and more human factors expert must be integrated into the software development approaches to create really truly safe AV."
- "I am concerned of a future of privately owned, "dynamically parked" (circulating empty while waiting for owner) AVs with person miles growing and vehicle miles exploding leading to grid locked cities suffocated by such a 'mobility' system."
- "I believe there are strong benefits from having AVs on our roads however these could be outweighed by the negative consequences of losing low skill jobs. There are also valid hacking a security concerns."
- "I fully support AVs but only if introduced as part of a regulatory framework which manages ownership, operation, access to vehicles, etc."
- "I have already tried AVs. The biggest issue is one of trust in the system to perform all the time. Also I would add the lack of control."
- "I think AVs are strong ethical, safety and robustness concerns at the moment. Besides, it is a myth that AVs will increase infrastructure capacity."
- "I think that we are a long way from having true AV on our roads, there are too many external factors that only a human can respond to. It will be so complicated to change road laws to allow for AVs, it'll have a huge impact on highway design, particularly in urban areas. However I think semi AV will be the norm very soon and will provide huge efficiencies particularly for freight movement on motorways for example."
- "I think the safety concerns over AVs and the issues surrounding legal liabilities will be problematic. But I can't even see a reason for introducing them unless people are willing to move to a shared model of ownership. If this doesn't happen they will just increase congestion and empty VKMs."
- "More government driven research and initiatives needed in order to prepare the industry, road users and the road network for the future with AVs. Too much has been left to private sector to push this technology though."
- "Not enough work has been done on the cost of rolling out AVs to those who are digitally isolated or poor"

- "Not opposed to AV's compared to regular vehicles, but opposed to motorized vehicles in town centres"
- "The key question is ownership. If AVs are communally owned they could be substantially beneficial to society. If they are privately owned they could increase traffic, congestion, emissions and create disbenefits for society as a whole."
- "The legal framework still needs to be established."
- "The safety benefit is the most convincing reason to adopt AVs; however, these may only be realised if AVs make up a significant portion of the fleet. There are so many challenges associated with entry to the market that it is difficult to know the fleet proportion that is possible."
- "The science and industry of the AVs are doing very well. So, I have no concern to adopt AVs except SAE "
- "They will come in bit by bit and we will accept it"
- "Would support Levels 3, 4, and above, but mostly keep them in a closed system, not free ranging on the road"
- I am concerned that AVs will lock in unsustainable car-dependence".

Table 5.9. Breakdown of the overall opinion

Breakdown of the overall opinion regarding the future use of AVs							
Which one of the following statements best sums up your opinion regarding the future use of AVs on public roads?			Where do you work for?				Total
			Government	Road authority	Academia	Private Sector	
Statement	No concern to adopt	Count	1	1	13	16	31
		%WS*	3.2	3.2	41.9	51.6	100.0
		%WG**	3.4	16.7	9.7	12.2	10.3
		%WT***	0.3	0.3	4.3	5.3	10.3
	Concerned but would like to try AVs	Count	10	1	32	33	76
		%WS*	13.2	1.3	42.1	43.4	100.0
		%WG**	34.5	16.7	23.9	25.2	25.3
		%WT***	3.3	0.3	10.7	11.0	25.3
	More R&D needed	Count	13	3	77	69	162
		%WS*	8.0	1.9	47.5	42.6	100.0
		%WG**	44.8	50.0	57.5	52.7	54.0
		%WT***	4.3	1.0	25.7	23.0	54.0
	Totally against AVs	Count	0	1	1	1	3
		%WS*	0.0	33.3	33.3	33.3	100.0
		%WG**	0.0	16.7	0.7	0.8	1.0
		%WT***	0.0	0.3	0.3	0.3	1.0
	Others	Count	5	0	11	12	28
		%WS*	17.9	0.0	39.3	42.9	100.0
		%WG**	17.2	0.0	8.2	9.2	9.3
		%WT***	1.7	0.0	3.7	4.0	9.3
Total		Count	29	6	134	131	300
		%WS*	9.7	2.0	44.7	43.7	100.0
		%WG**	100.0	100.0	100.0	100.0	100.0
		%WT***	9.7	2.0	44.7	43.7	100.0

* WG: Within Statement
** WG: Within Group
*** WT: Within Total

Figure 5.2 illustrates the word cloud for 'other' responses in this assessment, suggested by experts among which 'requirements of AVs' was the most substantial issue regarding the application of AVs. In this context, a substantial number of the answers outlined that the experts would support the application of AVs on public roads if some requirements are met. The requirements experts outlined included but were not limited to 'infrastructure development', 'technology development', 'safety measures', 'improvement in juridical issues' related to the use of AVs, providing comfortable conditions for 'vehicle ownership', and some others. Among other important topics that experts talked about, there were safety, concerns, AV users, and the requirements for the adoption of AVs.

Figure 5.2. Other responses regarding the future use of AVs on public roads

5.3.5. Feedback and Comments

The final section of the survey asked participants to give any additional comments regarding the application of AVs. Note that nearly all the questions in the survey were open-ended, and therefore, comments had already been provided for each question. Nevertheless, such a comments section provided an opportunity for the experts to represent any further statement and overall opinion they may have about AVs.

The most important topic discussed by the experts was related to the safety of AVs, AV-occupants, and the safety of pedestrians and people around the vehicle. Many of the experts highlighted the safety benefits mentioned in the survey, and some outlined the safety risks and concerns. Some declared AVs could improve road safety, and some indicated the opposite opinion. In general, safety was an essential topic in the comments section. Alongside safety, there were comments related to the technology of AVs, the privacy of AV-occupants, and security breaches and hacking, which might reduce safety by creating dangerous driving situations or accidents. Figure 5.3 shows the word cloud of feedback and comments.

Moreover, some experts focused on the topics related to traffic congestion, outlining that AVs might increase traffic congestion and reduce capacity due to an increase in the number of unnecessary trips and the fact that mobility would be increased for those who cannot drive already. However, some experts believed that AVs might make better use of the road capacity by providing smoother traffic flow at intersections.

In general, the discussion was more focused around safety concerns and traffic congestion, revealing that these two topics might be the most concerning issues for experts regarding the future use of AVs on public roads. Note that the experts had already mentioned security concern as the most concerning consequence of the adoption of AVs and the comments in the final section of the survey were complementary to the main responses.

Figure 5.3. Overall feedback and comments

Here are also the most common quotes provide in the "other" responses, which are the direct quotes from the experts:

- "AVs will be on roads sooner than automated highways or lanes (AH/L, I believe. If both are achieved, then the system (AV+AH/L) will be much safer, more convenient, and yield more throughput with less environmental effects. But, one more concern I have is that if AVs become so attractive, public transportation will be less preferred because older people and individuals without a driving license can ride it. Saying that, can AVs be used by people without a valid driving license?"
- "Although I think AV's are inevitable. My major concern is the security (e.g., hacking) and privacy issues. I expect short term issues to prevail during their adoption. In overall, I strongly believe that the AV's may completely alter our travel patterns and trip characteristics. One such example would be a trip may combine two activities together, you might binge-watch a new movie while you're travelling (home trip + leisure activity) or you might have a video conference while you are travelling (work trip + business activity)."
- "Autonomous vehicles are a technological advancement however, I am of the view that it is premature to do a complete rollout as much work needs to go into ensuring safety across all manufacturing brand types. More research and testing is required as well as the viability in African markets"
- "AV will undoubtedly enter the transport stage. The timescale presented by the industry today is quite challenging and a little bit commerce-driven. It will take at least until the mid-20ies to really see significant appearance."
- "AV's a coming. It's just when and where. There are still many issues to be resolved but technology will continue to evolve to a point we will have Level 5 in operation someday in the future but understanding and resolving liabilities is key to this."
- "AVs are good in countries where people strictly follow lane discipline. The gravity of problem in case of system failure need to be assessed properly."
- "AVs will need proper due diligence to garner regulatory approval, insurability and public acceptance but they are inevitable and necessary for safety reasons."
- "CAV adoption is upon us - it's the intermediate stages with mixed traffic that will cause most problems, not 100% adoption."
- "Concerns about moving to AV predominantly surround the semantic understanding of the objects around the car, while a human driver could choose to crash and injure themselves, a passenger would not have that ability if the car was driving itself."
- "For AVs to be able to stop and avoid incidents, in mixed traffic environments (like urban), they will need to go much more slowly than conventional vehicles, so travel time and congestion will increase. If most or all vehicles are AVs, then pedestrians and cyclists will have no more incentive to take care on the roads (use pedestrian crossings etc.), they can just go anywhere knowing that they will be safe because AVs will stop or avoid them. This could cause gridlock in urban areas. So they can only work if other road users treat them like they treat conventional vehicles now. e.g., if I knew all vehicles on the 4 lanes urban highway outside my office were AVs, then I could just walk across it to the shops without looking or using a pedestrian crossing because I know they will all stop for me. If hundreds of people an hour do that in cities, then traffic will not move at all."
- "I am not sure how the drivers will feel when they use a full AV without a steering wheel. I think this question worth investigation in a similar survey but for drivers"
- "I am wondering if we have lost track of the problem we are trying to solve by blindly applying technology. AVs make most sense for commuting and freight, but commuting requires more than just automation, it requires space efficiency also known as public transport. So I see most potential in automated public transport and freight movements."
- "I believe that data sharing and testing standards need to be codified and strictly enforced before Level 4-5 AVs start to be rolled out en masse to the public. I think the public discourse right now is full of speculation and the seriousness is not

communicated that well. I think this dialogue needs to be led by AV developers, then regulators, and then experts closely after that"

- "I do not think AVs will ever replace conventional vehicles since there is both a love of car ownership and car driving amongst the general, non-academic, population that academia is failing to either acknowledge or respond to."
- "I have no real concerns with the inevitable use of AVs but they must be autonomous, that includes 'self-sufficient', that is able to operate on public roads as they are without additional infrastructural demands on public resources. Being hacked is also a real risk but in terms of cybersecurity, traffic management centres are an easier target through external hacking or latent hacks built into operational software by suppliers..."
- "I have three main concerns about AVs: 1) Transition period: how will it work? 2) Economic impact: from drivers to vehicle maintenance people, there will be a substantial loss of jobs. Society needs to manage this carefully. 3) Ownership models: If AV's are privately owned they will only benefit a part of the population and increase traffic, congestion and emissions."
- "I think there will be market barriers to AVs beyond Level 4. Also, traditional American culture is committed to the individualism of conventional vehicles. This cultural factor could slow adoption of AVs."
- "If empty AVs are on the road picking up dry cleaning, it is unclear what the congestion implications of AVs will be. They stand to vastly increase road capacity."
- "I'm concerned that AVs seem to be largely technology-led with relative discussion of whether they are a good thing or not."
- "In General, I have no major concerns about the technology of AVs. Much of the technology is already in use today. I have concerns about the acceptance and legal ramifications of AVs. In particular, I question the value proposition for private owners. I see AV technology being adopted much quicker in public shared transport such as trams or shuttles."
- "In my opinion, we will have to wait more than two decades for the AV vehicle to become a reality. The projects should involve more specialists in defensive and efficient driving techniques, in the evolution of vehicles, which is not happening, hence the enormous difficulty of evolution."
- "Interesting times ahead. Needs much more policy debate on the role of the technology vs road authorities on responsibility for efficient allocation of capacity between competing interests for road space."
- "It's a long way off; substantial infrastructure investment will be required to make 'place' well defined; manually operated vehicles will always be present in the traffic stream; in special places and situations (e.g., Las Vegas) it seems highly likely that AVs will be implemented."
- "Lack of attention for effects on the road design concept and roadside safety in particular"
- "Level 4 will be dangerous. It skills drivers by doing most of the driving then requires them to either halt the journey or take over control. In a difficult situation, putting an unprepared deskilled person in control is bad. Google for Gartner hype cycle 2018 and see how the l4 autonomy is dropping down the expectation curve and l5 reversing the other way. You may find charting the history of AVs on that curve enlightening."
- "Many false dawns expected. AVs will only realise potential beyond a certain fleet proportion. Danger that this will lead to greater demand for road capacity as non-drivers are potentially able. Hence road pricing will replace fuel taxation/tolling?"
- "Ownership of AV vehicles, Uber-like VA transport, or public transport VA: the choice how to make use of AV vehicles will have a large impact on the road conditions and urban design (e.g. AV vehicles driving around empty)."

- "Regarding AVs, I see a huge difference between the outcome I expect and the outcome I would like. I would like the benefits of AVs in terms of safety, and mobility, but I am deeply concerned about congestion, pollution, and sprawl as an expected consequences."
- "Some stakeholders maintain that participatory processes (everybody needs to contribute and needs to be heard - even if distributed areas of non-knowledge/ignorance) this would not make it easier."
- "The difference between autonomous functions in a vehicle or a driverless is essential. Partly autonomy and inherent safe vehicles will happen. Driverless vehicles will remain to be a marginal phenomena, so much overrated."
- "The main risks relate to the interval leading up to level 5 AV; drivers may not concentrate enough when not driving, to enable them to take control if the AV fails."
- "The progress should be faster in this field"
- "The tech issues may mature to a sufficient level to deliver true autonomy but, like most grand tech and engineering challenges, it will be the social acceptance and application of such a tool that will need far greater thought and effort..."
- "There are many dependencies related to the adoption of AV's and many scenarios when AV's are adopted. I think it will increase road traffic in the long run, therefore 'stealing' shares of cyclists and PT modal shares. Also, depending on how 'green' the AV is, emissions etc are more or less important."
- "We believe that it can be implemented in a very long time and will be used in the future as a public vehicle in dedicated road infrastructures and not as a private vehicle. And especially for inter-city journeys."
- "We may need parallel levels for other roads users particularly the non-motorists. Now with level 3 systems, liability is a complex issue and owner has to assume responsibilities for damage. The society is not ready for AV or even connected. Open field for cyber-attack. Think of how we substitute our smart phones and TVs every 2-3 years for being old and obsolete... how often will I buy board computer to manage the progress and memory needs... 5G, 6G, 7G.... Safer through AV is a claim and needs to be proven. Gradual introduction with mixed mode is a major challenge and no concept for overcome is even close to enlighten this."
- "Will we ever get to 100% market penetration? If not, then how will these vehicles interact with human drivers?"
- I think the infrastructure is not ready and till now not cost-effectively. But should be start"

5.4. Results Analysis

The results of the survey and statistical assessments are presented in this Section. The results are classified into the groups of concerns, benefits, adoption impacts, and overall opinion and acceptance of the adoption of AVs on public roads.

5.4.1. Concerns

Section 5.2 explained the demographics of the participants and provided information about the professional segments which took part and divided participants into groups. This Section represents the results of the survey into expert concerns regarding the adoption of AVs.

5.4.1.1. Response Summaries

This Section provides the response summaries relating to safety and security concerns. In the next two Sections (Section 5.4.1.2 and Section 5.4.1.3), some statistical assessments are undertaken to ensure that the results are statistically significant and valid.

The experts were asked what they think would be the most concerning consequences of adopting AVs; participants were allowed to choose multiple responses. The response summary reveals that security concerns, such as getting hacked and losing control of the AVs, are considered the most substantial concern by 56.2% of the total participants (301 experts). Then, legal liability was seen as the second most substantial concern by 55.5% of the total participants. Safety, privacy, traffic issues and fuel consumptions represent the next level of concern. Table 5.10 represents the response summary.

Table 5.10. Summary of responses regarding the most concerning consequences of adopting AVs

Variable	%	N
Security concerns (such as getting hacked and losing control of the AV)	56.2	169
Legal liabilities (in case of an accident)	55.5	167
Safety concerns	46.8	141
Privacy concerns such as sharing trip data with different agencies (insurance companies, manufacturers, etc.)	33.6	101
Traffic issues such as congestion, queues, delays	20.3	61
Other	13.6	41
Fuel consumption and emission	5.7	17

The survey also allowed experts to provide other concerns in a text box. Here are the most common quotes provide in the "other" responses:

- "A loss of control of the vehicle"
- "Accessibility and use by non-licenced drivers"
- "Adoption of AVs particularly as shared vehicles could lead to significant increases in trips and overall car miles. This could lead to competition for space with public transport. There is often an assumption in cities there is sufficient capacity in the countervailing direction to accommodate the extra trips. This capacity does not exist in London, all approaches are saturated by time of day. Therefore the outcome is more congestion, delay, and competition with public transport for space, with consequences for public authority revenues."
- "AVs' effects on the built environment and on other users of public spaces, in particular pedestrians"
- "Change in safety of all types of road users - e.g. pedestrians, cyclists"
- "Cost of introducing AVs when many people only spend hundreds of pounds on buying a car"
- "Ethics concerns. Algorithms will value human's life differently"
- "Fully autonomous vs a mixed fleet of other users on the network"
- "I think unless people adopt shared usage of cars, they will increase congestion. And electric vehicles need not be automated. I don't see a case for AVs other than a political case - they're

exciting politically. But all the work I have seen so far is based on very dubious assumptions and assertions."

- "Impact on popularity of public transport"
- "Impacts on public transport and active modes"
- "Increased travel demand which might offset capacity increase and lead to further delays as well as additional environmental problems"
- "Increasing road capacity"
- "Interaction with non-AVs and vulnerable road users"
- "Lack of regulation & Infrastructure"
- "Last mile transportation delivery (identify people)"
- "Loss of human autonomy"
- "Loss of low-skilled jobs (e.g. taxi's, and truck drivers etc.)"
- "Mixed fleet issues, consistency in operating guidelines/behaviours between manufacturers"
- "Mixed fleet on same roads"
- "Mixture of AVs and conventional vehicles, also pedestrians, cyclists, animals, etc. How AVs deal with situations like obstructions in the road (stop, go round them, responding to directions of a police officer or other person directing traffic in case of an incident)"
- "More traffic because AV's might be chosen more often than public transport now"
- "Much more car travel"
- "Not considering the uncertainties related to the human-driven vehicles (conventional vehicles) in designing the AVs may cause severe accidents in the mixed traffic of them"
- "Potentially - all of these - main concern for me (for level 5, assuming it is possible) is that it might drive a growth in travel demand that existing infrastructure cannot support."
- "Public acceptance (which would include many of these topics but from a different perspective)"
- "Safety issues, trusting technology"
- "Safety of pedestrians and cyclists, and unaccompanied child occupants (if any)"
- "Societal acceptance of incidences even if overall significantly improved + system shutdown in bad weather"
- "Sprawl, and increase in VMT"
- "Sprawl-related costs and reductions in public transit investments"
- "The clumsiness of over-cautious AV will make them very very unpopular"
- "The combination of AVs and MaaS may result in greater congestion and poor public transport"
- "The integration phase between now and when the entire fleet is made up of AVs. Human driven vehicles may learn to abuse AVs and bully them, and so cause more erratic driving and cause more accidents, and the blame will be put on the AV"
- "The road safety implications for more vulnerable road users"
- "Trust. We're already seeing some people putting entirely too much faith in Autonomy Level 2 vehicles; and at the same time there's a whole other narrative surrounding the 'decisions' a vehicle has to make when engaging in collision avoidance. I hesitate to call this a 'significant' concern however ever it should be mentioned within the scope of the study."
- "Whether the AV network will be centrally controlled (most beneficial for society) or each car will truly be independent"

Figure 5.4 also illustrates a word cloud image of the analysis, which represents the most repeated words in the 'other' answer option provided by participants. In general, some experts expressed concerns about road users' safety and safe interaction between pedestrians and AVs. Some others highlighted the potential negative consequences of adopting AVs on traffic congestion and the need for higher capacity due to an increase in mobility as a result of adopting AVs. There were also some concerns about the cost of travel, safety concerns for cyclists, the interaction of AVs with TVs and pedestrians.

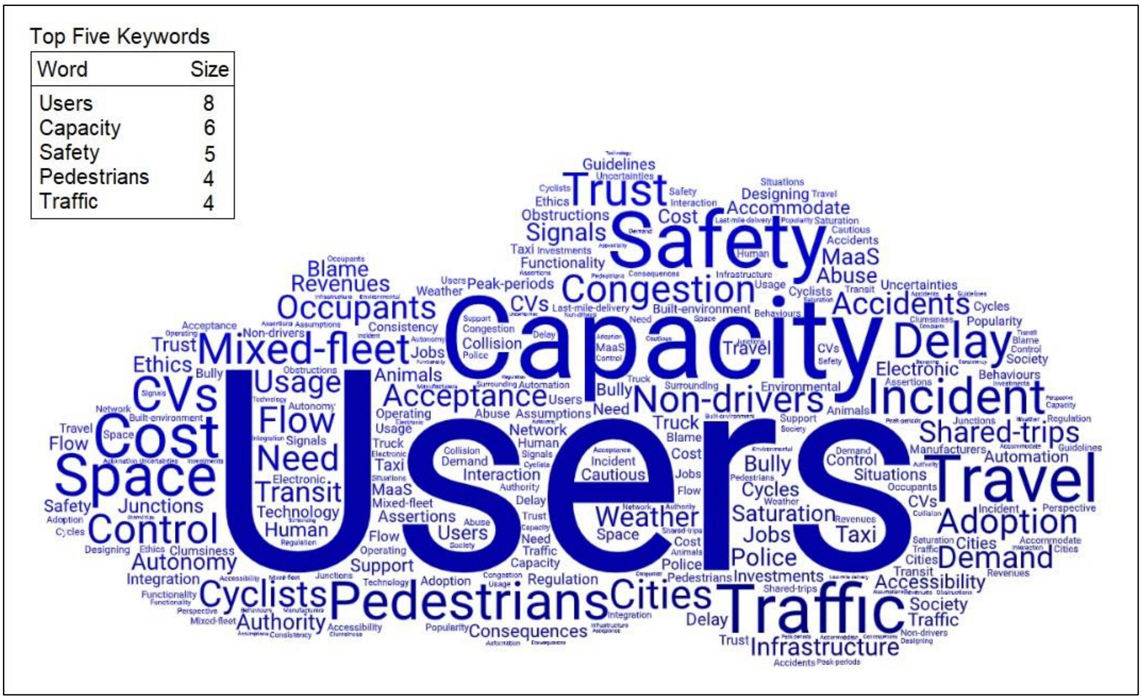


Figure 5.4. Other responses for the most substantial concerns regarding the application of AVs

Furthermore, an investigation was conducted to address group opinions regarding the concerns about adopting AVs. For this purpose, each concern in the assessment was cross-tabbed with groups, and the results are presented in the form of graphs. Such cross-tabulation explains which concern is most substantial to each group. Table 5.11 represents the most substantial concerns of each group regarding the application of AVs. For each security concern in Table 5.11, the percentage and number of participants in each group are provided.

Table 5.11 shows, around 41%–48% of the experts from government, academia, and the private sector believed that safety would be one of the most substantial concerns of adopting AVs. However, only 16.7% of the road authority experts agreed with other groups in this regard. In this context, it is worth noting that the road authority group had the lowest number of participants (6 experts) of all which should be taken into consideration when comparing results. Moreover, around 50%–69% of all groups agreed that security would also be a substantial concern in the adoption of AVs. Privacy was considered more concerning by 50.0% of the experts from the road authority group, while less than 39% of the other groups believed so. Furthermore, legal liability was considered a substantial concern by over 50% of the experts in all groups except road authority. Also, groups' opinion about traffic issues and fuel consumption are available in Table 5.11, but they were not considered substantial concerns regarding the application of AVs.

Table 5.11. The most substantial concerns regarding the application of AVs

Group	Government		Road authority		Academia		Private Sector		Total	
Participants	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**
Safety concerns would be the most substantial concern of the adoption of AVs										
No	58.6	17	83.3	5	52.2	70	51.5	68	53.2	160
Yes	41.4	12	16.7	1	47.8	64	48.5	64	46.8	141
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Security concerns would be the most substantial concern of the adoption of AVs										
No	31.0	9	50.0	3	46.3	62	43.9	58	43.9	132
Yes	69.0	20	50.0	3	53.7	72	56.1	74	56.2	169
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Privacy concerns would be the most substantial concern of the adoption of AVs										
No	65.5	19	50.0	3	61.2	82	72.7	96	66.5	200
Yes	34.5	10	50.0	3	38.8	52	27.3	36	33.6	101
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Legal liability would be the most substantial concern of the adoption of AVs										
No	44.8	13	66.7	4	44.0	59	43.9	58	44.5	134
Yes	55.2	16	33.3	2	56.0	75	56.1	74	55.5	167
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Traffic issues would be the most substantial concern of the adoption of AVs										
No	86.2	25	67.0	4	79.1	106	79.6	105	79.7	240
Yes	13.8	4	33.0	2	20.9	28	20.5	27	20.3	61
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Fuel consumption and emission would be the most substantial concern of the adoption of AVs										
No	96.6	28	83.0	5	91.0	122	97.7	129	94.4	284
Yes	3.5	1	17.0	1	9.0	12	2.3	3	5.7	17
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301

In general, the analysis illustrates that security concerns represented the most substantial concerns regarding the adoption of AVs among 169 experts out of a total of 301; this is verified by the results summary. The next issues examined were legal liability and safety while the negative consequences of adopting AVs on traffic and fuel consumption was not a substantial concern to groups. In this regard, a simulation study could be useful to evaluate such a declaration of experts about the impact of AVs on traffic and fuel consumption.

In another assessment, the experts in the survey were asked to select the most substantial technical concern in the adoption of AVs, where the selection of multiple responses allowed. These technical concerns might stem from any form of technical deficiencies or system failures, which might lead to an unsafe or insecure driving situation or even accidents. Table 5.12 demonstrates the response summary for such an assessment. Additionally, a statistical evaluation (shown in Table 5.29, Section 5.4.3.2) revealed that about 19.5% of the experts in this study thought that AVs would 'substantially increase' the number of accidents. Out of those (19.5%) experts, 32.8% were concerned about safety and security concerns of AVs, which might stem from one of the technical concerns of AVs. Further investigation in this regard is conducted in Section 5.4.3.2.

According to Table 5.12, 'incorrect understanding of the surrounding objects' by AVs was considered the most substantial technical concern in adopting AVs among 68.8% of the total participants. Then, 'sensor failure and system shut down' was identified as the second most substantial concern by 49.8% of the total participants. Furthermore, concerns such as 'limited driving operation by factory-defined settings' and 'not being as good as human drivers' were other substantial concerns.

Table 5.12. Summary of the responses regarding the most substantial technical concerns in adopting AVs

Variable	%	N
Incorrect understanding of the surrounding objects (humans, animals, and others)	68.8	207
Sensor failures and system shut down	49.8	150
Limited driving operation by factory-defined settings, i.e., AV drivers would not be as free as human drivers in driving actions such as speeding up/down, suddenly leaving a queue or merging with traffic and some others	14.6	44
Not being as good as human drivers in quick driving reactions (for example, some people believe AVs might not be fast enough to react when their leading vehicles suddenly reduce their speed)	13.0	39
Other	9.6	29

Here are also the most common quotes provide in the "other" responses:

- "Risk assessment of surroundings and traffic situations; and, over-the-air updates with unknown effects on driving behaviour, making it difficult to keep up with regulations for safe admission on public roads"
- "Ability to 'read the road' could determine reaction time. Connectedness would help"
- "All options listed are pretty much related to the Situation. Awareness of the Vehicle (sensors + computing power to understand and react to the environment)"
- "AVs are limited to software as manufacturer decisions"
- "Being incapable of responding to unanticipated situations, which could be safety critical"
- "Communications and control, finding a common, open standard for operation and data traffic. Admittedly, this might be considered more of a policy problem. But the ones mentioned are too, in the sense that society will essentially be free to agree on a yearly number of people it considers acceptable to be killed by 'machines', to put it bluntly. That number will always be much lower than the current accident statistics"
- "Cybersecurity"
- "Handover of control to the driver if required"
- "Human factors, e.g. human drivers of non-AV's in the traffic stream, but even more so pedestrians learning they can step out into moving traffic and AV's will stop (leading to complete paralysis of road traffic in city centres)"
- "I think the items on the list could all be solved in time - assuming that we had a pure level 5 vehicle fleet. What concerns me most is the unpredictable interaction between CAVs and traditionally driven vehicles, cyclists and pedestrians"

- "If a pedestrian like a kid runs to the street, a human driver may choose to hit another car or curb than hitting the human that obviously would get hurt the most"
- "Lack of ability for an AV to evolve and learn"
- "Operational Design Domains and their limits (as you stated in Sensor failures and system shut down)"
- "Poor handover - you are going to be trusting salesmen. Not understanding the AV technology and how to use it"
- "Programming might be incompatible with wider policies objectives"
- "Security and hacking"
- "Security, being hacked and losing the control of the vehicle"
- "Spoofing issues regarding sensors and communications, in particular for emergency communications"
- "The difficulty of the technology to react correctly to the many variables of the road scenario"
- "The human interfering, AV will be safe without human interference but as soon as human interferes, there will be too many degrees of freedom to know and control in humans, that is the biggest challenge"
- "The inability to apply unwritten rules. Absolute necessary and absolute no-go area for AV's"
- "The intelligence of the ACS[1] governs all aspects listed above. The key issue is the programming of the ACS and the technical integration and software processing which governs the operation of the vehicle"
- "Trying to drive in mixed traffic with human drivers"
- "Uniform Road design for all the different levels"
- "Unreliable communications and lack of robustness (hacking)"
- "Very rare driving conditions (e.g. unexpected slippery roads)"

Figure 5.5 also illustrates the word cloud of the words in this assessment. Cybersecurity, in e general, was mentioned as the most concerning technical barrier in adopting AVs among 'other responses'. There were also some other technical concerns among 'other responses' such as 'vehicle control', 'communication issues', 'software programming and sensory processing issues', and difficult operation of AVs (for users).

[1] ACS: Access Control System

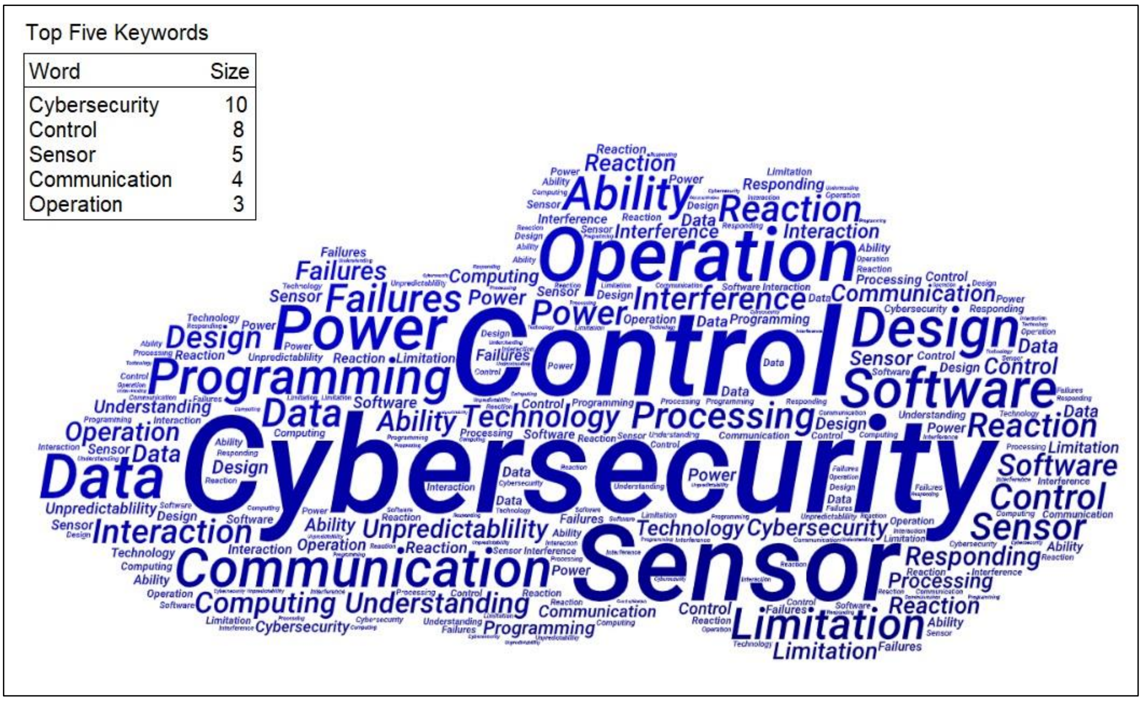


Figure 5.5. Other responses for the most substantial concerns regarding the application of AVs

Furthermore, an assessment was conducted on group responses relating to the significance of each technical concern to each group. The cross-tabulation of the concerns with groups in this assessment represents the number and percentage of participants within each group and their level of concern about each technical issue. Table 5.13 illustrates the results of the evaluation of group concerns.

Most of the groups agreed that 'sensor failure and system shut down' is a substantial concern in the adoption of AVs (see Table 5.13). Concern among the road authority group had the highest percentage of all groups, bearing in mind that the road authority group had only six participants who may not properly represent the group, though the results can give some insights in this regard.

Furthermore, 'incorrect understanding of the surrounding objects' was considered the most substantial technical concern by the majority of participants. However, experts from the government group showed a lower tendency than other groups to agree with this; yet more than half of the experts in the government group still agreed with other groups in this regard.

Other response options such as 'limited driving operation by factory-defined settings' and 'not being as good as human drivers' were recognised as substantial, with 11% of the experts on average.

Table 5.13. The most substantial technical concerns regarding the application of AVs

Group	Government		Road authority		Academia		Private Sector		Total	
Participants	%	N	%	N	%	N	%	N	%	N
Sensor failures and system shut down would be most concerning										
No	51.7	15	16.7	1	55.2	74	46.2	61	50.2	151
Yes	48.3	14	83.3	5	44.8	60	53.8	71	49.8	150
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Incorrect understanding of the surrounding objects (humans, animals, and others) would be most concerning										
No	44.8	13	33.3	2	30.6	41	28.8	38	31.2	94
Yes	55.2	16	66.7	4	69.4	93	71.2	94	68.8	207
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Getting limited by the factory-defined driving operations would be most concerning										
No	89.7	26	100.0	6	82.1	110	87.1	115	85.4	257
Yes	10.3	3	0.0	0	17.9	24	12.9	17	14.6	44
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Not being as good as human drivers in quick driving reactions would be most concerning										
No	93.1	27	100.0	6	83.6	112	88.6	117	87.0	262
Yes	6.9	2	0.0	0	16.4	22	11.4	15	13.0	39
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301

5.4.1.2. Safety Analysis

In order to assess the validity of responses related to safety, some statistical analysis was conducted using the cross-tabulation tool in SPSS. In this context, a safety question with a binary response option was correlated with the question asking about the support for AVs with or without a steering wheel. The results from such an analysis demonstrate the impact of safety concerns on experts' opinions regarding the support of a fully AV. Table 5.14 illustrates the cross-tabulation of this assessment.

As shown in Table 5.14, a total of 300 observations recorded in this evaluation. Around 53.3% of the respondents believed that safety concerns are not the most substantial concern regarding the application of AVs, with nearly half of them declaring that they would support an AV without a steering wheel. From another perspective, the results also revealed that 63.9% of the people who declared they would support AVs without a steering wheel believed that safety concerns are not the most substantial concern in the application of AVs, which verifies the correlation of these variables from both sides. Moreover, 46.7% of the participants in this assessment indicated that safety concerns are the most substantial concern in adopting AVs, with 64.3% of them declaring that they would not support an AV without a steering wheel.

In general, the assessment demonstrates that around 56.3% of the total participants do not support an AV without a steering wheel, and 3.0% do not support AVs at all. However, about

40.7% of the participants recommend full autonomous AVs, and most of these believed that safety concerns are not the most substantial concern in adopting AVs. The correlation of the parameters reveals that safety concerns had a meaningful impact on accepting or rejecting AVs without a steering wheel. Furthermore, the actual observed data were compared to the expected values using a Chi-square test (χ^2). The results of the evaluation showed a *p*-value of 0.007 for the Pearson test with 2 degrees of freedom, which represents statistical significance for the model.

Model 5.1. Cross tabulation
Table 5.14. Cross-tabulation of safety concerns versus supporting AVs without/without a steering wheel

Variable			**If the emergence of AVs was inevitable, which type of the following AVs would you support?**			**Total**
			An AV with a steering wheel	An AV without a steering wheel	None	
Safety concerns are the most substantial concerns regarding the application of AVs.	No	Count	79	78	3	160
		% within SC*	49.4	48.8	1.9	100.0
		% within T-AVs**	46.7	63.9	33.3	53.3
		% of Total	26.3	26.0	1.0	53.3
	Yes	Count	90	44	6	140
		% within SC*	64.3	31.4	4.3	100.0
		% within T-AVs**	53.3	36.1	66.7	46.7
		% of Total	30.0	14.7	2.0	46.7
Total		Count	169	122	9	300
		% within SC*	56.3	40.7	3.0	100.0
		% within T-AVs**	100.0	100.0	100.0	100.0
		% of Total	56.3	40.7	3.0	100.0

χ^2 = 9.902, degrees of freedom = 2, p-value = 0.007
* Safety Concerns
** Type of AVs

In the analysis of the impact of safety on participants' acceptance of AV, safety concerns were correlated with the results of the question on the acceptance of ridesharing in AVs. The experts in the survey were asked how likely they would be to support on-demand ridesharing AVs rather than private AVs. The responses to the question were correlated with the question of whether safety concerns are the most substantial concern regarding the application of AVs. Table 5.15 illustrates the results of the cross-tabulation.

In total, 301 correct responses were recorded for this assessment, with 53.2% believing that safety concerns are not the most substantial concerns regarding the application of AVs. Around 63.1% of the participants in this group were 'extremely likely' to support ridesharing AVs. From another perspective, the results also show that 62.0% of the people who declared they would be 'extremely likely' to support ridesharing AVs believed that safety concerns are not the most substantial concern regarding the application of AVs which verifies the correlation of these variables from both sides.

Furthermore, 46.8% of all the participants believed that safety concerns are the most substantial concern regarding the application of AVs, and 44.0% of them were 'extremely likely' to support ridesharing AVs. In this regard and from another perspective, 56.9% of the participants who were 'not at all likely' to support ridesharing AVs believed that safety concerns are the most substantial concerns regarding the application of AVs. In general, the assessment reveals that 54.2% of the experts are 'extremely likely', and 24.3% 'somewhat likely' to support ridesharing AVs. Even 73.8% of those who believed safety concerns are the most substantial concern in adopting AVs were 'extremely likely' to support ridesharing AVs. The results of the evaluation showed a *p*-value of 0.004 for the Pearson test with 2 degrees of freedom, which represents statistical significance.

Model 5.2. Cross tabulation
Table 5.15. Cross-tabulation of safety concerns versus supporting ridesharing AVs

			Supporting on-demand ridesharing AVs rather than private AVs			**Total**
			Not at all likely	Somewhat likely	Extremely likely	
Safety concerns are the most substantial concerns regarding the application of AVs.	No	Count	28	31	101	160
		% within SC*	17.5	19.4	63.1	100.0
		% within R-AVs**	43.1	42.5	62.0	53.2
		% of Total	9.3	10.3	33.6	53.2
	Yes	Count	37	42	62	141
		% within SC*	26.2	29.8	44.0	100.0
		% within R-AVs**	56.9	57.5	38.0	46.8
		% of Total	12.3	14.0	20.6	46.8
Total		Count	65	73	163	301
		% within SC*	21.6	24.3	54.2	100.0
		% within R-AVs**	100.0	100.0	100.0	100.0
		% of Total	21.6	24.3	54.2	100.0

χ^2 = 11.080, degrees of freedom = 2, p-value = 0.004
* Safety Concerns
** Ridesharing AVs

5.4.1.3. Security Analysis

Along with the safety analysis in this survey, a statistical assessment was also conducted on some of the survey questions related to security concerns and their relationship with the likelihood of supporting ridesharing AVs. In this regard, the survey question on security concerns in adopting AVs with a binary answer option correlated with experts' support of autonomous vehicle with or without a steering wheel. But the result gave a *p*-value of 0.229 and X^2 of 2.95, which means the assessed parameters are not statistically significant, and therefore, they are not correlated. In other words, there is no significant correlation between those two parameters. However, cross-tabulation of the security concerns with the question related to ridesharing AVs provided a *p*-value of 0.06. Whilst this is above 0.05, it is worth evaluating in order to find out if there is a significant correlation between the incorporated parameters. Table 5.16 illustrates the results of the cross-tabulation of security concerns versus supporting ridesharing AVs.

As shown in Table 5.16, around 56.1% of the respondents believed that security concerns are the most substantial concerns regarding the application of AVs. Of that 56.1%, about 52.7% were 'extremely likely' and 29.0% 'somewhat likely' to support ridesharing AVs rather than private AVs. From another perspective, 54.6% and 67.1% of the experts who were 'extremely likely' and 'somewhat likely', respectively, believed that security concerns are the most substantial concerns in adopting AVs.

Furthermore, 43.9% of the total participants did not believe that security concerns are the most substantial concerns, but more than half of them were 'extremely likely' to support ridesharing AVs.

The results indicated that security concerns could impact decision-making in terms of preference between ridesharing AVs and private AVs, but it might not be correct from the other perspective. In other words, not all the experts who supported ridesharing AVs believe that security concerns are the most substantial concerns regarding the application of AVs. As a proof of this, the results demonstrate that 52.3% of the experts who were 'not at all likely' to support ridesharing AVs, did not believe that security concerns would be the most substantial concerns in adopting AVs. However, more than half of the experts, in general, supported the application of ridesharing AVs rather than private AVs.

Model 5.3. Cross tabulation
Table 5.16. Cross-tabulation of security concerns versus supporting ridesharing AVs

Variable			**Supporting on-demand ridesharing AVs rather than private AVs**			**Total**
			Not at all likely	Somewhat likely	Extremely likely	
Security concerns are the most substantial concerns regarding the application of AVs.	No	Count	34	24	74	132
		% within SC*	25.8	18.2	56.1	100.0
		% within R-AVs**	52.3	32.9	45.4	43.9
		% of Total	11.3	8.0	24.6	43.9
	Yes	Count	31	49	89	169
		% within SC*	18.3	29.0	52.7	100.0
		% within R-AVs**	47.7	67.1	54.6	56.1
		% of Total	10.3	16.3	29.6	56.1
Total		Count	65	73	163	301
		% within SC*	21.6	24.3	54.2	100.0
		% within R-AVs**	100.0	100.0	100.0	100.0
		% of Total	21.6	24.3	54.2	100.0

χ^2 = 5.617, degrees of freedom = 2, p-value = 0.060
* Security Concerns
** Ridesharing AVs

5.4.2. Benefits

Section 5.4.1 explained experts' concerns relating to the adoption of AVs in highway transport. The results were presented for each group and some statistical analysis was conducted to address the correlations between results and incorporated parameters. This Section explains the results of the survey questions dealing with the benefits of the application of AVs. The same method of analysis will be employed to analyse group opinions about the benefits of adopting AVs on public roads. Moreover, the answer options for the survey questions in this context will be cross-tabbed to assess the correlation between the benefits of adopting AVs and experts' overall opinions regarding the use of these vehicles in highway transport.

5.4.2.1. Response Summary

The experts in the survey were asked about the most valuable outcomes of adopting AVs and choosing multiple responses was allowed. The response summary for the question demonstrates that 61.8% of the participants (301 experts) considered that 'safe driving' would be the most valuable outcome of the application of AVs. Then, 'reduction of traffic congestion, queues, and delays' and 'reduction of fuel consumption and emissions' were the next most valuable outcomes according to 32.6% and 25.6%, respectively. Table 5.17 illustrates the response summary for this analysis.

Table 5.17. Summary of the responses regarding the most valuable outcomes of adopting AVs (MRA)

Variable	%	N
Safe driving	61.8	186
Reduction of traffic congestion, queues, and delays	32.6	98
Reduction of fuel consumption and vehicle emissions	25.6	77
Other	25.3	76
Reduction of travel time	10.0	30
Vehicle security	5.6	17

Here are also the most common quotes provide in the "other" responses:

- "To liberate people from driving"
- "Journey reliability"
- "That we would have achieved 'Connected' vehicles FIRST! Note: Travel time per vehicle may reduce BUT total travel time increase! Similarly with the mixed fleet stage it is very difficult to generalise."
- "Reduction of transport cost"
- "There may be no benefits other than reduction/improved outcomes of crashes"
- "Non-drivers can use when necessary"
- "None of the above in an urban setting - and indeed likely to increase kilometrages, overall congestion (and hence emissions) and to have a number of (perhaps seemingly paradoxical) implications for safety"
- "I think the case for them is flimsy at best...so I don't see benefits as such."
- "Driver convenience"
- "Alternative (productive) use of travel time. No need for escorting (children, elderly, disabled, those without driving licence, etc.)"
- "Increased potential for vehicle sharing"
- "Reduction of required vehicles"
- "Removal of unused vehicles from road network"
- "Ability for older, younger and disabled people to travel independently"
- "Improved mobility for non-drivers. Unless implemented with more efficient road pricing, AVs are likely to increase traffic congestion and pollution emissions."
- "Improving accessibility for those who can't drive"
- "Enabling better use of time during a journey"
- "Less resistance to driving because drivers can use their time for other purposes."
- "Depending on the policy of a city, you might see valuable benefits such as land values uplifts."
- "Free time to divert to non-driving activity"
- "Reduction in land track for road vehicles"
- "It's depend on it is public or private Vehicle. As Public transport Vehicle, it could increase capacity.
- "Reduction of vehicle km"
- "Comfort"
- "Change in value-of-time, as time travelling can be spent on other activities (reading, working, playing, relaxing, sleeping, ...)"
- "Not necessarily any of the above. They remain to be proven."
- "Other use of travel time"
- "Ability to do other thing while travelling"
- "For level 5, value of time saving for the driver who can do other tasks. NB does not apply for any lower level."

- “Increased mobility”
- “Flexibility and broader access to car as a service for more people”
- “Ability for people with disability to have the convenience of cars”
- “Usage by people unable to drive”
- “Reduction in the number of vehicles and VMT through car and ride sharing (facilitated with an autonomous vehicle fleet)”
- “It is impossible to tell at this time”
- “Overall reduction in vehicle crashes (but not 100% safety)”
- “Safer for other (vulnerable) road users”
- “Mental health benefits - reduction of commuter stress”
- “Accessibility for people who have difficulties to walk, bike or drive a car”
- “Difficult to know. These are all current claims or aims but there is no evidence yet that they will be fulfilled. I would expect "safer" driving could be an expected outcome if the human factor is considered as responsible for 70 to 85% of the causes of collisions but maybe new vehicles and IT causes may arise.”
- “Possibility to do something else than drive (read, ...)”
- “Better use of travel time (work, read, sleep, ...)”
- “The productivity gains as a result of the freed up time”
- “More efficient use of the public space”
- “Road safety seems to be a key advantage, but this again depends on the penetration rate of fully AVs”
- “Efficient use of our road transport assets”
- “Reduction of salary costs”
- “Reduction of private car ownership”
- “Change in travel behaviour and frequency”
- “Making time in the vehicle more productive or pleasant”
- “Ability to use the time spent in car productively”
- “Increased mobility leading to less 'wasted' travel time hours”
- “If Shared autonomous vehicle will be dominating the demand then reduction in travel time, congestion and delay would achieved”
- “Liberate human minds from having to steer the vehicle”
- “Reduction of cars (ownership)”
- “Comfort!!! Not Safe!! as non-AV will be just as safe as AV and also no congestion; AV will increase congestion as people do not mind congestion so much anymore”
- “Optimization of time management”
- “Cost savings for those who employ drivers”
- “Just a stress free driving and nothing else”
- “Reduced disutility of time spent in-vehicle”
- “Increase in road capacity”
- “Facility to work while driving”
- “Saving lives due to fatalities from crashes of distracted or impaired drivers”
- “Availability of vehicles to people such as disabled people who cannot drive conventional vehicles”
- “Advancement of applied technology for technology's sake”
- "Choice for transport users to balance modes and usage of transport for different purposes”
- “Use of time during driving for other things”
- “Utilization of time spent in transit”
- “Easier access to transport and mobility for those who can't or don't want to drive”
- “Time in the car can be used for leisure activities, like reading books, watching movies, answering emails and so on.”

Moreover, Figure 5.6 illustrates the word cloud for the other responses and comments recorded for this question. Further responses and comments recorded for this question were benefits related to 'travel time', 'safety', 'traffic congestion', and 'emissions'. However, experts did not believe that AVs would substantially help in reducing travel time. Furthermore, participants pointed to topics such as 'providing mobility for disabled people', 'reduction in stress of driving', 'engaging in leisure activities during driving' and some others.

Figure 5.6. Other responses for the most valuable outcome/s of the adoption of AVs

Additionally, an assessment was conducted on groups' opinions about each of the benefits mentioned in Table 5.17. Table 5.18 illustrates the results of the evaluation. Table 5.18 shows that all the groups, with almost the same average (around 62%), agreed that 'safe driving' would be the most valuable outcome of the application of AVs. Regarding the 'increase in vehicle security', only 3.5% of the 'government' sector believed that AVs could be beneficial while 'road authority' and 'private sector' participants were more optimistic in this regard. However, it was not considered that AVs, in general, would be helpful for increasing vehicle security. Moreover, 90% of the experts rejected reduced travel time as a possible outcome of the application of AVs. Only a small percentage of experts from the 'road authority' and 'academia' groups agreed that AVs could reduce travel time.

Regarding the 'reduction in traffic congestion', government, academia, and private sector participants had almost similar opinions, and they believed AVs could be a helpful solution to traffic congestion. However, road authority participants disagreed as no expert from this sector considered AVs to be capable of reducing traffic congestion. A similar perspective was demonstrated in the results related to 'fuel consumption and emissions' with the only difference being that the government sector participants had a higher tendency to believe that AVs could be beneficial in reducing fuel consumption and emissions. In general, the results in this Section demonstrate that there is overall agreement among the respondents from the academia, government, road authority and private sector groups on the potential valuable outcomes of AVs and they all expect an increase in road safety from the adoption of AVs in highway transport. The groups, in general, showed agreement in indicating that they did not think the rest of the benefits were likely.

Table 5.18. The most valuable outcome/s of the adoption of AVs

Group	Government		Road authority		Academia		Private Sector		Total	
Participants	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**
Safe driving would be the most valuable outcome of the adoption of AVs										
No	41.4	12	33.3	2	37.3	50	38.6	51	38.2	115
Yes	58.6	17	66.7	4	62.7	84	61.4	81	61.8	186
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Vehicle security would be the most valuable outcome of the adoption of AVs										
No	96.6	28	83.0	5	95.5	128	93.2	123	94.4%	284
Yes	3.5	1	16.7	1	4.5	6	6.8	9	5.7	17
Total	100.0	29	99.7	6	100.0	134	100.0	132	100.0	301
Reduction of travel time would be the most valuable outcome of the adoption of AVs										
No	96.6	28	83.0	5	87.3	117	91.7	121	90.0	271
Yes	3.5	1	16.7	1	12.7	17	8.3	11	10.0	30
Total	100.0	29	99.7	6	100.0	134	100.0	132	100.0	301
Reduction of traffic congestion would be the most valuable outcome of the adoption of AVs										
No	69.0	20	100.0	6	67.9	91	65.2	86	67.4	203
Yes	31.0	9	0.0	0	32.1	43	34.9	46	32.6	98
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301
Reduction of fuel consumption would be the most valuable outcome of the adoption of AVs										
No	58.6	17	100.0	6	77.6	104	73.5	97	74.4	224
Yes	41.4	12	0.0	0	22.4	30	26.5	35	25.6	77
Total	100.0	29	100.0	6	100.0	134	100.0	132	100.0	301

5.4.2.2. Statistical Analysis

In addition to group analysis, some statistical assessments were conducted on the benefits of adopting AVs and their impact on overall decision-making about whether AVs should be introduced to highway transport or not.

The first assessment explains the results of cross-tabulation between safe driving of AVs and the overall opinion about adopting AVs. The cross-tabulation of safe driving of AVs with experts' overall opinions about adopting AVs provided a *p*-value of 0.06 which is above 0.05

but is still worth evaluating to find out if there is a significant correlation between the incorporated parameters.

As shown in Table 5.19, around 61.7% of the participants believed that 'safe driving' would be the most likely outcome of adopting AVs, with nearly 56.8% of them indicating that more research and development (R&D) is required before adopting AVs on public roads. From another perspective, the results also revealed that 64.8% of the participants who believed more R&D is required, 60.5% of those who were 'concerned but would like to try AVs', and 71.0% of those who had 'no concern in adopting AVs' believed that 'safe driving' would be the most valuable outcome of adopting AVs. Furthermore, 38.3% of the participants in this assessment indicated that 'safe driving' is not likely to be the most valuable outcome of adopting AVs, with 66.7% of them declaring that they are 'opposed to adopting AVs ever being allowed on public roads'. Additionally, around 49.6% of the participants who did not believe in 'safe driving' of AVs reported that 'more R&D is required' in this context. In general, the assessment demonstrates that over 50% of the participants believe that AVs are not yet ready for adoption on public roads, and so more R&D must be undertaken before their adoption.

Model 5.4. Cross-tabulation
Table 5.19. Cross-tabulation of safe driving of AVs versus overall opinion about adopting AVs

Variable			**Which one of the following statements best sums up your opinion regarding the future use of AVs on public roads?**					**Total**
			Not at all concerned	Concerned about safety and security	More R&D required	Opposed to AVs ever being adopted	Others	
Safe driving would be the most valuable outcome of adopting AVs.	No	Count	9	30	57	2	17	115
		% within SD*	7.8	26.1	49.6	1.7	14.8	100.0
		% within OO**	29.0	39.5	35.2	66.7	60.7	38.3
		% of Total	3.0	10.0	19.0	0.7	5.7	38.3
	Yes	Count	22	46	105	1	11	185
		% within SD*	11.9	24.9	56.8	0.5	5.9	100.0
		% within OO**	71.0	60.5	64.8	33.3	39.3	61.7
		% of Total	7.3	15.3	35.0	0.3	3.7	61.7
Total		Count	31	76	162	3	28	300
		% within SD*	10.3	25.3	54.0	1.0	9.3	100.0
		% within OO**	100.0	100.0	100.0	100.0	100	100.0
		% of Total	10.3	25.3	54.0	1.0	9.3	100.0

χ^2 = 8.807, degrees of freedom = 4, p-value = 0.066
* Safe Driving
** Overall Opinion

In another analysis, the responses to the question asking whether a reduction in 'travel time' would be one of the 'most valuable outcomes of adopting AVs' were correlated with experts' overall opinions regarding the future use of AVs on public roads. Table 5.20 illustrates the results of this cross-tabulation.

The results from Table 5.20 illustrate that around 90.3% of the participants believed the 'reduction of travel time' would not be one of the most valuable outcomes of adopting AVs, with 56.5% finding that 'more R&D is required' on this matter. From another perspective, 100.0% of those who were 'opposed to AVs ever being adopted' on public roads, 94.4% of those who believed 'more R&D is required', and 83.9% of those who were not 'concerned about safety and security', declared that 'reduction of travel time' would not be the most valuable outcome of adopting AVs. The assessment, in general, demonstrates that experts were not optimistic about a considerable reduction in travel time as a result of adopting AVs. Some experts believed AVs might be capable of reducing travel time; however, they also felt that more R&D is required in this regard. The actual observed data were compared to the expected values using a Chi-square test (χ^2). The results of the evaluation showed a *p*-value of 0.012 for the Pearson test with 2 degrees of freedom, which represents statistical significance for the model.

Model 5.5. Cross tabulation
Table 5.20. Cross-tabulation of travel time versus overall opinion about adopting AVs

Variable			**Which one of the following statements best sums up your opinion regarding the future use of AVs on public roads?**					**Total**
			Not at all concerned	Concerned about safety and security	More R&D required	Opposed to AVs ever being adopted	Others	
Reduction of travel time would be the most valuable outcome of adopting AVs	No	Count	26	62	153	3	27	271
		% within TT*	9.6	22.9	56.5	1.1	10.0	100.0
		% within OO**	83.9	81.6	94.4	100.0	96.4	90.3
		% of total	8.7	20.7	51.0	1.0	9.0	90.3
	Yes	Count	5	14	9	0	1	29
		% within TT*	17.2	48.3	31.0	0.0	3.4	100.0
		% within OO**	16.1	18.4	5.6	0.0	3.6	9.7
		% of total	1.7	4.7	3.0	0.0	0.3	9.7
Total		Count	31	76	162	3	28	300
		% within TT*	10.3	25.3	54.0	1.0	9.3	100.0
		% within OO**	100.0	100.0	100.0	100.0	100	100.0
		% of total	10.3	25.3	54.0	1.0	9.3	100.0

χ^2 = 12.801, degrees of freedom = 4, p-value = 0.012
* Travel Time
** Overall Opinion

Table 5.21 shows the results of the correlation between 'safe driving' of AVs and the question asking which type of AVs experts would support. There were three possible answer options for the question asking about AV type: 'an AV with a steering wheel', 'an AV without a steering wheel', and 'no AV at all'. Table 5.21 illustrates the cross-tabulation of this analysis.

According to Table 5.21, about 61.7% of the participants (185 experts) indicated that 'safe driving' was likely to be the most valuable outcome of driving AVs, with 51.9% declaring they would support 'an AV with a steering wheel' and 46.5% stating they would support 'AVs without a steering wheel'. In this regard, and from another perspective, over 50% of the experts who supported AVs and 33.3% of the participants who did not support any types of AV believed that AVs would offer safe driving. Moreover, 38.3% of the total participants did not believe that AVs would offer safe driving, with 63.5% declaring that they would support AVs with a steering wheel. From another perspective, 43.2% of the experts who indicated they would support 'AVs with a steering wheel' and 66.7% of the participants who did not support AVs at all believed that safe driving would not be the most valuable outcome of adopting AVs. In general, the assessment indicates that experts would support AVs, but a substantial percentage (56.3%) of them would support 'AVs with a steering wheel'. The statistical significance of the model is proved with a *p*-value of 0.012 for the Pearson test with 2 degrees of freedom.

Model 5.6. Cross tabulation
Table 5.21. Cross-tabulation of safe driving of AVs versus supporting AVs with or without a steering wheel

Variable			**If the emergence of AVs was inevitable, which type of the following AVs would you support?**			**Total**
			An AV with a steering wheel	An AV without a steering wheel	None	
Safe driving would be the most valuable outcome of adopting AVs.	No	Count	73	36	6	115
		% within SD*	63.5	31.3	5.2	100.0
		% within T-AVs**	43.2	29.5	66.7	38.3
		% of total	24.3	12.0	2.0	38.3
	Yes	Count	96	86	3	185
		% within SD*	51.9	46.5	1.6	100.0
		% within T-AVs**	56.8	70.5	33.3	61.7
		% of total	32.0	28.7	1.0	61.7
Total		Count	169	122	9	300
		% within SD*	56.3	40.7	3.0	100.0
		% within T-AVs**	100.0	100.0	100.0	100.0
		% of total	56.3	40.7	3.0	100.0

χ^2 = 8.766, degrees of freedom = 2, p-value = 0.012
* Safe Driving
** Type of AVs

An evaluation is conducted to address the correlation of the results between the 'reduction of traffic congestion' and 'support for AVs among the experts'. Table 5.22 illustrates the results of this cross-tabulation.

As shown in Table 5.22, 67.3% of the participants believed that 'reduction of traffic congestion, queues, and delays' would not be one of the most valuable outcomes of adopting AVs, with 51% of them indicating they would support 'an AV with a steering wheel'. From another perspective, about 61% of the experts who declared they would support 'AVs with a steering wheel' reported that they did not believe that AVs would be substantially capable of 'reducing traffic congestion, queues, and delays'. The same correlation was found in the results related to the support of 'AVs without a steering wheel'. Moreover, 32.7% of the participants in this assessment indicated that they thought the reduction of traffic congestion would be one of the outcomes of the adoption of AVs, with 67.3% of them declaring they would support 'AVs with a steering wheel'. In general, the study reveals that 56.3% of the participants would support 'AVs with a steering wheel' and the statistical significance of the model is proved with a *p*-value of 0.027 for the Pearson test with 2 degrees of freedom.

Model 5.7. Cross tabulation
Table 5.22. Cross-tabulation of the reduction of traffic congestion, queues, and delays versus supporting AV with or without a steering wheel

			If the emergence of AVs was inevitable, which type of the following AVs would you support?			**Total**
			An AV with a steering wheel	An AV without a steering wheel	None	
Reduction of traffic congestion, queues, and delays would be the most valuable outcomes of the adoption of AVs.	No	Count	103	92	7	202
		% within traffic*	51.0	45.5	3.5	100.0
		% within T-AVs**	60.9	75.4	77.8	67.3
		% of total	34.3	30.7	2.3	67.3
	Yes	Count	66	30	2	98
		% within traffic*	67.3	30.6	2.0	100.0
		% within T-AVs**	39.1	24.6	22.2	32.7
		% of total	22.0	10.0	0.7	32.7
Total		Count	169	122	9	300
		% within traffic*	56.3	40.7	3.0	100.0
		% within T-AVs**	100.0	100.0	100.0	100.0
		% of total	56.3	40.7	3.0	100.0

$\chi^2 = 7.19$, degrees of freedom = 2, p-value = 0.027
* Reduction of traffic congestion, queues, and delays
** Type of AVs

The following assessment explains the results of the correlation between opinions on a decrease in fuel consumption and emissions and experts' responses regarding support for AVs with or without a steering wheel. Table 5.23 illustrates the results of cross-tabulation for this assessment.

The results from Table 5.23 are in line with the results from Table 5.22. Around 74.3% of the participants disagreed that AVs would be capable of reducing fuel consumption and emissions; with 51.1% indicating they would support 'AVs with a steering wheel'. From another perspective, over 60% of the experts believed that the 'reduction of fuel consumption and emissions' would not be one of the most valuable outcomes of adopting AVs. Around 25.7% of the participants thought that AVs could reduce fuel consumption, with 71.4% declaring they would support 'AVs with a steering wheel'. In general, the assessment represents that a substantial percentage of the experts do not think AVs would be capable of reducing fuel consumption, and they mostly support 'AVs with a steering wheel'.

The overall assessment of expert opinions in this Section indicates that 'safe driving' would be one of the most valuable outcomes of the adoption of AVs, but experts did not think AVs would be able to reduce 'travel time', 'traffic congestion, queues, and delays', and 'fuel consumption and emissions'. In general, the experts supported AVs; however, they were more supportive of 'AVs with a steering wheel'. Furthermore, experts believed that 'more research and development is required' in the field of AVs.

Model 5.8. Cross tabulation
Table 5.23. Cross-tabulation of the reduction of fuel consumption and emissions versus supporting AVs with or without a steering wheel

Variable			**If the emergence of AVs was inevitable, which type of the following AVs would you support?**			**Total**
			An AV with a steering wheel	An AV without a steering wheel	None	
Reduction of fuel consumption and emissions would be the most valuabl e outcomes of the adoption of AVs	No	Count	114	102	7	223
		% within FC*	51.1	45.7	3.1	100.0
		% within T-AVs**	67.5	83.6	77.8	74.3
		% of total	38.0	34.0	2.3	74.3
	Yes	Count	55	20	2	77
		% within FC*	71.4	26.0	2.6	100.0
		% within T-AVs**	32.5	16.4	22.2	25.7
		% of total	18.3	6.7	0.7	25.7
Total		Count	169	122	9	300
		% within FC*	56.3	40.7	3.0	100.0
		% within T-AVs**	100.0	100.0	100.0	100.0
		% of total	56.3	40.7	3.0	100.0

χ^2 = 9.745, degrees of freedom = 2, p-value = 0.008
* Fuel consumption and emissions
** Type of AVs

5.4.3. Adoption Impacts

The study so far has explained the perceived benefits and concerns relating to the adoption of AVs in highway transport. This Section discusses the results of survey questions regarding the impact of adopting AVs on travel time, traffic congestion, road throughput, and some other issues. The experts who took part in the survey were asked their assessment of the extent to which AVs would increase or decrease the mentioned parameters. The findings from this assessment are presented in two sections: the response summary and statistical analysis.

5.4.3.1. Response Summary

The response summary for the assessment of the adoption impact of AVs demonstrates that 299 valid responses recorded for this assessment and they rated the efficiency of AVs through three answer options: ‘a substantial decrease’, ‘no impact’, and ‘substantial increase’. In general, the experts indicated the following anticipated improvements as a result of adopting AVs in highway transport (shown in Table 5.24):

Table 5.24. Anticipated improvements as a result of adopting AVs in highway transport

Parameter	Anticipated impact	% of respondents
Travel time	Reduction	41.4
Traffic congestion, queues, and delays	Reduction	46.0
Road throughput’	Increase	45.1
Fuel consumption and emissions	Reduction	47.5
Road users’ safety	Increase	57.6
Number of accidents	Reduction	68.8
Severity of accidents	Reduction	59.4

Table 5.25 represents the response summary of the adoption impacts of AVs, and also provides information about the percentage of experts who believed AVs would negatively affect the parameters mentioned above. The results of this assessment were weighted based on the answer options provided to the experts. In this context, a value of ‘1’ was given to ‘substantially decrease’, ‘2’ to ‘no impact’, and ‘3’ to ‘substantially increase’. As a result, the answer for each parameter was weighted in the range of 1 to 3, which reflects the level of decrease or increase of a parameter.

Table 5.25. Summary of the responses regarding the adoption impacts of AVs

Parameter	Substantially Decrease		No Impact		Substantially Increase		Total	Weighted Average
	%	N	%	N	%	N	N	1 – 3
Travel time	41.4	123	36.0	107	22.6	67	297	1.27
Traffic congestion: queues, delays, etc.	45.6	136	26.0	80	28.0	83	299	1.44
Road throughput	22.9	67	32.1	94	45.1	132	293	1.74
Fuel consumption and vehicle emissions	47.5	142	32.1	96	20.4	61	299	1.25
Road users' safety	30.3	90	12.1	36	57.6	171	297	2.09
Number of accidents	68.8	205	11.8	35	19.5	58	298	1.33
Severity of accidents	59.4	177	23.8	71	16.8	50	298	1.22

A further assessment was conducted on group opinions about the adoption impact of AVs. In this context, the groups' responses were classified for the parameters related to traffic streams such as 'travel time', 'traffic congestion', 'road throughput', and 'fuel consumption and emissions'. Table 5.26 represents the results of this evaluation. For each of the mentioned parameters, experts were evaluated within their group. For instance, 43.9% of the experts from academia believed that AVs would 'substantially decrease' travel time, and 23.5% indicated that they thought there would be 'a substantial increase' in travel time as a result of adopting AVs. In addition, around 32.6% declared that AVs would have 'no impact' on travel time.

Moreover, the experts from the academia group were evaluated within total participants (shown in Table 5.26). In this context, of the total responses recorded on the anticipated impact of AVs on travel time, 19.5% of those from academia believed that AVs would 'substantially decrease' travel time, and 17.5% of those from the private sector had the same belief as those from academia. Furthermore, Table 5.26 represents the results of this evaluation for all parameters related to traffic stream and the assessed impact of AVs on fuel consumption and emissions

Table 5.26. Groups' opinion about the effect of AVs on traffic and environment

		Government		Road authority		Academia		Private Sector		Total	
Response	**Response category**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**
How do you think AVs will affect travel Time?											
Substantially decrease	Group*	39.3	11	33.3	2	43.9	58	39.7	52	41.4	123
	Total**	3.7		0.7		19.5		17.5		41.4	
No impact	Group*	42.9	12	50.0	3	32.6	43	37.4	49	36.0	107
	Total**	4.0		1.0		14.5		16.5		36.0	
Substantially increase	Group*	17.9	5	16.7	1	23.5	31	22.9	30	22.6	67
	Total**	1.7		0.3		10.4		10.1		22.6	
Total	Group*	100.0	28	100.0	6	100.0	132	100.0	131	100.0	297
	Total**	9.4		2.0		44.4		44.1		100	
How do you think AVs will affect traffic congestion: queue, delay, etc.?											
Substantially decrease	Group*	46.4	13	16.7	1	48.5	64	44.6	58	45.9	136
	Total**	4.4		0.3		21.6		19.6		45.9	
No impact	Group*	21.4	6	50.0	3	28.0	37	23.8	31	26.0	77
	Total**	2.0		1.0		12.5		10.5		26.0	
Substantially increase	Group*	32.1	9	33.3	2	23.5	31	31.5	41	28.0	83
	Total**	3.0		0.7		10.5		13.9		28.0	
Total	Group*	100.0	28	100.0	6	100.0	132	100.0	130	100.0	296
	Total**	9.4		2.0		44.6		44.0		100.0	
How do you think AVs will road throughput?											
Substantially decrease	Group*	31.0	9	33.3	2	26.9	35	16.4	21	22.9	67
	Total**	3.1		0.7		11.9		7.2		22.9	
No impact	Group*	27.6	8	50.0	3	30.0	39	34.4	44	32.1	94
	Total**	2.7		1.0		13.3		15.0		32.1	
Substantially increase	Group*	41.4	12	16.7	1	43.1	56	49.2	63	45.1	132
	Total**	4.1		0.3		19.1		21.5		45.1	
Total	Group	100.0	29	100.0	6	100.0	130	100.0	128	100.0	293
	Total**	9.9		2.0		44.4		43.7		100.0	
How do you think AVs will affect fuel consumption and vehicle emission?											
Substantially decrease	Group*	51.7	15	33.3	2	41.7	55	53.0	70	47.5	142
	Total**	5.0		0.7		18.4		23.4		47.5	
No impact	Group*	31.0	9	33.3	2	31.1	41	33.3	44	32.1	96
	Total**	3.0		0.7		13.7		14.7		32.1	
Substantially increase	Group*	17.2	5	33.3	2	27.3	36	13.6	18	20.4	61
	Total**	1.7		0.7		12.0		6.0		20.4	
Total	Group*	100.0	29	100.0	6	100.0	132	100.0	132	100.0	299
	Total**	9.7		2.0		44.4		44.1		100.0	

* % within each group
** % within total participants

In the next step, the impact of the adoption of AVs was evaluated for the parameters related to accidents and safety such as road users' safety, number of accidents, and the severity of accidents. The same form of assessment was conducted on these parameters and experts were evaluated within their group and according to total participants. Table 5.27 represents the results of this evaluation for all parameters related to accidents and safety. Such an evaluation of the expert opinions represents insights into what each group believed about the possible impact of AVs and the extent to which the groups agreed on the subject.

Table 5.27. Groups' opinion about the effect of AVs on accidents and safety

		Government		Road authority		Academia		Private Sector		Total	
Response	**Response category**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**
How do you think AVs will affect road users' safety?											
Substantially decrease	Group*	34.5	10	50.0	3	26.0	34	32.8	43	30.3	90
	Total**	3.4		1.0		11.4		14.5		30.3	
No impact	Group*	13.8	4	0.0	0	15.3	20	9.2	12	12.1	36
	Total**	1.3		0.0		6.7		4.0		12.1	
Substantially increase	Group*	51.7	15	50.0	3	58.8	77	58.0	76	57.6	171
	Total**	5.1		1.0		25.9		25.6		57.6	
Total	Group*	100.0	29	100.0	6	100.0	131	100.0	131	100.0	297
	Total**	9.8		2.0		44.1		44.1		100	
How do you think AVs will affect the number of accidents?											
Substantially decrease	Group*	69.0	20	83.3	5	67.9	89	68.9	91	68.8	205
	Total**	6.7		1.7		29.9		30.5		68.8	
No impact	Group*	6.9	2	16.7	1	12.2	16	12.1	16	11.7	35
	Total**	0.7		0.3		5.4		5.4		11.7	
Substantially increase	Group*	24.1	7	0.0	0	19.8	26	18.9	25	19.5	58
	Total**	2.3		0.0		8.7		8.4		19.5	
Total	Group*	100.0	29	100.0	6	100.0	131	100.0	132	100.0	298
	Total**	9.7		2.0		44.0		44.3		100.0	
How do you think AVs will affect the severity of accidents?											
Substantially decrease	Group*	55.2	16	66.7	4	58.0	76	61.4	81	59.4	177
	Total**	5.4		1.3		25.5		27.2		59.4	
No impact	Group*	20.7	6	33.3	2	23.7	31	24.2	32	23.8	71
	Total**	2.0		0.7		10.4		10.7		23.8	
Substantially increase	Group*	24.1	7	0.0	0	18.3	24	14.4	19	16.8	50
	Total**	2.3		0.0		8.1		6.4		16.8	
Total	Group*	100.0	29	100.0	6	100.0	131	100.0	132	100.0	298
	Total**	9.7		2.0		44.0		44.3		100.0	

* % within each group
** % within total participants

5.4.3.2. Statistical Analysis

Section 5.4.3.1 presented a summary of responses about the adoption impact of AVs. This Section conducts some statistical assessments on the survey responses in order to make sure the results are significant.

In the first assessment in this Section, the results of the survey question asking about the adoption impact of AVs on travel time were correlated with the responses to the question asking experts about their overall opinion regarding the future use of AVs on public roads. Table 5.28 illustrates the results of this cross-tabulation.

As shown in Table 5.28, 41.2% of the participants believed that AVs would 'substantially decrease' travel time with 15.6% of them declaring they would have 'no concern' about adopting AVs. However, 43.4% of them indicated that 'more R&D is required' before the adoption of AVs on public roads. From another perspective, 63.3% of the experts who did not have any concerns about adopting AVs and 52.6% of those who were 'concerned about safety and security but interested in trying AVs' believed that AVs would 'substantially decrease' travel time.

Furthermore, around 33.3% of the experts who were 'opposed to AVs ever being allowed on public roads' believed that AVs would 'substantially increase' travel time. In this context, 14.9% of those who expected a substantial increase in travel time when adopting AVs indicated that more R&D is required.

In general, the assessment reveals that experts were hopeful about a reduction in travel time when adopting AVs on public roads, but they believed more research and development is needed in this context. Moreover, the actual observed data were compared to the expected values using a Chi-square test (χ^2). Results of the evaluation showed a p-value of 0.034 for the Pearson test with 8 degrees of freedom, which represents statistical significance for the model.

Model 5.9. Cross tabulation

Table 5.28. Cross-tabulation of the impact of AVs on travel time versus overall opinions about adopting AVs

Variable			Which one of the following statements best sums up your opinion regarding the future use of AVs on public roads?					Total
			Not at all concerned	Concerned about safety and security	More R&D required	Opposed to AVs ever being adopted	Others	
The impact of AVs on travel time	Substantial decrease	Count	19	40	53	1	9	122
		% within TT*	15.6	32.8	43.4	0.8	7.4	100.0
		% within OO**	63.3	52.6	32.9	33.3	34.6	41.2
		% of total	6.4	13.5	17.9	0.3	3.0	41.2
	No impact	Count	6	25	64	1	11	107
		% within TT*	5.6	23.4	59.8	0.9	10.3	100.0
		% within OO**	20.0	32.9	39.8	33.3	42.3	36.1
		% of total	2.0	8.4	21.6	0.3	3.7	36.1
	Substantial increase	Count	5	11	44	1	6	67
		% within TT*	7.5	16.4	65.7	1.5	9.0	100.0
		% within OO**	16.7	14.5	27.3	33.3	23.1	22.6
		% of total	1.7	3.7	14.9	0.3	2.0	22.6
Total		Count	30	76	161	3	26	296
		% within TT*	10.1	25.7	54.4	1.0	8.8	100.0
		% within OO**	100.0	100.0	100.0	100.0	100.0	100.0
		% of total	10.1	25.7	54.4	1.0	8.8	100.0

χ^2 = 16.647, degrees of freedom = 8, p-value = 0.034
* Travel Time
** Overall Opinion

Moreover, an evaluation is conducted on the impact of adopting AVs on the number of accidents versus overall opinion about adopting AVs. As shown in Table 5.29, around 68.7% of the participants declared that AVs would ‘substantially decrease’ the number of accidents. However, more than half of them believed that ‘more R&D [is] required’ before the adoption of AVs on public roads. In this context, and from another perspective, around 80% of the experts who were ‘not at all concerned’ about adopting AVs and approximately 72.2% of those who indicated that ‘more R&D [is] required’ in the field of AVs believed that AVs would reduce the number of accidents. Moreover, about 19.5% of the participants in this study thought that AVs would ‘substantially increase’ the number of accidents, yet none of them was ‘opposed to AVs ever being allowed on public roads’, but they indicated ‘more R&D [is] required’ in this context. In general, more than half of the experts believed AVs could be useful in reducing the number of accidents, but they highlighted research and development as a necessary action before the adoption of AVs. The correlation of the parameters in this assessment was verified by a *p*-value of 0.000, which shows the results are statistically significant.

Model 5.10. Cross tabulation
Table 5.29. Cross-tabulation of the impact of adopting AVs on the number of accidents versus overall opinion about adopting AVs

			Which one of the following statements best sums up your opinion regarding the future use of AVs on public roads?					Total
			Not at all concerned	Concerned about safety and security	More R&D required	Opposed to AVs ever being adopted	Others	
The impact of adopting AVs on the number of accidents	Substantial decrease	Count	25	45	117	0	17	204
		% within A*	12.3	22.1	57.4	0.0	8.3	100.0
		% within O**	80.6	59.2	72.2	0.0	68.0	68.7
		% of total	8.4	15.2	39.4	0.0	5.7	68.7
	No impact	Count	0	12	19	3	1	35
		% within A*	0.0	34.3	54.3	8.6	2.9	100.0
		% within O**	0.0	15.8	11.7	100.0	4.0	11.8
		% of total	0.0	4.0	6.4	1.0	0.3	11.8
	Substantial increase	Count	6	19	26	0	7	58
		% within A*	10.3	32.8	44.8	0.0	12.1	100.0
		% within O**	19.4	25.0	16.0	0.0	28.0	19.5
		% of total	2.0	6.4	8.8	0.0	2.4	19.5
Total		Count	31	76	162	3	25	297
		% within A*	10.4	25.6	54.5	1.0	8.4	100.0
		% within O**	100.0	100.0	100.0	100.0	100.0	100.0
		% of total	10.4	25.6	54.5	1.0	8.4	100.0

χ^2 = 33.455, degrees of freedom = 8, p-value = 0.000
* Accidents
** Opinion

Furthermore, the study investigated the impact of adopting AVs on the severity of accidents versus overall opinion about adopting AVs. The results relating to the assessment of the effects of adopting AVs on the severity of accidents were almost in line with the findings associated with the number of accidents. According to Table 5.30, around 60% of the participants believed that AVs would substantially reduce the severity of accidents, with 57.1% indicating that ‘more R&D [is] required’. Approximately 23.9% indicated that they felt that adopting AVs would have ‘no impact’ on the severity of accidents, and 16.5% declared that AVs would increase the severity of accidents. In general, more than half of the experts believed AVs would be useful in reducing the severity of accidents, but they indicated that more research and development is needed before the adoption of AVs on public roads.

Model 5.11. Cross tabulation
Table 5.30. Cross-tabulation of the impact of adopting AVs on the severity of accidents versus overall opinions about adopting AVs

Variable			Which one of the following statements best sums up your opinion regarding the future use of AVs on public roads?					Total
			Not at all concerned	Concerned about safety and security	More R&D required	Opposed to AVs ever being adopted	Others	
The impact of adopting AVs on the severity of accidents	Substantial decrease	Count	21	40	101	0	15	177
		% within A*	11.9	22.6	57.1	0.0	8.5	100.0
		% within O**	67.7	52.6	62.3	0.0	60.0	59.6
		% of total	7.1	13.5	34.0	0.0	5.1	59.6
	No impact	Count	5	20	39	3	4	71
		% within A*	7.0	28.2	54.9	4.2	5.6	100.0
		% within O**	16.1	26.3	24.1	100.0	16.0	23.9
		% of total	1.7	6.7	13.1	1.0	1.3	23.9
	Substantial increase	Count	5	16	22	0	6	49
		% within A*	10.2	32.7	44.9	0.0	12.2	100.0
		% within O**	16.1	21.1	13.6	0.0	24.0	16.5
		% of total	1.7	5.4	7.4	0.0	2.0	16.5
Total		Count	31	76	162	3	25	297
		% within A*	10.4	25.6	54.5	1.0	8.4	100.0
		% within O**	100.0	100.0	100.0	100.0	100.0	100.0
		% of total	10.4	25.6	54.5	1.0	8.4	100.0

χ^2 = 14.991, degrees of freedom = 8, p-value = 0.059
* Accidents
** Opinion

5.5. Discussion

This Chapter has explained the concerns, benefits, and the adoption impacts of AVs on public roads using the results of an expert survey. The participants in the survey were divided into four groups based on their professional segment.

The results related to experts' concerns in adopting AVs revealed that 'security concerns such as getting hacked and losing control of the vehicle' would be the most concerning consequence of the application of AVs on public roads (Table 5.10). In this context, the experts from the government sector indicated the highest level of concern of all groups. The evaluation of the experts' opinions in the current study validates the results of studies conducted by Sheehan et al. (2018) and Faife (2017) in this regard. Moreover, 'legal liability' – which was only slightly smaller in significance compared to security – was recognised as the second most concerning consequence, with academia, private sector, and government all agreeing on the issue. 'Safety', 'privacy', and 'traffic congestion' were the next most substantial concerns recognised by the experts.

Furthermore, the assessment regarding technical concerns relating to the adoption of AVs (Table 5.12, & Table 5.13) revealed that 'incorrect understanding of the surrounding objects such as humans and animals' would be the most substantial technical concern about adopting AVs, and the private sector and academia groups were most concerned about this issue. Then, 'sensor failure and system shut down' was indicated as being the following most concerning issue, most commonly recognised by experts from the private sector. The government and academia groups – with a lower level of concern than the private sector – had a similar perspective on this matter. Besides these, 'cybersecurity', 'software processing and programming issues', and 'vehicle control and operation' were other technical concerns highlighted by experts. The technical concerns of adopting AVs and their negative impact on the safety concerns of AVs have already been argued by Noy et al. (2018), Chan (2017), and Rakotonirainy et al. (2014), which are now validated by the results of the expert survey.

Several studies, such as Papadoulis et al. (2019), Noy et al. (2018) and Beirgo et al. (2018) evaluated the safety benefits of adopting AVs; their studies approved that AVs would be very beneficial in achieving a safe transport. The current study revealed that 'safe driving', among the majority of experts, was considered to be the most valuable outcome of the application of AVs (Table 5.18), which validates the results of the studies in the literature in this regard (mentioned above). Academia, the private sector, and the government had a similar tendency to count on safety as a benefit of adopting AVs. Then, 'the reduction of traffic congestion, queues, and delays' was recognised as the second most valuable benefit of adopting AVs, similarly by all three sectors mentioned above. Furthermore, participants pointed out topics such as 'providing access for disabled people', 'reduction in stress of driving', 'engaging in leisure activities' during driving and some others as being potential benefits. However, despite the fact that some experts indicated AVs might help to reduce travel time, they did not think reducing travel time would be one of the most valuable outcomes of the application of AVs (Table 5.18,

Model 5.5, & Model 5.9). Similarly, the experts indicated that AVs might reduce vehicle security.

The study evaluated parameters relating to traffic stream including 'travel time', 'traffic congestion, queues, delays', 'road throughput', and 'fuel consumption and emissions', which are also dependent on traffic congestion. Results of the evaluation on parameters related to traffic stream demonstrated that AVs, in general, were likely to enhance the quality of the traffic stream considerably, which is in line with the results of studies conducted by Cui et al. (2018), Li et al. (2018), and Schoettle and Sivak (2014b). Such an improvement in traffic would occur by helping to reduce travel time, traffic congestion, queues, and delays, and increasing road throughput by making better use of road capacity. Between the mentioned improvements, the experts from the private sector and academia had a greater tendency to believe that 'increasing road throughput' would be the most powerful impact of the application of AVs on traffic. Then, 'reducing traffic congestion, queues, and delays' was recognised as the next most substantial potential impact of AVs on traffic outlined by experts from academia, the government, and the private sector. However, it is worth noting that, the result of the current study regarding a reduction in traffic congestion contradicts with the results of studies conducted by Fagnant and Kockelman (2015) and Smith (2013) as they pointed out to an increase in traffic congestion as a result of adopting AVs.

A reduction in accidents as a result of adopting AVs has been suggested by several studies, such as Bansal et al. (2016), Underwood (2014), and Schoettle and Sivak (2014a, 2014b). The assessment on road safety and accidents in the current study (Table 5.27, Model 5.10, & Model 5.11) revealed that AVs would substantially help to reduce the number and severity of accidents, and consequently, help to increase road safety, which validates the results of the studies in the literature in this regard (mentioned in this paragraph). In this context, academia and the private sector had a greater tendency to believe in the capability of AVs to improve road safety. Then, the experts from the government and road authority were the next most likely groups to indicate that AVs would substantially increase road users' safety.

Legal liability has been identified as the main concern of adopting AVs in several studies such as Kyriakidis et al. (2015) and Howard and Dai (2014). However, there was a lack of study in the literature regarding which group or agency should accept the highest legal liability of AVs in case of an accident. Such a gap has now been identified in the expert survey of the current study. The majority of the experts indicated that 'AV manufacturers' should accept the highest legal liability in case of accidents involving AVs (Table 5.3). In this context, the experts from academia had the highest tendency to recognise 'AV manufacturers' as the sector with the greatest responsibility, and the government and private sector groups were the next most likely groups to agree with academia. Then, 'insurance companies' and 'AV owners or drivers' were the next most likely sectors to be identified as being legally liable for accidents. However, among the comments, other responses for this element of the study suggested that experts, in general, believed that assigning legal responsibility for AVs in the case of accidents depends on the nature of each accident and therefore some investigation of an accident scene would be required in this context.

Moreover, there was a lack of knowledge regarding the possible benefits of adopting an on-demand ridesharing service of AVs, which was addressed in the current study. The majority of experts declared they would 'highly recommend' on-demand ridesharing AVs rather than the application of private AVs (Table 5.4). In this context, 25.6% of the total participants from the private sector, and 22.9% from academia declared they would be 'extremely likely' to support on-demand ridesharing services for AVs if such services were available (Table 5.5).

The assessment regarding the support of 'AVs without a steering wheel' revealed that the majority of experts were against removing the steering wheel from the vehicle and the experts declared they would support 'AVs with a steering wheel and manual override control system' (Table 5.6, Model 5.6, Model 5.7, & Model 5.8). The primary supporters of such a statement were experts from academia. However, a considerable number of participants from the private sector and government tended to support AVs without a steering wheel (Table 5.7).

In general, as shown in the assessments, and based on the overall opinions, more than half of the experts supported the application of AVs on public roads (Table 5.8, Model 5.9, Model 5.10, & Model 5.11). However, the experts indicated that a lot more investigation, research, and development are required before the adoption of AVs. Therefore, experts did not recommend adopting AVs until further investigations have confirmed that AVs would be safe, secure, and efficient according to the discussion points in this study. The primary supporters of such a statement were the experts from academia and the private sector. Additionally, some experts declared that they are 'concerned about safety and security, but they would like to try AVs'. Around one-tenth of the participants indicated they would have 'no concern' about the application of AVs on public roads, while only 1% of the experts were 'opposed to AVs ever being allowed on public roads in any condition'.

Furthermore, the experts who supported the application of AVs indicated that adopting AVs requires infrastructure development, technology development, safety measures, improvement in juridical issues related to the use of the AVs, providing comfortable conditions for vehicle ownership, and some other conditions.

The results in this Chapter illustrated that around 90.3% of the participants believed the 'reduction of travel time' would not be one of the most valuable outcomes of adopting AVs (Table 5.17), except a small percentage of the experts from the 'road authority' and 'academia' groups which agreed that AVs could reduce travel time (Table 5.18). Out of those 90% experts, around 56.5% indicated that 'more R&D is required' on this matter (

Model 5.5, & Model 5.9). Additionally, the findings from this Chapter revealed that experts did not think AVs would be able to reduce 'traffic congestion, queues, and delays', and 'fuel consumption and emissions' (Table 5.26). In total, around half of the experts participated in this study indicated that a lot more R&D is required regarding the possible change in travel time, traffic congestion, and fuel consumption and emission resulting from the adoption of AVs on public roads (Table 5.8). Therefore, this study optimised TVs (available in Chapter 6) for the simulation of AVs (available in Chapter 7) to replicate the impacts of AVs on traffic congestion, travel time, and some other parameters evaluated in this study.

6. OPTIMISATION

6.1. Introduction

This Chapter presents the method, model design, and results of the optimisation of driving behaviours. Since there is no official experience of the application of AVs on public roads, their driving behaviours are not yet available, other than small trials. For this reason, this study optimised a traditional driving behaviour model (Wiedemann-99) acquired in traffic simulations such. The optimisation of this study was conducted using Sensitivity Analysis and microsimulation modelling to improve human driving behaviours. In this regard, Section 6.2 explains the optimisation method and model design and Section 6.3 represents the optimisation results. Finally, Section 6.4 discussed the main findings of this Chapter and they are going to be used in Chapter 7 (simulation).

6.2. Model Design

Multiple studies such as Menneni et al. (2008), Russo (2008), and Woody (2006) showed that CC1 and CC2 are essential parameters of Wiedemann-99 when calibrating the simulation model to capacity and indicated to the substantial influence of these parameters on the freeway traffic flow. Besides, Menneni et al. (2008) explain that the combined effect of CC0, CC1 and CC2 can result in multiple solutions for the desired capacity value. In this context, the study for this research seeks to perform optimisation using "sensitivity analysis (SA)" which is also referred to as "what-if" or simulation analysis. SA is a method used for predicting the outcome of a decision given a specific range of variables; it addresses how much changes in one variable might affect the outcome.

In order to optimise the parameters of Wiedemann-99 (W99), CC0 to CC9 were changed using SA and then applied to the VISSIM model for simulation. Then, the simulation results were evaluated for travel time, the total number of vehicles generated in the model (which is an indication of the network throughput and capacity), queue length, queue delay, the number of stops, stop delay and LOS. In this context, 86 simulation scenarios were defined to find a combination of parameters which provide improvements in characteristics of the trip such as least travel time, fewest queues, delays and highest capacity, throughput, etc. The change in values could be a decrease in one parameter, or it could involve an increase or decrease in the range of certain parameters, e.g. in CC4 and CC5. The optimisation flowchart is shown in Figure 6.1.

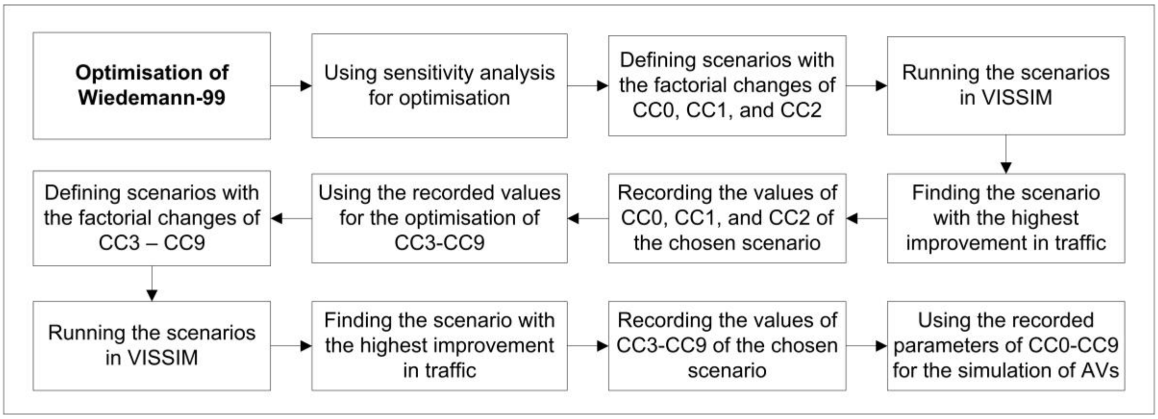


Figure 6.1. Optimisation flowchart

Regarding the increase or decrease of CC-parameters[1], the study conducted some (trial) simulations to capture the effect of reducing CC-parameters on the simulation results. The results showed that small changes in CC-parameters have negligible impacts on the simulation results. In light of this, taking account of all the possible reductions from 0–100% would have been very time consuming and unnecessary. Hence, the study made use of three factorial percentages of 25%, 50% and 75% changes in the values of CC-parameters, which represent the percentages below and above them (between 0–100%). Also, a 100% change in value was applied to some CC-parameters where it was possible, such as for CC4 and CC5.

When a parameter like CC0 decreased by 25%, other CC-parameters from CC1 to CC9 were used in the simulation without a change of value. Then, the same procedure was implemented for all the rest of the parameters one by one.

Other than the applied factorial percentages (25%, 50% and 75%), some other factorial percentages were also evaluated – namely 15%, 35% and 60% reductions in CC-parameters – to assess the differences in their results to the results from the applied factorial percentages. The assessment revealed negligible differences in simulation results related to travel time, queue, delay, LOS and some other parameters, meaning that the applied factorial percentages (25%, 50%, and 75%) are representative of all reduction percentages in the range of 0-100%. Table 6.1 demonstrates factorial changes to CC0.

As shown in Table 6.1, three factorial changes were implemented to CC0. Each of the factorial changes represents a simulation scenario whereby CC0 was reduced for each scenario while

[1] In order to avoid confusion with the parameters of Wiedemann-99, they are referred to as CC-parameters.

the rest of the parameters (CC1 to CC9) were applied with the same values as in Wiedemann-99. Such a factorial change was also applied to CC1 and CC2, thereby forming nine scenarios in total. Note that 100% reduction of CC0 would have reduced it to zero, which was not possible. Therefore, it was not considered as a scenario for simulation, but it is only presented in Table 6.1 for the readers' consideration. Also, Tables 20 and 21 show the factorial changes to CC1 and CC2, respectively.

Table 6.1. Factorial changes to CC0

Model parameter	W99	Factorial changes to CC0			
		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4***
		25% reduction in CC0 (1.5)	50% reduction in CC0 (1.5)	75% reduction in CC0 (1.5)	100% reduction in CC0 (1.5)
CC0	**1.50**	**1.12**	**0.75**	**0.38**	**0.00**
CC1	0.90	0.90	0.90	0.90	0.90
CC2	4.00	4.00	4.00	4.00	4.00
CC3	-8.00	-8.00	-8.00	-8.00	-8.00
CC4	-0.35	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35	0.35
CC6	11.44	11.44	11.44	11.44	11.44
CC7	0.25	0.25	0.25	0.25	0.25
CC8	3.50	3.50	3.50	3.50	3.50
CC9	1.50	1.50	1.50	1.50	1.50

* Not considered as a scenario for simulation

Table 6.2. Factorial changes to CC1

Model parameter	W99	Factorial changes to CC1			
		Scenario 5	**Scenario 6**	**Scenario 7**	**Scenario 8***
		25% reduction in CC1 (0.9)	50% reduction in CC1 (0.9)	75% reduction in CC1 (0.9)	100% reduction in CC1 (0.9)
CC0	1.50	1.50	1.50	1.50	1.50
CC1	**0.90**	**0.68**	**0.45**	**0.23**	**0.00**
CC2	4.00	4.00	4.00	4.00	4.00
CC3	-8.00	-8.00	-8.00	-8.00	-8.00
CC4	-0.35	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35	0.35
CC6	11.44	11.44	11.44	11.44	11.44
CC7	0.25	0.25	0.25	0.25	0.25
CC8	3.50	3.50	3.50	3.50	3.50
CC9	1.50	1.50	1.50	1.50	1.50

* Not considered as a scenario for simulation

Table 6.3. Factorial changes to CC2

Model parameter	**W99**	**Factorial changes to CC2**			
		Scenario 9	**Scenario 10**	**Scenario 11**	**Scenario 12***
		25% reduction in CC2 (4)	50% reduction in CC2 (4)	75% reduction in CC2 (4)	100% reduction in CC2 (4)
CC0	1.50	1.50	1.50	1.50	1.50
CC1	0.90	0.90	0.90	0.90	0.90
CC2	**4.00**	**3.00**	**2.00**	**1.00**	**0.00**
CC3	-8.00	-8.00	-8.00	-8.00	-8.00
CC4	-0.35	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35	0.35
CC6	11.44	11.44	11.44	11.44	11.44
CC7	0.25	0.25	0.25	0.25	0.25
CC8	3.50	3.50	3.50	3.50	3.50
CC9	1.50	1.50	1.50	1.50	1.50

* Not considered as a scenario for simulation

In the next step, the factorial change method was used to design scenarios with the combined effect of two CC-parameters at a time. Table 6.4 shows scenarios with factorial changes in two CC-parameters at a time.

As shown in Table 6.4, scenario 13, CC0 is reduced by 50% from its original value (1.5) to 0.75. In addition, CC1 with the original value of 0.9 is reduced by 75% to 0.23. Therefore, scenario 13 is a simulation scenario wherein two CC-parameters of CC0 and CC1 were reduced at one time. The rest of the CC-parameters from CC2 to CC9 in this scenario were adopted with the original values from Wiedemann-99. Likewise, scenarios 14, 15 and 16 represent simulation scenarios which involve changes to two CC-parameters at a time.

Note that each of the simulation scenarios was executed in VISSIM and assessments were conducted on the results related to travel time, queue length, delay, fuel consumption and other parameters assessed in this study. Results of the simulation in this context will be presented in Chapter 6.

Table 6.4. Factorial changes in two CC-parameters at a time

Model parameter	W99	Factorial changes in two CC-parameters at a time			
		Scenario 13	**Scenario 14**	**Scenario 15**	**Scenario 16**
		50% reduction in CC0 (1.5) and 75% reduction in CC1 (0.9)	50% reduction in CC1 (1.5) and 50% reduction in CC2 (0.9)	25% reduction in CC0 (1.5) and 75% reduction in CC2 (0.9)	75% reduction in CC0 (1.5) and 75% reduction in CC2 (0.9)
CC0	**1.50**	**0.75**	1.50	**1.12**	**0.38**
CC1	**0.90**	**0.23**	**0.45**	0.90	0.90
CC2	**4.00**	4.00	**2.00**	**1.00**	**1.00**
CC3	-8.00	-8.00	-8.00	-8.00	-8.00
CC4	-0.35	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35	0.35
CC6	11.44	11.44	11.44	11.44	11.44
CC7	0.25	0.25	0.25	0.25	0.25
CC8	3.50	3.50	3.50	3.50	3.50
CC9	1.50	1.50	1.50	1.50	1.50

In the next step, the factorial change method was applied to design scenarios to demonstrate the combined effect of changes to three CC-parameters at a time. Table 6.5 shows some examples of scenarios in this context.

For each scenario in Table 6.5, three CC-parameters were reduced according to the same method as that used for the reduction of two CC-parameters at a time. For example, in scenario 19, CC0, CC1 and CC2 were reduced by 75%, 75%, and 50%, respectively.

Table 6.5. Factorial changes in three CC-parameters at a time

Model parameter	W99	Factorial changes in three CC-parameters at a time		
		Scenario 17	**Scenario 18**	**Scenario 19**
		25% reduction in CC0 (1.5), 25% reduction in CC1 (0.9), and 50% reduction in CC2	50% reduction in CC0 (1.5), 25% reduction in CC1 (0.9), and 75% reduction in CC2	75% reduction in CC0 (1.5), 75% reduction in CC1 (0.9), and 50% reduction in CC2
CC0	**1.50**	**1.12**	**0.75**	**0.38**
CC1	**0.90**	**0.68**	**0.68**	**0.23**
CC2	**4.00**	**2.00**	**1.00**	**2.00**
CC3	-8.00	-8.00	-8.00	-8.00
CC4	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35
CC6	11.44	11.44	11.44	11.44
CC7	0.25	0.25	0.25	0.25
CC8	3.50	3.50	3.50	3.50
CC9	1.50	1.50	1.50	1.50

Note that the Tables in this Section – so far – only presented some of the examples of the scenarios used in this study. In total, 63 simulation scenarios were designed for the optimisation of CC0, CC1 and CC2, which are available in Appendix A (A13).

After running the simulation scenarios in VISSIM and analysing the results, the scenarios that provided the best simulation results for travel time, queue, delay and other parameters were separated, and the related CC-parameters were selected as the optimum CC-parameters.

In the next step, and after finding the optimised values of CC0, CC1 and CC2, the optimisation procedure was continued for CC3 to CC9 – one by one – while CC0, CC1 and CC2 were added to the new scenarios with their optimised values.

Since the optimised parameters in each step were applied to the next steps of optimisation, the optimisation procedure is presented in the order in which the parameters were optimised not based on the order of the CC-parameters. Thus, after optimising CC0, CC1 and CC2, CC4 and CC5 were optimised in the next step followed by CC9, CC6, CC7 and CC3.

Table 6.6 shows the optimisation scenarios for CC4 and CC5. As shown in Table 6.6, the ranges for CC4 and CC5 were decreased by 50% from their original values of -0.35 and 0.35 to -0.18 and 0.18, respectively. The ranges for CC4 and CC5 were also increased by 100% to -0.7 and 0.7, respectively, to cover a higher range of change for these two parameters.

Table 6.6. Scenarios for optimisation of CC4 and CC5

Model parameter	**W99**	**Scenarios for optimisation of CC4 and CC5**					
		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
		50% decrease in CC4 and CC5	25% decrease in CC4 and CC5	25% increase in CC4 and CC5	50% increase in CC4 and CC5	75% increase in CC4 and CC5	100% increase in CC4 and CC5
CC0	1.50	0.38	0.38	0.38	0.38	0.38	0.38
CC1	0.90	0.45	0.45	0.45	0.45	0.45	0.45
CC2	4.00	2.00	2.00	2.00	2.00	2.00	2.00
CC3	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00
CC4	**-0.35**	**-0.18**	**-0.26**	**-0.44**	**-0.53**	**-0.61**	**-0.70**
CC5	**0.35**	**0.18**	**0.26**	**0.44**	**0.53**	**0.61**	**0.70**
CC6	11.44	11.44	11.44	11.44	11.44	11.44	11.44
CC7	0.25	0.25	0.25	0.25	0.25	0.25	0.25
CC8	3.50	3.50	3.50	3.50	3.50	3.50	3.50
CC9	1.50	1.50	1.50	1.50	1.50	1.50	1.50

Table 6.7 shows the optimisation scenarios for CC9. As shown in Table 6.7, CC9 was decreased by 25%, 50% and 75% from its original value of 1.5 to 1.87, 2.25 and 2.62, respectively. Note that CC9 is controlled by the maximum acceleration, which is less than 2.5 m/s^2 for TVs and 1 m/s^2 for AVs in this study. Therefore, a 100% increase in the original value of CC9 (1.5) would have resulted in an acceleration of 3 m/s^2, which would not have been applicable to this study.

Table 6.7. Scenarios for optimisation of CC9

Model parameter	W99	Scenarios for optimisation of CC9		
		Scenario 1	**Scenario 2**	**Scenario 3**
		25% increase in CC9	50% increase in CC9	75% increase in CC9
CC0	1.50	0.38	0.38	0.38
CC1	0.90	0.45	0.45	0.45
CC2	4.00	2.00	2.00	2.00
CC3	-8.00	-8.00	-8.00	-8.00
CC4	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35
CC6	11.44	11.44	11.44	11.44
CC7	0.25	0.25	0.25	0.25
CC8	3.50	3.50	3.50	3.50
CC9	**1.50**	**1.88**	**2.25**	**2.63**

Moreover, Table 6.8 shows the optimisation scenarios for CC6. As shown in Table 6.8, CC6 was decreased by 25%, 50%, 75%, and 100% from its original value of 11.48 to 8.58, 5.72, 2.86 and 0, respectively. Results of the assessment in this Section will be presented in Chapter 6.

Table 6.8. Scenarios for optimisation of CC6

Model parameter	W99	Scenarios for optimisation of CC6			
		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
		25% reduction in CC6	50% reduction in CC6	75% reduction in CC6	100% reduction in CC6
CC0	1.50	0.38	0.38	0.38	0.38
CC1	0.90	0.45	0.45	0.45	0.45
CC2	4.00	2.00	2.00	2.00	2.00
CC3	-8.00	-8.00	-8.00	-8.00	-8.00
CC4	-0.35	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35	0.35
CC6	**11.44**	**8.58**	**5.72**	**2.86**	**0.00**
CC7	0.25	0.25	0.25	0.25	0.25
CC8	3.50	3.50	3.50	3.50	3.50
CC9	1.50	1.88	2.25	2.63	2.63

Furthermore, CC7 was decreased by 25%, 50%, 75% and 100% from its original value of 0.25 to 0.18, 0.13, 0.06, and 0, respectively. Table 6.9 shows optimisation scenarios for CC7.

Table 6.9. Scenarios for the optimisation of CC7

Model parameter	W99	Scenarios for optimisation of CC7			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
		25% reduction in CC7	50% reduction in CC7	75% reduction in CC7	100% reduction in CC7
CC0	1.50	0.38	0.38	0.38	0.38
CC1	0.90	0.45	0.45	0.45	0.45
CC2	4.00	2.00	200	2.00	2.00
CC3	-8.00	-8.00	-8.00	-8.00	-8.00
CC4	-0.35	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35	0.35
CC6	11.44	11.44	11.44	11.44	11.44
CC7	**0.25**	**0.18**	**0.13**	**0.06**	**0.00**
CC8	3.50	3.50	3.50	3.50	3.50
CC9	1.50	1.88	2.25	2.63	2.63

In the final step (shown in Table 6.10), CC3 was reduced to -2 in Scenario 1. Then, the reduction percentage increased by 25% for each scenario until CC3 involved a 75% reduction in its original value. Note that the terms *increase* and *decrease* are adopted based on an increase or decrease in the changing percentage, not the parameter value, which does not have an effect on the assessment.

Table 6.10. Scenarios for the optimisation of CC3

Model parameter	W99	Scenarios for optimisation of CC3					
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
		75% reduction in CC3	50% reduction in CC3	25% reduction in CC3	25% increase in CC3	50% increase in CC3	75% increase in CC3
CC0	1.50	0.38	0.38	0.02	0.09	0.38	0.38
CC1	0.90	0.45	0.45	0.45	0.45	0.45	0.45
CC2	4.00	2.00	2.00	2.00	2.00	2.00	2.00
CC3	**-8.00**	**-2.00**	**-4.00**	**-6.00**	**-10.00**	**-12.00**	**-14.00**
CC4	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35	0.35	0.35	0.35
CC6	11.44	11.44	11.44	11.44	11.44	11.44	11.44
CC7	0.25	0.25	0.25	0.25	0.25	0.25	0.25
CC8	3.50	3.50	3.50	3.50	3.50	3.50	3.50
CC9	1.50	2.63	2.25	1.88	1.88	2.25	2.63

6.3. Results

6.3.1. Introduction

The results of the optimisation of driving behaviours can be divided into two parts. The first part of the results relates to the results obtained during the optimisation of driving behaviours. The second part of the results relates to the impact of driving behaviours on the characteristics of the trip evaluated in this study (travel time, queue, delay, and some others). In this context, this Chapter firstly presents the results of the optimisation of CC0, CC1, and CC2 (Shown in TablesTable 3.6 – Table 6.5), with the discussion of results, which leads to the next steps of the optimisation. Then, the Chapter presents the findings related to the optimisation of CC3 to CC9 and the reason as to why they are not recommended for a change in their initial values. The optimised values of driving behaviours in this Chapter will be used for the simulation of AVs. Additionally, the Chapter presents the results of assessments on the impact of CC0, CC1, and CC2 on each of the characteristics of the trip, which were evaluated in this study. To do this, scenarios with the most substantial improvement in each of those characteristics were chosen for further assessments. Then, an evaluation was conducted to find which factorial changes of CC0, CC1, and CC2 have had the highest frequency in those selected scenarios sorted for each characteristic (for example, travel time). Such an assessment represented the importance of each of the factorial changes.

It is worth noting that some of the results in this Chapter are converted from their initial units – extracted from VISSIM – to the common metric values in line with the adopted measurement systems in Ireland. For example, the result related to fuel consumption was "US liquid gallon" in VISSIM, which is converted to "Litre" in this study in line with the metric unit of fluid measure used in Ireland.

It is also worth noting that VISSIM presents the LOS value in a range between 1 and 6 as a quantitative measure of the quality of traffic service, which corresponds to the qualitative LOS index range of A to F. Both types of measurements are presented in the main results related to the simulation. However, the quantitative results were used for the evaluation of scenario improvements.

6.3.2. Results Obtained During the Optimisation of Driving Behaviours

This Section explains some of the results obtained during optimisation. Such results include the results of the simulation of TVs and the simulation of 86 scenarios designed for the optimisation of driving behaviours in this study. Additionally, as explained in the optimisation methodology, the optimised parameters in each step were applied to the next optimisation steps. Therefore, the optimisation procedure is presented in the order in which the parameters were optimised, rather than being based on the order of the CC-parameters. Thus, after optimising CC0, CC1 and CC2, then CC4 and CC5 were optimised in the next step followed by CC9, CC6, CC7 and CC3.

6.3.2.1. Simulation Results for the Optimisation of CC0, CC1, and CC2

The basis of assessing any improvement in the optimisation results was a comparison of the results of the simulation of optimisation scenarios (1 – 63) with the results of the simulation of TVs. Table 6.11 represents the results of the simulation of TVs in VISSIM. Note that the parameters in Table 6.11 are chosen as the most relevant parameters (out of the many VISSIM outputs) related to traffic flow such as the number of vehicles as an index of flow and volume. The rest of the parameters are dependents of the traffic flow such as travel time, queue, delay, LOS, fuel consumption and emissions and they vary based on the number of vehicles, their speed, headway and gap. However, since the simulation was done using VISSIM, only those available outputs with the highest relevance to traffic flow are selected for evaluations in this study, which are represented in Table 6.11.

Table 6.11. The results of the simulation of TVs in VISSIM

Characteristic	Unit	Simulation result
Travel time from beginning to end	hh:mm	02:17
Vehicles from beginning to end	Count	1,139
Total vehicles in the model	Count	34,931
Queue delay	hh:mm	01:23
Queue length	km	2.46
Vehicle delay	hh:mm	01:18
Number of stops	Count	1,112
Stop delay	hh:mm	00:17
Emission CO	Ton.	2.18
Fuel consumption	Litre	117,821
LOS value	1 - 6	3.70

It is also worth noting that the purpose of optimisation in this study was using optimised driving behaviours together with some other model configuration for replicating autonomous behaviours. Therefore, the optimisation scenarios are considered to be the simulation scenarios which represent AVs in this study. However, the results in this Chapter are not the simulation results related to the application of AVs. Those results will be presented in Chapter 7.

For a better representation of the improvements resulting from the adoption of AVs in this study, hereafter the term will be referred to as the “quality of traffic”. The quality of traffic refers to the average improvements in the characteristics in Table 6.11; thus, it is necessary to evaluate the improvements of optimisation scenarios – for each characteristic – to the results related to TVs. In this context, after running the simulation scenarios designed for optimisation (1–63), the results for each of the characteristics will be compared to those of TVs. An increase or decrease of the values attained by the optimisation scenario will show how much they could improve such characteristics or deteriorate them. Table 6.12 represents an example of the assessment in this context.

As shown in Table 6.12, the average improvement of the AVs (optimisation scenario) to TVs is calculated by assessing the percentage change for each characteristic related to the simulation of AVs to that of TVs.

It is worth noting that the number of vehicles in the model indicates the road capacity or throughput. Therefore, an increase in vehicle numbers is considered an improvement[1] in road throughput. However, for the remainder of the characteristics in Table 6.12, a decrease of values from TVs to AVs is considered an improvement in the quality of traffic, such as the decrease in travel time, queue delay, queue length, vehicle delay, and the number of stops, stop delay, and LOS. The average improvement of all characteristics represents the overall improvement of AVs compared to TVs. In this context, the average improvement of scenarios related to AVs compared to the scenario TVs in Table 6.12 is 45.2% improvement in traffic efficiency. The assessment results in Table 6.12 show that adopting AVs could improve the overall quality of the trip characteristics by 45.2%.

It is worth noting that the current study is aiming to provide an overall assessment which the results could be used in any future studies and so not focusing on only one or a few specific parameters. In this regard, the parameters evaluated in Table 6.12 are considered with equal weight regarding the improvements in the quality of traffic. However, future studies can define various weights depending on their project aim i.e., if a future study aims

[1] Any improvement to the base scenario (here referred to TVs) is considered an improvement, so there is no specific scale for this assessment.

to obtain the highest reduction in queue length; then, this parameter (queue length) can have a higher weight than the rest of the parameters. The same rule applies to all the rest of the parameters explained in Table 6.12.

Table 6.12. Calculating the improvement of AVs compared to TVs in trip characteristics

Parameter	Unit	Simulation results		Improvement* of AVs to TVs
		TVs	AVs	
Travel time from beginning to end	hh:mm	02:17	02:03	-10.2%
Vehicles from beginning to end	Count	1,139	1,734	+34.3%
Total vehicles in the model	Count	34,931	44,362	+21.3%
Queue delay	hh:mm	01:23	00:49	-41.0%
Queue length	km	2.46	1.50	-39.0%
Vehicle delay	hh:mm	01:18	00:38	-51.3%
Number of stops	Count	1,112	289	-74.0%
Stop delay	hh:mm	00:17	00:06	-64.7%
Emission CO	Ton.	2.18	0.74	-66.1%
Fuel consumption	Litre	117,821	39,841	-66.2%
LOS value	1 - 6	3.70	2.63	-28.9%
Average improvement				**-45.2%**

* An increase or decrease of improvement is shown with a "+" and "-", respectively.

In total, this stage simulated 63 scenarios with various combinations of CC0, CC1, and CC2 according to what is explained in the methodology of optimisation (Section 6.2 of this Chapter). The optimisation Table of the 63 scenarios is available in Appendix A (A13). Also, the simulation results of those 63 scenarios are available in Appendix D (D1) along with other results related to optimisation. Table 6.13 represents each simulation's improvement scenario compared with the results of the simulation of TVs. For this purpose, the results related to scenario TVs (shown in Appendix D, D1) are considered as the reference category for assessing the improvement of the designed scenarios. In this context, the result of each simulation scenario (1–63), for any specific characteristic in Table 6.13, are compared to those of TVs, according to what has been previously explained about the improvement assessment of the simulation scenarios.

For a better representation of the changes in simulation results related to the optimisation of CC0, CC1, and CC2, a conditional colour is applied to the results of Table 6.13. In this context, red colour represents a value which is close to the findings related to the simulation of TVs, whereas any improvement is shown in green. The colour intensity represents the significance of improvement. Figure 6.2 shows the colour bar used for the conditional colouring of the simulation results of CC0, CC1, and CC2.

Figure 6.2. Conditional colour applied to the simulation results of CC0, CC1, and CC2

Table 6.13. Improvement of each optimisation scenario compared with that of TVs

Scenario	Travel time from beginning to end	Vehicles from beginning to end	Total vehicles in the model	Queue delay	Queue length	Vehicle delay	Number of stops	Stop delay	Emission CO	Fuel consumption	LOS value	Average improvement
	%	%	%	%	%	%	%	%	%	%	%	%
1	5.2	28.2	20.6	14.0	31.6	33.8	35.7	13.9	34.2	34.2	18.4	24.5
2	5.9	29.9	21.3	16.5	37.5	36.6	35.9	19.8	33.1	33.1	20.5	26.4
3	6.3	32.4	22.0	18.8	38.4	39.0	38.0	26.6	34.8	34.8	20.5	28.3
4	6.5	35.3	22.1	20.1	34.9	38.1	44.1	23.8	41.2	41.2	16.8	29.4
5	8.6	46.3	25.1	31.0	37.0	46.9	63.6	47.2	56.6	56.6	22.2	40.1
6	9.9	52.2	27.0	40.8	39.0	51.1	74.0	60.6	66.2	66.2	28.9	46.9
7	6.2	32.0	21.4	24.4	30.4	37.8	46.3	28.3	42.2	42.2	15.4	29.7
8	7.1	36.3	23.2	37.0	29.9	43.2	58.8	49.7	52.4	52.4	18.4	37.1
9	7.2	37.4	23.7	46.9	28.4	45.7	71.0	64.5	62.7	62.7	15.9	42.4
10	7.7	39.9	23.9	25.5	38.5	42.4	48.7	33.8	44.2	44.2	20.5	33.6
11	9.2	50.0	26.2	33.5	42.3	47.7	62.9	48.3	56.3	56.3	25.1	41.6
12	9.5	54.3	27.6	43.1	40.9	53.5	77.1	66.6	68.0	68.0	28.9	48.9
13	6.1	32.4	22.0	25.4	31.5	38.6	43.5	32.9	39.6	39.6	18.4	30.0
14	8.0	41.3	24.6	41.3	33.3	46.1	61.1	55.2	54.4	54.4	19.7	39.9
15	6.9	37.1	24.6	48.9	26.3	46.5	72.9	68.5	63.7	63.7	18.4	43.4
16	6.4	32.5	22.0	20.7	35.0	39.2	41.5	29.9	37.0	37.0	18.9	29.1
17	10.4	50.7	26.4	43.1	47.6	54.8	76.5	67.9	67.1	67.1	31.1	49.3
18	10.4	56.5	28.7	43.1	47.6	54.8	76.5	67.9	67.1	67.1	31.1	50.1
19	7.0	35.6	23.2	29.2	35.4	42.5	49.1	38.4	43.1	43.1	18.9	33.2
20	7.9	40.9	24.9	41.6	32.5	47.1	63.9	59.0	54.9	54.9	18.4	40.5
21	8.0	41.4	25.7	50.7	32.0	50.2	75.8	73.8	66.1	66.1	22.7	46.6
22	8.2	45.0	25.2	29.8	44.5	46.5	53.5	44.7	46.3	46.3	22.7	37.5
23	9.9	52.3	28.1	40.8	44.5	53.0	68.8	65.4	59.2	59.2	28.9	46.4
24	10.2	54.3	29.0	46.8	46.1	56.7	79.8	74.3	69.5	69.5	31.1	51.6
25	7.7	42.0	24.3	32.2	39.2	46.0	54.0	48.1	47.0	47.0	20.5	37.1
26	8.4	44.0	26.0	44.0	36.0	49.8	66.2	65.2	56.7	56.7	23.5	43.3
27	8.8	47.0	27.4	54.9	35.8	52.6	79.3	80.4	69.0	69.0	22.7	49.7
28	8.6	44.5	25.1	36.6	36.8	46.9	60.7	48.2	53.0	53.0	19.7	39.4
29	8.9	48.3	26.9	48.9	35.0	51.5	74.9	67.8	65.5	65.5	22.2	46.8
30	8.8	49.3	27.5	59.3	34.0	53.8	83.5	79.7	73.7	73.7	21.4	51.3
31	9.4	50.8	27.4	45.3	37.2	51.3	73.7	64.5	65.2	65.2	24.3	46.8
32	9.7	50.7	27.7	53.8	35.4	53.8	81.8	76.9	72.6	72.6	22.2	50.7
33	9.5	50.7	28.6	60.6	36.1	55.3	86.6	83.4	76.7	76.7	24.3	53.5
34	9.6	51.6	27.6	52.3	35.5	53.8	81.8	74.0	72.9	72.9	27.3	50.8
35	10.6	57.9	29.8	58.1	37.9	57.0	84.6	78.1	74.9	74.9	30.3	54.0
36	10.8	55.1	29.8	63.2	36.9	57.3	86.5	79.9	76.8	76.8	29.5	54.8
37	8.0	43.7	25.6	36.2	35.7	47.2	60.7	50.2	52.6	52.6	21.4	39.4
38	8.9	48.0	26.9	49.3	27.7	52.3	75.7	71.5	65.9	65.9	22.2	46.8
39	9.7	51.1	28.6	60.2	35.5	56.4	85.3	83.6	75.1	75.1	22.7	53.0
40	9.2	49.6	27.3	45.8	38.4	52.1	75.4	68.0	65.5	65.4	25.7	47.5
41	9.8	51.9	28.7	56.6	38.7	55.6	83.5	80.1	73.6	73.6	25.7	52.5

42	9.7	51.1	29.3	61.0	37.6	55.8	87.4	85.7	77.4	77.4	27.3	54.5
43	9.8	53.5	28.3	51.8	38.3	54.8	81.7	74.5	72.2	72.2	28.1	51.4
44	10.7	55.6	29.9	60.1	40.1	57.9	85.3	79.3	75.1	75.1	29.5	54.4
45	9.8	54.0	29.8	60.2	38.2	56.5	85.6	80.0	75.3	75.3	28.9	54.0
46	8.5	45.2	25.9	38.6	39.0	49.5	65.1	58.0	55.7	55.7	20.5	42.0
47	9.4	50.2	28.0	51.1	38.2	53.4	77.2	74.8	66.9	66.9	23.5	49.1
48	9.3	49.8	28.7	60.8	38.7	55.9	86.0	85.9	75.7	75.7	24.3	53.7
49	9.8	53.3	28.2	49.0	42.1	54.8	78.3	73.0	68.6	68.6	28.1	50.3
50	9.6	52.8	29.0	56.4	39.0	56.2	84.8	82.5	74.4	74.4	26.5	53.2
51	9.7	52.4	29.5	60.8	41.3	55.9	87.5	87.9	77.5	77.5	30.3	55.5
52	10.5	56.3	30.0	53.4	43.3	56.8	82.8	77.0	72.9	72.9	32.4	53.5
53	10.5	56.4	30.4	58.8	42.6	56.7	85.6	81.5	75.4	75.4	28.1	54.0
54	9.8	52.6	29.8	58.4	39.8	54.0	84.6	81.2	74.2	74.2	28.9	53.4
55	8.3	45.8	26.4	39.5	42.6	50.1	66.1	61.4	56.1	56.1	21.4	43.1
56	9.5	50.1	28.5	52.7	38.5	54.8	77.1	79.4	68.8	68.8	25.1	50.3
57	9.6	50.8	28.9	58.6	39.1	55.7	85.4	86.6	75.0	75.0	26.5	53.7
58	10.1	53.6	29.2	49.5	43.5	56.6	80.1	78.5	69.7	69.7	28.9	51.8
59	10.4	56.8	30.5	57.6	45.3	57.3	86.1	85.9	75.5	75.5	30.3	55.6
60	9.10	49.6	29.6	58.8	41.1	54.1	86.4	87.9	75.6	75.6	27.3	54.1
61	10.5	58.4	30.5	52.5	48.2	56.8	82.9	79.5	72.7	72.7	32.4	54.3
62	10.5	56.3	30.8	57.3	45.9	56.0	85.0	83.0	74.1	74.1	31.1	54.9
63	10.4	56.2	30.7	60.1	43.2	55.0	85.2	84.2	74.4	74.4	31.1	55.0

Based on the results from Table 6.13, three scenarios that presented the greatest improvement compared to the simulation results of TVs are selected as the optimised scenarios. Table 6.14 shows the simulation results of scenarios 59, 51, and 63, which presented the greatest average improvements compared with the results of the simulation of TVs.

Table 6.14. Scenarios with the greatest average improvement compared with the results of the simulation of TVs

Parameter		**Scenario code**		
		59	**51**	**63**
Travel time from beginning to end	%	10.4	9.7	10.4
Vehicles from beginning to end	%	56.8	52.4	56.2
Total vehicles in the model	%	30.5	29.5	30.7
Queue delay	%	57.6	60.8	60.1
Queue length	%	45.3	41.3	43.2
Vehicle delay	%	57.3	55.9	55
Number of stops	%	86.1	87.5	85.2
Stop delay	%	85.9	87.9	84.2
Emission CO	%	75.5	77.5	74.4
Fuel consumption	%	75.5	77.5	74.4
LOS value	%	30.3	30.3	31.1
Average improvement	**%**	**55.6**	**55.5**	**55.0**

Table 6.15 represents the values of CC0, CC1, and CC2 used for simulations in scenarios 59, 51, and 63. It is worth noting that scenarios 59, 51, and 63 earned almost the same overall improvement percentage compared with the results of the simulation of TVs. Therefore, any of these scenarios could be adopted as the optimised scenario for the simulation of AVs in this study. Additionally, the CC-parameters in Table 6.15 could be used for any future simulations associated with the parameters of Wiedemann-99.

Table 6.15. The recommended combination of CC0, CC1, and CC2 for obtaining the greatest improvement in the simulation model

Parameter	Definition	Unit	Scenario Code		
			59	**51**	**63**
CC0	Standstill Distance	m	0.38	0.75	0.38
CC1	Headway Time	s	0.45	0.45	0.22
CC2	"Following" Variation	m	2	1	1

This study selected scenario 59 as the optimised scenario of this study, with an overall improvement of 55.6% compared with the simulation result of TVs. Therefore, the CC-parameters related to scenario 59 were used as the optimised CC-parameters of this study and were applied to the optimisation of CC3 to CC9. The related values of CC0, CC1, and CC2 for scenario 59 are 0.38, 0.45, and 2, respectively.

After finding the optimised values of CC0, CC1 and CC2, the optimisation procedure was continued for CC3 to CC9 – one by one – while CC0, CC1 and CC2 were added to the new scenarios with their optimised values. Since the optimised parameters in each step were applied to the next steps of optimisation, the optimisation procedure is presented in the order in which the parameters were optimised not based on the order of the CC-parameters. Thus, after optimising CC0, CC1 and CC2, CC4 and CC5 were optimised in the next step followed by CC9, CC6, CC7 and CC3.

6.3.2.2. Simulation Results for the Optimisation of CC4 and CC5

In this step of optimisation, the study used CC0, CC1, and CC2 with their optimised value. However, CC4 and CC5 are changed according to what is explained in the methodology related to the factorial changes of these two parameters. Table 6.16 shows the simulation results for the optimisation of CC4 and CC5. Note that Table 6.16 adopts the same colour format as shown in Figure 6.2 with a small difference in interpretation in colour. The red colour in Figure 6.2 represented the values close of simulation results of TVs, but in this

Section, red colour represents the deterioration of the simulation results, whereas green shows an improvement.

Table 6.16. Results of the simulations on different ranges of CC4 and CC5

Parameter	Scenario 59	Factorial changes on CC4* and CC5**					
		CC4 & CC5	CC4 & CC5	CC4 & CC5	CC4 & CC5	CC4 & CC5	CC4 & CC5
	CC0: 0.38 CC1: 0.45 CC2: 2	**-25%**	**-50%**	**25%**	**50%**	**75%**	**100%**
Travel time from beginning to end (hh:mm:ss)	02:02:52	02:03:36	02:03:36	02:03:46	02:04:41	02:03:05	02:02:45
Number of vehicles from beginning to end	1,786	1,764	1,756	1,739	1,730	1,781	1,780
Total number of vehicles in the model (count)	45,590	45,516	45,272	45,352	45,259	45,653	45,565
Queue delay (hh:mm:ss)	00:35:35	00:36:39	00:36:51	00:36:25	00:37:25	00:35:35	00:35:20
Queue length (km)	1.34	1.42	1.45	1.38	1.46	1.39	1.34
Vehicle delay (hh:mm:ss)	00:33:21	00:34:13	00:33:54	00:34:33	00:34:52	00:33:07	00:32:51
Number of stops	155	162	161	159	166	150	156
Stop delay (hh:mm:ss)	00:02:26	00:02:31	00:02:36	00:02:33	00:02:37	00:02:23	00:02:34
Emission CO (Tonnes)	0.53	0.55	0.54	0.54	0.56	0.52	0.54
Fuel consumption (kg)	109,318	112,313	111,568	110,952	113,904	107,370	110,708
LOS value (1-6)	2.58	2.61	2.61	2.66	2.61	2.61	2.58

* CC4: Negative "following" threshold
** CC5: Positive "following" threshold

The improvement of simulation scenarios related to the optimisation of CC0, CC1, and CC2 was compared with the results of the simulation of TVs. However, in this step of the simulation, the study has an optimised scenario (59), which could make 55.6% overall improvement compared with TVs. Therefore, to assess any further development in the model, the simulation results of the optimisation scenarios – hereafter – will be compared with the results from scenario 59. In this regard, if a scenario with the proposed factorial changes can improve the results of scenario 59, it means that the new optimisation scenario could enhance the optimisation process. Otherwise, the new optimisation scenario will be rejected if it deteriorates the results of scenario 59. For this purpose, the simulation results of the optimisation scenario related to CC4 and CC5 are compared to those of scenario 59.

Table 6.17 represents the results obtained by applying the factorial changes to CC4 and CC5 compared to the results from scenario 59. This Table represents the value of deterioration occurring by applying the factorial changes of CC4 and CC5 compared to the optimised scenario (59). The red colour in Table 6.17 represents the (%) deterioration of a trip characteristic, and the colour density varies with the significance of values. Also, any improvements in the results are described in green cells. According to the results in Table 6.17, none of the factorial changes of CC4 and CC5 could improve the results of scenario 59; most deteriorated them. There were only some improvements for specific parameters in some scenarios (shown in green cells in Table 6.17). However, the scenarios with such small improvements showed an overall deterioration of results. Therefore, CC4 and CC5 are not recommended for a change in their initial values.

Table 6.17. The improvement percentage obtained by applying the factorial changes of CC4 and CC5 compared to the optimised scenario (59)

Parameter	Factorial changes on CC4* and CC5**					
	-25%	-50%	25%	50%	75%	100%
Travel time from beginning to end	-0.60%	-0.60%	-0.73%	-1.48%	-0.18%	0.09%
Number of vehicles from beginning to end	-1.25%	-1.71%	-2.63%	-3.14%	-0.28%	-0.34%
Total number of vehicles in the model	-0.16%	-0.70%	-0.52%	-0.73%	0.14%	-0.05%
Queue delay	-3.00%	-3.56%	-2.34%	-5.15%	0.00%	0.70%
Queue length	-5.65%	-8.18%	-3.13%	-9.23%	-4.02%	0.22%
Vehicle delay	-2.60%	-1.65%	-3.60%	-4.55%	0.70%	0.64%
Number of stops	-4.52%	-3.87%	-2.58%	-7.10%	3.23%	-0.65%
Stop delay	-3.42%	-6.85%	-4.79%	-7.53%	2.05%	-5.48%
Emission CO	-2.75%	-2.06%	-1.50%	-4.20%	1.78%	-1.27%
Fuel consumption	-2.74%	-2.06%	-1.49%	-4.19%	1.78%	-1.27%
LOS value	-1.16%	-1.16%	-3.10%	-1.16%	-1.16%	0.00%
Average improvement	**-2.53%**	**-2.95%**	**-2.40%**	**-4.40%**	**0.37%**	**-0.67%**

* CC4: Negative "following" threshold
** CC5: Positive "following" threshold

In the next step, the study continues the optimisation of other CC-parameters using optimised CC0, CC1, and CC2. However, CC4 and CC5 will be used with their initial values as defined by Wiedemann-99.

6.3.2.3. Simulation Results for the Optimisation of CC9

The simulation results related to the CC9 optimisation are presented in this Section. Similar to the explanation of the CC4 and CC5 optimisation, scenario 59 is the base scenario and results from any new scenario will be compared to those of scenario 59. Table 6.18 represents the simulation results for the applied factorial changes to CC9.

Table 6.18. Results of the simulations of different factorial changes of CC9

Parameter	**Scenario 59**	**Factorial changes on CC9***		
		CC9	CC9	CC9
	CC0: 0.38 CC1: 0.45 CC2: 2	**-25%**	**-50%**	**-75%**
Travel time from beginning to end (hh:mm:ss)	02:02:52	02:02:45	02:02:53	02:02:58
Number of vehicles from beginning to end	1,786	1,819	1,789	1,755
Total number of vehicles in the model	45,590	45,809	45,722	45,499
Queue delay (hh:mm:ss)	00:35:35	00:35:34	00:34:59	00:36:18
Queue length (km)	1.344	1.347	1.35	1.37
Vehicle delay (hh:mm:ss)	00:33:21	00:32:22	00:32:54	00:33:46
Number of Stops	155	153	151	159
Stop delay (hh:mm:ss)	00:02:26	00:02:28	00:02:20	00:02:29
Emission CO (Tonnes)	0.53	0.53	0.53	0.54
Fuel consumption (Kg)	28,879	28,603	28,481	29,401
LOS value (1-6)	2.58	2.55	2.63	2.52

* CC9: Acceleration at 80 km/h

Additionally, Table 6.19 represents the average improvement of the factorial changes of CC9 compared with scenario 59. The red colour in Table 6.19 represents the (%) deterioration of a trip characteristic, and the colour density varies with the significance of values. Also, any improvements in the results are described in green cells.

As shown in Table 6.19, the factorial changes of 25% and 50% reductions in CC9 provide some minor improvements in some evaluated parameters. Yet, the average improvement in these scenarios was 1%, which is not substantial. Note that any improvement to Scenario 59 is considered an improvement, so there is no specific scale for this assessment. Additionally, the results show that a 75% reduction in CC9 could deteriorate the quality of traffic by -1.00%. Generally, it could be stated that none of the factorial changes could improve the traffic quality in scenario 59, but made them worse. Therefore, CC9 is not recommended for any change in its initial value.

Table 6.19. The average improvement percentage resulted by using the factorial changes of CC9 compared to the optimised scenario (59)

Parameter	Factorial changes on CC9*		
	-25%	**-50%**	**-75%**
Travel time from beginning to end	0.09%	-0.01%	-0.08%
Number of vehicles from beginning to end	1.81%	0.17%	-1.77%
Total number of vehicles in the model	0.48%	0.29%	-0.20%
Queue delay	0.05%	1.69%	-2.01%
Queue length	-0.22%	-0.89%	-2.23%
Vehicle delay	2.95%	1.35%	-1.25%
Number of stops	1.29%	2.58%	-2.58%
Stop delay	-1.37%	4.11%	-2.05%
Emission CO	0.96%	1.37%	-1.82%
Fuel consumption	0.96%	1.38%	-1.81%
LOS value	1.16%	-1.94%	2.33%
Average improvement	**1.00%**	**1.00%**	**-1.00%**

* CC9: Acceleration at 80 km/h

6.3.2.4. Simulation Results for the Optimisation of CC6

Table 6.20 shows the simulation results for CC6 optimisation using four factorial changes in this regard. Table 6.20 adopts the same colour code as it was used in previous Sections where red colour in represents the deterioration percentage of a trip characteristic, and any improvements in the results are described in green cells.

Table 6.20. Results of simulations on different ranges of CC6

Parameter	Scenario 59	Factorial changes on CC6*			
		CC6	CC6	CC6	CC6
	CC0: 0.38 CC1: 0.45 CC2: 2	**-25%**	**-50%**	**-75%**	**-100%**
Travel time from beginning to end (hh:mm:ss)	02:02:52	02:02:58	02:03:34	02:03:22	02:02:01
Number of vehicles from beginning to end	1,786	1,770	1,739	1,786	1,775
Total number of vehicles in the model	45,590	45,619	45,343	45,627	45,587
Queue delay (hh:mm:ss)	00:35:35	00:35:48	00:36:28	00:37:29	00:34:53
Queue length (km)	1.344	1.354	1.385	1.371	1.340
Vehicle delay (hh:mm:ss)	00:33:21	00:33:32	00:34:51	00:33:24	00:33:24
Number of Stops	155	157	161	163	157
Stop delay (hh:mm:ss)	00:02:26	00:02:22	00:02:33	00:02:36	00:02:21
Emission CO (Tonnes)	0.53	0.54	0.55	0.56	0.53
Fuel consumption (Kg)	28,879	29,148	27,361	30,155	28,958
LOS value (1-6)	2.58	2.61	2.63	2.66	2.66

* CC6: Speed Dependency of Oscillation

Table 6.21 represents the average improvement of the factorial changes of CC6 compared with scenario 59. As shown in Table 6.21, all of the factorial changes in CC6 decreased traffic quality compared with the results of scenario 5. Thus, the initial value of CC6 defined by Wiedemann-99 will be used for the rest of the study simulations.

Table 6.21. The average improvement percentage of the factorial changes of CC6 compared to the optimised scenario (59)

Parameter	**Factorial changes on CC6***			
	-25%	**-50%**	**-75%**	**-100%**
Travel time from beginning to end	-0.08%	-0.57%	-0.41%	0.69%
Number of vehicles from beginning to end	-0.90%	-2.70%	0.00%	-0.62%
Total number of vehicles in the model	0.06%	-0.54%	0.08%	-0.01%
Queue delay	-0.61%	-2.48%	-5.34%	1.97%
Queue length	-0.74%	-3.05%	-2.01%	0.30%
Vehicle delay	-0.55%	-4.50%	-0.15%	-0.15%
Number of stops	-1.29%	-3.87%	-5.16%	-1.29%
Stop delay	2.74%	-4.79%	-6.85%	3.42%
Emission CO	-0.94%	-2.62%	-4.42%	-0.27%
Fuel consumption	-0.93%	5.26%	-4.42%	-0.28%
LOS value	-1.16%	-1.94%	-3.10%	-3.10%
Average improvement	**-0.40%**	**-1.98%**	**-2.89%**	**0.06%**

* CC6: Speed Dependency of Oscillation

6.3.2.5. Simulation Results for the Optimisation of CC7

Table 6.22 shows the simulation results for CC7 optimisation. The same colour bar is applied to this Table as that of Table 6.20, where red shows deterioration and green shows an improvement in the quality of a parameter.

Table 6.22. Results of the simulations on factorial changes of CC7

Parameter	**Scenario 59**	**Factorial changes on CC7***			
		CC7	CC7	CC7	CC7
	CC0: 0.38 CC1: 0.45 CC2: 2	**-25%**	**-50%**	**-75%**	**-100%**
Travel time from beginning to end (hh:mm:ss)	2:02:52	2:02:34	2:03:09	2:02:10	2:02:52
Number of vehicles from beginning to end	1,786	1,791	1,775	1,782	1,783
Total number of vehicles in the model	45,590	45,627	45,647	45,627	45,615
Queue delay (hh:mm:ss)	0:35:35	0:35:51	0:36:00	0:34:58	0:35:20
Queue length (km)	1.34	1.34	1.36	1.33	1.31
Vehicle delay (hh:mm:ss)	0:33:21	0:32:53	0:32:55	0:32:56	0:32:46
Number of Stops	155	146	140	125	103
Stop delay (hh:mm:ss)	0:02:26	0:02:21	0:02:24	0:02:17	0:02:22
Emission CO (Tonnes)	533,271	513,641	503,344	466,773	413,393
Fuel consumption (Kg)	28,879	27,815	27,259	25,279	22,387
LOS value (1-6)	2.58	2.58	2.61	2.55	2.58

* CC7: Oscillation Acceleration

Additionally, Table 6.23 represents the average improvement of the factorial changes of CC7 compared with those of scenario 59. The results in Table 6.23 show a small improvement in traffic quality, where the most considerable development relates to the scenario with a 100% reduction in the CC7 initial value. The overall improvement in this scenario was 7.86%, and it occurred when CC7 was considered as 0. Such a reduction might be acceptable for AVs, but there is not a supportive reference in this regard. Moreover, Menneni et al. (2008) and a report from the Wisconsin Department of Transportation (Wisconsin DOT, 2018) did not recommend any change in the value of CC7. Consequently, the current research uses the initial value of CC7 (0.25) for the rest of the study simulations.

Table 6.23. The average improvement percentage of the factorial changes of CC7 compared to the optimised scenario (59)

Parameter	**Factorial changes on CC7***			
	25%	**50%**	**75%**	**100%**
Travel time from beginning to end	0.24%	-0.23%	0.57%	0.00%
Number of vehicles from beginning to end	0.28%	-0.62%	-0.22%	-0.17%
Total number of vehicles in the model	0.08%	0.12%	0.08%	0.05%
Queue delay	-0.75%	-1.17%	1.73%	0.70%
Queue length	0.60%	-1.49%	1.19%	2.83%
Vehicle delay	1.40%	1.30%	1.25%	1.75%
Number of stops	5.81%	9.68%	19.35%	33.55%
Stop delay	3.42%	1.37%	6.16%	2.74%
Emission CO	3.68%	5.61%	12.47%	22.48%
Fuel consumption	3.68%	5.61%	12.47%	22.48%
LOS value	0.00%	-1.16%	1.16%	0.00%
Average improvement	**1.68%**	**1.73%**	**5.11%**	**7.86%**

* CC7: Oscillation Acceleration

6.3.2.6. Simulation Results for the Optimisation of CC3

The last CC-parameter in the optimisation process was CC3. CC3 was reduced to -2 in Scenario 1; then, the reduction percentage increased by 25% for each scenario until CC3 involved a 75% reduction in its original value, which in total resulted in six factorial changes. Table 6.24 represents the simulation results related to CC3. Note that the colour bar applied in this Table is also the same as that which is applied to Table 6.23, where red shows deterioration and green improvement in the quality of a parameter.

Table 6.24. Results of the simulations on different ranges of CC3

Parameter	Scenario 59	Factorial changes on CC3*					
		CC3	CC3	CC3	CC3	CC3	CC3
	CC0: 0.38 CC1: 0.45 CC2: 2	**-25%**	**-50%**	**-75%**	**25%**	**50%**	**75%**
Travel time from beginning to end (hh:mm:ss)	2:02:52	2:03:34	2:03:11	2:04:39	2:03:17	2:03:57	2:03:22
Number of vehicles from beginning to end	1,786	1,750	1,784	1,695	1,774	1,739	1,761
Total number of vehicles in the model	45,590	45,396	45,538	44,879	45,582	45,346	45,411
Queue delay (hh:mm:ss)	0:35:35	0:36:14	0:34:10	0:33:58	0:37:36	0:38:24	0:37:30
Queue length (km)	1.344	1.420	1.422	1.536	1.360	1.419	1.340
Vehicle delay (hh:mm:ss)	0:33:21	0:33:56	0:33:16	0:34:49	0:33:41	0:34:24	0:33:49
Number of Stops	155	154	146	146	171	173	174
Stop delay (hh:mm:ss)	0:02:26	0:02:30	0:02:19	0:02:24	0:02:41	0:02:42	0:02:42
Emission CO (Tonnes)	0.533	0.531	0.510	0.507	0.574	0.572	0.577
Fuel consumption (Kg)	28,879	28,762	27,641	27,429	31,082	30,976	31,230
LOS value (1-6)	2.58	2.63	2.58	2.66	2.61	2.69	2.63

* CC3: the threshold for entering to “following” phase

Additionally, Table 6.25 represents the average improvement of the factorial changes of CC3 compared with the results of scenario 59. The colour bar applied in this Table is the same as that applied to Table 6.19, where red shows deterioration and white represents a parameter quality improvement.

As Table 6.25 indicates, all of the factorial changes resulted in a deterioration in the quality of traffic, except the scenario with a (-) 50% reduction in the initial value of CC3, which had 1.56% improvement of results, which is not substantial. Therefore, the study does not recommend changing the CC3 value and applies its initial value to the rest of the study simulations.

Table 6.25. The average improvement percentage of the factorial changes of CC3 compared to the optimised scenario (59)

Parameter	Factorial changes on CC3*					
	-25%	**-50%**	**-75%**	**25%**	**50%**	**75%**
Travel time from beginning to end	-0.57%	-0.26%	-1.45%	-0.34%	-0.88%	-0.41%
Number of vehicles from beginning to end	-2.06%	-0.11%	-5.37%	-0.68%	-2.70%	-1.42%
Total number vehicles in the model	-0.43%	-0.11%	-1.58%	-0.02%	-0.54%	-0.39%
Queue delay	-1.83%	3.98%	4.54%	-5.67%	-7.92%	-5.39%
Queue length	-5.65%	-5.80%	-14.29%	-1.19%	-5.58%	0.30%
Vehicle delay	-1.75%	0.25%	-4.40%	-1.00%	-3.15%	-1.40%
Number of stops	0.65%	5.81%	5.81%	-10.32%	-11.61%	-12.26%
Stop delay	-2.74%	4.79%	1.37%	-10.27%	-10.96%	-10.96%
Emission CO	0.41%	4.29%	5.02%	-7.63%	-7.26%	-8.14%
Fuel consumption	0.41%	4.29%	5.02%	-7.63%	-7.26%	-8.14%
LOS value	-1.94%	0.00%	-3.10%	-1.16%	-4.26%	-1.94%
Average improvement	**-1.41%**	**1.56%**	**-0.77%**	**-4.17%**	**-5.65%**	**-4.56%**

* CC3: the threshold for entering to "following" phase

6.3.2.7. Overall Results for the Optimisation of CC0-CC9

The results indicated that, except for CC0, CC1, CC2, the rest of the Wiedemann parameters evaluated in this study should not be changed. Such a result has also been previously shown in a report by Wisconsin DOT (2018). Therefore, the study used the optimised parameters of CC0, CC1, and CC2 for the AV simulations while CC3 – CC9 were used with their initial value. Table 6.26 represents the recommended values for AV driving behaviours. However, as discussed in the research methodology, the optimised driving behaviours will be applied to the VISSIM model of AVs with some other model configurations to replicate autonomous behaviours.

Table 6.26. Recommended values for the driving behaviours of AVs

Model Parameter	Definition	W99	Status	Recommended
CC0	Standstill Distance	1.5	Changed	0.38
CC1	Headway Time	0.9	Changed	0.45
CC2	“Following” Variation	4	Changed	2
CC3	The Threshold for Entering to “Following” Phase	-8	Not changed	-8
CC4	Negative “Following” Threshold	-0.35	Not changed	-0.35
CC5	Positive “Following” Threshold	0.35	Not changed	0.35
CC6	Speed Dependency of Oscillation	11.44	Not changed	11.44
CC7	Oscillation Acceleration	0.25	Not changed	0.25
CC8	Standstill Acceleration	3.5	Not changed	3.5
CC9	Acceleration at 80 km/h	1.5	Not changed	1.5

6.3.3. The Impacts of CC0, CC1, and CC2 on Highway Trip Characteristics

This Section addresses the impacts of CC0, CC1, and CC2 on specific highway trip characteristics evaluated in the study (travel time, queue length, delays, and some others). In this context, the study estimated how these characteristics are affected by driving behaviour changes. The results from this evaluation provide a useful guideline to provide a target framework for driving behaviours and information on the extent to which driving behaviour must change to attain the desired improvements in travel time, queues, delays, and all the other assessed parameters.

6.3.3.1. The Impact of CC0, CC1, and CC2 on Travel time

In order to address how driving behaviour affects travel time, the results of all 63 simulation scenarios presented in Table 6.13 are sorted for travel time. Then, three scenarios with the greatest improvement in travel time (lowest value of travel time) were selected for further assessments. However, because of the subtle changes in the results between the scenarios, selecting the top three scenarios was not found to be representative of the impact of the CC-parameters in travel time. Then, the study tested 10, and 20 scenarios for a wider range of assessment. The trial evaluation showed that 20 scenarios would provide a sufficient range of results for addressing the impact of CC0, CC1, and CC2 on travel time. Therefore, the study considered 20 scenarios with the greatest improvement in travel time for further assessments. It is also worth noting that such an approach with the similar number of scenarios (20 scenarios) had been acquired in the assessments of the rest of the parameters in this Section.

Table 6.27 describes the scenarios, which give the lowest travel times of all 63 scenarios evaluated for the optimisation of CC0, CC1, and CC2. Moreover, the (%) improvement in travel time for each scenario compared with the travel time of TVs is shown in Table 6.27. Additionally, the applied values of CC0, CC1, and CC2 in those parameters are available.

Table 6.27. Results of the simulation regarding the impact of CC0, CC1, and CC2 on travel time

Count	Scenario	Travel time	Improvement compared to TVs	CC0	CC1	CC2
1	36	02:02:25	10.8%	1.50	0.23	1.00
2	44	02:02:29	10.7%	1.13	0.23	2.00
3	35	02:02:40	10.6%	1.50	0.23	2.00
4	62	02:02:45	10.5%	0.38	0.23	2.00
5	52	02:02:46	10.5%	0.75	0.23	3.00
6	61	02:02:46	10.5%	0.38	0.23	3.00
7	53	02:02:49	10.5%	0.75	0.23	2.00
8	59	02:02:52	10.4%	0.38	0.45	2.00
9	63	02:02:56	10.4%	0.38	0.23	1.00
10	18	02:02:57	10.4%	0.75	0.23	4.00
11	24	02:03:12	10.2%	0.38	0.23	4.00
12	58	02:03:20	10.1%	0.38	0.45	3.00
13	23	02:03:34	9.9%	0.38	0.45	4.00
14	6	02:03:39	9.9%	1.50	0.23	4.00
15	41	02:03:41	9.8%	1.13	0.45	2.00
16	49	02:03:45	9.8%	0.75	0.45	3.00
17	45	02:03:47	9.8%	1.13	0.23	1.00
18	43	02:03:48	9.8%	1.13	0.23	3.00
19	54	02:03:48	9.8%	0.75	0.23	1.00
20	42	02:03:49	9.7%	1.13	0.45	1.00
Base	**TVs**	**02:17:11**	**-**	**1.50**	**0.90**	**4.00**

In the following step, an assessment is conducted to find which factorial changes of CC0, CC1, and CC2 have had the highest frequency in those top 20 scenarios sorted for travel time. These assessments represent the importance of each of the factorial changes. For instance, the evaluation related to travel time in this context showed that CC0 with a factorial change of 75% reduction (0.38) from its initial value (1.5) was used seven times in the top 20 scenarios with the lowest travel time. However, CC0 with 25% (1.13) and 50% (0.75) reduction from its initial value was adopted five times each. Such an assessment shows that CC0 with 75% reduction from its initial value had the highest impact compared with the other (two) factorial changes applied to CC0 in 20 scenarios with the lowest travel time. In other words, the results reveal that CC0 when it was considered 0.38 had the highest impact on the reduction of travel time.

The same assessment was applied to the factorial changes related to CC1 and CC2. In this regard, the results showed that CC1 with a 75% reduction (0.23) from its initial value (0.9) was used 14 times in 20 scenarios that provided the lowest travel times. Consequently, CC1, when it was considered 0.23, had the highest impact on travel time reduction. However, CC2 with a 50% reduction (2) from its initial value (4) showed a higher impact on the reduction of travel time than the other two factorial changes related to CC2. Table 6.28 represents the results related to the frequency of factorial changes regarding the impact of CC0, CC1, and CC2 on travel time.

Table 6.28. The frequency of factorial changes regarding the impact of CC0, CC1, and CC2 on travel time

CC-parameter	**CC0**			**CC1**			**CC2**		
Initial value	1.5			0.9			4		
Factorial change	-25%	-50%	-75%	-25%	-50%	-75%	-25%	-50%	-75%
Reduced value	1.13	0.75	0.38	0.68	0.45	0.23	3.00	2.00	1.00
Frequency	5	5	7	0	6	14	5	6	5
Total frequency	**17**			**20**			**16**		

In overall, the assessment in this Section revealed that CC1 had the highest impact of all driving behaviours on the reduction of travel time. Therefore, to achieve the lowest travel time of the simulation, CC1 must be considered of the highest importance of all driving behaviours. Moreover, according to the results of this study, CC1 must be regarded as 0.23 to achieve the lowest travel time.

6.3.3.2. The Impact of CC0, CC1, and CC2 on the Number of Vehicles

The number of vehicles in the network indicates to the road throughput or the capacity of the road for providing traffic streams. Therefore, finding the CC-parameter, which highly impacts upon the increase of road throughput, would be beneficial for future studies.

According to what has been explained for the assessments related to the impact of CC0, CC1, and CC2 on travel time, the study sorted 20 scenarios, which had the highest number of vehicles in the simulation. Table 6.29 shows the simulation results in regard to the impact of CC0, CC1, and CC2 on vehicle numbers.

Table 6.29. Results of the simulation regarding the impact of CC0, CC1, and CC2 on the number of vehicles

Count	Scenario	Number of vehicles	Improvement compared to TVs	CC0	CC1	CC2
1	62	45,689	30.8%	0.38	0.23	2.00
2	63	45,657	30.7%	0.38	0.23	1.00
3	59	45,590	30.5%	0.38	0.45	2.00
4	61	45,589	30.5%	0.38	0.23	3.00
5	53	45,541	30.4%	0.75	0.23	2.00
6	52	45,393	30.0%	0.75	0.23	3.00
7	44	45,390	29.9%	1.13	0.23	2.00
8	45	45,348	29.8%	1.13	0.23	1.00
9	35	45,347	29.8%	1.50	0.23	2.00
10	54	45,338	29.8%	0.75	0.23	1.00
11	36	45,323	29.8%	1.50	0.23	1.00
12	60	45,277	29.6%	0.38	0.45	1.00
13	51	45,221	29.5%	0.75	0.45	1.00
14	42	45,149	29.3%	1.13	0.45	1.00
15	58	45,145	29.2%	0.38	0.45	3.00
16	24	45,077	29.0%	0.38	0.23	4.00
17	50	45,069	29.0%	0.75	0.45	2.00
18	57	45,011	28.9%	0.38	0.68	1.00
19	48	44,973	28.7%	0.75	0.68	1.00
20	18	44,970	28.7%	0.75	0.23	4.00
Base	**TVs**	**34,931**	**-**	**1.50**	**0.90**	**4.00**

Additionally, Table 6.30 represents the frequency of factorial changes of CC0, CC1, and CC2 in 20 scenarios with the highest number of vehicles in the model. The assessment, therefore, shows that CC1, when it was reduced by 75% (0.23) from its initial value (0.9), had the highest association with vehicle number increases on the network. Moreover, CC0 and CC2 had the same overall impact on the improvement of road throughput.

Table 6.30. The frequency of factorial changes regarding the impact of CC0, CC1, and CC2 on the number of vehicles

CC-parameter	**CC0**			**CC1**			**CC2**		
Initial value	1.5			0.9			4		
Factorial change	-25%	-50%	-75%	-25%	-50%	-75%	-25%	-50%	-75%
Reduced value	1.13	0.75	0.38	0.68	0.45	0.23	3.00	2.00	1.00
Frequency	3	7	8	2	6	12	3	6	9
Total frequency	**18**			**20**			**18**		

6.3.3.3. The Overall Impact of CC0, CC1, and CC2 on Trip Characteristics

To avoid repeating the assessment procedure related to the effects of CC0, CC1, and CC2 on each specific characteristics of the trip evaluated, this Section provides the brief results. More information about the Table of results (Table 6.31) related to the effect of CC0, CC1, and CC2 on the rest of the characteristics of the trips are available in Appendix D (D3 – D14).

Table 6.31 represents the frequency of the applied factorial changes in this study, which shows how many times each of the factorial changes was used on each specific characteristic. The results in this Section help to have a targeted simulation and to address which CC-parameter should be changed, and by how much, to achieve the best results for each of the specific characteristics of the trip.

The assessment of the total frequency of the factorial changes defined for CC0, CC1, and CC2 revealed that CC1 with 75% reduction (0.23) from its initial value (0.9) had the highest impact (of all factorial changes) on the quality of traffic flow. In total, CC1 (0.23) was used 93 times in 180 scenarios with the greatest improvements in the characteristics of traffic in this study. Such a result implies that CC1 when it is considered 0.23, plays an essential role in simulations related to the improvement in the quality of traffic. Overall, CC1 (0.23) had the highest impact on the reduction of travel time, queue length, LOS, and increasing the number of vehicles.

Moreover, results showed that CC2 had the second-highest impact on the quality of traffic (after CC1) when CC2 was decreased by 75% (1) from its initial value (4). In total, CC2 with the value of 1 was used 85 times in 180 scenarios with the most considerable improvements in the characteristics of traffic in this study. CC2, when it was considered 1, had the highest impact on the reduction of queue delay, the number of stops, stop delay, fuel consumption and CO emissions.

Table 6.31. Assessment of the overall impact of CC0, CC1, and CC2

CC-parameter	**CC0**			**CC1**			**CC2**		
Initial value	1.5			0.9			4		
Factorial change	-25%	-50%	-75%	-25%	-50%	-75%	-25%	-50%	-75%
Reduced value	1.13	0.75	0.38	0.68	0.45	0.23	3	2	1
Frequency in 20 scenarios with the greatest improvement on each characteristic									
Travel time	5	5	7	0	6	14	5	6	5
Number of Vehicles	3	7	8	2	6	12	3	6	9
Queue length	3	8	9	1	8	11	4	5	4
Queue delay	5	5	6	4	7	8	0	7	13
Number of Stops	5	5	6	4	7	9	1	7	12
Stop delay	4	5	8	5	7	7	1	5	13
Fuel consumption	5	6	5	4	7	9	1	7	12
CO emission	5	6	5	4	7	9	1	7	12
LOS	5	6	7	0	6	14	5	4	5
Total	**40**	**53**	**61**	**24**	**61**	**93**	**21**	**54**	**85**

6.4. Discussion

The optimisation results in this Chapter presented into two parts. One part of the results was related to the results obtained during the optimisation of driving behaviours. The other part of the results associated with the impact of driving behaviours on the quality of traffic.

In order to assess the improvement of optimisation scenarios, the results for each of the characteristics evaluated in this study (such as travel time, queue length, emission CO, and others) were compared to those of TVs. An increase or decrease of the values attained by the optimisation scenario represented how much they improved such characteristics or deteriorated them. Then, the average improvement of all characteristics represented the overall improvement of AVs to TVs.

In total, the study simulated 63 scenarios with various combinations of CC0, CC1, and CC2. Among which scenario 59 was selected as the optimised scenario of this study, with an overall improvement of 55.6% compared with the simulation result of TVs (see Table 6.15). The CC-parameters related to scenario 59 were used as the optimised CC-parameters of this study and were applied to the optimisation of CC3 to CC9. The related values of CC0, CC1, and CC2 for scenario 59 are 0.38, 0.45, and 2, respectively.

In order to assess any further development in the model with the optimisation of CC3–CC9, the simulation results of the optimisation scenarios (for CC3–CC9) were compared with the results from scenario 59. In this regard, any improvement in the results of scenario 59 was considered an enhancement to the optimisation process. Otherwise, the new optimisation scenarios (for CC3–CC9) were being rejected if they deteriorated the results of scenario 59.

In this regard, the simulation results related to the optimisation of CC3–CC9 revealed that none of the optimisation scenarios of CC3–CC9 could improve the results of scenario 59; most deteriorated them. Therefore, the results indicated that, except for CC0, CC1, CC2, the rest of the Wiedemann parameters evaluated in this study should not be changed. Such a result had also been indicated in a report by Wisconsin DOT (2018).

Moreover, Section 6.3.3 addressed the impact of CC0, CC1, and CC2 on the characteristics of highway trip evaluated in the study such as travel time, queue length, delays, and some others. The study estimated how these characteristics were affected by driving behaviour changes. The idea for such evaluation was to provide a target framework for driving behaviours and information on the extent to which driving behaviour must change to attain the desired improvements in those characteristics. In this context, 20 scenarios with the most substantial improvement in each of those characteristics were chosen for further assessments. Then, an evaluation was conducted to find which factorial changes of CC0, CC1, and CC2 have had the highest frequency in those top 20 scenarios sorted for each characteristic (for example, travel time). Such an assessment represented the importance of each of the factorial changes.

The assessment regarding the impact of CC0, CC1, and CC2 on travel time revealed that CC1 had the highest impact of all driving behaviours on the reduction of travel time. Therefore, to achieve the lowest travel time of the simulation, CC1 must be considered of the highest importance of all driving behaviours, and it must be regarded as 0.23. Also, CC0 and CC2, when they were considered 0.38 and 2, respectively, had the highest impact on the reduction of travel time, after CC1. Such an assessment provided a target framework for driving behaviours on the extent to which driving behaviours must change to attain the desired improvements in travel time.

The assessment regarding the impact of CC0, CC1, and CC2 on the number of vehicles revealed that CC1 when it was reduced by 75% (0.23) from its initial value (0.9), had the highest association with the increase in the vehicle number on the network and improving LOS. Moreover, CC0 and CC2 had the same overall impact on the number of vehicles in the network, which indicates to the road throughput or the capacity of the road for providing traffic streams, while CC0 was more effective in improving LOS.

Moreover, results revealed that CC0 and CC1 – by similar effect – had the highest impact on the reduction of queue length. The highest reduction in queue length achieved when CC0 and CC1 were regarded as 0.38 and 0.23, respectively. CC2 had the lowest impact on the decrease in queue length.

Also, the investigation in this Chapter revealed that CC1, and CC2, when they were regarded as 0.23 and 1, respectively, had the highest association with the reduction in the number of stops and stop delay. Besides, CC1 and CC2 had the highest association with the decrease in fuel consumption and CO emissions with such values, while CC0 had the lowest impact on the number of stops, stop delay, fuel consumption, and CO emission.

In the next step (available in Chapter 7) the optimised parameters of driving behaviours from this Chapter will be used for the simulation of AVs in the single mode of occupancy and the shared road with TVs. In this regard, the optimised values of CC0 (0.38), CC1 (0.45), and CC2 (2) will be adopted for the simulation of AVs along with other model configurations conducted for the replication of autonomous behaviours (explained in Chapter 3). The rest of the Wiedemann parameters (CC3 – CC9) will be adopted with the default values defined by Wiedemann. The results of simulations with the optimised driving behaviours from this Chapter will provide an understanding of how efficiently AVs might operate if they drive with optimised human driving behaviours.

7. SIMULATION

7.1. Introduction

This Chapter presents the results of a reliability test conducted on a simulation model developed for this study. The results of the simulation of TVs and AVs using the optimised driving behaviours identified, in Chapter 6, along with the model configurations applied to VISSIM for defining some autonomous driving behaviours. The Chapter also presents the results of simulations of TVs and AVs sharing the road. Finally, the Chapter presents the results of simulations performed with the new driving behaviours (that mimic AV's) suggested by PTV and compares them to driving behaviours of this study.

7.2. Reliability Test of the Simulation Model with Cronbach's Alpha

As previously explained in Chapter 3 (Section 3.6.2, Pg. 46), due to the limitations regarding the data collection in this study, the model of this study was designed as a conceptual model of the M50. Hence, certain assumptions are made for the VISSIM model in this study such as that the M50 has six junctions in total, and that half of the traffic from the approaching roads to the M50 junctions is heading towards the airport. Furthermore, the M50 was assumed to have four lanes (in one direction) across its entire length, and all cars on the M50 move towards the airport and none leave the M50.

As previously explained in Chapter 3 (Section 3.7.2, Pg. 72), Cronbach's Alpha was used to measure the internal consistency of the simulation results. For this purpose, a random traffic condition (on 4th of May 2017) was chosen for the evaluation of the simulation results of TVs to ensure model consistency. In this regard, the number of vehicles in simulation results related to the 4th of May for TVs were classified based on the time-intervals defined in the simulation model, which is shown in Appendix E (E1). For each row of the simulation results in that Table, information is available about the simulation run and the data collection points that recorded the data. The simulation results represented in Table E1 were used for the reliability assessment of Cronbach's Alpha according to what explained in Chapter 3 (Section 3.7.2, Pg. 72).

Table 7.1 represents the results of the reliability assessment of the number of vehicles (for TVs) in the simulation. Available in this Table, there are item statistics, which show the mean and standard deviation of the number of vehicles recorded at each time interval. Additionally, the inter-item correlation matrix represents the correlation of the recorded data between time-intervals, which is ranged from 0 – 1. A higher value represents a higher correlation of results between time-intervals' data. As shown in Table 7.1, the value of the Cronbach's Alpha in this evaluation is 0.839 which represents a good internal consistency of the data recorded for travel time (based on the criteria defined for Cronbach's Alpha in Chapter 3 (Section 3.7.2, Pg. 72).

Table 7.1. Reliability Assessment of the number of vehicles in the test condition (May, 4th)

Item Statistics						
Simulation time interval* (s)		**Mean**		**Std. Deviation**		**N**
0–600		**		**		**
600–1200		1063.352		181.325		105
1200–1800		1074.771		171.328		105
1800–2400		986.133		129.263		105
2400–3000		965.676		149.029		105
3000–3600		946.133		140.977		105
3600–4200		931.752		164.175		105
Inter-Item Correlation Matrix						
	600-1200	1200-1800	1800-2400	2400-3000	3000-3600	3600-4200
0–600	1.000	0.806	0.465	0.601	0.377	0.440
600–1200	0.806	1.000	0.500	0.366	0.191	0.249
1200–1800	0.465	0.500	1.000	0.277	0.473	0.286
1800–2400	0.601	0.366	0.277	1.000	0.641	0.720
2400–3000	0.377	0.191	0.473	0.641	1.000	0.609
3000–3600	0.440	0.249	0.286	0.720	0.609	1.000
Reliability Statistics						
Cronbach's Alpha		Cronbach's Alpha Based on Standardised Items				N of Items (time intervals)
0.839		0.840				6

* Information about the simulation time intervals is available in Chapter 3 (Table 3.19)
** Not recorded for evaluations.

In the next step, the reliability test was conducted for all the evaluated parameters of this study (see Chapter 6, Section 6.3.2.1) for both TVs and AVs' simulation results, which is shown in Table 7.2. As previously explained in the research methodology (see Chapter 3, Section 3.7.2), the reliability test demonstrates model ability in presenting consistent results over various traffic situations. In this context, travel time, queue length, stop delay, and other parameters are statistically evaluated for internal consistency using Cronbach's Alpha (α) method. Then, the average of the Alpha values of TVs and AVs were calculated to find the reliability range of each parameter (such as travel time).

According to the assessments in Table 7.2, nine out eleven evaluated parameters of the simulation model represented good (and very good) reliability according to Siswaningsih et al. (2017) and Taber (2018) as explained in Chapter 3 (Section 3.9.2, Pg. 73). Also, two parameters, the number of vehicles from origin to destination (O–D), and stop delay represented acceptable consistency for TVs according to the studies mentioned above. In general, the simulation model of this study represented an overall α value of 0.848, which is good reliability. Therefore, the simulation model showed to be reliable to represent consistent results.

Table 7.2. Reliability Assessment of the simulation model in the test condition (May, 4th)

Evaluated parameter	**Cronbach's Alpha (α)**			**Reliability**
	TVs	**AVs**	**Average**	
Travel time	0.913	0.906	0.910	Very good
Number of vehicles (O–D)*	0.456	0.851	0.654	Acceptable
Number of vehicles (total)	0.839	0.986	0.913	Very good
Queue delay	0.867	0.889	0.878	Good
Queue length	0.834	0.883	0.859	Good
Vehicle delay	0.855	0.887	0.871	Good
Stop delay	0.773	0.719	0.746	Acceptable
Number of stops	0.779	0.886	0.833	Good
CO emission	0.825	0.924	0.875	Good
Fuel consumption	0.825	0.924	0.875	Good
LOS	0.929	0.912	0.921	Very good
Average reliability	0.809	0.888	**0.848**	**Good**

* Origin – Destination

7.3. Simulation of TVs and AVs in Various Traffic Conditions

The TVs and AVs used in this study were simulated under various traffic conditions (peak, normal, and off-peak) at various times throughout the year; the TV and AV results were then compared. This Section presents the overall results of the TV and AV simulations in peak, normal, and off-peak traffic conditions to compare the quality of traffic created by these two types of vehicles. More information about the simulation results for each traffic condition is available in Appendix E (E2 – E19) and will be denoted within the Chapter as appropriate. The results of this Section represent the reliability of the simulation model. In this context, the comparison of results from various peak traffic conditions of the year represents how well the model consistently gets the same results.

7.3.1. Comparison of Results from the Simulation of TVs and AVs in Peak Traffic Condition

TV performance and AV performance were simulated and compared in peak traffic hours for a peak month (May), peak traffic for a normal month (September), and peak traffic for an off-peak month (February). Such an evaluation reveals how well AVs can operate in different peak traffic hours throughout the year.

As previously explained in Chapter 3 (Section 3.6.7, Pg. 62), there is no practical application of AVs on public roads, to date, so there is not sufficient information available against which to validate these results. However, a reliability assessment was conducted in Section 7.2 to ensure the simulation model is reliable and provides consistent results, which was called Cronbach's Alpha (Heale and Twycross, 2015). In this regard, the ratio of the “Mean Squared Error (MSE)” and “Mean Squared Row (MSR)” of the data for each characteristic such as the results of travel time were assessed. The results represented similar alpha values for both TVs and AVs, meaning that the simulation model was able to provide results with little variation between TVs and AVs; otherwise, the model would have been considered unreliable.

Also, a further assessment was performed on the overall simulation results to ensure reliability, which the results are represented in this Section, using the CV[1] method according to what previously explained in Chapter 3 (Section 3.7.2, Pg. 72). In this regard, the SD[2] of the average results for multiple traffic conditions (peak, normal, and off-peak) were measured to quantify the variation in results. From this, a CV value was generated to measure the dispersion. For instance, for the characteristics evaluated in this Section, AVs showed an average 54.3% improvement over TVs in the quality of traffic in all peak traffic hours (of May, September, and February) assessed in this study. A standard deviation of 0.001 and a CV of 0.001 verify that AVs achieved almost the same results across all peak traffic hours, which approves the simulation model’s reliability.

Table 7.3 compares TV and AV simulation results in peak traffic hours at various times in the year. More information about the results for each of the traffic conditions is available in Appendix E (E2 – E19).

---

[1] CV: Coefficient of Variation (the ratio of the standard deviation to the mean value)
[2] SD: Standard Deviation

Table 7.3. Comparison of results from the simulation of TVs and AVs in various peak traffic hours

Parameter	Peak traffic in May			Peak traffic in September			Peak traffic in February		
	Average of 10 peak hours in the peak month (May)			Average of 10 peak hours in the normal month (Sep)			Average of 10 peak hours in the off-peak month (Feb)		
	TVs	**AVs**	**Improvement**	**TVs**	**AVs**	**Improvement**	**TVs**	**AVs**	**Improvement**
Travel time (hh:mm:ss)	03:09:51	02:45:06	13.04%	03:08:38	02:43:29	13.33%	03:06:07	02:42:05	12.91%
# of vehicles (O–D)*	1,362	2,182	37.58%	1,354	2,176	37.78%	1,408	2,207	36.20%
# of vehicles (total)	41,655	50,502	17.52%	41,139	49,956	17.65%	41,328	49,929	17.23%
Queue delay (hh:mm:ss)	02:23:28	00:52:31	63.39%	02:18:20	00:49:59	63.87%	02:14:15	00:48:05	64.18%
Queue length (km)	4.03	1.97	51.12%	3.83	1.96	48.83%	3.66	1.81	50.55%
Vehicle delay (hh:mm:ss)	02:05:41	00:53:55	57.10%	02:01:54	00:51:19	57.90%	01:56:27	00:48:35	58.28%
Stops (num)	1,382	200	85.53%	1,329	190	85.70%	1,259	179	85.78%
Stop delay (hh:mm:ss)	00:29:44	00:02:03	93.11%	00:29:17	00:01:52	93.63%	00:27:48	00:01:49	93.47%
CO emission (tons)	2.53	0.66	73.91%	2.44	0.65	73.36%	2.35	0.62	73.62%
Fuel consumption (litres)	137,118	35,832	73.87%	132,268	34,953	73.57%	127,204	33,551	73.62%
LOS value (1–6)	4.43	3.09	30.25%	4.42	3.02	31.67%	4.34	2.96	31.80%
Average			**54.2%**			**54.3%**			**54.3%**
Reliability of the model results									
Average of all traffic conditions			The SD of the three average values			The CV of the three average values			
54.3%			**0.0006**			**0.001**			

* Origin – Destination

7.3.2. Comparison of Results from the Simulation of TVs and AVs in Normal Traffic Condition

Table 7.4 shows the comparison of results from the simulations of TVs and AVs in normal traffic hours at three time-points in the year: a month with peak traffic (May), a month with normal traffic (September), and a month with off-peak traffic (February). This evaluation indicates that AVs could improve the quality of traffic by 67.3% in various normal traffic hours. The precision of the simulation results is confirmed by the CV value of 0.003, which is close to zero, meaning there is little dispersion of result values around the mean value and the model is reliable in normal traffic condition.

More information about the simulation results for each of the traffic conditions in this Section is available in Appendix E (E2 – E19).

Table 7.4. Comparison of results from the simulation of TVs and AVs in various normal traffic hours

Parameter	Normal traffic in May			Normal traffic in September			Normal traffic in February		
	Average of 10 normal hours in the peak month (May)			Average of 10 normal hours in the normal month (Sep)			Average of 10 normal hours in the off-peak month (Feb)		
	TVs	**AVs**	**Improvement**	**TVs**	**AVs**	**Improvement**	**TVs**	**AVs**	**Improvement**
Travel time (hh:mm:ss)	02:34:42	02:06:39	18.13%	02:30:35	02:05:01	16.98%	02:26:51	02:03:36	15.83%
# of vehicles (O–D)*	1,208	1,752	31.05%	1,308	1,868	29.98%	1,321	1,823	27.54%
# of vehicles (total)	33,736	39,542	14.68%	33,900	39,618	14.43%	33,699	39,130	13.88%
Queue delay (hh:mm:ss)	01:02:10	00:05:41	90.86%	00:54:45	00:04:20	92.09%	00:48:59	00:03:09	93.57%
Queue length (km)	1.12	0.05	95.54%	0.91	0.02	97.80%	0.89	0.01	98.88%
Vehicle delay (hh:mm:ss)	00:51:24	00:06:40	87.03%	00:44:23	00:05:08	88.43%	00:40:00	00:03:52	90.33%
Stops (num)	487	21	95.69%	402	15	96.27%	358	11	96.93%
Stop delay (hh:mm:ss)	00:12:16	00:00:31	95.79%	00:10:20	00:00:27	95.65%	00:09:23	00:00:23	95.91%
CO emission (tons)	1.09	0.20	81.65%	0.94	0.19	79.79%	0.86	0.17	80.23%
Fuel consumption (litres)	58,773	10,965	81.34%	51,030	10,169	80.07%	46,565	9,397	79.82%
LOS Value (1–6)	3.31	1.78	46.22%	3.18	1.61	49.37%	3.03	1.51	50.17%
Average			**67.1%**			**67.4%**			**67.6%**

Reliability of the model results		
Average of all traffic conditions	The SD of the three average values	The CV of the three average values
67.4%	**0.002**	**0.003**

* Origin – Destination

7.3.3. Comparison of Results from the Simulation of TVs and AVs in Off-peak Traffic Condition

This Section presents the TV and AV simulation results for off-peak traffic hours during the peak traffic month of May, the normal traffic month of September, and the off-peak traffic month of February. As shown in Table 7.5, AVs showed a slightly lower level of improvement in May off-peak traffic than in the other conditions in this assessment. In general, AVs improved the quality of traffic an average of 63.5% during off-peak traffic hours. The CV of the simulation results in this Section showed a negligible dispersion of 0.037, which represents the model's reliability in off-peak traffic hours. Table 7.5 provides detailed information about the simulation results in off-peak traffic. More information about these results is available in Appendix E (E2 – E19).

Table 7.5. Comparison of results from the simulation of TVs and AVs in various off-peak hours

Parameter	**Off-peak of May**			**Off-peak of September**			**Off-peak of February**		
	Average of 10 off-peak hours in the peak month (May)			Average of 10 off-peak hours in the normal month (Sep)			Average of 10 off-peak hours in the off-peak month (Feb)		
	TVs	**AVs**	**Improvement**	**TVs**	**AVs**	**Improvement**	**TVs**	**AVs**	**Improvement**
Travel time (hh:mm:ss)	02:04:08	02:00:15	3.13%	02:12:31	02:00:25	9.13%	02:02:50	01:50:09	10.33%
# of vehicles (O–D)*	1,836	2,016	8.93%	1,792	2,131	15.91%	1,826	2,593	29.58%
# of vehicles (total)	32,728	34,072	3.94%	33,961	36,563	7.12%	28,881	33,060	12.64%
Queue delay (hh:mm:ss)	00:13:03	00:00:17	97.83%	00:25:24	00:00:40	97.38%	00:11:51	00:00:16	97.75%
Queue length (km)	0.26	0.00	100.00%	0.48	0.00	100.00%	0.23	0.00	100.00%
Vehicle delay (hh:mm:ss)	00:12:12	00:00:22	96.99%	00:20:59	00:00:44	96.51%	00:10:57	00:00:19	97.11%
Stops (num)	81	1	98.77%	159	2	98.74%	74	1	98.65%
Stop delay (hh:mm:ss)	00:02:25	00:00:02	98.62%	00:04:47	00:00:06	97.91%	00:02:13	00:00:02	98.50%
CO emission (tons)	0.30	0.12	60.00%	0.48	0.13	72.92%	0.29	0.12	58.62%
Fuel consumption (litres)	16,465	6,669	59.50%	25,872	7,308	71.75%	15,435	6,440	58.28%
LOS value (1–6)	1.81	1.03	43.09%	2.40	1.07	55.42%	1.71	1.03	39.77%
Average			**61.0%**			**65.7%**			**63.8%**

Reliability of the model results		
Average of all traffic conditions	The SD of the three average values	The CV of the three average values
63.5%	**0.024**	**0.037**

* Origin – Destination

7.3.4. Comparison of TVs and AVs in the Heaviest, near Normal, and Lightest Traffic Hours of the Year

Table 7.6 represents a comparison of results from the simulation of TVs and AVs under all traffic conditions in various months of the year (May, September, and February) evaluated in this study. The results are presented for the heaviest traffic hours of the year (peak traffic in May – assessed in Table 7.3), the normal traffic hours in the month with normal traffic (normal traffic in September – assessed in Table 7.4), and the lightest traffic hours of the year in the month with off-peak traffic (off-peak traffic in February – assessed in Table 7.5).

As shown in Table 7.6, AVs achieved the highest overall improvements (67.4%) in normal traffic hours, followed by off-peak traffic hours, with AVs demonstrating the lowest level of overall improvement during peak traffic hours.

According to the results from Table 7.6, one of the reasons for the lower level of improvement AVs showed in peak traffic was the high queue length and queue delay, which also impacted the vehicle delay and LOS. Therefore, it could be stated that AVs might not be quite efficient in high traffic volumes, as they result in long queues and delays on the road.

AVs in off-peak traffic hours, on the other hand, showed smaller improvements in travel time and in the total number of vehicles on the road than they did during peak and normal traffic hours. One reason for reduced improvement levels in these measures during the off-peak traffic hours could be the limitations defined for AVs such as the speed limit of 100km/h and the constraints related to their acceleration function, described in Chapter 3 (Section 3.6.5, Pg. 56). However, AVs demonstrated a high average improvement (67.4%) in the normal traffic hours when the road network was carrying normal traffic volumes. Therefore, it could be stated that the highest efficiency of AVs on the road might occur when AVs are adopted under normal traffic hours. Table 7.6 represents the comparison of the (overall) simulation results of TVs and AVs in peak, normal, and off-peak traffic hours evaluated in this study.

A visual evaluation (using graphs) was also assembled representing the change of each highway characteristic evaluated in this study (travel time, the number of vehicles, and several others) during peak, normal, and off-peak traffic hours. The resulting graphs are available in Appendix E (E2 – E19).

Table 7.6. Comparison of TVs and AVs in the heaviest, near normal, and lightest traffic hours of the year

Parameter	**Peak traffic in the peak month (the heaviest traffic of the year)**			**Normal traffic in the normal month (the normal traffic of the year)**			**Off-peak traffic in the off-peak month (the lightest traffic of the year)**		
	Average of 10 peak traffic hours in May			Average of 10 normal traffic hours in September			Average of 10 off-peak traffic hours in February		
	TVs	**AVs**	**Improvement**	**TVs**	**AVs**	**Improvement**	**TVs**	**AVs**	**Improvement**
Travel Time (hh:mm:ss)	03:09:51	02:45:06	13.04%	02:30:35	02:05:01	16.98%	02:02:50	01:50:09	10.33%
# of vehicles (O–D)*	1,362	2,182	37.58%	1,308	1,868	29.98%	1,826	2,593	29.58%
# of vehicles (total)	41,655	50,502	17.52%	33,900	39,618	14.43%	28,881	33,060	12.64%
Queue delay (hh:mm:ss)	02:23:28	00:52:31	63.39%	00:54:45	00:04:20	92.09%	00:11:51	00:00:16	97.75%
Queue length (km)	4.03	1.97	51.12%	0.91	0.02	97.80%	0.23	0.00	100.00%
Vehicle delay (hh:mm:ss)	02:05:41	00:53:55	57.10%	00:44:23	00:05:08	88.43%	00:10:57	00:00:19	97.11%
Stops (num)	1,382	200	85.53%	402	15	96.27%	74	1	98.65%
Stop Delay (hh:mm:ss)	00:29:44	00:02:03	93.11%	00:10:20	00:00:27	95.65%	00:02:13	00:00:02	98.50%
CO emission (tons)	2.53	0.66	73.91%	0.94	0.19	79.79%	0.29	0.12	58.62%
Fuel consumption (litres)	137,118	35,832	73.87%	51,030	10,169	80.07%	15,435	6,440	58.28%
LOS Value (1-6)	4.43	3.09	30.25%	3.18	1.61	49.37%	1.71	1.03	39.77%
Average	-	-	**54.2%**	-	-	**67.4%**	-	-	**63.8%**

* Origin – Destination

Figure 7.1 illustrates the improvement percentage of AVs over TVs in all highway trip characteristics evaluated in this study. The results show that AVs, in general, could improve the quality of traffic by an overall average of 62% across all traffic conditions.

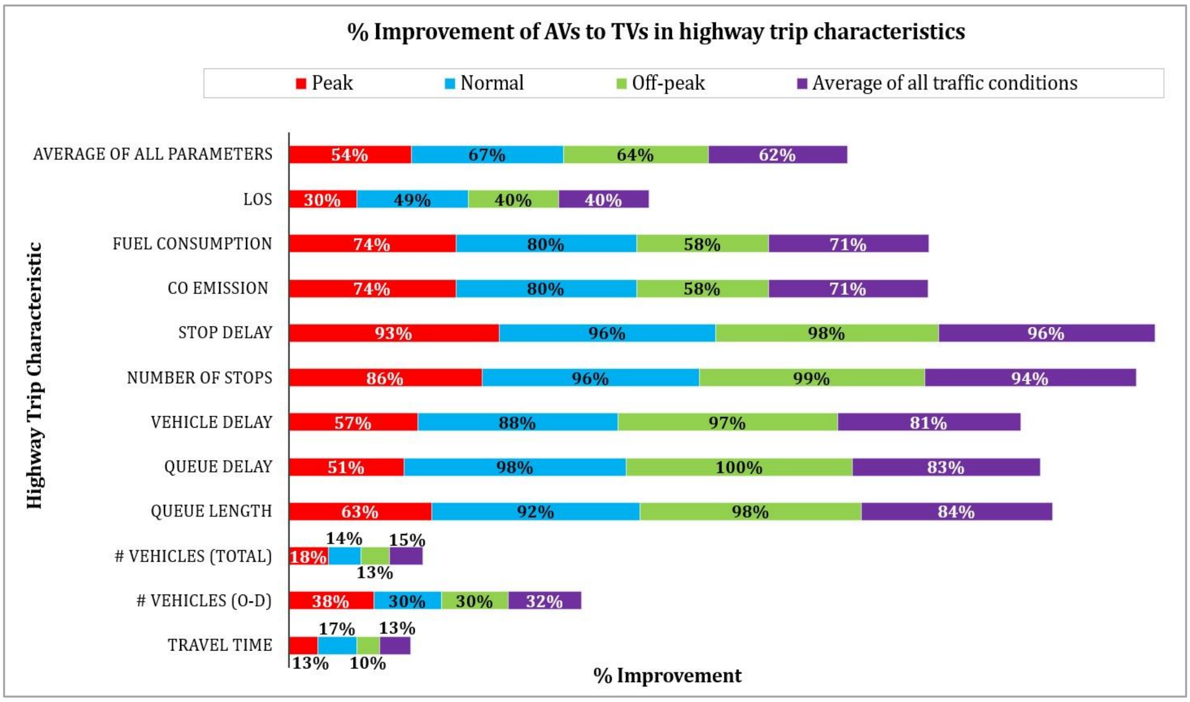


Figure 7.1. Improvement of AVs over TVs in different traffic hours

7.4. Simulation Results of the TV–AV Shared Road

This Section presents the results of the simulation of TVs and AVs in shared traffic mode. In this context, various scenarios with different proportions of TVs and AVs on the road were simulated for peak, normal, and off-peak traffic conditions for the year 2017. For this purpose, a random day from 2017 was selected and simulated from each of the three evaluated months: May (heaviest traffic of the year), September (close to normal traffic), and February (lightest traffic).

The simulation results were evaluated for the highway characteristics explained in Chapter 6 (Table 6.11, Pg. 198). The improvement for each characteristic was calculated – for each of the shared scenarios – and compared with the results from the simulation of TVs, which were the reference category for the analysis.

To better represent the improvements of AVs over TVs for each shared scenario, a colour bar was adopted for use in the assessments in this Section. The red colour represents the results from the simulation of TVs (the reference category in this Section), and green shows high improvement in the quality of the evaluated characteristics exhibited by AVs. Yellow represents more moderate improvements for the evaluated scenarios or characteristics. Figure 7.2 illustrates the colour bar applied to the simulation results of the TV–AV shared road in this evaluation.

Figure 7.2. Colour bar applied to the simulation results of the TV–AV shared road

7.4.1. Simulation Results of the Shared Road in the Month with Peak Traffic (May)

This Section presents the results from the simulation of the TV–AV shared road in the heaviest traffic condition of the year 2017. The selected day for this assessment was the 16th of May, which was a random day that represents those days with the heaviest traffic hours of the year.

As shown in Table 7.7, travel time, queue length, queue delay, CO emission, fuel consumption, and LOS were reduced with an increase in the share of AVs on the road. On the other hand, the number of vehicles from beginning to end (O–D)[1], and the total number of vehicles in the model were increased with an increase in the share of AVs.

Table 7.7. Simulation results of the TV–AV shared road in peak traffic in the peak month (16th of May)

Scenario	Travel time (hh:mm:ss)	Number of vehicles (O-D)	Total vehicles in the model	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS (1-6)
100% TVs	03:09:41	1,350	41,450	02:22:11	3.97	02:05:11	1,368	00:29:14	2.5	135,152	4.47
10% AVs	03:05:33	1,452	42,703	02:07:55	3.61	01:52:53	1,203	00:25:27	2.3	124,755	4.22
20% AVs	03:02:53	1,556	43,967	01:53:37	3.3	01:42:13	1,028	00:21:36	2.06	111,653	4.22
30% AVs	02:59:11	1,696	45,294	01:37:53	2.97	01:29:22	806	00:16:30	1.73	93,957	4.08
40% AVs	02:56:38	1,750	46,226	01:21:26	2.78	01:20:56	552	00:11:13	1.31	70,773	3.92
50% AVs	02:55:19	1,802	47,107	01:09:50	2.59	01:15:18	393	00:07:25	1.04	56,185	3.97
60% AVs	02:53:58	1,851	47,813	01:01:17	2.05	01:11:04	280	00:04:26	0.82	44,141	3.89
70% AVs	02:53:26	1,877	48,092	00:58:25	2.29	01:09:38	243	00:03:24	0.74	39,922	3.75
80% AVs	02:52:53	1,910	48,429	00:57:04	2.22	01:05:44	221	00:02:45	0.69	37,339	3.5
90% AVs	02:48:59	2,015	49,225	00:53:34	2.05	00:59:52	200	00:02:08	0.65	35,200	3.36
100% AVs	02:43:45	2,171	50,347	00:50:31	1.88	00:52:13	191	00:01:55	0.64	34,523	2.97

Table 7.8 represents the improvement in the shared-road scenarios compared with the results from the simulation of TVs only. According to the results in Table 7.8, when AVs comprised 100% of the network, the number of stops and length of stop delay were reduced

[1] O–D: Origin to Destination, which is also called 'from beginning to the end of trip'

by 86.0% and 93.4%, respectively, from the results of the TV-only simulation. Such a substantial reduction in the number of stops and the length of stop delay when the share of AVs increased could be an indication of the efficient interaction of AVs. After stops and stop delay time, fuel consumption and CO emissions were the characteristics that had the next greatest reductions. In general, a network with an equal proportion of TVs and AVs (50%–50%) provided 41.3% improvement in the quality of traffic, whereas a road entirely populated by AVs demonstrated a 57.6% improvement. Such an evaluation indicates how efficient a road shared by TVs and AVs can be in improving traffic quality, and how much a dedicated lane for AVs can be beneficial in this matter.

Table 7.8. The average improvement of the shared scenarios compared with the results from the simulation of 100% TVs for the 16th of May

Scenario	Travel time	Vehicles (O-D)	Total vehicles	Queue delay	Queue length	Vehicle delay	Stops	Stop delay	CO emission	Fuel consumption	LOS	Average
	%	%	%	%	%	%	%	%	%	%	%	%
100% CVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10% AVs	2.2	7.6	3.0	10.0	9.1	9.8	12.1	12.9	7.7	7.7	5.6	8.0
20% AVs	3.6	15.3	6.1	20.1	17.0	18.3	24.9	26.1	17.4	17.4	5.6	15.6
30% AVs	5.5	25.6	9.3	31.2	25.1	28.6	41.1	43.6	30.5	30.5	8.7	25.4
40% AVs	6.9	29.6	11.5	42.7	30.0	35.3	59.6	61.6	47.6	47.6	12.3	35.0
50% AVs	7.6	33.5	13.6	50.9	34.9	39.8	71.3	74.6	58.4	58.4	11.2	41.3
60% AVs	8.3	37.1	15.4	56.9	48.4	43.2	79.5	84.8	67.3	67.3	13.0	47.4
70% AVs	8.6	39.0	16.0	58.9	42.4	44.4	82.2	88.4	70.5	70.5	16.1	48.8
80% AVs	8.9	41.5	16.8	59.9	44.0	47.5	83.8	90.6	72.4	72.4	21.7	50.9
90% AVs	10.9	49.3	18.8	62.3	48.5	52.2	85.4	92.7	74.0	74.0	24.8	53.9
100% AVs	13.7	60.8	21.5	64.5	52.7	58.3	86.0	93.4	74.5	74.5	33.6	57.6

Figure 7.3 illustrates the improvement of each characteristic evaluated in this study obtained with the increase in the proportion of AVs on the road. Each of the evaluated characteristics in Figure 7.3 is represented with a coloured line, which is introduced in the Figure legend. The solid black line represents the average improvement of all characteristics in each scenario of the TV–AV mixed traffic.

Figure 7.3 also indicates the required share of AVs on the road, based on the target overall improvement. For instance, to obtain around a 40% improvement in traffic quality, approximately 50% of the road traffic has to be AVs. Furthermore, these results represent how travel time, queue length, and other characteristics are changed with an increase in the percentage of AVs. For example, when 80% of the road traffic was AVs, queue delay had decreased by 59.9% compared to when the road was entirely populated by TVs.

Furthermore, Figure 7.3 shows that there was no substantial improvement in the quality of traffic after the share of AVs on the road exceeded 60%. In this context, and as described in Table 7.8, a 60% share of AVs represented a 47.4% overall improvement in the quality of traffic, whereas a road with 100% AVs achieved 57.6% overall improvement. Therefore, dedicating 100% of the road traffic to AVs or devoting a dedicated lane for AVs in peak traffic hours might be as efficient as a shared road with 60% AVs was in this context.

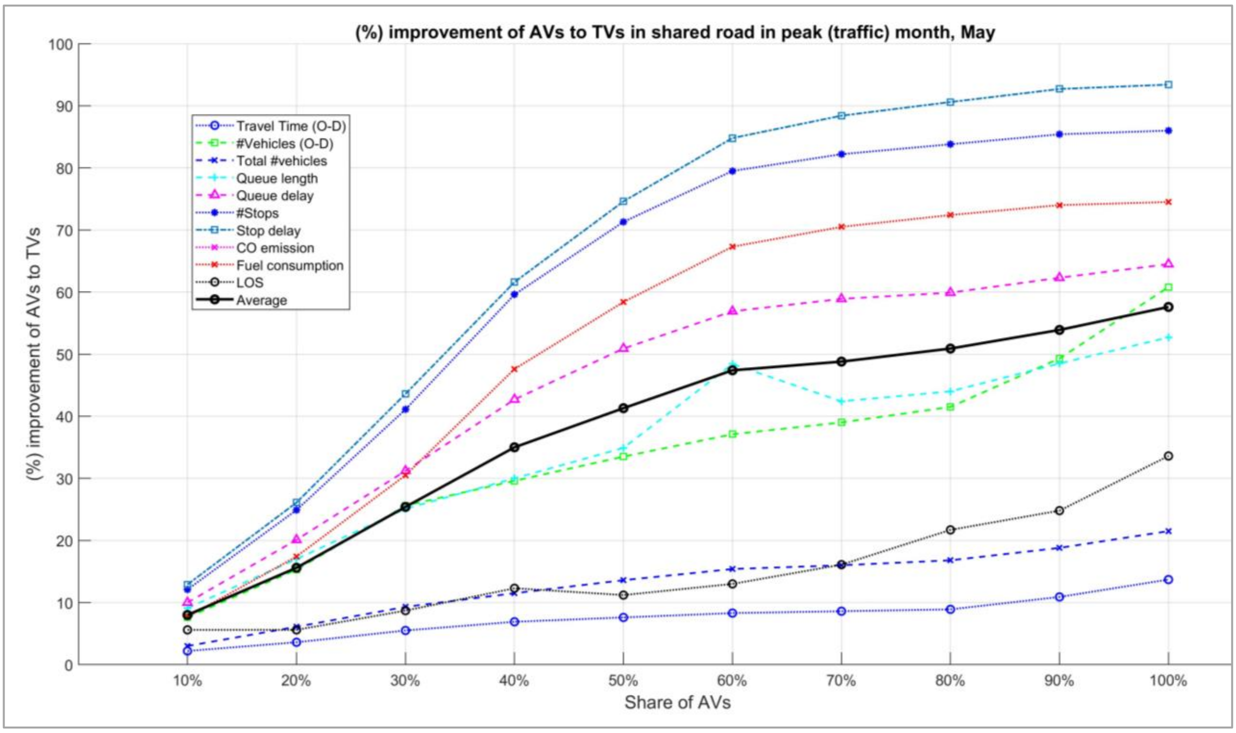


Figure 7.3. Improvement percentage of the shared scenarios compared to 100% TVs in the peak traffic month, May

7.4.2. Simulation Results of the Shared Road in the Month with Near Normal Traffic (September)

This Section presents the results from the simulation of the TV–AV shared road in the normal traffic condition of the year 2017. The selected day for this assessment was the 25th of September, which represents the days with normal traffic hours. Table 7.9 describes the result of the simulation in this context.

Table 7.9. Simulation results of the TV–AV shared road in normal traffic condition of the month with normal traffic (25th of September)

Scenario	Travel time (hh:mm:ss)	Number of vehicles (O-D)	Total vehicles in the model	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
100% TVs	02:27:19	1,322	33,720	00:50:47	0.94	00:40:11	381	00:09:27	0.89	48,405	3.00
10% AVs	02:22:26	1,411	34,597	00:40:46	0.83	00:31:35	284	00:07:19	0.74	40,091	2.81
20% AVs	02:18:24	1,488	35,426	00:32:52	0.64	00:24:29	208	00:05:37	0.61	33,251	2.53
30% AVs	02:15:02	1,557	36,200	00:23:34	0.48	00:19:24	146	00:04:05	0.5	26,933	2.33
40% AVs	02:13:00	1,600	36,935	00:16:22	0.48	00:16:09	107	00:02:48	0.42	22,642	2.28
50% AVs	02:12:20	1,632	37,314	00:12:26	0.41	00:14:26	73	00:01:52	0.34	18,173	2.28
60% AVs	02:09:23	1,692	37,833	00:07:25	0.24	00:11:27	40	00:01:03	0.25	13,714	2.06
70% AVs	02:09:02	1,697	37,965	00:05:52	0.18	00:10:43	26	00:00:40	0.22	11,812	2.03
80% AVs	02:08:50	1,733	38,073	00:06:13	0.09	00:10:08	25	00:00:37	0.21	11,602	2.03
90% AVs	02:05:05	1,786	38,504	00:03:52	0.01	00:05:51	14	00:00:26	0.18	9,872	1.69
100% AVs	02:02:53	1,838	38,861	00:02:30	0.01	00:03:08	8	00:00:20	0.16	8,895	1.42

Table 7.10 represents the improvement of each simulation scenario compared with the results from the simulation of TVs in this study. According to the results in Table 7.10, when AVs accounted for 100% of road traffic, the queue length and queue delay and the number of stops and stop delay decreased by more than 95%. Additionally, fuel consumption and CO emissions were reduced by 81.6%. In general, a network with a 50% share of AVs provided a 50.0% improvement in the quality of traffic, whereas a road network entirely populated by AVs demonstrated a 69.8% improvement.

Table 7.10. The average improvement of the shared scenarios compared with the results from the simulation of 100% TVs, associated with the 25th of September

Scenario	Travel time	Vehicles (O-D)	Total vehicles	Queue delay	Queue length	Vehicle delay	Stops	Stop delay	CO emission	Fuel consumption	LOS	Average
	%	%	%	%	%	%	%	%	%	%	%	%
100% CVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10% AVs	3.3	6.7	2.6	19.7	11.9	21.4	25.5	22.6	17.2	17.2	6.3	14.0
20% AVs	6.1	12.6	5.1	35.3	32.3	39.1	45.4	40.6	31.3	31.3	15.7	26.8
30% AVs	8.3	17.8	7.4	53.6	48.6	51.7	61.7	56.8	44.4	44.4	22.3	37.9
40% AVs	9.7	21.0	9.5	67.8	49.2	59.8	71.9	70.4	53.2	53.2	24.0	44.5
50% AVs	10.2	23.4	10.7	75.5	56.0	64.1	80.8	80.2	62.5	62.5	24.0	50.0
60% AVs	12.2	28.0	12.2	85.4	74.5	71.5	89.5	88.9	71.7	71.7	31.3	57.9
70% AVs	12.4	28.4	12.6	88.4	81.0	73.3	93.2	92.9	75.6	75.6	32.3	60.5
80% AVs	12.5	31.1	12.9	87.8	90.2	74.8	93.4	93.5	76.0	76.0	32.3	61.9
90% AVs	15.1	35.1	14.2	92.4	99.0	85.4	96.3	95.4	79.6	79.6	43.7	66.9
100% AVs	16.6	39.0	15.2	95.1	99.5	92.2	97.9	96.5	81.6	81.6	52.7	69.8

Figure 7.4 illustrates the improvement of the evaluated characteristics in this study with the increase in the share of AVs on the road. As shown in Figure 7.4, the improvement of characteristics under normal traffic volume in the shared road – compared to the road with 100% TVs – is in line with the improvements that occurred in peak traffic hours. In this context, for instance, CO emissions were reduced by 62.5% when 50% of the traffic was AVs. Also, Figure 7.4 suggests that LOS might not continuously improve with an increase in the share of AVs since scenarios with a 70% and 80% share of AVs similarly represented 32.30% improvement in LOS. In this context, it is worth noting that such similarities in the results of some scenarios – if they are not too numerous - can be ignored given the stochastic nature of the simulation procedures.

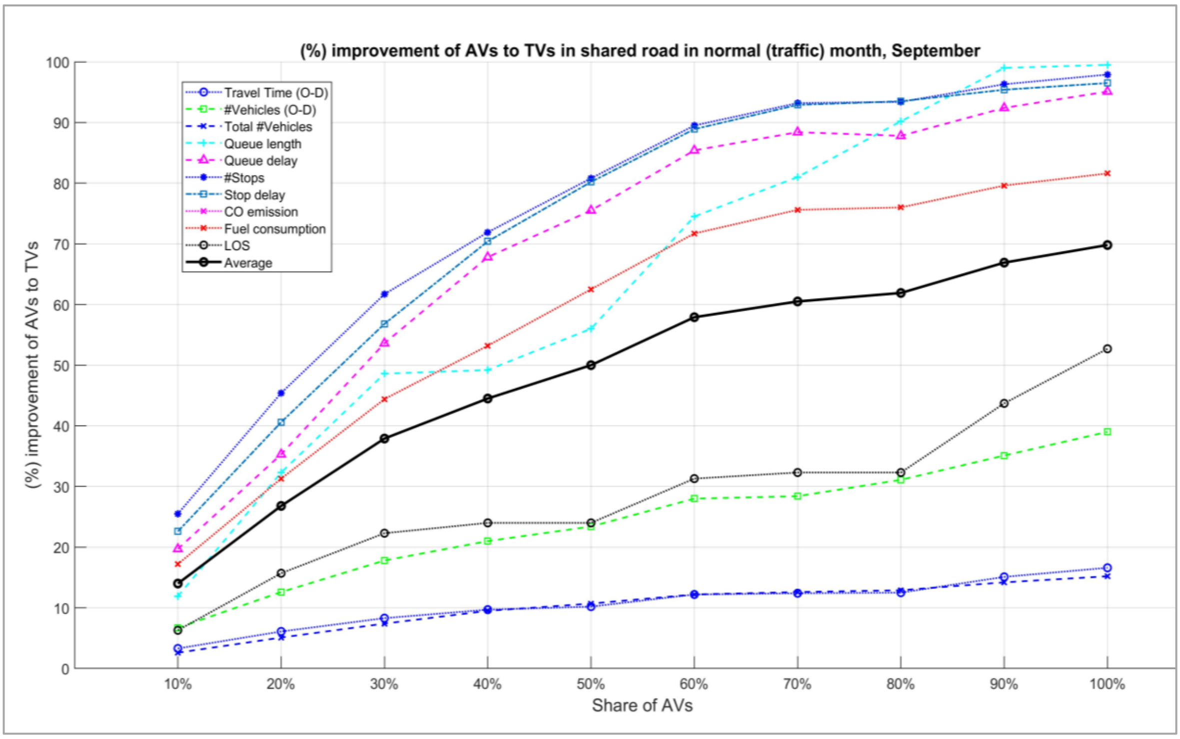


Figure 7.4. Improvement percentage of the shared scenarios to TVs in the normal traffic month, September

7.4.3. Simulation of the Shared Road in the Off-peak Month (February)

This Section presents the results from the simulation of the TV–AV shared road in the lightest traffic condition of the year 2017. The selected day for this assessment was the 18th of February, which represents the days with the lightest traffic of the year.

Table 7.11 describes the results of the simulation in this context.

Table 7.11. Simulation results of the TV–AV shared road in the off-peak traffic of the month with the lightest traffic of the year (18th of February)

Scenario	Travel time (hh:mm:ss)	Number of vehicles (O-D)	Total vehicles in the model	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
100% TVs	02:07:20	1,810	33,106	00:14:53	0.34	00:14:20	89	00:02:58	0.33	17,874	2.03
10% AVs	02:02:29	1,920	33,851	00:07:19	0.22	00:08:31	47	00:01:34	0.24	12,992	1.58
20% AVs	01:58:35	2,008	34,526	00:02:07	0.07	00:04:10	15	00:00:31	0.17	9,147	1.31
30% AVs	01:57:27	2,057	34,788	00:00:24	0.02	00:02:12	3	00:00:07	0.14	7,510	1.08
40% AVs	01:58:11	2,048	34,741	00:00:19	0.00	00:02:09	2	00:00:06	0.13	7,337	1.11
50% AVs	01:58:27	2,048	34,726	00:00:05	0.00	00:01:32	0	00:00:02	0.13	6,984	1.00
60% AVs	01:59:11	2,044	34,726	00:00:06	0.00	00:01:27	0	00:00:02	0.13	6,956	1.00
70% AVs	01:59:44	2,039	34,699	00:00:11	0.00	00:01:18	1	00:00:02	0.13	6,912	1.00
80% AVs	02:00:01	2,038	34,703	00:00:07	0.00	00:00:59	0	00:00:02	0.13	6,823	1.00
90% AVs	02:00:07	2,036	34,704	00:00:04	0.00	00:00:35	0	00:00:01	0.12	6,758	1.00
100% AVs	02:00:03	2,039	34,716	00:00:04	0.00	00:00:09	0	00:00:01	0.12	6,700	1.00

ent in the quality of traffic.

Table 7.12 represents the improvement of each simulation scenario compared with the results from the simulation of TVs. According to the results in Table 8, when AVs represented 100% of the traffic, the number of stops, queue length, and delay were almost eliminated from the road. In general, a road with a 100% share of AVs provided a 63.4% improvement in the quality of traffic.

Table 7.12. The average improvement of the shared scenarios compared with the results from the simulation of 100% TVs, associated with the traffic stream of the 18th of February

Scenario	Travel time	Total vehicles	Total vehicles	Queue delay	Queue length	Vehicle delay	Stops	Stop delay	CO emission	Fuel consumption	LOS	Average
	%	%	%	%	%	%	%	%	%	%	%	%
100% CVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10% AVs	3.8	6.1	2.3	50.8	36.8	40.6	47.2	47.2	27.3	27.3	22.2	28.3
20% AVs	6.9	10.9	4.3	85.8	80.4	70.9	83.1	82.6	49.0	48.8	35.5	50.7
30% AVs	7.8	13.6	5.1	97.3	94.7	84.7	96.6	96.1	58.0	58.0	46.8	59.9
40% AVs	7.2	13.1	4.9	97.9	99.4	85.0	97.8	96.6	58.9	59.0	45.3	60.5
50% AVs	7.0	13.1	4.9	99.4	100.0	89.3	100.0	98.9	60.9	60.9	50.7	62.3
60% AVs	6.4	12.9	4.9	99.3	100.0	89.9	100.0	98.9	61.1	61.1	50.7	62.3
70% AVs	6.0	12.7	4.8	98.8	100.0	90.9	98.9	98.9	61.3	61.3	50.7	62.2
80% AVs	5.7	12.6	4.8	99.2	100.0	93.1	100.0	98.9	61.8	61.8	50.7	62.6
90% AVs	5.7	12.5	4.8	99.6	100.0	95.9	100.0	99.4	62.2	62.2	50.7	63.0
100% AVs	5.7	12.7	4.9	99.6	100.0	99.0	100.0	99.4	62.5	62.5	50.7	63.4

Figure 7.5 illustrates the improvement in each characteristic evaluated in this study that was obtained with the increase in the proportion of AVs on the road in the off-peak traffic condition. The general trend of the characteristic improvement in Figure 7.5 indicates that there was no substantial improvement in travel time and the number of vehicles as the percentage of AVs on the road increased from 30% to 100%. However, other characteristics, such as the queue length and queue delay and the number of stops and stop delay time, obtained their greatest possible improvement when AVs represented a 30% share of the traffic.

Moreover, from the results in this Section, it can be seen that travel time increases after a 30% share of AVs. One interpretation for such a phenomenon could be that the 30% share of AVs in the road might be a point that AVs make the most efficient use of the road capacity and the ratio of volume to capacity is in its most efficient amount. After this amount, the ratio of volume to capacity goes toward zero, which means the capacity is much higher than what needed for the related volume. Such an issue lead to a higher level of service or a free-flow traffic stream. As a result, since AVs are limited to operate at a maximum speed of 100 km/h (see Chapter 3, Section 3.6.5.1), they will not be able to make the most use out of the available capacity though no improvement will occur in AVs' efficiency after 30% share of the mixed traffic. A solution for this issue would be increasing the speed limit of AVs so they can make more use of the capacity in free-flow traffic condition. Yea and Yamamoto (2018) recommended defining a higher speed flow for AVs than TVs in order to achieve higher performance of AVs in dedicated lanes, which would also be viable for merged traffic; therefore, validates the results of the current study in this regard. Such a declaration increase require further investigation.

In general, according to the results in this Section, it could be stated that more than a 30% share of AVs in off-peak traffic hours might not make a substantial improvement in the quality of traffic. Therefore, devoting a 30% share of the road to AVs would suffice to obtain the highest possible efficiency of traffic quality in off-peak traffic hours.

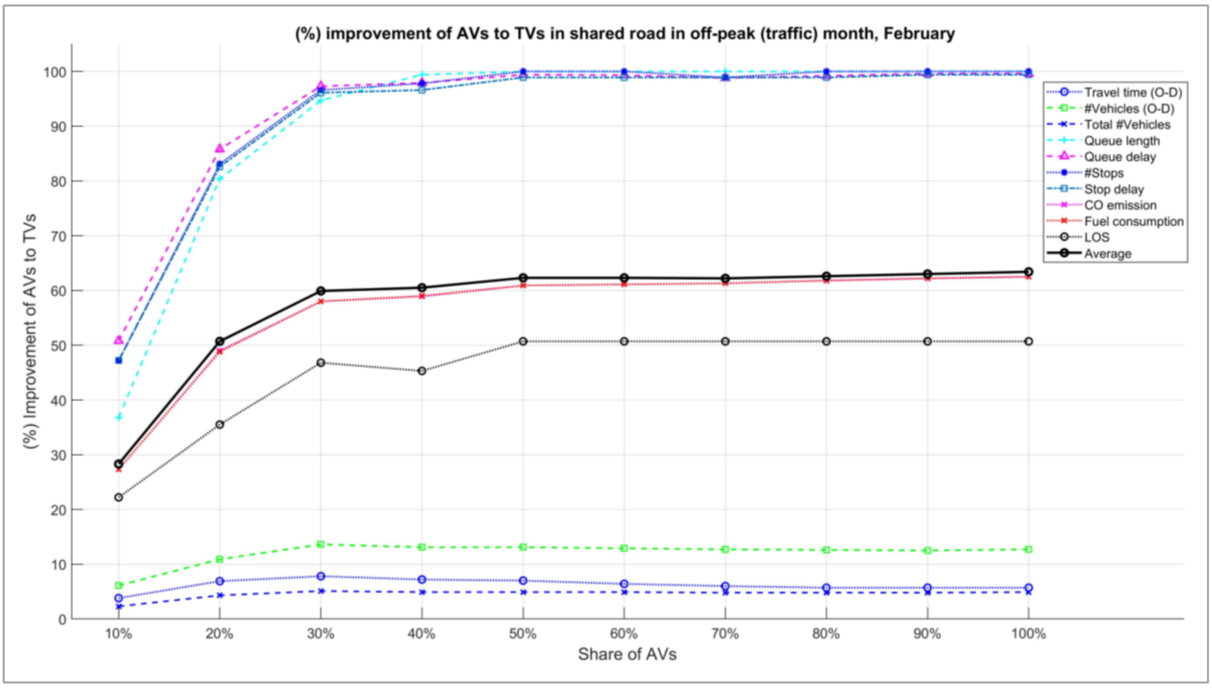


Figure 7.5. Improvement percentage of the shared scenarios to TVs in the off-peak month, February

7.5. Simulation of AVs with PTV Values and Comparison of Results with Those of This Study

In this Section, the simulation results are made available for the driving behaviours defined by PTV for AVs in an aggressive mode of driving, AVs with normal driving behaviours, and AVs with cautious driving behaviours.

In this study's simulation results, AVs achieved their highest efficiency in normal traffic conditions. Therefore, in this Section, AVs using the PTV driving behaviours are simulated under 10 normal traffic hours (in 10 days) in September. These results are compared with previous AV simulation results of this study. More information about the simulation results for each simulation hour (of each day) and the characteristics evaluated in this context is available in Appendix G (G1 – G3).

7.5.1. Average Results for the Simulation of the AVs of PTV in Normal Traffic Month (September)

This Section represents the overall results from the simulation of AVs with the driving behaviours defined by PTV compared to those of this study. Table 7.13 describes the average results for 10 normal traffic hours[1] within the month with a normal traffic stream (September).

In Table 7.13, the results from the simulation of TVs were considered as the reference category, and the rest of the simulation results were compared with them. Then, the AV simulation results of this study are compared with the results from the simulation of the AVs of PTV. In this context, a colour bar is applied to the results, where red shows the findings related to the reference category (TVs). Any substantial improvement compared with the results from TVs are shown in green, and yellow represents a median improvement.

Table 7.13. Overall results of the simulation of AVs in this study and those of PTV

Parameter	TVs	AVs of this study	AVs with PTV Value		
			AV Aggressive	AV Normal	AV Cautious
Travel time (hh:mm:ss)	02:30:35	02:05:01	02:00:16	02:06:14	02:21:36
# Vehicles (O–D)	1,308	1,868	1,956	1,805	1,464
# Vehicles (total)	33,900	39,618	40,113	39,541	32,639
Queue delay(hh:mm:ss)	00:54:45	00:04:20	00:00:11	00:00:42	01:15:20
Queue length (km)	1.00	0.02	0.00	0.00	1.82
Vehicle delay (hh:mm:ss)	00:44:23	00:05:08	00:00:48	00:05:00	00:56:28
Stops (num)	402	15	0	4	131
Stop delay (hh:mm:ss)	00:10:20	00:00:27	00:00:01	00:00:15	00:29:59
CO emission (tons)	0.22	0.19	0.15	0.16	0.37
Fuel consumption (litres)	51,030	10,169	7,972	8,658	20,183
LOS value (1-6)	3.18	1.61	1.01	1.41	4.27

Table 7.14 presents the improvement or deterioration obtained by the AVs of PTV and those of this study compared with the results from the simulation of TVs.

As shown in Table 7.14, and according to what has previously been explained in this Chapter, compared with TVs, the AVs of the current study obtained a 67.4% improvement in the quality of traffic under normal traffic hours. The results in Table 7.14 show that AVs with cautious driving behaviours defined by PTV lowered the quality of traffic by 27.3%

[1] Each hour represents a normal traffic hour of a day with normal traffic in September (for example, 7:00 am – 8:00 am, 20th Sep.)

compared to the scenario with 100% TVs on the road. Table 7.14 also shows that, by contrast, AVs with aggressive driving behaviours improved the quality of traffic by 73.0%, which is slightly more (by 5.6%) than what AVs of the current study obtained, considering the substantial change of values that PTV made in Wiedemann parameters. Finally, AVs with normal driving behaviours defined by PTV achieved a 69.4% overall improvement compared with TVs, which is close to the results of this study.

Table 7.14. Percent improvement of current study AVs and PTV AVs over TVs

Parameter	**AVs of this study**	**AVs of PTV**		
		AV Aggressive	**AV Normal**	**AV Cautious**
	%	%	%	%
Travel time	17.0	20.1	16.2	6.0
# Vehicles (O–D)	30.0	33.1	27.5	10.7
# Vehicles (Total)	14.4	15.5	14.3	-3.9
Queue delay	92.1	99.7	98.7	-37.6
Queue length	97.8	100.0	100.0	-100.0
Vehicle delay	88.4	98.2	88.7	-27.2
Stops	96.3	100.0	99.0	67.4
Stop delay	95.6	99.8	97.6	-190.2
CO emission	79.8	84.0	83.0	60.6
Fuel consumption	80.1	84.4	83.0	60.4
LOS	49.4	68.2	55.7	-34.3
Overall improvement	67.4	73.0	69.4	-27.3

In general, the comparison of results from the simulation of various driving behaviours of AVs defined by PTV indicates that the cautious driving behaviours defined by PTV lower the quality of traffic. Additionally, there is only a 3.6% difference in the overall average improvement achieved by AVs with normal driving behaviours compared to AVs with aggressive driving behaviours (both defined by PTV). Such a difference is negligible, given the stochastic nature of the simulations. Therefore, one of those sets of driving behaviours would be representative of the other one with some margin of error.

Moreover, the comparison of AV simulation results of this study to those of PTV validates the optimisation and simulation of this study. The optimised driving behaviours of this study obtained an overall improvement of 67.4%, which is in line with the simulation result improvements shown by the PTV's normal driving behaviours (69.4%) and aggressive driving behaviours (73.0%), with negligible variations of 2% and 5.6%, respectively.

It is also worth noting that PTV has substantially decreased the range of many parameters of Wiedemann 99, as explained in the methodology of this thesis. However, the optimisation of the current study revealed that only the three parameters of CC0, CC1, and CC2 have to be changed, and a change of value for the rest of the parameters is not required. In this context, simulation results in this Section validate the optimisation of the current study, as AVs of PTV did not show a substantial improvement over the AVs of this study.

7.5.2. Simulation of the TV–AV Shared Road with PTV Values

Following the comparison of the AVs of this study and those of PTV, this Section represents the simulation results of the TV–AV shared road with PTV values. In this context, a day with normal traffic hours within the month with normal traffic (25th of September) was chosen. The driving behaviour selected for this analysis was PTV's normal driving behaviour, as it had provided efficiency similar to that of the AVs of this study. Table 7.15 presents the results of this simulation.

As shown in Table 7.15, the share of AVs increased by 10% in each successive scenario, until finally, AVs occupied the entire road. Similar to what has previously been explained for the evaluation of the scenario improvement, TVs were considered as the reference category, and the simulation results of the shared scenarios were compared to those of TVs.

Table 7.15. Simulation of the TV–AV shared road for PTV (AV – normal)

Scenario	Travel time (hh:mm:ss)	Vehicles (O–D)* (number)	Total vehicles (number)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
100% TVs	02:27:19	1,322	33,720	00:50:47	1	00:40:11	381	00:09:27	0.89	48,405	3.00
10% AVs	02:23:00	1,390	34,515	00:38:51	1	00:32:29	277	00:06:03	0.73	39,308	2.81
20% AVs	02:19:30	1,461	35,340	00:29:20	1	00:26:13	189	00:04:13	0.58	31,206	2.58
30% AVs	02:13:42	1,525	36,043	00:20:52	1	00:21:05	123	00:02:45	0.44	23,925	2.33
40% AVs	02:11:47	1,624	37,002	00:12:41	0	00:15:38	67	00:01:33	0.32	17,411	2.22
50% AVs	02:08:43	1,696	37,668	00:07:20	0	00:11:44	37	00:00:57	0.25	13,395	2.00
60% AVs	02:05:32	1,760	38,157	00:04:07	0	00:08:10	16	00:00:25	0.19	10,256	1.69
70% AVs	02:03:44	1,801	38,441	00:02:02	0	00:05:47	7	00:00:12	0.17	8,999	1.36
80% AVs	02:01:09	1,865	38,909	00:00:28	0	00:02:32	1	00:00:03	0.15	8,030	1.17
90% AVs	02:00:37	1,882	39,072	00:00:16	0	00:01:25	1	00:00:02	0.15	7,856	1.00
100% AVs	02:00:13	1,883	39,106	00:00:09	0	00:00:40	0	00:00:01	0.14	7,729	1.00

* Number of vehicles from beginning to end

Table 7.16 represents the improvement percentage of the TV–AV shared road in a normal traffic hour in September adopting PTV AVs with normal driving behaviours compared to the TVs of this study.

As shown in Table 7.16, the number of stops, queue length, and delay showed the largest reductions of all evaluated characteristics in this assessment, similar to the reductions previously found for the TV–AV shared road of the current study. Also, the evaluation in this Section represented an average improvement of 73.6% when AVs represented 100% of the road traffic, an improvement average close to that of this study (69.8%). Moreover, there was no substantial improvement in the quality of traffic once the percentage of AVs rose above 60%. Such a result has already been found in the simulation results of the TV–AV shared road of the current study.

Table 7.16. Percent improvement of the TV–AV shared road of PTV with normal driving behaviours compared to TVs

Scenario	Travel time	Total vehicles	Total vehicles	Queue delay	Queue length	Vehicle delay	Stops	Stop delay	CO emission	Fuel consumption	LOS	Average
	%	%	%	%	%	%	%	%	%	%	%	%
100% CVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10% AVs	2.9	5.1	2.4	23.5	8.0	19.2	27.3	36.0	18.8	18.8	6.3	15.3
20% AVs	5.3	10.5	4.8	42.2	20.3	34.8	50.4	55.4	35.5	35.5	14.0	28.1
30% AVs	9.2	15.4	6.9	58.9	34.5	47.5	67.7	70.9	50.6	50.6	22.3	39.5
40% AVs	10.5	22.8	9.7	75.0	58.8	61.1	82.4	83.6	64.0	64.0	26.0	50.7
50% AVs	12.6	28.3	11.7	85.6	73.0	70.8	90.3	89.9	72.3	72.3	33.3	58.2
60% AVs	14.8	33.1	13.2	91.9	86.2	79.7	95.8	95.6	78.8	78.8	43.7	64.7
70% AVs	16.0	36.2	14.0	96.0	94.4	85.6	98.2	97.9	81.4	81.4	54.7	68.7
80% AVs	17.8	41.1	15.4	99.1	100.0	93.7	99.7	99.5	83.4	83.4	61.0	72.2
90% AVs	18.1	42.4	15.9	99.5	100.0	96.5	99.7	99.6	83.8	83.8	66.7	73.3
100% AVs	18.4	42.4	16.0	99.7	100.0	98.3	100.0	99.8	84.0	84.0	66.7	73.6

Appendix H (H1 – H11) presents comparative graphs comparing results from the TV–AV shared road of this study and results from the TV–AV shared road of PTV. The simulation results for each of the highway characteristics evaluated in this study are compared to those obtained by PTV. It is worth noting that the graph results of Appendix H are a cell-by-cell comparison of the results of Table 7.10 and Table 7.16.

7.6. Discussion of Chapter

This Chapter presented the results of the simulation of TVs and the simulation of AVs using the optimised parameters of Wiedemann-99 from Chapter 6. The Chapter then reported simulation results when the road was shared by various proportions of TVs to AVs. Finally, the Chapter presented simulation results for AVs with driving behaviours defined by PTV and compared those results with the AVs of this study.

The simulation of TVs and AVs in various traffic hours throughout the year revealed that AVs achieved the most substantial overall improvements in traffic quality under normal traffic hours when the road network carried normal traffic volumes. The lowest level of improvement was seen during peak traffic hours. One reason for this low improvement of AVs in peak traffic hours was the long queue and delays, which also impacted the LOS. Therefore, AVs might not be quite as efficient in the high traffic volumes as they are in normal traffic conditions. Moreover, AVs provided less improvement in travel time and the number of vehicles during off-peak traffic times, which could be due to the speed limit and acceleration constraints defined for them. AVs also showed higher efficiency in reducing the number of stops, stop delay, queue length, and queue delay, which could be due to their near-constant speed and the low variation in their acceleration and decelerations.

Results related to the TV–AV shared road revealed that the number of stops, queue length, and delay were substantially decreased when the roads were entirely populated by AVs. Such substantial reductions indicate that AVs might be more efficient when they represent a large share of the traffic. However, the results related to peak traffic hours in this context revealed that there was not substantial improvement in the quality of traffic after AV share rose above 60%. Therefore, dedicating 100% of the road traffic to AVs or devoting a dedicated lane for AVs in peak traffic hours might be as efficient as a shared road with 60% AVs. The simulation results of the shared road in the normal and off-peak traffic hours confirm such a declaration. According to the results in this context, there is an insignificant improvement in the overall results after a 60% share of AVs is reached in normal traffic hours and a 30% share for off-peak traffic hours.

The investigation of PTV driving behaviours for AVs revealed that cautious driving behaviours reduce traffic quality. Additionally, there is only a 3.6% difference in the overall average improvement achieved by AVs with normal driving behaviours compared to AVs with aggressive driving behaviours (both defined by PTV). Such a difference is negligible given the stochastic nature of the simulations. Therefore, one of those sets of driving behaviours, preferably AVs with normal driving behaviours, would be representative of the other one with some margin of errors.

The comparison of results from the simulation of the AVs of this study and those of PTV validates the simulation of this study. The simulation of AVs using the optimised driving behaviours of this study obtained an overall improvement of 67.4% in traffic quality, which is in line with simulated 69.4% improvement from the PTV's normal driving behaviours. The PTV aggressive driving behaviours resulted in an overall improvement of 73.0% in the quality of traffic, which is also close to the overall improvement obtained by the AVs of the current study, representing another validation for the simulation of the current study.

Moreover, the comparison of the simulation results of the AVs of this study and those of PTV also validates the optimisation of the current study. It is worth highlighting that the optimisation of the current study revealed that only the three parameters of CC0, CC1, and CC2 have to be changed, and a change of value for the rest of the parameters is not required. The simulation results in this Chapter validate such a declaration for the current study, as PTV AVs did not substantially improve on the AVs of this study with regard to the substantial changes PTV made on all parameters of driving behaviours.

Moreover, the simulation of the TV–AV shared road of PTV returned results similar to those of this study. The shared scenarios showed no substantial improvement in the quality of traffic once the AV share of the road rose above 60%. Such a result has already been seen in the simulation results of the TV–AV shared road of the current study.

In general, the simulation results in this study indicated that AVs could substantially improve the quality of traffic in normal traffic hours, especially by reducing the number of stops, queues, and delay time. Moreover, according to the results from the peak and normal traffic hours in this Chapter, a road with a 60% share of AVs can improve traffic quality as much as a road entirely populated by AVs. Likewise, a 30% share of AVs on the road in off-peak traffic hours provides approximately the same improvement as a 100% share of AVs. Therefore, the required share of AVs on the road varies based on the traffic condition, on what level of overall improvement is favoured, and on how much funding is going to be invested for this purpose.

8. CONCLUSIONS AND DISCUSSION

8.1. Introduction

The main objective of this research was to investigate the efficiency of AVs in highway transport. The study adopted multiple approaches, such as the review of past literature, to obtain an understanding of the benefits and risks of the application of AVs. The study also conducted public and expert surveys regarding the assessment of human perspectives on the implementation of AVs. Finally, the study optimised human driving behaviours for use in the modelling of AVs, and it simulated AVs under various traffic conditions. This Chapter discusses the main findings of this research and provides directions for future research in this area. In this context, Section 8.2 summarises the main results of each Chapter in the thesis, followed by the discussion of findings in this study in Section 8.3 and a descriptive Table of the discussion in 8.4. Section 8.5 outlines the contribution of the research to the application of AVs in highway transport and 8.6 highlights the weaknesses regarding the data collection, model design and assessments. Additionally, Sections 8.7 and 8.8 provides directions for expanding research in the field based on the results of this study and the remaining gaps. Finally, Section 8.9 provides an overall conclusion for this research.

8.2. Summary of Chapters

This Section outlines the key findings from each Chapter to provide an overview of the main results of this research.

Chapter 2 – Literature Review

Chapter 2 reviewed the relevant studies on benefits and concerns related to the adoption of AVs in highway transport. This review found several questions which remained unanswered. These included the following: To what extent will people accept liability for AVs if they know an AV is recording data? Who should have access to the data recorded by AVs? Which group or agency should accept liability for AVs in case of accidents? To what extent does their level of interest in driving AVs impact people's decisions about adopting and paying for them? Do people prefer a ridesharing AV or a private AV? To answer these questions, this thesis assessed expert opinion on and public acceptance of the use of AVs on public roads.

Chapter 2 also reviewed the studies related to the microsimulation of traffic flow and some previous analysis of the parameters of driving behaviours. This review found that there were no defined driving behaviours for AVs to date. There was also a gap in research on how AV driving behaviours might affect the factors evaluated in this study (travel time, queue length, and delays, among others). Additionally, previous studies were focused primarily on theoretical aspects related to AV use, such as price and interest, and there was a gap in understanding what would actually happen to highway traffic flow during long-distance travel. Finally, the literature review also identified a gap in research on whether AVs will be able to cooperate with TVs in merged traffic or will need a dedicated lane. Such gaps are all filled in this thesis.

Chapter 3 – Survey, Data Collection, Optimisation, and Model Design Methodology

Chapter 3 presented the research methodology and explained the data collection procedures used in the study's surveys. This Chapter also conducted a review of the Wiedemann-99 car-following model and its parameters, since driving behaviours are an essential aspect of simulation modelling in this field. This review explained the step-by-step process of optimisation and provided a detailed description of the structure of the study's simulations.

Chapter 3 also assessed data for the entire 2017 year to assemble input traffic data for modelling. The evaluation revealed that May, September, and February experienced peak, normal, and off-peak traffic conditions, respectively. Therefore, these months were selected for further analysis and simulation. In this context, the traffic data were analysed in greater detail to find the peak, normal, and off-peak traffic conditions within each of these three months. Such an assessment covered a diverse range of traffic conditions with the minimum, normal, and maximum traffic conditions for the whole year included in the evaluation.

The Chapter then addressed the methodology for designing the VISSIM model of the study over a 40-km length of the M50 motorway in Dublin, which is the busiest motorway in Ireland. Several configurations were applied to the VISSIM model to replicate autonomous behaviours and optimised driving behaviours were later added to the model. Finally, the Chapter explained the structure of the simulation's single-vehicle-type models and TV–AV shared road model under various traffic conditions throughout the year.

Chapter 4 – Public Survey

The study in this Chapter analysed peoples' perceptions and acceptance of AVs along with their willingness to pay and willingness to adopt. The results showed that people, in general, were not interested in driving AVs; only one-fifth of the population expressed a high level of interest. Additionally, results showed that females, in general, were more neutral and less likely to be interested in driving AVs than males. People in the 26–35 age range appeared to be the most enthusiastic about AVs, yet concerns about recording data had an extreme and negative impact on interest since the majority of respondents were not ready to accept AVs' recording of data because of their concerns about privacy. Moreover, people, in general, were not interested in AVs without steering wheels.

People were also mostly unsure about or not likely to believe in the safety and security of AVs' operation, and they were not at all willing to accept liability for AVs. User's perceptions as to whether AVs are safer and more secure than vehicles with human drivers could substantially impact their decisions to purchase AVs. People who did not believe in AVs' safe and secure operation were not willing to purchase them. Furthermore, the study showed that extreme concern about whether AVs could react quickly enough could reduce people's likeliness to purchase an AV.

In addition, the results revealed that cost substantially impacts people's AV purchasing decisions, as when the cost was not an issue, people were much more interested in purchasing an AV. The study survey found that nearly half of the participants had a WTP below USD 5,900 for the additional cost of an AV over the base price of the same vehicle in the traditional mode. As a result, the total average price users in this study were willing to pay for an AV was around USD 65,377, which is far below the estimated price of an AV (USD 150,000) in 2012 (Howard and Dai, 2014; KPMG, 2012b; Priddle and Woodyard, 2012).

The assessment of the purchase option between private AVs and ridesharing AVs showed that feeling safe and secure about AVs' operation substantially affected users' opinions about purchasing private AVs. Results indicated that people had a slightly greater preference for ridesharing AVs than the private AVs, a preference that was more pronounced among women. However, for men in general, and for those who were interested in driving AVs and those who felt safe and secure in driverless AVs, the private AV was a favourite choice.

Chapter 5 – Expert Survey

Chapter 5 dealt with concerns about AVs and their benefits and impacts on public roads. The results related to experts' concerns about adopting AVs on public roads revealed that 'security concerns such as getting hacked and losing control of the vehicle' were the most troubling consequences of the application of AVs. In this context, the majority of experts were against removing the steering wheel from the vehicle, declaring they would support 'AVs with a steering wheel and manual override control system'. Moreover, 'legal liability' was recognised as the second most worrisome consequence, ranking as only slightly less of a concern than security.

The survey also revealed that 'incorrect understanding of the surrounding objects such as humans and animals' was the most substantial technical concern about adopting AVs. This was followed by 'sensor failure and system shut down'. 'Cybersecurity', 'software processing and programming issues', and 'vehicle control and operation' were other technical concerns highlighted by experts.

Regarding the benefits of adopting AVs, the study revealed that experts considered 'safe driving' and 'the reduction of traffic congestion, queues, and delays' the most valuable outcomes of the application of AVs. Participants also pointed out topics such as 'providing access for disabled people', 'reduction in stress of driving', 'engaging in leisure activities' during driving as other potential benefits. In general, however, the experts did not think reducing travel time would be one of the most valuable outcomes of the use of AVs. Additionally, the results of the survey of experts revealed that AVs would be likely to reduce traffic congestion, queues, and delays, and to increase road throughput by making better use of road capacity. The assessment on road safety and accidents also indicated that AVs would help substantially reduce the number and severity of accidents, and consequently, help increase road safety.

In the area of legal liability, the majority of experts indicated that 'AV manufacturers' should accept the highest legal liability in case of accidents involving AVs. 'Insurance companies' and 'AV owners or drivers' were the next most likely sectors to be identified as being legally liable for accidents. However, some experts believed that assigning legal responsibility for AVs in the case of accidents depends on the nature of each accident, and therefore, some investigation of an accident scene would be required in this context.

In general, more than half of the experts supported the application of AVs on public roads, with the majority of experts declaring they would 'highly recommend' on-demand ridesharing AVs rather than the application of private AVs. However, the experts also indicated that much more investigation, research, and development are required before the adoption of AVs. Experts did not recommend adopting AVs until further studies confirm that they would be safe, secure, and efficient. Additionally, the experts who supported the application of AVs indicated that adopting them requires infrastructure development, technology development, safety measures, improvement in juridical issues related to the use of the AVs, and provision of comfortable conditions for vehicle ownership, among other conditions.

Chapter 6 – Optimisation

Chapter 6 presented results of simulations related to optimisation of driving behaviours and provided the optimised values for the simulation of AVs. Additionally, the Chapter reported results of assessments of each driving behaviour's impact on specific characteristics of the highway trip.

The investigation into the optimisation of driving behaviours revealed that CC0, CC1, and CC2, when they are regarded as 0.38, 0.45, and 2, respectively, can provide the greatest overall improvement in the quality of traffic. Changes of CC3–CC9 were not found to improve on the optimised scenario associated with CC0, CC1, and CC2; most had deleterious effects. Optimisation results indicated that, except for CC0, CC1, CC2, the rest of the Wiedemann parameters evaluated in this study should not be changed.

The assessment of the impacts of CC0, CC1, and CC2 on the characteristics evaluated in this study revealed that CC1 with 75% reduction (0.23) from its initial value (0.9) had the greatest impact (of all factorial changes) on the quality of traffic. Overall, CC1 (0.23) had the greatest impact on reducing travel time, queue length, and LOS, and on increasing the number of vehicles. Results showed that CC2 had the second-greatest effect on the quality of traffic (after CC1) when it was decreased by 75% (1) from its initial value (4). CC2 with a value of 1 had the most substantial impact among all factors on the reduction of queue delay, the number of stops, stop delay, fuel consumption, and CO emissions.

Chapter 7 – Simulation

Chapter 7 dealt with the simulation of TVs and the simulation of AVs using optimised driving behaviours. The simulations were conducted in the single-vehicle-type and shared-road modes of transport along with the simulation of AVs using the parameters defined by PTV.

The simulation results under various traffic conditions of the year revealed that AVs achieved the most substantial overall improvements in traffic quality under normal traffic conditions, whereas the lowest level of improvement was seen in peak traffic conditions, where AVs resulted in long queues and delays and low LOS. In general, the measures on which AVs had the greatest impact were in reducing the number of stops, stop delay, queue length, and queue delay, which could be due to their near-constant speed and the low variation in their acceleration and deceleration.

Results related to the TV–AV shared road in peak and normal traffic conditions revealed that there was not a substantial improvement in the quality of traffic after AVs' share of the road rose above 60%. Also, for off-peak traffic conditions, there was no substantial improvement in the overall results after a 30% share. Therefore, devoting a dedicated lane for AVs might be as efficient as a shared road with 60% AVs in peak and normal traffic conditions, and 30% AVs in off-peak traffic conditions.

The investigation of PTV driving behaviours for AVs revealed that cautious driving behaviours reduce traffic quality. Moreover, there was a negligible difference in the overall results achieved by AVs with normal driving behaviours compared to AVs with aggressive driving behaviours.

The comparison of AV simulations results of this study to those of PTV validated the optimisation and simulation of this study. AV simulations using the optimised driving behaviours of this study obtained an overall improvement of 67.4% in traffic quality, which is in line with simulated 69.4% and 73.0% improvements from the PTV's normal and aggressive driving behaviours, respectively. Moreover, the simulation of the TV–AV shared road of PTV returned results similar to those of this study. Additionally, the shared-road simulations of both studies (this study and PTV) showed no substantial improvement in the quality of traffic once the AV share of the road rose above 60%.

8.3. Discussion of the Thesis

The current study aimed to evaluate the efficiency of AVs on public roads. For this purpose, the study obtained an understanding of the benefits and risks of the application of AVs by reviewing previous studies in this context and found the gaps in the knowledge (Chapter 2). Such gaps included a lack of research into concerns regarding the assignment of legal liability for AVs in accidents, concerns about the recording of travel data by AVs and people's acceptance of this issue, people's interest in adopting AVs, and their WTP for these vehicles. Moreover, the study found that no simulation had been done for AVs' operation in freeway transport, before this study, due to the gap in AVs' driving behaviours. Therefore, the study conducted two surveys to help fill these knowledge gaps.

The findings from the surveys in Chapters 4 and 5 answered a diverse range of questions regarding the application of AVs. However, it was deemed necessary to carry out experiments to determine the extent to which the results are in line with public and experts' perceptions in this matter. Therefore, the study simulated AVs in a case study on the M50 motorway in Dublin (Chapter 7). For this, the study optimised the parameters of Wiedemann-99 together with several model configurations to replicate autonomous driving behaviours (Chapter 6).

This Section conducts a comparative assessment of the results of the public survey, expert survey, and the simulation of this study with the results of studies in the literature review to evaluate similarities and differences. The assessment of this Section is also briefed in a comparative Table, available in Section 8.4, in line with the triangulation validation method explained in Chapter 3 (Section 3.7.3).

KPMG (2012a) and Kesting et al. (2008) indicated a substantial reduction in travel time as a result of the adoption of AVs on public roads. However, the public survey of the current study revealed that the general public did not recognise travel time as one of the most important benefits of AVs (Table 4.9). Furthermore, approximately 41% of the experts surveyed for this study stated that AVs might reduce travel time, but in general, they did not expect a substantial reduction in this regard (Table 5.18, &

Model 5.5). The study's simulation suggested an average 13.4% reduction in travel time (Table 7.6) under various traffic conditions and at various times of the year as a result of adopting AVs, which accords with the results of the public and expert surveys in this matter. This study finds that AVs cannot substantially reduce travel time, thus rejecting the declarations of other studies in the literature in this context.

Regarding traffic congestion, including queue length, queue delay, number of stops, and stop delay, Fagnant and Kockelman (2015) and Smith (2013) indicated an increase in traffic congestion as a result of the adoption of AVs. However, several studies such as Cui et al. (2018) and Li et al. (2018) suggested an improvement in traffic and a reduction of traffic congestion, and the results of the public survey by Schoettle and Sivak (2014b) reveal expectations that AVs might reduce traffic congestion. In this regard, around 30% of the public surveyed for this study believed that AVs would reduce traffic congestion (Table 4.9). Additionally, traffic congestion was considered the fourth most important consideration in people's decision as to whether to buy an AV (Table 4.9). Roughly 46% of the experts surveyed believed AVs might reduce traffic congestion on public roads, but they did not expect a substantial reduction (Model 5.7, & Table 5.24). By contrast, another 20% of experts were concerned that adding AVs to the road network could increase traffic congestion. However, the results of simulations in this study indicate that AVs could improve traffic congestion, with an average 87.5% reduction in queue length, queue delay, number of stops, and stop delay (Table 7.6, & Figure 7.1). Therefore, the results from the simulation of this study support the findings of the studies conducted by Cui et al. (2018), Li et al. (2018), Schoettle and Sivak (2014b), and others that suggest AVs will reduce traffic congestion.

Talebpour and Mahmassani (2016) and Yea and Yamamoto (2018) showed a substantial potential for AVs to increase traffic stream and road throughput. In this context, around 45% of the experts in the current study stated that AVs might increase road throughput but not substantially (Table 5.26). The present study's simulation supports the opinions of these experts by showing an average improvement of 29% in the number of vehicles and LOS where AVs were incorporated (Table 7.6, & Figure 7.1). Such results also (partially) validate the results of studies reviewed in the literature in this context (mentioned in the first line of this paragraph).

Regarding the impact of AVs on the environment, Fox-Penner et al. (2018) and Schwartz et al. (2017) predicted an increase in emissions from AVs burning fossil fuel. However, several studies reviewed, such as Moriarty and Wang (2017), Ross and Guhathakurta (2017), and Mersky and Samaras (2016), indicated a reduction of fuel consumption and emissions, energy savings, improved fuel economy, and many other benefits from AVs. In addition, Bansal et al. (2016), and Schoettle and Sivak (2014b, 2014c) found that AVs would reduce fuel consumption and emissions by an average of approximately 72%. In this context, around 43% of the public in the current study recognised the reduction of fuel consumption and emissions as the second most substantial factor to consider in deciding whether to buy an AV' (Table 4.9). Around 48% of the experts in the current study also indicated that AVs would reduce fuel consumption and CO emissions, highlighting it as one of the most valuable outcomes of the adoption of AVs (Table 5.24, & Table 5.26). In this regard, the simulation of AVs with fossil fuel in the current study rejects the results of studies conducted by Fox-Penner et al. (2018) and Schwartz et al. (2017), which suggested an increase in emissions. According to the simulation results, AVs can reduce fuel consumption and CO emissions by an average of 71% (Table 7.6, & Figure 7.1), which is close to the reductions predicted by Bansal et al. (2016) and Schoettle and Sivak (2014b, 2014c). The simulation also supports the opinions of the public and expert surveys in this regard.

Several studies, such as Papadoulis et al. (2019), Hulse et al. (2018), Noy et al. (2018), Beirigo et al. (2018), and many others, indicated safety benefits from adopting AVs. On the other hand, studies such as Noy et al. (2018), Rakotonirainy et al. (2014), and Schoettle and Sivak (2014c) highlighted safety concerns from AVs, such as obscured perception of humans, animals, and other objects; software failures; and not being as good as human drivers at driving operations. The public surveyed in the current study believed that AVs would be somewhat safer than human drivers. Approximately 48% of them indicated safe driving as the most substantial factor they would consider in deciding whether to buy an AV (Table 4.9, Model 4.13, & Model 4.14). In this context, about 62% of the experts in this study supported the public's opinions that safe driving would be the most valuable outcome of the adoption of AVs (Model 5.4, & Model 5.6). Around 58% of the experts also believed that AVs would substantially increase road users' safety. However, approximately 47% of the experts also had safety concerns, such as an AV's incorrect understanding of surrounding objects, sensor failures, or system shut down along with concerns about other factors, which might endanger road users' safety (Table 5.27). Such results support the study of Chan (2017), which said safety would be the main reason for users to adopt AVs. The surveys of the current study, however, identified safety as only the third greatest concern about AVs, while the greatest concern was security.

Regarding the security of AVs and AV users, several studies such as Sheehan et al. (2018), Faife (2017), and Kyriakidis et al. (2015) pointed to issues such as security breaches, hacking, car hijacking, kidnapping, and misuse of the vehicles by hackers. Moreover, some studies of public opinion, such as Kaur and Rampersad (2018), Schoettle and Sivak (2014b), Vallet (2013), and KPMG (2012a), found that security was one of the main concerns about adopting AVs. The public survey in the current study revealed similar concerns, suggesting that people do not feel secure about using AVs. The public also believed that AVs would not be more secure than vehicles with human drivers (Model 4.13). Additionally, around 56% of the experts in the current study also identified security issues (such as concerns about being hacked and losing control of the AV) as the most substantial concern regarding the application of AVs (Model 5.3).

Rose (2017) and Heaps (2016) pointed to several concerns about privacy with AVs, such as data privacy, tracking of individuals' location, and access to recorded data by third parties. Additionally, public opinion studies such as those of Kaur and Rampersad (2018) and Schoettle and Sivak (2014b) showed that privacy of AV users was a concern. In this study, around 46% of people in the public survey and 33% of experts were extremely concerned about the privacy of data in AVs (Model 4.8, & Table 5.10). Individuals surveyed in this study also indicated that if the recording of data by AVs is mandatory, local and national transportation authorities should be the first organisations with access to such data, followed by insurance companies and AV manufacturers.

Moreover, legal liability has been identified as a main concern of the public in many studies, such as Kyriakidis et al. (2015), Howard and Dai (2014), and Schoettle and Sivak (2014a, 2014b). In this context, around 57% of participants in the public survey of the current study were not willing to accept any legal liability for an AV in case of an accident (Model 4.9, Model

4.10, & Model 4.11). Additionally, around 71% of the public and 69% of the experts indicated that AV manufacturers should face the greatest legal responsibility for AVs in accidents (Table 4.8, & Table 5.2). Insurance companies were considered the second most responsible agency.

Liu et al. (2019), Bansal et al. (2016), and Schoettle and Sivak (2014c) indicated high prices for AVs, and that the average WTP to add full self-driving automation to a traditional vehicle is around USD 5,500, which is far below the estimated price of an AV. The public survey in this study also found that nearly 43% of participants had a WTP that was less than USD 5,900 beyond the traditional vehicle's base price (Table 4.10). This means the average price those 43% are willing to pay for one of the vehicles evaluated in this study (Table 4.40) is around USD 65,377, which is far below the estimated price of an AV (USD 150,000) in 2012 (Howard and Dai, 2014; KPMG, 2012b; Priddle and Woodyard, 2012).

Furthermore, several studies such as Muoio (2016), Eldredge (2016), and KPMG (2012b) highlighted that there might be a need for new installations of infrastructure sensor technologies; as otherwise, there might be performance difficulties on roads without clear lane markings. However, Fagnant and Kockelman's (2015) study shows that the existing infrastructure capacity of roadways should be adequate to accommodate the added demands imposed by AVs. The participants in the public survey in the current study indicated that they would not be likely to adopt AVs if the existing infrastructure cannot provide full support for them. In this context, around 67% of respondents indicated they would not adopt AVs if they could operate only in limited areas in the city rather than everywhere around the country (Table 4.5). The experts in the current study also indicated that much more investigation is required in this area, and much additional preparation might be needed before the adoption of AVs on public roads. The simulation of the current study revealed that AVs could be work on the existing infrastructure without the need for any sensor installations. However, CAVs might require technologies to facilitate communications of V2V, V2I, and V2X (KPMG, 2012b).

Yea and Yamamoto (2018) studied the need for dedicated lanes for CAVs, which are a form of AV. Their results indicated that dedicated lanes for CAVs might increase the performance only for medium traffic densities. Such a finding looks similar to the simulation results of the current study, which revealed the highest performance of AVs in normal traffic conditions (Table 7.6). Additionally, Yea and Yamamoto (2018) highlighted that infrastructure changes such as devoting dedicated lanes to AVs might increase the performance of AVs. However, this study's simulation results for the shared road in peak and normal traffic conditions revealed that there was not substantial improvement in the quality of traffic after AV share rose above 60% (Table 7.8, & Table 7.10). The same findings applied for the off-peak traffic condition after the percentage of AVs on the road reached 30% (Table 7.12). Therefore, the simulation of this study indicates that devoting a dedicated lane for AVs might be as efficient as a shared road with 60% AVs in peak and normal traffic conditions and 30% AVs in off-peak traffic conditions, which rejects Yea and Yamamoto's (2018) declaration in this regard.

A reduction in accidents as a result of adopting AVs has been suggested by several studies, such as Bansal et al. (2016), Continental (2015), and Underwood (2014). Schoettle and Sivak (2014a, 2014b) also found that AVs would help to reduce the number and severity of accidents, and Papadoulis et al. (2019) and Laan and Sadabadi (2017) pointed to the safer and quicker reactions of AVs compared with human drivers. However, the public surveyed in the current study did not believe that AVs would be safer and more secure, and people were somewhat concerned about AVs' quick reactions in unexpected driving incidents (Table 5.4, & Model 4.5). Around 13% of the experts had the same fear that AVs might not be as good as human drivers in reacting quickly (Table 5.10, Model 5.6). People also said they did not feel safe and secure riding in a vehicle without a steering wheel, and they trusted more in AVs with override control systems and AVs with a steering wheel, an opinion supported by around 56% of the experts in the current study (Table 5.7). Additionally, the investigation of passengers' concerns about riding TVs and AVs revealed that people, in general, were slightly more concerned about riding AVs than TVs in the same driving conditions (Table 4.25). However, about 64% of the experts of the current study indicated that AVs would reduce the number and severity of accidents (Table 5.25, Model 5.10, & Model 5.11), which is in line with the results of the study conducted by Schoettle and Sivak (2014a, 2014b) and others in the literature.

The level of general interest in adopting AVs averages 66% overall in several studies, such as Haboucha et al. (2017), Bansal et al. (2016), and Kyriakidis et al. (2015). However, the current study found only 28% of people were very interested in adopting AVs, whereas 41% were not at all interested (Table 4.3) because of several concerns such as safety, security, and privacy. Around 54% of the experts believed that much more research and preparation is needed before AVs can be adopted on public roads (Table 5.8). Thus, the experts were not opposed to AVs, but they did not recommend adopting them until further investigations prove AVs' safety, security, and efficiency.

In general, the investigation into the optimisation of driving behaviours (as of research objective three) revealed that human driving behaviour models could be modified to replicate autonomous behaviours. In the case of optimising Wiedemann-99 as a human driving behaviour model, except for CC0, CC1, CC2, the rest of the Wiedemann parameters evaluated should not be changed.

Also, the assessment of the impacts of CC0, CC1, and CC2 on the trip characteristics (as of research objective four) revealed that CC1 and CC2 had the greatest impact of all Wiedemann parameter on the quality of traffic. Results showed that CC1 with a value of 0.23 had the greatest impact on reducing travel time, queue length, and LOS, and on increasing the number of vehicles. Also, CC2 with a value of 1 had the most substantial impact among all factors on the reduction of queue delay, the number of stops, stop delay, fuel consumption, and CO emissions

The simulation results in this study (as of research objective five) indicated that AVs could substantially improve the quality of traffic in normal traffic conditions, especially by reducing the number of stops, queue length, and delay time. The study also found that TVs and AVs can efficiently share their road (which explains the research objective six), and the improvement in the quality of traffic increases with an increase in the proportion of AVs to TVs, up to a specific level, on the road. In this regard, according to the results from the peak and normal traffic conditions, a road with a 60% share of AVs can see its traffic quality improved as much as a road entirely populated by AVs. Likewise, a 30% share of AVs on the road in off-peak traffic conditions provides approximately the same improvement as a 100% share of AVs. Therefore, the optimum percentage of AVs on the road varies based on the traffic conditions, on what level of overall improvement is favoured, and on how much funding is to be invested for this purpose.

Furthermore, the investigation into perceptions about adopting AVs in people's daily lives (as of research objective one) revealed that people, in general, were not very interested in driving AVs; only one-fifth of the population expressed a high interest. The majority of respondents did not accept AVs' recording of data, because of concerns about privacy. Additionally, people were mostly unsure about or not likely to believe in AVs' safe and secure operation, they were not interested in AVs without steering wheels, and they were not at all willing to accept liability for AVs. Moreover, people had great concerns about AVs' quick reactions and their safe and secure operation compared with vehicles with human drivers, concerns which impacted how likely they are to purchase AVs. The results also revealed that the cost of AVs substantially influenced people's decisions about purchasing them, since the total average amount the users in this study would spend for an AV was far below the estimated price of an AV. However, the study showed that if the cost were not an issue, people would be more interested in purchasing an AV. Results also indicated that women, and respondents overall, had a slightly greater preference for ridesharing AVs than the private AVs. For men, however, and for those who were interested in driving AVs and those who felt safe and secure in driverless AVs, the private AV was a favourite choice.

The investigation of experts' concerns (as of research objective two) in adopting AVs on public roads revealed that security concerns, legal liability, incorrect interpretations of the surrounding objects, sensor failure and subsequent system shut down, cybersecurity, software processing, and vehicle control would be the areas of greatest concerns. However, experts also believed that safe driving and the reduction of traffic congestion, queues, and delays would be the most valuable outcomes of the use of AVs. Additionally, experts believed that AVs would be likely to increase road throughput and reduce the number and severity of accidents. Most experts were of the opinion that AV manufacturers should face the highest level of legal liability in case of accidents involving AVs, followed by insurance companies and then AV owners. However, some experts believed that assigning legal responsibility for AVs depends on the nature of each accident, and therefore, some investigation of an accident scene would be required in this context. In general, more than half of the experts supported the use of AVs on public roads, especially the use of on-demand ridesharing AVs rather than private AVs. However, the experts indicated that much more investigation, research, and development are required before the adoption of AVs.

8.4. Descriptive Table of the Discussion of Research

The values and discussions provided in this Appendix are related to the adoption impacts of AVs which are obtained from the simulation assessment of this study. Additionally, discussions are provided for the possible impacts of AVs evaluated in the public and expert surveys of this study. Also, some results might be related to the shared road of TVs and AVs, which is indicated in the text.

"Correlation" in this section refers to the similarity of results and opinions between various means of assessments in this study (literature review, public participants, expert participants, and simulation). By contrast, "opposition" colour represents how much the results from various means of evaluations are in conflict with each other.

A colour bar is adopted to evaluate the correlation of responses obtained from the means of this study.

The acronym "PP" in this section refers to the percentage of participants (where there was a statistics) involved with an answer or opinion.

Point of view	**Definition**	**Colour Bar**
Correlation	High correlation	
	Medium correlation	
Explaining a fact		
Not possible for evaluation in the adopted instrument (simulation or survey)		
Opposition		

Parameter	Literature	This study			Conclusion
		Public Survey	Expert Survey	Simulation	
Travel time	KPMG (2012a) and Kesting et al. (2008): Substantial reduction	Not recognised as an essential benefit	PP: 41%: AVs might reduce travel time, but not substantially	About 13.4% reduction	• Rejection of the literature • Approval of the public and expert opinion
Traffic congestion: queue length, queue delay, number of stops, stop delay	Fagnant and Kockelman (2015), Smith (2013): increase in congestion	PP: 30%: reduction of traffic congestion	PP: 46%: AVs would reduce traffic congestion, but not substantially	Average of 87.5% reduction in queue length, queue delay, number of stops, and stop delay	• Rejection of Fagnant and Kockelman (2015), Smith (2013), and experts of the current study (to some extent) • Approval of the public individuals of the present study (to some extent), Cui et al. (2018), Li et al. (2018), Schoettle and Sivak (2014b), and several others, which believed in the reduction in congestion.
	Cui et al. (2018), Li et al. (2018), Schoettle and Sivak (2014b), and several others: reduction in congestion	Reduction in traffic congestion was considered as the fourth-most important aspect of the AVs, which make people buy them	PP: 20%: concerned about an increase in congestion		
Road throughput & LOS	Talebpour and Mahmassani (2016), Yea and Yamamoto (2018): Substantial potential to increase in road throughput	Not evaluated as it is a technical issue, which experts should answer	PP: 45%: AVs might increase road throughput, but not substantially	Average of 29% increase in the number of vehicles and improvement in LOS	• Approval of the literature and experts of this study
Environment: fuel consumption and emissions	Fox-Penner et al. (2018), Schwartz et al. (2017): increase in emission from AVs burning fossil fuel	PP: 43%: recognised as the second-most exciting aspects of the AVs, which make people buy AVs	PP: 48%: reduction of fuel consumption and CO emissions	Average of 71% reduction in fuel consumption and CO emission	• Rejection of the results of studies conducted by Fox-Penner et al. (2018) and Schwartz et al. (2017)

	Moriarty and Wang (2017), Ross and Guhathakurta (2017), Mersky and Samaras (2016), and several others: reduction of fuel consumption and emissions, saving energy, improving fuel economy and many other benefits		Known as one of the most valuable outcomes of the adoption of AVs		• Approval of Bansal et al. (2016) and Schoettle and Sivak • Approval of public individuals and experts
	Bansal et al. (2016) and Schoettle and Sivak (2014b, 2014c): reduction of fuel consumption and emissions by an approximate average of 72%				
Safety	Papadoulis et al. (2019), Hulse et al. (2018), Noy et al. (2018), Beirigo et al. (2018) and several others: many safety benefits would result from the adoption of AVs	AVs would be somewhat safer than human drivers	PP: 62%: approved public opinions that safe driving would be the most valuable outcome of the adoption of AVs	Out of the scope of the simulation in this study	• Approval of the research conducted by Chan (2017) with regard to the fact that safety would be the main reason for users to adopt AVs • Rejection of the study conducted by Chan (2017) in relation to the fact that safety would be the primary concern of the adoption of AVs. The surveys of the current study found safety as the third-most concerning aspect of using AVs, while security was
	Noy et al. (2018), Rakotonirainy et al. (2014), and Schoettle and Sivak (2014c): many safety concerns would result from the adoption of AVs such as obscure understanding of humans, animals, and other		PP: 58%: AVs would substantially increase road users' safety		

	objects, software failures, and not being as good as human drivers at driving operations	PP: 48%: safe driving would be the most interesting aspect of the AVs, which make people buy them	PP: 47%: concerned about incorrect understanding of the surrounding objects, sensor failures and system shut down, and some other concerns, which might endanger road users' safety		found as the most concerning aspect.
Security	Sheehan et al. (2018), Faife (2017), and Kyriakidis et al. (2015), and several others: many concerns would result from the adoption of AVs such as security breaches, hacking, car hijacking, kidnapping, misuse of the vehicles by hackers, and many other concerns	People, in general, did not feel secure about using AVs	PP: 56%: security concerns such as getting hacked and losing control of the AV would be the most substantial concern regarding the application of AVs	Out of the scope of the simulation in this study	• The public and expert surveys of this study approved the studies in the literature
	Kaur and Rampersad (2018), Schoettle and Sivak (2014b), Vallet (2013), and KPMG (2012a), and several others: one of the main concerns of public individuals for adopting AVs	AVs would not be more secure than human drivers			

Privacy (of data)	Rose (2017), Heaps (2016): several privacy concerns of AVs such as data privacy, tracking individuals' location, access to the recorded data by third-parties and some other concerns	PP: 46%: extremely concerned about the privacy of data	PP: 33%: extremely concerned about the privacy of data	Out of the scope of the simulation in this study	• Approval of the studies in the literature by the results of the public and experts surveys of this study
	Kaur and Rampersad (2018) and Schoettle and Sivak (2014b): privacy of the AV users was one of the concerns of individuals for adopting AVs	If recording data is mandatory, local and national transport authorities should be the first organisation who should have access to such data; then, insurance companies, and AV manufacturers			
Legal liability	Kyriakidis et al. (2015), Howard and Dai (2014), Schoettle and Sivak (2014a, 2014b), and several others: one of the main concerns of adopting AVs	PP: 57%: not at all willing to accept AVs' legal liability in case of an accident	PP: 69%: AV manufacturers should accept the highest legal responsibility of AVs in accidents; then, insurance companies	Not possible to be assessed in simulation	• Approval of the public survey results by the experts of this study • Approval of the studies in the literature with respect to the results of the public and experts surveys of this study
		PP: 71%: AV manufacturers should accept the highest legal responsibility of AVs in accidents; then, insurance companies			

WTP	Liu et al. (2019), Bansal et al. (2016), Schoettle and Sivak (2014c), and several others: the high price of AV would be a concern for user acceptance	PP: 43%: showed below USD 5,900 WTP in addition to the base price of the same vehicle in Traditional mode	Not evaluated since WTP is related to people. Experts were not investigated as a buyer but specialist in technical outcomes	Not possible to be assessed in simulation	• Approval of the studies in the literature by the results of the public survey of this study
	The average WTP to add full self-driving feature is around USD 5,500, which is far below the estimated price of an AV				
Infrastructure	Muoio (2016), Eldredge (2016), KPMG (2012b), and several others: installations of infrastructure sensor technologies might be required	People would not be likely to adopt AVs if the existing infrastructure cannot provide full support of AVs	A lot more investigation is required in this context, and many preparations might be needed before the adoption of AVs on public roads	AVs could work on the existing infrastructure without the need for any sensor installations	• Rejection of the studies in the literature with regard to the fact that the current infrastructure would (necessarily) need the installation of particular sensor technologies for adopting AVs • Approval of Fagnant and Kockelman's (2015) declaration • Approval of KPMG's (2012b) results. CAVs might require technologies to facilitate vehicles communications, but not necessarily AVs (as the simulation showed)
	Fagnant and Kockelman (2015): the existing infrastructure would be able to accommodate AVs				
	KPMG (2012b): CAVs might require technologies to facilitate communications of V2V, V2I, and V2X	PP: 67%: people would not adopt AVs if AVs could only operate in some limited areas in the city and not everywhere around the country			

Dedicate lane	Yea and Yamamoto (2018): dedicated lanes for CAVs might increase the performance only for medium traffic densities.	Public individuals were not investigated in this matter as it is a technical issue, which required technical evaluations	Experts were asked about ridesharing. Dedicated lane is assessed through simulation	Devoting a dedicated lane for AVs might be as efficient as a shared road with 60% AVs in peak and normal traffic conditions, and 30% AVs in off-peak traffic condition	• Partial acceptance of Yea and Yamamoto's (2018) declaration as such study didn't specify a limit for the proportion of AVs in mixed traffic.
	Yea and Yamamoto (2018): infrastructure changes, such as devoting dedicated lanes to AVs might increase the performance of AVs.				
Accidents	Bansal et al. (2016), Continental (2015), Underwood (2014), and several others: reduction of accidents	AVs would not be safer and more secure than human drivers	PP: 13%: AVs might not be as good as human drivers in quick driving reactions in accidents	The purpose of the simulation was the efficiency of AVs in traffic. Accidents would be a separate topic to investigate in future studies	• Rejection of the studies in the literature by the public survey of this study. People did not believe AVs to be safer and more secure than human drivers • Evidence of similar concerns between public individuals and experts in this context • Approval of some studies in the literature by experts of this study with regard to the reduction in the number and severity of accidents
		Somewhat concerned about AVs' immediate reaction in unexpected driving incidents			
	Schoettle and Sivak (2014a, 2014b): reduction in the number and severity of accidents	Not felt safe and secure about riding a vehicle without a steering wheel	PP: 56%: not felt safe and secure about riding a vehicle without a steering wheel		
	Papadoulis et al. (2019) and Laan and Sadabadi (2017): AVs would have safer and	Trusted more on AVs with steering wheel and override control systems	Trusted more on AVs with steering wheel and override control systems		

	quicker reaction compared with human drivers	Slightly more concerned about operating with AVs than TVs in the same driving conditions	PP: 64%: reduction in the number and severity of accidents by adopting AVs		
Interest	Haboucha et al. (2017), Bansal et al. (2016), Kyriakidis et al. (2015), and several others: an average of 66% of the people were interested	PP: 28%: very interested PP: 31%: somewhat interested* PP: 41%: not at all interested	PP: 54%: a lot more investigations and preparation needed before AVs' adoption on public roads The experts were not opposed to adopting AVs, but they did not recommend adopting AVs until further investigations approve AVs' safety, security and efficiency.	Not possible to be assessed in simulation	• Partial acceptance of the studies in the literature by the public survey of this study (when "somewhat interested" and "very interested" results are merged) ***Note:** "somewhat interested" could also implicate to a neutral or unsure perception. So, in that case, the public study rejects the literature as only 28% were very interested in adopting AVs.

8.5. Research Contributions

This research has contributed the following findings to the state of knowledge in the field of AVs:

1. ***Assessing the public's opinion and acceptance of the application of AVs in their daily transport routines.*** This assessment was conducted by running a public survey among 475 Irish road users. The results revealed public concerns about the use of AVs generally. This study also showed how much people are willing to pay for an AV and how willing they are to adopt an AV if the cost is not an issue.
2. ***Identifying experts' concerns and thoughts regarding the adoption of AVs in highway transport.*** The study undertook an international survey of 301 experts in fields related to AVs, with 71% participation from transportation experts in academia and industry. The outcomes of this survey will be beneficial for transport researchers, car manufacturers, legislators, insurance companies, traffic and transport consultancies, and other related groups with a focus on AVs.
3. ***Proposing a method for optimising human driving behaviours using sensitivity analysis over 86 simulation scenarios with 1,003 hours of simulation***. As mentioned in the discussion of research methods, previously there were no defined driving behaviours for AVs. This study optimised the driving behaviours of Wiedemann-99 (using sensitivity analysis) for the modelling of AVs along with some model configurations for AVs. Results of the simulations with optimised Wiedemann-99 parameters provided a vision of what might happen if AVs can drive with optimised human driving behaviours and the extent to which they can improve the quality of trip characteristics.
4. ***Addressing the impact of each driving behaviour on specific characteristics of highway trip evaluated in this study (travel time, queue length, delays, fuel consumption, emissions, and LOS).*** As part of the optimisation process, the study estimated how these characteristics are affected by changes in driving behaviours. The results of this evaluation provided a useful guideline for developing a target framework for driving behaviour and information on how driving behaviour must change to attain the desired improvements in travel time, queues, delays, and the other assessed parameters.
5. ***Examining the efficiency of AVs on long trips by modelling AVs in a case study in Dublin, Ireland.*** For this purpose, the 40-km road network of the M50 motorway was modelled on VISSIM. The simulation comprised 180 scenarios for a diverse

range of traffic conditions with 3,150 hours of traffic simulation; this amount of simulation is unprecedented in terms of the number of scenarios and the total simulation time conducted. The results provide a profound understanding of what would practically happen to traffic flow over long travel distances. The results of the simulation were assessed for travel time, queue length, delays, LOS, road throughput, fuel consumption, and emissions.

6. ***Examining the operability of TVs and AVs in mixed traffic over 33 simulation scenarios with 576 hours of simulation.*** For this part of the study, TVs and AVs were designed to work in separate modes and then in mixed traffic situations with different proportions on the road. For this purpose, the proportion of AVs increases by 10% in each scenario from entirely regular traffic flow using only TVs to a network operating fully with AVs. The results clearly showed how flexibly TVs and AVs can interact with each other and what proportion of AVs is needed on a motorway to cause considerable reductions in queues, delays, fuel consumption, and emissions along with increases in the network throughput and an improvement in LOS.

7. ***Adopting Cronbach's Alpha reliability test in highway traffic engineering.*** Cronbach's Alpha is a very well-known reliability test for evaluating the internal consistency of a statistical model (Heale and Twycross, 2015; Tavakol and Dennik, 2011). However, to the best of (this research) author's knowledge, Cronbach's Alpha has not been used for assessing the internal consistency of the highway traffic simulation models. Hence, due to the high performance, ease of use, and availability of this reliability test in the statistical software IBM SPSS 25 (which has already been used for survey' analysis in Chapters 4 and 5), Cronbach's Alpha method was adopted as a model reliability test in this research. The evaluation of results in this regard revealed that Cronbach's Alpha could be adopted as a reliable and efficient tool for investigating the reliability of the traffic simulation models.

8. ***Assessing the new PTV-tuned driving behaviours for AVs, over 41 simulation scenarios with 717 hours of simulation.*** For this purpose, the driving behaviours suggested by PTV in 2018 were used for simulation of AVs, and the results for single-mode and shared-road mode for TVs and AVs were compared to previous results from this study. Such an evaluation showed the great extent to which the optimised parameters of the current research were already in line with the tuned parameters recommended by PTV.

9. ***Adopting a mixed methodology approach using qualitative and quantitative studies, and traffic simulation.*** The study adopted various research methods (and instruments) and compared the findings of them against each other. In this regard, the current study reviewed past studies in the field and conducted a national public survey, a global expert survey, and an extensive traffic simulation study as the research instruments. Then, the study triangulated the findings of the mentioned instruments against each other to see which one those investigations confirm or reject the findings of the rest of the investigations.

8.6. Weaknesses

The results of evaluations in this study validated the employed research methodology. However, there were some limitations in the study which could be improved on in future studies.

Running the pilot survey was a challenging procedure with several limitations. One limitation was that there was a very low willingness to participate in the survey since many of those who were contacted to participate in the survey knew that their responses were not going to be used for statistical assessments or to get published at all. Therefore, several potential candidates refused to participate. In addition, running a pilot study for the expert survey was not possible since there was no willingness to take part in a trial study.

Also, while efforts were made to contact a representative sample, it is mindful to consider that the public survey was conducted online and those who did not have access to the Internet were not covered in the survey. Also, many potential candidates might have been at work or so busy so that they couldn't participate.

Also, the initial assessment of the (main) surveys revealed that some of the demographic groups had a smaller number of participants than the rest. However, those small groups were not merged or so they can be comparable with the Census (CSO, 2018) groups. Such an issue might be considered as a weakness of the survey. However, before running the analysis, all demographic groups were checked for model fitting, standard deviation, and errors to make sure that such an issue does not make a substantial (negative) impact on the survey results.

As mentioned in Chapter 3 (Section 3.6.6, Pg. 59), the traffic data for the simulations were generated from TII, which is the source of traffic data in Ireland. Despite the fact that TII provides detailed data for each road, they do not provide turning ratios for the junctions on M50. Therefore, there is no exact information about the number of vehicles approaching

M50 and heading towards the airport. The TII officers explained that they do not capture all movements entering and leaving the M50 interchanges (D. Kennan, D. Brenna, personal communication, Feb 12, 2019). Such a lack of data required the current study to make assumptions regarding the input traffic volumes, which impacted the conformity of the simulation results with actual traffic running in M50.

Also, the lack of traffic data for the turning ratios at M50 junctions and making assumptions in this regard made the simulation model, a conceptual model of the M50 motorway, and not an exact model, which was another limitation in this research. Therefore, a comprehensive calibration of the model for TVs was not possible since the lack of such traffic data would also impact the rest of the model parameters. It means that even if the study calibrated the simulation model for any other parameter such as the travel time, the model would [still] be lacking the impact of those missing traffic volumes. As a result, the model would provide a travel time which conformed the current travel time of M50 without considering the impact of those missing traffic. Such an issue would also impact the results related to the LOS, queue length, delay time, fuel consumption, and emission as all these parameters are related to the traffic volumes.

One might ask whether the current study considered the effect of accidents, if any, on the simulation model or not. The answer is that due to the high number of the simulation scenarios and extensive simulation time of this study, the researcher (of this study) could not focus on other road characteristics, such as the consideration of accidents, as model input for further assessments. Also – as explained in Section 3.6.6 – no accident data was found (at RSA data site) for the year 2017. Therefore, there was not sufficient information to check whether any of the days in the TII database had any form of a traffic accident or not, which would be considered as a limitation of this study.

Additionally, the current study evaluated the efficiency of AVs on long highway trips, and due to the vastness of the evaluations in this context, the urban application of AVs was not assessed. Therefore, further investigation would be required if the results of this study are going to be applied to an urban traffic condition, as there are differences between the simulation parameters of the freeway traffic and those of the urban roads.

Finally, there are a few VISSIM limitations regarding model design and operation. Designing a 40-km length network in VISSIM requires many road sections and connectors, which could be problematic sometimes, especially when reducing the number of lanes (e.g., from a 4-lane road section to a 3-lane road). The connectors should direct all the traffic from one section of the road to the other side (using routing decisions); a very small mistake in design aspects can make some vehicles disappear or lost their way. Even when the model is very well-designed, some (random) vehicles cannot properly recognise the routing decision at connectors. When this occurs, the vehicles reduce their speed or they might stop and proceed to a lane change (to the adjacent lane) and then move forward, which might create a delay or initiate a waving traffic stream. Also, VISSIM adopts several different types of control parameters for managing vehicles driving operations, which increase the calibration flexibility but also makes it very complex and time-consuming. Another issue is that the running process could get very time-consuming when the model is large and the simulation resolution in high. Moreover, despite that VISSIM is upgrading its features, the VISSIM manual is still not easy to work with and there are not many teaching materials for the design and operation of emerging technologies like AVs.

8.7. Future Research Directions

Regarding the survey assessments, future studies are recommended to hire a survey company for running the pilot survey with a fair number of participants, which are from the same sample type. For example, if the main survey is going to be a public survey on local drivers; then, the pilot survey should be done on local drivers. The feedback and comments from such a pilot study would be very helpful in designing the main survey which fairly considers the requirements (technical terms, language, and needs) of the participants.

Future studies are recommended to run expert surveys in the form of Delphi surveys. Running a Delphi research has several advantages such as that the survey could be conducted with a fewer number of participants. Also, such a survey study could be conducted in several rounds which provide the experts with the opportunity of thinking (and reviewing) their responses and provide more information or new feedbacks in the following rounds of the survey. Moreover, a Delphi survey would (probably) provide consistent results as it studies various perspective of a system on the same participants. Furthermore, such a survey can be longer and more comprehensive as it is done in several rounds, not at once.

Future studies are recommended to install their own digital counters at the junction for several days to obtain the average turning proportion for each approach to the junction. This could be done using automatic traffic counters such as JTC[1], ATC[2], and ANPR[3]. In this way, they would be able to capture the full impact of the traffic stream at the junctions of M50 and use those data for a comprehensive model calibration, which can be representative of all

[1] Junction Traffic Count
[2] Automatic Traffic Count
[3] Automatic number-plate recognition

traffic parameters (travel time, traffic volume, queue length, delay time, LOS, fuel consumption, and emissions). Also, the future studies are recommended to capture the impact of minor junctions at M50 (as TII does not record them) to achieve a more realistic simulation of M50.

Future studies are recommended to integrate the effects of accidents on M50 and how much those accidents impact travel time, queue length, delays, and the number of stops for TVs. Future studies can also model those accidents when simulating AVs to investigate how AVs might react to accidents on the road and to what extent AVs can neutralise their impact on travel time, queues, delay, LOS, fuel consumption and emission.

Future studies are also recommended to investigate the application of AVs in urban traffic, such as their impact in coordinated signalised intersections. AVs' performance in roundabouts could also be evaluated to determine how they interact and communicate with other AVs and TVs to make the best decisions for yielding the way or advancing in the roundabout. Such a scenario could also be applied to AVs at an intersection, with results being compared with the results related to the roundabout scenario. In this way, AVs could be investigated for whether they operate more efficiently in roundabouts or intersections. Such an evaluation could address the best application of AVs at junctions with several approaches.

The simulation results related to the operation of AVs in the off-peak traffic condition (see Section 7.4.3) revealed that AVs might not be efficient after 30% penetration on the road; even they might have adverse implications such as an increase in travel time. This thesis (Section 7.4.3) explained that increasing the speed limit of AVs might be a solution in this regard as it might provide AVs with the opportunity of making more use of the capacity in free-flow traffic condition. This declaration is in line with the results of a study conducted by Yea and Yamamoto (2018) in this regard. Therefore, future studies are recommended to further the investigation in this context and simulate AVs with a higher speed limit in mixed traffic with TVs.

8.8. Policy and Industry Recommendations

Industry professionals are recommended to focus more on the improvements of technologies required for the production of safe and secure AVs as follows:

- Producing high-quality sensors and cameras with consideration of the total vehicle price
- Advancing AI algorithms related to AVs' perception of its surrounding objects

- Advancing AVs' safety and security against cyber attacks
- Designing new methods for the safe and secure record of the vehicle data, if it is going to be recorded, in a form of local data servers which cannot be penetrated by hackers
- Testing AVs under various road conditions (not just the controlled environments) to make sure they can operate safely in any situations

Also, policymakers are recommended to focus on the political, and juridical issues related to the adoption of AVs such as:

- Legal liabilities of the vehicles in case of accidents; addressing how much the legal liability should be divided between the participants in accidents related to AVs
- The overall price of AVs and whether it will be affordable for public individuals or not
- Insurance of the AVs and their occupants; addressing the financial coverage the insured bodies can expect in case of the possible accidents involved with their AVs
- The authorised agency for accessing the recorded travel data, if the record of data by AV is necessary
- Whether the society is ready for accepting AVs in daily life commute and whether there is a mass market for it or not; if not, many manufacturers might face bankruptcy
- Whether the government are able to manage the huge cost of replacing the old infrastructure and traditional vehicles with smart infrastructure and AVs; if not, what would be the consequences
- Whether the countries' economy has any plan for the loss of jobs which occur because of the automation of things i.e., what would taxi drivers do if future AV taxis would not need drivers anymore, or several other delivery jobs which would not need drivers or operators
- Which government body or agency should take responsibility if the big project of adopting AVs fails and what would be the best course of action in such a case
- Whether the economy is strong enough to compensate for the loss of the investments if AVs are not successful and a shift back to the traditional model transport deemed necessary if such thing would be (even) possible.

8.9. Overall Conclusion

Overall, the current study revealed that AVs could substantially improve the quality of traffic. However, they require more research, technology development, safety and security measures, improvements in juridical issues and legal liabilities related to their use, and the provision of acceptable conditions for vehicle ownership, especially in terms of the cost of the vehicle. In this way, many concerns regarding the adoption of these vehicles on the road would be resolved. However, according to the evaluations of this study, and based on the current status of AV research and development, the present study does not recommend adopting AVs until further studies confirm that the requirements for their adoption – mentioned above – are met.

REFERENCES

Adnan, N., Nordin, S.M., Bahruddin, M.A.B., & Ali, M. (2018). How Trust Can Drive Forward The User Acceptance to the Technology? In-Vehicle Technology for Autonomous Vehicle. *Transportation Research Part A, 118*, 819-836. Retrieved from https://doi.org/10.1016/j.tra.2018.10.019.

Aghabayk, K., Sarvi, M., Young, W., & Kautzsch, L. (2013). A Novel Methodology for Evolutionary Calibration of VISSIM by Multi-threading. *The 36th Australasian Transport Research Forum (ATRF)*. Brisbane, Queensland, Australia. Retrieved from https://trid.trb.org/view/1285361

Agresti, A. (2019). An Introduction to Categorical Data Analysis. Third Edition. WILEY. Retrieved from https://books.google.ie/books?id=pHZyDwAAQBAJ&pg=PT107&lr=&source=gbs_toc_r&cad=3#v=onepage&q&f=false.

Alam, Md.J., & Habib, M.A. (2018). Investigation of the Impacts of Shared Autonomous Vehicle Operation in Halifax, Canada Using a Dynamic Traffic Microsimulation Model. *Procedia Computer Science*, *130*, 496-503. Retrieved from https://doi.org/10.1016/j.procs.2018.04.066.

Anderson, J.M., Kalra, N., Stanley, K.D., Sorensen, P., Samaras, C., Oluwatola, & O.A. (2014). Autonomous Vehicle Technology - A Guide for Policymakers. *RAND Corporation*. Retrieved from http://www.rand.org/pubs/research_reports/RR443-2.html.

Awal, T., Murshed, M., & Ali, M. (2015). An Efficient Cooperative Lane-Changing Algorithm for Sensor- And Communication-Enabled Automated Vehicles. *2015 IEEE Intelligent Vehicles Symposium (IV)*. Retrieved from https://doi.org/10.1109/IVS.2015.7225900.

Bansal, P., & Kockelman, K.M. (2016). Forecasting Americans' Long-Term Adoption of Connected and Autonomous Vehicle Technologies. *Transportation Research Part A: Policy and Practice*, 49-63. Retrieved from https://doi.org/10.1016/j.tra.2016.10.013.

Bansal, P., Kockelman, K.M., & Singh, A. (2016). Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. *Transportation Research Part C: Emerging Technologies*, *67*, 1-14. Retrieved from http://dx.doi.org/10.1016/j.trc.2016.01.019.

Bartolini, C., Tettamanti, T., & Varga, I. (2017). Critical Features of Autonomous Road Transport from the Perspective of Technological Regulation and Law. *Transportation Research Procedia*, *27*, 791-798. Retrieved from https://doi.org/10.1016/j.trpro.2017.12.002.

Beirigo, B.A., Schulte, F., & Negenborn, R.R. (2018). Integrating People and Freight Transportation Using Shared Autonomous Vehicles with Compartments. *IFAC-PapersOnLine*, *51*(9), 392-397. Retrieved from https://doi.org/10.1016/j.ifacol.2018.07.064.

Bell, L. (2015). Humans vs Robots: Driverless Cars Are Safer than Human Driven Vehicles. *The Inquirer.* Retrieved from http://www.theinquirer.net/inquirer/feature/2426988/humans-vs-robots-driverless-cars-are-safer-than-human-driven-vehicles.

Bischoff, J., & Maciejewski, M. (2016). Simulation of City-wide Replacement of Private Cars with Autonomous Taxis in Berlin. *Procedia Computer Science*, *83*, 237-244. Retrieved from https://doi.org/10.1016/j.procs.2016.04.121.

Borhan, M.N., Ibrahim, A.N.H., & Miskeen, M.A.A. (2019). Extending the Theory of Planned Behaviour to Predict the Intention to Take the New High-Speed Rail for Intercity Travel in Libya: Assessment of the Influence of Novelty Seeking, Trust and External Influence. *Transportation Research Part A, 130*, 373-384. Retrieved from https://doi.org/10.1016/j.tra.2019.09.058.

Bosch, P.M., Becker, F., Becker, H., & Kay, W.A. (2018). Cost-based Analysis of Autonomous Mobility Services. *Journal of Transport Policy*, *64*, 76-91. Retrieved from https://doi.org/10.1016/j.tranpol.2017.09.005.

Briscoe, N. (2019). Audi's New Tech Can Help You Catch Green Lights. *The Irish Times*. Retrieved from https://www.irishtimes.com/life-and-style/motors/audi-s-new-tech-can-help-you-catch-green-lights-1.3801585#.XG6l_1O3cFw.linkedin.

Browne, D., O'Mahony, M., & Caulfield, B. (2012). How Should Barriers To Alternative Fuels And Vehicles Be Classified And Potential Policies To Promote Innovative Technologies Be Evaluated? *Journal of Cleaner Production*, *35*, 140-151. Retrieved from http://dx.doi.org/10.1016/j.jclepro.2012.05.019

Brummelen, J.V., O'Brien, M., Gruyer, D., & Najjarian, H. (2018). Autonomous Vehicle Perception: The Technology of Today and Tomorrow. *Transportation Research Part C: Emerging Technologies*, *89*, 384-406. Retrieved from https://doi.org/10.1016/j.trc.2018.02.012.

Bruyne, J.D., & Werbrouck, J. (2018). Merging Self-Driving Cars with the Law. *Journal of Computer Law & Security Review, 34*(5), 1150-1153. Retrieved from https://doi.org/10.1016/j.clsr.2018.02.008.

Byrne, M.D. (2013). How Many Times Should a Stochastic Model Be Run? An Approach Based on Confidence Intervals. *Semantic Scholar*. Retrieved from https://www.semanticscholar.org/paper/How-Many-Times-Should-a-Stochastic-Model-Be-Run-An-Byrne/f4f02f993ea31188efe4feaae21bd7c5c1749d41#citing-papers.

Byungkyu, B.P., & Won, J. (2006). Microscopic Simulation Model Calibration and Validation Handbook. *Virginia Transportation Research Council*. Report No.: FHWA/VTRC 07-CR6. Retrieved from https://trid.trb.org/view/798078.

Carroll, P., Caulfield, B., & Ahern, A. (2017). Examining the Potential for Car-Shedding in the Greater Dublin Area. *Transportation Research Part A: Policy and Practice, 106,* 440-452. Retrieved from https://doi.org/10.1016/j.tra.2017.10.019.

Casley, S.V., Jardim, A.S., & Quartulli, A.M. (2013). A Study of Public Acceptance of Autonomous Cars. BSc Thesis. *Computer Science Department, Worcester Polytechnic Institute*. Retrieved from https://web.wpi.edu/Pubs/E-project/Available/E-project-043013-155601/unrestricted/A_Study_of_Public_Acceptance_of_Autonomous_Cars.pdf.

Chan, C.H. (2017). Advancements, Prospects, and Impacts of Automated Driving Systems. *International Journal of Transportation Science and Technology. 6*(3), 208-216. Retrieved from https://doi.org/10.1016/j.ijtst.2017.07.008.

Chen, C.D., Fan, Y.W., & Farn, C.K. (2007). Predicting Electronic Toll Collection Service Adoption: An Integration of the Technology Acceptance Model and the Theory of

Planned Behaviour. *Transportation Research Part C, 15*, 300-311. Retrieved from https://doi.org/10.1016/j.trc.2007.04.004.

Chen, C.F., & Chao, W.H. (2011). Habitual or Reasoned? Using the Theory of Planned Behaviour, Technology Acceptance Model, and Habit to Examine Switching Intentions toward Public Transit. *Transportation Research Part F, 14*, 128-137. Retrieved from https://doi.org/10.1016/j.trf.2010.11.006.

Chen, C.F., & Chen, P.C. (2011). Applying the TAM to Travellers' Usage Intentions of GPS Devices. *Expert Systems with Applications, 38,* 6217-6221. Retrieved from https://doi.org/10.1016/j.eswa.2010.11.047.

Chu, L., Liu, H., Oh, J., & Recker, W. (2003). A Calibration Procedure for Microscopic Traffic Simulation. *IEEE International Conference on Intelligent Transportation Systems, ITSC 2003*, *2*, 1574-1579. Retrieved from https://doi.org/10.1109/ITSC.2003.1252749.

Collingwood, L. (2017). Privacy Implications and Liability Issues of Autonomous Vehicles, Information & Communications Technology Law. *Taylor & Francis*, *26*(1), 32-45. Retrieved from http://dx.doi.org/10.1080/13600834.2017.1269871.

Continental. (2015). Continental Mobility Study - International Perspective and Project Modules. Retrieved from https://www.conti-online.com/www/download/pressportal_com_en/themes/initiatives/channel_mobility_study_en/ov_mobility_study2015_en/download_channel/mobistud2015_praesentation_en.pdf.

CSO. (2017). *Central Statistics Office*. Retrieved from https://www.cso.ie/en/media/csoie/newsevents/documents/census2016summaryresultspart1/Census2016SummaryPart1.pdf.

Cui, S. Seibold, B., Stern, R., & Work, D.B. (2018). Stabilizing Traffic Flow via a Single Autonomous Vehicle: Possibilities and Limitations. *2017 IEEE Intelligent Vehicles Symposium (IV)*. Retrieved from https://doi.org/10.1109/IVS.2017.7995897.

Curtis, S. (2015). Self-Driving Cars Can Be Hacked Using A Laser Pointer. *The Telegraph*. Retrieved from https://www.telegraph.co.uk/technology/news/11850373/Self-driving-cars-can-be-hacked-using-a-laser-pointer.html.

DMV. (2016). Autonomous Vehicles in California - Testing and Deployment of Autonomous Vehicles for Public Use. *Department of Motor Vehicles (DMV) - State of California*. Retrieved from https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/bkgd.

Durrani, U., Lee, C. &, Zhao, P. (2016). Understanding the Differences in Lane Change Maneuvers of Cars and Heavy Vehicles on Freeways. *Canadian Transportation Research Forum 51st Annual Conference*. Retrieved from https://trid.trb.org/view/1483962

Eldredge, B. (2016). 5 Ways Driverless Cars Will Change Our Roads and Highways - Our Entire Transportation Infrastructure Needs To Move Away From a Design Focus on Human Drivers. *VOX Media – CURBED*. Retrieved from http://www.curbed.com/2016/9/6/12804434/driverless-cars-highways-roads-uber-google.

El-Habil, A. (2012). An Application on Multinomial Logistic Regression Model. *Pakistan Journal of Statistics and Operation Research, 8*(2)*,* 271-291. Retrieved from http://dx.doi.org/10.18187/pjsor.v8i2.234.

Essa, M. (2015). Calibration and Validation of Traffic Micro-Simulation Models for Safety Evaluation Using Automated Video-Based Conflict Analysis. MSc Thesis, *The University* *of British Columbia, Vancouver, Canada.* Retrieved from https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0165811

Fagnant, D.J. (2014). The Future of Fully Automated Vehicles: Opportunities for Vehicle-And Ride-Sharing, With Cost and Emission Savings. PhD Thesis. *The University of Texas at Austin*. Retrieved from https://repositories.lib.utexas.edu/handle/2152/25932.

Fagnant, D.J., & Kockelman, K. (2015). Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations. *Transportation Research Part A: Policy and Practice*, *77*, 167-181. Retrieved from http://dx.doi.org/10.1016/j.tra.2015.04.003.

Faife, C. (2017). Why Self-Driving Cars Could Be a Dream Come True for Car Thieves. *Motherboard.* Retrieved from https://motherboard.vice.com/en_us/article/mgxak8/why-self-driving-cars-could-be-a-dream-come-true-for-car-thieves.

Fox-Penner, P., Hatch, J., & Gorman, W. (2018). Spread of Self-Driving Cars Could Cause More Pollution – Unless The Electric Grid Transforms Radically. *The Conversation*. Retrieved from https://theconversation.com/spread-of-self-driving-cars-could-cause-more-pollution-unless-the-electric-grid-transforms-radically-101508.

Furnham, A., & Boo, H.C. (2011). A Literature Review of the Anchoring Effect. *The Journal of Socio-Economics, 40(1),* 35-42. Retrieved from https://doi.org/10.1016/j.socec.2010.10.008.

Gallelli, V., Guido, G., Vitale, A., & Vaiana, R. (2018). Effects of Calibration Process on the Simulation of Rear-End Conflicts at Roundabouts. *Journal of Traffic and Transportation Engineering*. Retrieved from https://doi.org/10.1016/j.jtte.2018.03.006.

Gao. Y. (2008). Calibration and Comparison of the VISSIM and INTEGRATION Microscopic Traffic Simulation Models. MSc Thesis. *Virginia Polytechnic Institute and State University*. Retrieved from https://vtechworks.lib.vt.edu/handle/10919/35005.

Gardes, Y., May, A., Dahlgren, J., & Skabardonis, A. (2002). Freeway Calibration and Applications of the PARAMICS Model. *The 81st Annual Meeting on Transportation Research Board, Washington, D.C., USA.* Retrieved from https://www.researchgate.net/publication/229049478_Freeway_calibration_and_application_of_the_PARAMICS_model.

Ge, Q., & Menendez, M. (2014). An Efficient Sensitivity Analysis Approach for Computationally Expensive Microscopic Traffic Simulation Models. *Transportation Research Board: International Journal of Transportation, 2*(2), 49-64. Retrieved from http://dx.doi.org/10.14257/ijt.2014.2.2.04.

Gerado, C.G.J., Jesus, A.L., & Ricardo, O.M. (2015). Modelling the Turning Speed and Car Following Behaviors of Autonomous Vehicles in a Virtual World. *Ingenieria*, *16*(3), 391-405. Retrieved from https://doi.org/10.1016/j.riit.2015.05.013.

Gerdes J.C., & Thornton S.M. (2016). Implementable Ethics for Autonomous Vehicles. *Autonomous Driving, Springer*, 87-102. Retrieved from https://doi.org/10.1007/978-3-662-48847-8_5.

Greenough, J. (2016). The Transformation of the Automobile 2016: Forecasts, Trends, and Analyses on the Disruption of the Automotive Industry. *Business Insider UK*. Retrieved from http://uk.businessinsider.com/the-transformation-of-the-automobile-2016-forecasts-trends-and-analyses-on-the-disruption-of-the-automotive-industry-2016-4?r=US&IR=T.

Guion, L.A., Diehl, D.C., & McDonald, D. (2011). Triangulation: Establishing the Validity of Qualitative Studies. *The University of Central Florida*. Report no.: FCS6014. Retrieved from http://www.ie.ufrj.br/intranet/ie/userintranet/hpp/arquivos/texto_7_-_aulas_6_e_7.pdf.

Haboucha, C., Ishaq, R., & Shiftan, Y. (2017). User Preferences Regarding Autonomous Vehicles. *Transportation Research Part C: Emerging Technologies*, *78*, 37-49. Retrieved from https://doi.org/10.1016/j.trc.2017.01.010.

Hancock, P.A., Nourbakhsh, I., & Stewart, J. (2019). On the Future of Transportation in an Era of Automated and Autonomous Vehicles. *Proceedings of the National Academy of Sciences, 116* (16), *7684-7691.* Retrieved from https://doi.org/10.1073/pnas.1805770115.

Hawkins, A.J. (2018). Inside Waymo's Strategy to Grow the Best Brains For Self-Driving Cars. *THE VERGE*. Retrieved from https://www.theverge.com/2018/5/9/17307156/google-waymo-driverless-cars-deep-learning-neural-net-interview.

Heale, R., & Twycross, A. (2015). Validity and Reliability in Quantitative Studies. BMJ Journal. Retrieved from http://dx.doi.org/10.1136/eb-2015-102129.

Heaps, R. (2016). Data Collection for Self-Driving Cars Could Be Risking Your Privacy. *Autotrader.* Retrieved from https://www.autotrader.com/car-shopping/data-collection-self-driving-cars-could-be-risking-257144.

Higgs, B., Abbas, M.M., & Medina, A. (2011). Analysis of the Wiedemann Car Following Model over Different Speeds using Naturalistic Data. *The 3rd International Conference on Road Safety and Simulation. Procedia of RSS Conference.* Retrieved from https://scholar.google.com/citations?user=MHHCNQUAAAAJ&hl=en.

Howard, D., & Dai, D. (2014). Public Perceptions of Self-Driving Cars: The Case of Berkeley, California. *Transportation Research Board, 93rd Annual Meeting*. Retrieved from https://trid.trb.org/view/1289421.

Hulse, L., Xie, H., & Galea, E. (2018). Perceptions of Autonomous Vehicles: Relationships with Road Users, Risk, Gender and Age. *Journal of Safety Science*, *102*, 1-13. Retrieved from https://doi.org/10.1016/j.ssci.2017.10.001.

Igliński, H., & Babiak, M. (2017). Analysis of the Potential of Autonomous Vehicles in Reducing the Emissions of Greenhouse Gases in Road Transport. *Journal of Procedia Engineering*. *192*, 353-358. Retrieved from https://doi.org/10.1016/j.proeng.2017.06.061.

IrishTimes. (2017). M50 blues: Ireland's Busiest Road, Dublin's biggest Car Park. *The Irish Times*. Retrieved from https://www.irishtimes.com/life-and-style/people/m50-blues-ireland-s-busiest-road-dublin-s-biggest-car-park-1.3259694

IrishTimes. (2019). Top 100 Cars for 2019. *The Irish Times.* Retrieved from https://www.irishtimes.com/life-and-style/motors/top-100.

Jiang, K., Ling, F., Feng, Z., Wang, K., & Shao, C. (2017). Why Do Drivers Continue Driving While Fatigued? An Application of the Theory of Planned Behaviour. *Transportation Research Part A, 98*, 141-149. Retrieved from https://doi.org/10.1016/j.tra.2017.02.003.

Jones, S.L., Sullivan, A., Anderson, M., Malave, D., & Cheekoti, N. (2004). Traffic Simulation Software Comparison Study. *Department of Civil & Environmental Engineering. The*

University of Alabama at Birmingham. Report No.: FHWA/CA/OR. Retrieved from https://trid.trb.org/view/740386.

Katrakazas, C., Quddus, M., Chen, W. H, & Deka, L. (2015). Real-Time Motion Planning Methods for Autonomous On-Road Driving: State-Of-The-Art And Future Research Directions. *Transportation Research Part C: Emerging Technologies*, *60*, 416-442. Retrieved from https://doi.org/10.1016/j.trc.2015.09.011.

Kaur, K., & Rampersad, G. (2018). Trust in Driverless Cars: Investigating Key Factors Influencing the Adoption of Driverless Cars. *Journal of Engineering and Technology Management, 48*, 87-96. Retrieved from https://doi.org/10.1016/j.jengtecman.2018.04.006.

Kesting A., Treiber M., Schönhof M., Kranke F., & Helbing D. (2007). Jam-Avoiding Adaptive Cruise Control (ACC) and Its Impact on Traffic Dynamics. *SpringerLink: Traffic and Granular Flow'05*, 633-643. Retrieved from https://doi.org/10.1007/978-3-540-47641-2_62.

Kotusevski, G., & Hawick, K.A. (2009). A Review of Traffic Simulation Software. Institute of Information & Mathematical Sciences. *Massey University at Albany, Auckland, New Zealand*. Retrieved from https://www.researchgate.net/publication/228966705_A_Review_of_Traffic_Simulation_Software.

KPMG. (2012a). Self-Driving Cars: Are We Ready? Klynveld Peat Marwick Goerdeler (*KPMG) & Center for Automotive Research (CAR), Connected Vehicle Technology (CVT).* Retrieved from https://home.kpmg.com/us/en/home/insights/2014/01/self-driving-cars-are-we-ready.html.

KPMG. (2012b). Self-Driving Cars: The Next Revolution. Klynveld Peat Marwick Goerdeler (*KPMG) & Center for Automotive Research (CAR), Connected Vehicle Technology (CVT).* Retrieved from http://cargroup.org/?module=Publications&event=View&pubID=87.

Krueger, R., Rashidi, T.H., & Rose, J.M. (2016). Preferences for Shared Autonomous Vehicles. *Transportation Research Part C: Emerging Technologies*, *69*, 343-355. Retrieved from http://dx.doi.org/10.1016/j.trc.2016.06.015.

Kyriakidis, M., Happee, R., & De-Winter, J.C.F. (2015). Public Opinion on Automated Driving: Results of an International Questionnaire among 5000 Respondents. *Transportation Research Part F: Traffic Psychology and Behaviour*, *32*, 127-140. Retrieved from http://dx.doi.org/10.1016/j.trf.2015.04.014.

Laan, Z.V., & Sadabadi, K.F. (2017). Operational Performance of a Congested Corridor With Lanes Dedicated to Autonomous Vehicle Traffic. *International Journal of Transportation Science and Technology*, *6*, 42-52. Retrieved from https://doi.org/10.1016/j.ijtst.2017.05.006.

LaMondia, J.J., Fagnant, D.J., Qu, H., Barrett, J., & Kockelman, K. (2016). Shifts in Long-Distance Travel Mode Due to Automated Vehicles: Statewide Mode-Shift Simulation Experiment and Travel Survey Analysis. *Transportation Research Board, 95rd Annual Meeting*. Retrieved from http://dx.doi.org/10.3141/2566-01.

Levin, M.W. (2017). Congestion-Aware System Optimal Route Choice for Shared Autonomous Vehicles. *Transportation Research Part C: Emerging Technologies*, *82*, 229-247. Retrieved from https://doi.org/10.1016/j.trc.2017.06.020.

Li, B., & Shao, Z. (2015). A Unified Motion Planning Method for Parking An Autonomous Vehicle In The Presence Of Irregularly Placed Obstacles. *Journal of Knowledge-Based Systems*, *86*, 11-20. Retrieved from https://doi.org/10.1016/j.knosys.2015.04.016.

Li, X., Ghiasi, A., Xu, Z., & Qu, X. (2018). A Piecewise Trajectory Optimization Model for Connected Automated Vehicles: Exact Optimization Algorithm and Queue Propagation Analysis. *Transportation Research Part B: Methodological, 118*, 492-456. Retrieved from https://doi.org/10.1016/j.trb.2018.11.002.

Litman, T. (2016). Autonomous Vehicle Implementation Predictions. *Victoria Transport Policy Institute.* Retrieved from: http://www.vtpi.org/documents/evaluation.php.

Liu, P., Guo, Q., Ren, F., Wang, L., & Xu, Z. (2019). Willingness to Pay for Self-Driving Vehicles: Influences of Demographic and Psychological Factors. *Transportation Research Part C: Emerging Technologies. 100*, 306-317. Retrieved from https://doi.org/10.1016/j.trc.2019.01.022.

Lu, Z., Fu, T., Fu, L., Shirvani, S., & Jiang, C. (2016). A Video-Based Approach to Calibrating Car-Following Parameters in VISSIM for Urban Traffic*. International Journal of Transportation Science and Technology, 5*(1), 1-9. Retrieved from https://doi.org/10.1016/j.ijtst.2016.06.001.

Ma, T., & Abdulhai, B. (2002). Genetic Algorithm-Based Optimisation Approach and Generic Tool for Calibrating Traffic Microscopic Simulation Parameters. *Transportation Research Record: Journal of the Transportation Research Board*, *1800*(1), 6-15. Retrieved from http://dx.doi.org/10.3141/1800-02.

Ma, Z., Sun, J., & Wang, Y. (2017). A Two-Dimensional Simulation Model for Modelling Turning Vehicles at Mixed-Flow Intersections. *Transportation Research Part C: Emerging Technologies, 75,* 103-119. Retrieved from https://doi.org/10.1016/j.trc.2016.12.005.

Macher, G., Armengaud, E., Brenner, E., & Kreiner, C. (2016). Threat and Risk Assessment Methodologies in the Automotive Domain. *Procedia Computer Science, 83*, 1288-1294. Retrieved from https://doi.org/10.1016/j.procs.2016.04.268.

Madley-Dowd, P., Hughes, R., Tilling, K., & Heron, J. (2016). The Proportion Of Missing Data Should Not Be Used to Guide Decisions on Multiple Imputation. Journal of Clinical Epidemiology, 110, 63-73. Retrieved from https://doi.org/10.1016/j.jclinepi.2019.02.016.

Marczak, F., Leclercq, L., & Buisson, C. (2015). A Macroscopic Model for Freeway Weaving Sections. *Computer-Aided Civil and Infrastructure Engineering*. *30*, 464-477. Retrieved from https://doi.org/10.1111/mice.12119.

Mars, L., Arroyo, R., & Ruiz, T. (2016). Qualitative Research in Travel Behaviour Studies. *Transportation Research Procedia, 18, 434*-445. Retrieved from https://doi.org/10.1016/j.trpro.2016.12.057.

Martinez, L., & Viegas, J.M. (2017). Assessing the Impacts of Deploying a Shared Self-Driving Urban Mobility System: An Agent-Based Model Applied to the City of Lisbon, Portugal. *International Journal of Transportation Science and Technology, 6*(1), 13-27. Retrieved from https://doi.org/10.1016/j.ijtst.2017.05.005.

Matsumi, R., Raksincharoensak, P., & Nagai, M. (2013). Autonomous Braking Control System for Pedestrian Collision Avoidance by Using Potential Field. *IFAC Proceedings Volumes, 46*(21), 328-334. Retrieved from https://doi.org/10.3182/20130904-4-JP-2042.00064.

McCarthy, O., Caulfield, B., & O'Mahony, M. (2016). How Transport Users Perceive Personal Safety Apps. *Transportation Research Part F: Traffic Psychology and Behaviour, 43,* 166–182. Retrieved from https://doi.org/10.1016/j.trf.2016.10.005.

McCarthy, O.T, Caulfield, B., & O'Mahony, M. (2016). How Transport Users Perceive Personal Safety Apps. *Transportation Research Part F: Traffic Psychology and Behaviour, 43,* 166-182. Retrieved from https://doi.org/10.1016/j.trf.2016.10.005.

Menneni, S, Sun, C, & Vortisch, P. (2008). Micro-Simulation Calibration Using Speed-Flow Relationships. *Transportation Research Record: Transportation Research Board*, *2088*(1), 1-14. Retrieved from https://doi.org/10.3141%2F2088-01.

Mersky, A. C., & Samaras, C. (2016). Fuel Economy Testing of Autonomous Vehicles. *Transportation Research Part C: Emerging Technologies. 65*, 31-48. Retrieved from https://doi.org/10.1016/j.trc.2016.01.001.

Millard-Ball, A. (2019). The Autonomous Vehicle Parking Problem. *Journal of Transport Policy. 75*, 99-108. Retrieved from https://doi.org/10.1016/j.tranpol.2019.01.003.

Mirabeau, L., Mignerat, M., & Grange, C. (2013). The Utility of Using Social Media Networks for Data Collection in Survey Research. *The 34th International Conference on Information Systems, Milan, Italy*. Retrieved from https://www.researchgate.net/publication/258243791_The_Utility_of_Using_Social_Media_Networks_for_Data_Collection_in_Survey_Research.

Moody, J., Wang, S., Chun, J., & Jinhua, X.N. (2019). Transportation Policy Profiles of Chinese City Clusters: A Mixed Methods Approach. *Transportation Research Interdisciplinary Perspectives, 2, 100053*. Retrieved from https://doi.org/10.1016/j.trip.2019.100053.

Moriarty, P., & Wang, S.J. (2017). Could Automated Vehicles Reduce Transport Energy? *Energy Procedia, 142*, 2109-2113. Retrieved from https://doi.org/10.1016/j.egypro.2017.12.613.

Muoio, D. (2016). 6 Scenarios Self-driving Cars Still Can't Handle. *Business Insider*. Retrieved from https://www.businessinsider.com/autonomous-car-limitations-2016-8?r=US&IR=T.

NCSL. (2016). Autonomous | Self-Driving Vehicles Legislation. *National Conference of State Legislatures, Autonomous Vehicles (NCSL)*. Retrieved from http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.

Neiger, C. (2016). How Much Do Driverless Cars Cost? *The Motley Fool*. Retrieved from http://www.fool.com/investing/2016/08/04/how-much-do-driverless-cars-cost.aspx

NHTSA. (2015). Motor Vehicle Crashes - Report DOT HS 812 318. *National Highway Traffic Safety Administration, the US Department of Transportation*. Retrieved from https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812318

NHTSA. (2016). Federal Automated Vehicles Policy. *National Highway Traffic Safety Administration, the US Department of Transportation.* Retrieved from https://www.transportation.gov/AV/federal-automated-vehicles-policy-september-2016.

NHTSA. (2019). Automated Vehicles for Safety. *National Highway Traffic Safety Administration, the US Department of Transportation.* Retrieved from https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.

Noy, I., Shinar, D., & Horrey, W. (2018). Automated Driving: Safety Blind Spots. *Journal of Safety Science, 2,* 68-78. Retrieved from https://doi.org/10.1016/j.ssci.2017.07.018.

OECD. (2017). International Transport Forum (ITF) Outlook 2017. *Organisation for Economic Co-Operation and Development.* Retrieved from http://dx.doi.org/10.1787/9789282108000-en.

Olstam, J.J., & Tapani, A. (2004). Comparison of Car-Following Models. *Swedish National Road and Transport Research Institute*. 5-12. Retrieved from https://www.diva-portal.org/smash/get/diva2:673977/FULLTEXT01.pdf.

Osswald, S., Wurhofer, D., Trösterer, S., Beck, E., & Tscheligi, M. (2012). Predicting Information Technology Usage in the Car: Towards a Car Technology Acceptance Model. *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications,* 51-58. Retrieved from DOI: 10.1145/2390256.2390264.

Papadoulis, A., Quddus, M., & Imprialou, M. (2019). Evaluating the Safety Impact of Connected and Autonomous Vehicles on Motorways. *Accident Analysis and Prevention*, *124*, 12-22. Retrieved from https://doi.org/10.1016/j.aap.2018.12.019.

Park, B., & Schneeberger, J. (2003). Microscopic Simulation Model Calibration and validation: a case study of the VISSIM simulation model for a coordinated actuated Signal system. *Transportation Research Record: Journal of the Transportation Research Board, 1856*(1), 185-192. Retrieved from http://doi.org/10.1109/ITSC.2006.1707431.

Payre, W., Cestac, J., & Delhomme, P. (2014). Intention to Use a Fully Automated Car Attitude and a Priori Acceptability. *Transportation Research Part F: Traffic Psychology and Behaviour*, *27*, 252-263. Retrieved from: http://dx.doi.org/10.1016/j.trf.2014.04.009.

Paz, A., Molano, V., Martinez, E., Gaviria, C., & Arteaga, C. (2015). Calibration of Traffic Flow Models Using a Memetic Algorithm. *Transportation Research Part C: Emerging Technologies, 55*, 432-443. Retrieved from https://doi.org/10.1016/j.trc.2015.03.001.

PennDOT. (2016). Pennsylvania Takes Steps to Lead on Autonomous Vehicle Development, Testing with Newly Established Task Force, Legislation. *Pennsylvania Department of Transportation (PennDOT)*. Retrieved from: http://www.penndot.gov/Pages/all-news-details.aspx?newsid=233#.V1COyNkrKUl

Potard, C., Kubiszewski, V., Camus, G., Courtois, R., & Gaymard, S. (2018). Driving Under the Influence of Alcohol and Perceived Invulnerability Among Young Adults: An Extension of the Theory of Planned Behaviour. *Transportation Research Part F, 55*, 38-46. Retrieved from https://doi.org/10.1016/j.trf.2018.02.033.

Priddle, A., & Woodyard, C. (2012). Google discloses costs of its driverless car tests. *USA Today*. Retrieved from http://content.usatoday.com/communities/driveon/post/2012/06/google-discloses-costs-of-its-driverless-car-tests/1#.WB0i7oXXJfo.

PTV Group. (2015). VISSIM Manual. Microscopic Multi-modal Traffic Flow Simulation Software Package. *PTV Planung Transport Verkehr AG.* Retrieved from http://vision-traffic.ptvgroup.com/en-us/products/ptv-vissim/.

PTV Group. (2017). VISSIM Manual. Microscopic Multi-modal Traffic Flow Simulation Software Package. *PTV Planung Transport Verkehr AG.* Retrieved from http://vision-traffic.ptvgroup.com/en-us/products/ptv-vissim/.

Quach, K. (2018). Waymo Presents Chauffeurnet, a Neural Net Designed To Copy Human Driving. *The Register.* Retrieved from https://www.theregister.co.uk/2018/12/12/waymo_presents_chauffernet/.

Rakotonirainy, A., Schroeter, R., & Soro, A. (2014). Three Social Car Visions to Improve Driver Behaviour. *Pervasive and Mobile Computing*, *14*, 147-160. Retrieved from http://dx.doi.org/10.1016/j.pmcj.2014.06.004.

Rhoades, C., Wang, X., & Quyang, Y. (2016). Calibration of Nonlinear Car-Following Laws for Traffic Oscillation Prediction. *Transportation Research Part C: Emerging Technologies*, *69*, 328-342. Retrieved from https://doi.org/10.1016/j.trc.2016.05.018.

Rizvi, S., Willet, J., Perino, D., Marasco, S., & Condo, C. (2017). A Threat to Vehicular Cyber Security and the Urgency for Correction. *Procedia Computer Science, 114,* 100-105. Retrieved from https://doi.org/10.1016/j.procs.2017.09.021.

Rojas-Rueda, D., Nieuwenhuijsen, M., & Khreis, H. (2017). 1859 – Autonomous Vehicles and Public Health: A Literature Review*. Journal of Transport and Health*. *5*, S13. Retrieved from https://doi.org/10.1016/j.jth.2017.05.292.

Ronaldo, A. (2012). Comparison of the Micro-Simulation Software Aimsun & Ihcm-1997 for Highway Traffic Performance Analysis. *Ministry of Transportation Republic of Indonesia - Civil Engineering Forum*. XXI/3. Retrieved from https://jurnal.ugm.ac.id/jcef/article/view/18924.

Rose, N. (2017). The Privacy Implications of Autonomous Vehicles. *Data Protection Report*. Retrieved from https://www.dataprotectionreport.com/2017/07/the-privacy-implications-of-autonomous-vehicles/.

Ross, C., & Guhathakurta, S. (2017). Autonomous Vehicles and Energy Impacts: A Scenario Analysis. *Energy Procedia, 143*, 47-52. Retrieved from https://doi.org/10.1016/j.egypro.2017.12.646.

RSA (2017). Accident Database. *Road Safety Authority of Ireland.* Retrieved from: https://www.rsa.ie/RSA/Road-Safety/RSA-Statistics/Collision-Statistics/Ireland-Road-Collisions/.

Russo, C. (2008). The Calibration and Verification of Simulation Models for Toll Plazas. MSc Thesis. *The University of Central Florida*. Retrieved from https://stars.library.ucf.edu/etd/3480/.

SAE. (2016). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. *Society of Automotive Engineers.* Report J3016_201609. Retrieved from https://www.sae.org/standards/content/j3016_201609/.

Saidallah, M., El-Fergougui, A., Elalaoui, A.E. (2016). A Comparative Study of Urban Road Traffic Simulators. *The 5th International Conference on Transportation and Traffic Engineering (ICTTE 2016). 81*. Retrieved from https://doi.org/10.1051/matecconf/20168105002.

Sappin, E. (2018). Will Self-Driving Cars End The Big Automakers? *Forbes.* Retrieved from https://www.forbes.com/sites/forbesnycouncil/2018/04/13/will-self-driving-cars-end-the-big-automakers/#1bf60085356d.

Schafer, J.L. (1999). Multiple Imputation: A Primer. *PubMed, 8*(1), 3-15. Retrieved from https://doi.org/10.1177%2F096228029900800102.

Schoettle, B., & Sivak, M. (2014a). A survey of Public Opinion about Autonomous and Self-Driving Vehicles in the U.S., the U.K., and Australia. *University of Michigan, Ann Arbor,* *Transportation Research Institute, UMTRI-2014-10.* Retrieved from https://deepblue.lib.umich.edu/handle/2027.42/108384

Schoettle, B., & Sivak, M. (2014b). A survey of Public Opinion about Autonomous and Self-Driving Vehicles in the U.S., the U.K., and Australia. *University of Michigan, Ann Arbor, Transportation Research Institute, UMTRI-2014-21*. Retrieved from https://deepblue.lib.umich.edu/handle/2027.42/108384

Schoettle, B., & Sivak, M. (2014c). Public Opinion about Self-Driving Vehicles in China, India, Japan, the U.S., the U.K., and Australia, Michigan, USA. University *of Michigan, Ann Arbor, Transportation Research Institute, UMTRI-2014-30.* Retrieved from *https://deepblue.lib.umich.edu/bitstream/handle/2027.42/109433/103139.pdf?sequence=1*.

Schwarting, W., Alonso-Mora, J., & Rus, D. (2018). Planning and Decision-Making for Autonomous Vehicles. *Annual Review of Control, Robotics, and Autonomous Systems*. Retrieved from https://doi.org/10.1146/annurev-control-060117-105157.

Schwartz, S., & Lee, K. (2017). 1706 – Autonomous Vehicles: Good or Bad for our Health? *Journal of Transport and Health*, *5*, S4. Retrieved from https://doi.org/10.1016/j.jth.2017.05.280.

Sheehan, B., Murphy, F., Mullins, M., & Ryan, C. (2018). Connected and Autonomous Vehicles: A Cyber-Risk Classification Framework. *Transport Research Part A: Policy and Practice*, In Press. Retrieved from https://doi.org/10.1016/j.tra.2018.06.033.

Siddharth, S.M.P., & Ramadurai, G. (2013). Calibration of VISSIM for Indian Heterogeneous Traffic Conditions. *Procedia – Social and Behavioral Sciences*, *104,* 380-389. Retrieved from https://doi.org/10.1016/j.sbspro.2013.11.131.

Siswaningsih, W., Firman, H., Zackiyah, & Khoirunnisa, A. (2017). Development of Two-Tier Diagnostic Test Pictorial-Based for Identifying High School Students Misconceptions on the Mole Concept. *Journal of Physics: Conf. Series 812* (2017) 012117, 1-7. Retrieved from https://doi.org/10.1088/1742-6596/812/1/012117.

Smith, B.W. (2013). Managing Autonomous Transportation Demand. *Santa Clara Law Review, 52*, 1401. Retrieved from https://cyberlaw.stanford.edu/files/publication/files/BWS-2012-ManagingAutonomousTransportationDemand.pdf.

Song, G., Yu, L., & Geng, Z. (2015). Optimization of Wiedemann and Fritzsche Car-following Models for Emission Estimation. *Transportation Research Part D: Transport and Environment, 34,* 318-329. Retrieved from https://doi.org/10.1016/j.trd.2014.11.023.

Steinmetz-wood, M., Pluye, P., & Ross, N.A. (2019). The Planning and Reporting of Mixed Methods Studies on the Built Environment and Health. *Preventive Medicine, 126, 105752*. Retrieved from https://doi.org/10.1016/j.ypmed.2019.105752.

Sukennik, P. (2018, July 5). Default Behavioural Parameter Sets for Automated Vehicles (AVs). CoEXist, Deliverable 2.3. Retrieved from https://www.h2020-coexist.eu/wp-content/uploads/2018/10/D2.3-default-behavioural-parameter-sets_final.pdf.

Survey Monkey. (2019). Sample Size Calculator. *Survey Monkey*. Retrieved from https://www.surveymonkey.com/mp/sample-size-calculator/.

Taber, K.S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Springer Netherlands, 48,* 6, 1273–1296. Retrieved from https://doi.org/10.1007/s11165-016-9602-2.

Tabitha, S.C., Sandt, L.S., Clamann, M.P., & McDonald, N.C. (2018). Automated Vehicles and Pedestrian Safety: Exploring the Promise and Limits of Pedestrian Detection. *American Journal of Preventive Medicine, 56*(1), 1-7. Retrieved from https://doi.org/10.1016/j.amepre.2018.06.024.

Taeihagh, A., & Lim, H.S.M. (2019). Governing Autonomous Vehicles: Emerging Responses for Safety, Liability, Privacy, Cybersecurity, and Industry Risks. *Transport Reviews, 39(1),* 103-128. Retrieved from https://doi.org/10.1080/01441647.2018.1494640.

Talebpour, A., & Mahmassani, H.S. (2016). Influence of Connected and Autonomous Vehicles on Traffic Flow Stability and Throughput. *Transportation Research Part C: Emerging Technologies*, *71*, 143–163. Retrieved from https://doi.org/10.1016/j.trc.2016.07.007.

Tavakol, M., & Dennick, R. (2011). Making Sense of Cronbach's Alpha. *International Journal of Medical Education, 2*, 53-55. Retrieved from https://www.statisticshowto.datasciencecentral.com/cronbachs-alpha-spss/.

TII. (2017). TII Traffic Data Site. *Transport Infrastructure Ireland*. Retrieved from https://www.nratrafficdata.ie/c2/gmapbasic.asp?sgid=ZvyVmXU8jBt9PJE$c7UXt6.

Treiber, M., & Kesting, A. (2013). Microscopic Calibration and Validation of Car-Following Models – A Systematic Approach. *Procedia – Social and Behavioral Sciences*, *80*, 922-939. Retrieved from https://doi.org/10.1016/j.sbspro.2013.05.050.

Underwood, S. (2014). Automated Vehicles Forecast: Expert Forecast and Roadmap for Sustainable Transportation - Automated, Connected, and Electric Vehicle Systems. Vehicle Symposium Opinion Survey. *Institute for Advanced Vehicle Systems, University of Michigan - Dearborn.* Retrieved from http://graham.umich.edu/media/files/LC-IA-ACE-Roadmap-Expert-Forecast-Underwood.pdf.

Vallet, M. (2013). Are drivers Ready to Trust Robot Cars? *CarInsurance.com*. Retrieved from http://www.foxbusiness.com/features/2013/11/04/survey-drivers-ready-to-trust-robot-cars.html.

Vasconcelos, L., Neto, L., Santos, S., Silva, A. B., & Seco, A. (2014). Calibration of the Gipps Car-following Model Using Trajectory Data. *Transport Research Procedia, 3,* 952-961. Retrieved from https://doi.org/10.1016/j.trpro.2014.10.075.

Weiss, C. (2011). V2X Communication in Europe – From Research Projects towards Standardization and Field Testing of Vehicle Communication Technology. *Computer Networks, 55,* 3103–3119. Retrieved from http://dx.doi.org/10.1016/j.comnet.2011.03.016

Wisconsin DOT (2018). VISSIM Calibration Settings. *Wisconsin Department of Transportation.* Last Updated: May 31st, 2018. Retrieved from http://wisconsindot.gov/dtsdManuals/traffic-ops/manuals-and-standards/teops/16-20att6.3.pdf.

Wisdom, J., & Creswell, J.W. (2013). Mixed Methods: Integrating Quantitative and Qualitative Data Collection and Analysis While Studying Patient-Centered Medical Home Models. *Agency for Healthcare Research and Quality, U.S. Department of Health and Human Services, 13-0028-EF. Retrieved from https://pcmh.ahrq.gov/page/mixed-methods-integrating-quantitative-and-qualitative-data-collection-and-analysis-while.*

Woody, T. (2006). Calibrating Freeway Simulation Models in Vissim. MSc Thesis. *The University of Washington*. Retrieved from http://courses.washington.edu/cee500/VISSIMCalibration_FinalReport.doc.

Xavier Rhodes, B. (2014). An Analysis of Economically Efficient Insurance Schemes for Automated Vehicles. BSc Thesis. *Operations Research and Financial Engineering, Princeton University.* Retrieved from http://docplayer.net/1299822-An-analysis-of-economically-efficient-insurance-schemes-for-automated-vehicles-brandon-xavier-rhodes-june-2014-advised-by-professor-alain-kornhauser.html.

Yea, L., & Yamamoto, T. (2018). Modelling Connected and Autonomous Vehicles in Heterogeneous Traffic Flow. *Physica A: Statistical Mechanics and its Applications*, *490*, 269-277. Retrieved from https://doi.org/10.1016/j.physa.2017.08.015.

Yu, M., & Fan, W. (2017). Calibration of Microscopic Traffic Simulation Models Using Metaheuristic Algorithms. *International Journal of Transportation Science and Technology. 6*(1), 63-77. Retrieved from https://doi.org/10.1016/j.ijtst.2017.05.001.

Yuen, K.F., Wang, X., Wong, Y.D., & Zhou, Q. (2017). Antecedents and Outcomes of Sustainable Shipping Practices: The Integration of Stakeholder and Behavioural Theories. *Transportation Research Part E, 108,* 18-35. Retrieved from https://doi.org/10.1016/j.tre.2017.10.002.

Zaiontz, C. (2019). Cronbach's Alpha. *Real Statistics Using Excel*. Retrieved from http://www.real-statistics.com/reliability/cronbachs-alpha/.

Zhichu, C. (1989). Allowable Limit of Error in Clinical Chemistry Quality Control. *Scientific Notes*. Retrieved from http://clinchem.aaccjnls.org/content/clinchem/35/4/630.full.pdf.

Zhu, F., & Ukkusuri, S. (2018). Modelling the Proactive Driving Behaviour of Connected Vehicles: A Cell-Based Simulation Approach. *Computer-Aided Civil and Infrastructure Engineering, 33,* 262-281. Retrieved from https://doi.org/10.1111/mice.12289.

APPENDIX A: Data Tables of the Methodology of Research

A1. Variable coding of the public survey in SPSS

Note: A copy of the public survey questionnaire is available in APPENDIX B (B3).

Variable and answer options	**Coding for each answer option**
Respondent	None
Having heard about AV	Nothing at all = 1, Somewhat = 2, A great deal = 3
Being interested in driving AVs	Not interested = 1, Neither = 2, Very interested = 3
Preferences for spending time in an AV: A = Sleeping, resting, and reading, B = enjoying the scenery, C = Social activities, D = Working, E = Other	No = 0, Yes = 1
Owning an AV in limited areas of the city	Not at all likely = 1, Somewhat likely = 2, Extremely likely = 3
AVs would be safer and more secure than human drivers	Not at all = 1, Somewhat = 2, Extremely = 3
Feeling safe and secure in an AV without a steering wheel	Not at all = 1, Somewhat = 2, Extremely = 3
Feeling safe and secure in an AV with manual control	Not at all = 1, Somewhat = 2, Extremely = 3
Feeling safe and secure about AVs' quick reaction in accidents	Not at all concerned = 1, Somewhat concerned = 2, Extremely concerned = 3
Passengers' concern of driving a TV: A = Travelling at night, B = Road is slippery, C = Vehicle is at speed limit	Not at all concerned = 1, Somewhat concerned = 2, Extremely concerned = 3
Passengers' concern of driving an AV: A = Travelling at night, B = Road is slippery, C = Vehicle is at speed limit	Not at all concerned = 1, Somewhat concerned = 2, Extremely concerned = 3
Previous knowledge that AVs might record travel data	No = 0, Yes = 1
Concerned about the privacy of the recorded data in AVs	Not at all concerned = 1, Somewhat concerned = 2, Extremely concerned = 3
Agree that AVs should record data	Disagree = 1, Undecided = 2, Agree = 3
Preferences of sharing the vehicle data: A = Car manufacturer, B = Transport authorities, C = Consultants, D = Insurance companies, E = Other	No = 0, Yes = 1
How much will you accept AVs' liability	Nothing at all = 1, Somewhat = 2, A great deal = 3
The group or agency which should accept liability: A = NTA, B = Manufacturers, C = AV owners, D = Traffic control centres, E = Insurance companies, F = Others	No = 0, Yes = 1
Reason to buy an AV:	No = 0, Yes = 1

A = Safe driving, B = Auto navigation, C = Enjoying free time, D = Reduction in congestion, E = Reduction in emission, F = Others	
Prefer to purchase an AV when it is fully developed and tested	Not at all likely = 1, Somewhat likely = 2, Extremely likely = 3
Prefer to wait to see the early adopters' opinions about the application of AVs	Not at all likely = 1, Somewhat likely = 2, Extremely likely = 3
WTP for AV in addition to the price of the same vehicle in Traditional mode	Below 10% = 1, 10%-20% = 2, Above 20%, 3
Prefer to purchase AV if the cost was not an issue	Not at all likely = 1, Somewhat likely = 2, Extremely likely = 3
An on-demand ridesharing AV is more efficient than owning AV	Not at all likely = 1, Somewhat likely = 2, Extremely likely = 3
Prefer to purchase an AV even if a ridesharing service of AVs provided	No = 0, Yes = 1
Gender	Female = 0, Male = 1
Age	18 - 25 years old = 1, 26-35 years old = 2, 36-50 years old = 3, Above 50 years old = 4
County	{1, Antrim} ...
Possessing driving license	No = 0, Yes = 1
Owning at least one car	No = 0, Yes = 1
Number of cars	1 = 1, 2 = 2, 3 =3, 4 = 4, 5 = 5+
Age of car	0-2 years = 1, 2-5 years = 2, 5-7 years = 3, 7-10 years = 4, Above 10 years = 5
Owning a mobile phone	No = 0, Yes = 1
Mobile purchasing time	In the past 12 months = 1, 1-2 years ago = 2, 2-4 years ago = 3, 4-7 years ago = 4, More than 7 years ago = 5
When buying the mobile phone, it was the latest version of its brand	No = 0, Yes = 1
Interest in the latest smart technologies	Nothing at all = 1, Somewhat = 2, A great deal = 3

A2. Variable coding of the expert survey in SPSS

Note: A copy of the expert survey questionnaire is available in APPENDIX C (C2).	
Variable and answer options	**Coding (for each answer option)**
Respondent ID	None
Question: The most valuable outcome/s of the adoption of AVs: A = Safe driving, B = Vehicle security, C = Reduction of travel time, D = Reduction of traffic congestion, E = Reduction of fuel consumption and emission	No = 0, Yes = 1
The adoption impact of AVs on some trip characteristics: A = Travel time, B = Traffic congestion, C = Road throughput, D = Fuel consumption and vehicle emissions, E = Road users' safety, F = The number of accidents, G = The severity of accidents	Substantially decrease = 1, No impact = 2, Substantially increase = 3
The most substantial concerns regarding the application of AVs: A = Safety concerns, B = Security concerns, C = Privacy concerns, D = Legal liabilities, E = Traffic issues, F = Fuel consumption and emissions	No = 0, Yes = 1
The most concerning technical issue regarding the application of AVs: A = Sensor failures and system shut down, B = Incorrect understanding of the surrounding objects, C = Getting limited by the factory-defined driving operations, D = Not being as good as human drivers in quick driving reactions	No = 0, Yes = 1
The group or agency which accept the highest liability: A = AV owners, B = Legal authorities, C = AV manufacturers, D = Insurance companies, E = Local traffic control centres	No = 0, Yes = 1
The overall opinion regarding the future use of AVs on public roads: A = The science and industry of the AVs are doing very well. So, I have no concern to adopt AVs., B = I am concerned about safety, security and hacking threats but I'd like to try AVs., C = A lot more investigations and preparation needed before AVs' adoption on public roads., D = I am opposed to AVs ever being allowed on public roads in any condition., E = Others	A = 1, B = 2, C = 3, D = 4, E = 5
Supporting on-demand ridesharing AVs rather than the application of private AVs	Not at all likely = 1, Somewhat likely = 2, Extremely likely = 3
The recommended type of AVs by experts: A = An AV in a dual-mode of driving (manual and autopilot) with manual override control systems., B = An AV without a steering wheel - Fully Autonomous., C = None	A = 1, B = 2, C = 3
Experts' experience in the field	1-3 years = 1, 3-5 years = 2, 5-10 years = 3, 10-20 years = 4, Above 20 years = 5
Main area of expertise: A = Transportation (Engineering/Planning/Modelling/Policy/Economics/etc.)., B = Civil Engineering., C = Electronic Engineering., D = Computer Engineering., E = Mechanical Engineering., F = Behavioural and Social Sciences	A = 1, B = 2, C = 3, D = 4, E = 5, F = 6
Experts' group	Government = 1, Road authority = 2, Academia = 3, Private sector = 4, Other = 5

A3. Speed distribution for TVs

X: Speed (km/h)	Fx: Distribution range
80	0.00
82	0.05
84	0.10
86	0.15
88	0.20
90	0.25
92	0.30
94	0.35
96	0.40
98	0.45
100	0.50
102	0.55
104	0.60
106	0.65
108	0.70
110	0.75
112	0.80
114	0.85
116	0.90
118	0.95
120	1.00

Source: PTV Manual (2017)

A4. Speed distribution for AVs

X: Speed (km/h)	Fx: Distribution range
100	0
100	1

A5. Desired acceleration for TV and AVs

Speed	**TVs**			**AVs**
	Lower bound	Mean	Upper bound	No distribution
0	1.96	3.00	3.50	3.00
10	1.49	2.70	3.50	2.70
20	1.30	2.29	3.50	2.29
30	1.15	1.97	3.50	1.97
40	1.03	1.70	3.50	1.70
50	0.92	1.46	3.27	1.46
60	0.82	1.31	2.92	1.31
70	0.73	1.25	2.59	1.25
80	0.64	1.18	2.29	1.18
90	0.56	1.11	2.00	1.11
100	0.48	1.04	1.73	1.04
110	0.45	0.97	1.61	0.97
120	0.42	0.90	1.50	0.90
130	0.39	0.83	1.38	0.83
140	0.36	0.76	1.27	0.76
150	0.32	0.69	1.15	0.69
160	0.29	0.62	1.04	0.62
170	0.26	0.55	0.92	0.55
180	0.23	0.48	0.81	0.48
190	0.19	0.42	0.69	0.42
200	0.16	0.35	0.58	0.35
210	0.13	0.28	0.46	0.28
220	0.10	0.21	0.35	0.21
230	0.07	0.14	0.23	0.14
240	0.03	0.07	0.12	0.07
250	0.00	0.00	0.00	0.00

Source: PTV Manual (2017)

A6. Maximum acceleration for TV and AVs

Speed	TVs			AVs
	Lower bound	Mean	Upper bound	No distribution
0	1.96	3.50	3.50	3.50
10	1.49	3.20	3.50	3.20
20	1.30	2.79	3.50	2.79
30	1.15	2.47	3.50	2.47
40	1.03	2.20	3.50	2.20
50	0.92	1.96	3.27	1.96
60	0.82	1.75	2.92	1.75
70	0.73	1.55	2.59	1.55
80	0.64	1.37	2.29	1.37
90	0.56	1.20	2.00	1.20
100	0.48	1.04	1.73	1.04
110	0.45	0.97	1.61	0.97
120	0.42	0.90	1.50	0.90
130	0.39	0.83	1.38	0.83
140	0.36	0.76	1.27	0.76
150	0.32	0.69	1.15	0.69
160	0.29	0.62	1.04	0.62
170	0.26	0.55	0.92	0.55
180	0.23	0.48	0.81	0.48
190	0.19	0.42	0.69	0.42
200	0.16	0.35	0.58	0.35
210	0.13	0.28	0.46	0.28
220	0.10	0.21	0.35	0.21
230	0.07	0.14	0.23	0.14
240	0.03	0.07	0.12	0.07
250	0.00	0.00	0.00	0.00

Source: PTV Manual (2017)

A7. Desired deceleration for TVs and AVs

Speed	TVs			AVs
	Lower bound	Mean	Upper bound	Mean
0	-3.00	-2.75	-2.55	-2.75
10	-3.00	-2.75	-2.55	-2.75
20	-3.00	-2.75	-2.55	-2.75
30	-3.00	-2.75	-2.55	-2.75
40	-3.00	-2.75	-2.55	-2.75
50	-3.00	-2.75	-2.55	-2.75
60	-3.00	-2.75	-2.55	-2.75
70	-3.00	-2.75	-2.55	-2.75
80	-3.00	-2.75	-2.55	-2.75
90	-3.00	-2.75	-2.55	-2.75
100	-3.00	-2.75	-2.55	-2.75
110	-3.00	-2.75	-2.55	-2.75
120	-3.00	-2.75	-2.55	-2.75
130	-3.00	-2.75	-2.55	-2.75
140	-3.00	-2.75	-2.55	-2.75
150	-3.00	-2.75	-2.55	-2.75
160	-3.00	-2.75	-2.55	-2.75
170	-3.00	-2.75	-2.55	-2.75
180	-3.00	-2.75	-2.55	-2.75
190	-3.00	-2.75	-2.55	-2.75
200	-3.00	-2.75	-2.55	-2.75
210	-3.00	-2.75	-2.55	-2.75
220	-3.00	-2.75	-2.55	-2.75
230	-3.00	-2.75	-2.55	-2.75
240	-3.00	-2.75	-2.55	-2.75
250	-3.00	-2.75	-2.55	-2.75

Source: PTV Manual (2017)

A8. Maximum deceleration for TVs and AVs

Speed	TVs			AVs
	Lower bound	Mean	Upper bound	No distribution
0	-8.50	-7.50	-6.50	-7.50
10	-8.40	-7.40	-6.40	-7.40
20	-8.30	-7.30	-6.30	-7.30
30	-8.20	-7.20	-6.20	-7.20
40	-8.10	-7.10	-6.10	-7.10
50	-8.00	-7.00	-6.00	-7.00
60	-7.90	-6.90	-5.90	-6.90
70	-7.80	-6.80	-5.80	-6.80
80	-7.70	-6.70	-5.70	-6.70
90	-7.60	-6.60	-5.60	-6.60
100	-7.50	-6.50	-5.50	-6.50
110	-7.40	-6.40	-5.40	-6.40
120	-7.30	-6.30	-5.30	-6.30
130	-7.20	-6.20	-5.20	-6.20
140	-7.10	-6.10	-5.10	-6.10
150	-7.00	-6.00	-5.00	-6.00
160	-6.90	-5.90	-4.90	-5.90
170	-6.80	-5.80	-4.80	-5.80
180	-6.70	-5.70	-4.70	-5.70
190	-6.60	-5.60	-4.60	-5.60
200	-6.50	-5.50	-4.50	-5.50
210	-6.40	-5.40	-4.40	-5.40
220	-6.30	-5.30	-4.30	-5.30
230	-6.20	-5.20	-4.20	-5.20
240	-6.10	-5.10	-4.10	-5.10
250	-6.00	-5.00	-4.00	-5.00

Source: PTV Manual (2017)

A9. Breakdown of the monthly traffic data (Sep. 2017) for node 1 (TII, 2017)

Site Name: TMU N81 000.0 N Site ID: 000000001812 Grid: 310397227589 Description: N81 Between Tallaght Village and M50, Tallaght, Co. Dublin

Setup: N81 1812 ▾ | Channel: All Eastbound ▾ | Time Period: 1 hour ▾ | Class: Any ▾ | Precision: Normal ▾ | Exclude data: None ▾

	Fri 1 Sep	Sat 2 Sep	Sun 3 Sep	Mon 4 Sep	Tue 5 Sep	Wed 6 Sep	Thu 7 Sep	Fri 8 Sep	Sat 9 Sep	Sun 10 Sep	Mon 11 Sep	Tue 12 Sep	Wed 13 Sep	Thu 14 Sep	Fri 15 Sep	Sat 16 Sep	Sun 17 Sep	Mon 18 Sep	Tue 19 Sep	Wed 20 Sep	Thu 21 Sep
00:00	92	142	155	100	89	100	67	100	152	192	78	89	78	103	103	144	166	142	85	79	88
01:00	76	116	129	78	40	65	68	72	126	144	47	49	59	67	79	132	142	84	74	70	65
02:00	54	89	108	48	35	45	39	59	102	129	31	42	33	42	49	94	129	57	46	45	42
03:00	53	100	112	53	45	41	39	58	86	121	47	34	36	44	52	84	112	57	46	49	57
04:00	66	96	97	79	58	58	61	81	93	116	62	56	69	59	71	90	111	71	79	57	72
05:00	167	89	76	163	156	155	166	165	102	66	158	152	154	164	149	98	92	173	190	153	166
06:00	565	210	109	575	605	613	654	610	240	129	636	612	654	641	609	230	112	591	725	614	683
07:00	1299	392	180	1310	1378	1425	1373	1367	387	210	1359	1366	1410	1380	1375	398	198	1343	1450	1429	1450
08:00	1292	519	217	1254	1381	1295	1210	1215	537	240	1302	1306	1312	1347	1342	571	227	1295	1399	1310	1308
09:00	1062	673	359	924	1021	994	941	956	672	388	1018	1024	1032	1003	1084	678	370	997	1129	950	1038
10:00	885	777	499	843	900	865	841	878	764	512	822	959	919	869	886	745	512	855	942	854	857
11:00	1014	951	731	819	954	976	1022	933	957	674	903	935	986	968	939	927	669	884	942	942	944
12:00	1140	1032	839	1017	1011	1057	1056	1140	1027	800	935	1035	1130	1027	1153	1084	840	976	997	1007	1050
13:00	1176	1061	927	1043	1094	1157	1116	1186	1103	1031	1044	1058	1043	1175	1164	1096	871	1109	1055	1152	1097
14:00	1183	1069	1003	1181	1089	1073	1086	1258	993	1034	996	1017	1081	1107	1164	1055	944	945	1020	1148	1094
15:00	1286	944	889	1205	1183	1187	1248	1284	1054	1005	1202	1236	1185	1260	1353	1022	743	1175	1243	1126	1255
16:00	1317	1028	768	1401	1442	1455	1430	1402	1123	893	1367	1323	1376	1391	1309	1114	606	1391	1384	1408	1404
17:00	1152	877	721	1385	1537	1409	1382	1272	970	843	1382	1419	1397	1419	1255	1304	628	1370	1490	1457	1489
18:00	957	694	676	957	1063	1063	1059	954	779	696	1024	1043	1089	1082	976	869	666	1017	948	1097	1174
19:00	748	571	482	712	681	753	752	791	565	587	709	693	800	798	784	595	537	718	750	796	839
20:00	631	439	438	542	536	656	672	666	460	450	566	587	640	725	638	462	432	512	578	708	681
21:00	591	339	297	405	364	424	512	620	334	274	460	443	482	545	409	330	320	444	510	514	559
22:00	510	248	225	260	253	274	341	394	276	223	261	294	297	307	306	263	231	274	284	295	326
23:00	235	207	138	131	160	166	208	212	205	141	157	165	204	233	234	221	175	145	155	187	223
07-19	13763	10017	7809	13339	14053	13956	13764	13845	10366	8326	13354	13721	13960	14028	14000	10863	7274	13357	13999	13880	14160
06-22	16298	11576	9135	15573	16239	16402	16354	16532	11965	9766	15725	16056	16536	16737	16440	12480	8675	15622	16562	16512	16922
06-24	17043	12031	9498	15964	16652	16842	16903	17138	12446	10130	16143	16515	17037	17277	16980	12964	9081	16041	17001	16994	17471
00-24	17551	12663	10175	16485	17075	17306	17343	17673	13107	10898	16566	16937	17466	17756	17483	13606	9833	16625	17521	17447	17961
am Peak	07:00	11:00	11:00	07:00	08:00	07:00	07:00	07:00	11:00	11:00	07:00	07:00	07:00	07:00	07:00	11:00	11:00	07:00	07:00	07:00	07:00
Peak Volume	1299	951	731	1310	1381	1425	1373	1367	957	674	1359	1366	1410	1380	1375	927	669	1343	1450	1429	1450
pm Peak	16:00	14:00	14:00	16:00	17:00	16:00	16:00	16:00	16:00	14:00	17:00	17:00	17:00	17:00	15:00	17:00	14:00	16:00	17:00	17:00	17:00
Peak Volume	1317	1069	1003	1401	1537	1455	1430	1402	1123	1034	1382	1419	1397	1419	1353	1304	944	1391	1490	1457	1489

A10. Top 10 peak, normal and off-peak traffic conditions in February

Traffic condition	Day	Traffic volume (veh/h)							
		Origin	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Total
Peak	AM-1st	1,439	720	2,443	2,401	1,858	1,212	217	10,289
	AM–3rd	1,359	680	2,483	2,535	1,882	1,115	228	10,281
	AM–7th	1,460	730	2,368	2,475	1,808	1,235	221	10,296
	AM–9th	1,475	738	2,458	2,558	1,849	1,250	226	10,552
	AM–14th	1,531	766	2,388	2,456	1,876	1,231	224	10,471
	AM–15th	1,477	739	2,406	2,531	1,799	1,258	235	10,444
	AM–16th	1,459	730	2,453	2,538	1,919	1,196	239	10,532
	AM–17th	1,389	695	2,383	2,515	1,866	1,146	244	10,237
	AM–21st	1,329	665	2,423	2,453	1,884	1,177	222	10,151
	AM–27th	1,401	701	2,441	2,486	1,859	1,191	233	10,311
Normal	PM-1st	2,320	727	2,109	1,666	1,613	844	435	9,713
	PM-14th	2,333	762	2,159	1,641	1,622	874	419	9,808
	PM-15th	2,301	753	2,094	1,670	1,650	909	432	9,809
	PM-17th	2,628	680	2,091	1,757	1,534	740	404	9,832
	PM-20th	2,386	694	2,128	1,618	1,628	861	432	9,745
	PM-21st	2,422	709	2,143	1,682	1,628	874	397	9,854
	PM-22nd	2,517	786	1,910	1,717	1,555	886	406	9,776
	PM-23rd	2,524	707	2,127	1,711	1,566	855	417	9,907
	PM-24th	2,851	672	2,073	1,688	1,524	768	423	9,997
	PM-28th	2,277	760	2,128	1,614	1,601	864	419	9,662
Off-peak	AM-4th	2,515	449	1,474	1,354	1,213	536	199	7,740
	PM-4th	3,067	561	1,575	1,659	1,355	570	268	9,054
	AM-5th	2,177	318	1,152	1,278	989	375	143	6,431
	AM-11th	2,670	448	1,454	1,468	1,175	480	218	7,911
	AM-12th	2,289	288	1,220	1,328	954	357	164	6,600
	PM-12th	3,228	451	1,557	1,722	1,385	491	269	9,102
	AM-18th	2,657	433	1,461	1,613	1,214	531	228	8,136
	AM-19th	2,372	340	1,290	1,382	1,016	371	167	6,937
	AM-25th	2,624	433	1,606	1,595	1,224	493	211	8,184
	AM-26th	2,302	318	1,129	1,293	1,006	392	195	6,632

A11. Top 10 peak, normal and off-peak traffic conditions in May

Traffic condition	Day	Traffic volume (veh/h)							
		Origin	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Total
Peak	AM-04th	5,154	700	2,547	2,580	1,973	1,229	237	14,420
	AM-09th	5,045	700	2,578	2,583	1,962	1,271	248	14,386
	AM-10th	5,077	718	2,355	2,506	1,941	1,276	262	14,135
	AM-11th	5,014	702	2,471	2,628	1,935	1,251	258	14,258
	AM-16th	4,973	700	2,618	2,384	1,996	1,256	254	14,180
	AM-17th	5,174	709	2,477	2,643	2,003	1,250	261	14,516
	AM-24th	4,993	706	2,539	2,562	2,004	1,213	257	14,272
	AM-25th	4,894	698	2,469	2,610	1,935	1,199	268	14,072
	AM-30th	5,076	676	2,456	2,527	1,933	1,226	258	14,151
	AM-31st	5,257	682	2,470	2,598	1,980	1,206	260	14,452
Normal	PM-02nd	2,403	745	2,135	1,703	1,720	935	463	10,103
	PM-03rd	2,508	760	2,211	1,711	1,677	938	438	10,241
	PM-09th	2,504	728	2,190	1,736	1,708	938	410	10,213
	PM-11th	2,649	725	2,116	1,739	1,700	907	430	10,264
	PM-15th	2,334	731	2,185	1,683	1,698	899	477	10,005
	PM-16th	2,352	735	2,205	1,698	1,674	974	431	10,068
	PM-18th	2,464	705	2,163	1,751	1,696	927	422	10,127
	PM-23rd	2,461	715	2,194	1,723	1,701	924	445	10,162
	PM-25th	2,615	721	2,152	1,733	1,641	889	453	10,203
	PM-30th	2,427	733	2,203	1,757	1,692	920	446	10,177
Off-peak	AM-01st	2,370	293	1,179	1,358	985	383	167	6,735
	AM-06th	2,597	480	1,480	1,607	1,176	512	221	8,071
	PM-06th	3,089	542	1,730	1,736	1,411	539	274	9,319
	AM-07th	2,420	387	1,459	1,638	1,250	459	178	7,790
	AM-13th	2,635	481	1,522	1,638	1,247	538	230	8,290
	AM-14th	2,502	345	1,214	1,430	1,065	386	179	7,120
	AM-20th	2,788	511	1,614	1,749	1,176	528	237	8,603
	AM-21st	2,615	319	1,352	1,534	1,107	447	195	7,567
	AM-27th	2,825	448	1,627	1,622	1,227	449	239	8,437
	AM-28th	2,491	354	1,306	1,440	1,171	547	177	7,485

A12. Top 10 peak, normal and off-peak traffic conditions in September

Traffic condition	Day	Traffic volume (veh/h)							
		Origin	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Total
Peak	AM-4th	4,942	655	2,414	2,642	1,875	1,198	270	13,996
	AM-7th	4,576	687	2,451	2,758	1,961	1,273	274	13,978
	AM-8th	4,888	684	2,442	2,578	1,946	1,219	258	14,014
	AM-11th	4,827	680	2,384	2,619	1,862	1,228	275	13,873
	AM-12th	4,950	683	2,393	2,484	1,932	1,308	260	14,008
	AM-13th	5,101	705	2,265	2,586	1,824	1,292	276	14,048
	AM-14th	5,050	690	2,334	2,582	1,939	1,289	274	14,157
	AM-19th	5,022	725	2,194	2,561	1,892	1,297	270	13,960
	AM-20th	4,978	715	2,386	2,735	1,940	1,295	240	14,288
	AM-21st	4,833	725	2,393	2,665	1,884	1,264	300	14,063
Normal	AM-7th	2,469	715	2,152	1,762	1,596	851	458	10,002
	AM-10th	3,540	517	2,048	1,921	1,455	520	281	10,280
	AM-13th	2,377	699	2,140	1,737	1,562	917	446	9,876
	AM-14th	2,401	710	2,220	1,726	1,433	936	441	9,866
	AM-19th	2,409	745	2,126	1,825	1,615	872	420	10,011
	AM-20th	2,421	729	1,935	1,827	1,607	852	403	9,774
	AM-21st	2,470	745	1,993	1,937	1,559	868	432	10,002
	AM-22nd	2,689	673	2,100	1,763	1,513	734	423	9,893
	AM-25th	2,459	708	2,046	1,619	1,585	875	432	9,722
	AM-26th	2,303	740	2,168	1,737	1,589	879	395	9,810
Off-peak	AM-2nd	2,751	476	1,640	1,775	1,298	520	240	8,699
	AM-3rd	2,988	366	2,035	2,044	1,203	415	211	9,260
	AM-9th	2,762	479	1,682	1,748	1,278	494	291	8,732
	AM-10th	2,770	337	1,438	1,553	1,102	412	211	7,823
	AM-16th	2,781	464	1,571	1,732	1,264	542	281	8,634
	AM-17th	2,720	335	1,705	2,123	1,315	461	243	8,902
	AM-23rd	2,917	346	1,575	1,695	1,289	510	276	8,608
	AM-24th	2,585	316	1,359	1,520	1,134	398	197	7,507
	AM-30th	2,862	490	1,576	1,649	1,299	545	248	8,667
	PM-23rd	2,937	374	1,752	1,895	1,451	560	312	9,280

A13. 63 scenarios for the optimisation of CC0, CC1 and CC2

Scenario	**Change**	**CC0**	**CC1**	**CC2**	**CC3**	**CC4**	**CC5**	**CC6**	**CC7**	**CC8**	**CC9**
W99	**No change**	**1.5**	**0.9**	**4**	**-8**	**-0.35**	**0.35**	**11.44**	**0.25**	**3.5**	**1.5**
1	CC0-25%	1.13	0.9	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
2	CC0-50%	0.75	0.9	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
3	CC0-75%	0.38	0.9	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
4	CC1-25%	1.13	0.68	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
5	CC1-50%	1.13	0.45	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
6	CC1-75%	1.13	0.23	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
7	CC2-25%	1.5	0.9	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
8	CC2-50%	1.5	0.9	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
9	CC2-75%	1.5	0.9	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
10	CC0-25% CC1-25%	1.13	0.68	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
11	CC0-25% CC1-50%	1.13	0.45	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
12	CC0-25% CC1-75%	1.13	0.23	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
13	CC0-25% CC2-25%	1.13	0.9	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
14	CC0-25% CC2-50%	1.13	0.9	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
15	CC0-25% CC2-75%	1.13	0.9	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
16	CC0-50% CC1-25%	0.75	0.68	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
17	CC0-50% CC1-50%	0.75	0.45	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
18	CC0-50% CC1-75%	0.75	0.23	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
19	CC0-50% CC2-25%	0.75	0.9	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
20	CC0-50% CC2-50%	0.75	0.9	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
21	CC0-50% CC2-75%	0.75	0.9	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
22	CC0-75% CC1-25%	0.38	0.25	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
23	CC0-75% CC1-50%	0.38	0.45	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
24	CC0-75% CC1-75%	0.38	0.23	4	-8	-0.35	0.35	11.44	0.25	3.5	1.5
25	CC0-75% CC2-25%	0.38	0.9	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
26	CC0-75% CC2-50%	0.38	0.9	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
27	CC0-75% CC2-75%	0.38	0.9	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
28	CC1-25% CC2-25%	1.5	0.68	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
29	CC1-25% CC2-50%	1.5	0.68	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
30	CC1-25% CC2-75%	1.5	0.68	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
31	CC1-50% CC2-25%	1.5	0.45	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5

32	CC1-50% CC2-50%	1.5	0.45	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
33	CC1-50% CC2-75%	1.5	0.45	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
34	CC1-75% CC2-25%	1.5	0.23	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
35	CC1-75% CC2-50%	1.5	0.23	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
36	CC1-75% CC2-75%	1.5	0.23	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
37	CC0-25% CC1-25% CC2-25%	1.13	0.68	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
38	CC0-25% CC1-25% CC2-50%	1.13	0.68	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
39	CC0-25% CC1-25% CC2-75%	1.13	0.68	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
40	CC0-25% CC1-50% CC2-25%	1.13	0.45	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
41	CC0-25% CC1-50% CC2-50%	1.13	0.45	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
42	CC0-25% CC1-50% CC2-75%	1.13	0.45	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
43	CC0-25% CC1-75% CC2-25%	1.13	0.23	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
44	CC0-25% CC1-75% CC2-50%	1.13	0.23	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
45	CC0-25% CC1-75% CC2-75%	1.13	0.23	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
46	CC0-50% CC1-25% CC2-25%	0.75	0.68	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
47	CC0-50% CC1-25% CC2-50%	0.75	0.68	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
48	CC0-50% CC1-25% CC2-75%	0.75	0.68	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
49	CC0-50% CC1-50% CC2-25%	0.75	0.45	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
50	CC0-50% CC1-50% CC2-50%	0.75	0.45	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
51	CC0-50% CC1-50% CC2-75%	0.75	0.45	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
52	CC0-50% CC1-75% CC2-25%	0.75	0.23	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5

53	CC0-50% CC1-75% CC2-50%	0.75	0.23	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
54	CC0-50% CC1-75% CC2-75%	0.75	0.23	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
55	CC0-75% CC1-25% CC2-25%	0.38	0.68	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
56	CC0-75% CC1-25% CC2-50%	0.38	0.68	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
57	CC0-75% CC1-25% CC2-75%	0.38	0.68	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
58	CC0-75% CC1-50% CC2-25%	0.38	0.45	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
59	CC0-75% CC1-50% CC2-50%	0.38	0.45	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
60	CC0-75% CC1-50% CC2-75%	0.38	0.45	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5
61	CC0-75% CC1-75% CC2-25%	0.38	0.23	3	-8	-0.35	0.35	11.44	0.25	3.5	1.5
62	CC0-75% CC1-75% CC2-50%	0.38	0.23	2	-8	-0.35	0.35	11.44	0.25	3.5	1.5
63	CC0-75% CC1-75% CC2-75%	0.38	0.23	1	-8	-0.35	0.35	11.44	0.25	3.5	1.5

APPENDIX B: Public Survey Questionnaire and Result Tables

B1. Generic Email Invitation Sent by Delve Research

Subject line: Take our new €250 prize draw survey
Dear Panellist, We would like to invite you to take our new survey which should take about 10 minutes to complete. After taking part you will have a chance to enter a draw for **3 cash prizes - first prize of €150 and 2 prizes of €50 each**. **Click here to take part in this survey** There will be **3 winners of prizes - the top prize is €150 plus two €50 prizes** Your unique draw entry code is Refid* (you will be asked to enter this at the end of the survey). This is a very important academic survey concerning **self-driving vehicles**, your participation will be greatly appreciated. The survey will close at midnight on Friday, February 1st, or when we have reached our target number of responses. Thank you, *If you experience problems opening the link, please copy and paste the following into your browser address bar: https://www.surveymonkey.com/r/AVs_Public* *You are receiving this email because you are a member of the Ask Me... Pay Me! survey panel. If you would not like to receive any further communication about this, please reply to this email with "unsubscribe" in the subject line and we will remove your details from the panel.*

* "Refid" was populated with a unique draw entry code for each panellist to administer the prize draw.

B2. Reminder Email Sent by Delve Research

Subject line: Reminder - Our new €250 prize draw survey ends soon
Dear Panellist, You can still take our €250 prize draw survey which is closing this Friday. After taking part you will have a chance to enter a draw for **3 cash prizes - first prize of €150 and 2 prizes of €50 each**. **Click here to take part in this survey** It should take about 10 minutes to complete. There will be **3 winners of prizes - the top prize is €150 plus two €50 prizes** Your unique draw entry code is Refid* (you will be asked to enter this at the end of the survey). This is a very important academic survey concerning **self-driving vehicles**, your participation will be greatly appreciated. The survey will close at midnight on Friday, February 1st, or when we have reached our target number of responses. Thank you, *If you experience problems opening the link, please copy and paste the following into your browser address bar: https://www.surveymonkey.com/r/AVs_Public* *You are receiving this email because you are a member of the Ask Me... Pay Me! survey panel. If you would not like to receive any further communication about this, please reply to this email with "unsubscribe" in the subject line and we will remove your details from the panel.*

* "Refid" was populated with a unique draw entry code for each panellist to administer the prize draw.

B3. Public Survey Questionnaire

Introduction

Dear Participant,

Thank you for participating in this survey. Your feedback is important. This survey forms part of a PhD study at Trinity College Dublin.

Introduction: An Autonomous Vehicle which is also known as the self-driving car, or driverless car is a vehicle that can guide itself without human conduction. Autonomous Vehicles combine a variety of sensors to perceive their surroundings and interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signage.

Aim: We're conducting research on User Acceptance of Autonomous Vehicles in highway transport.

Survey length: This survey should take no longer than 13 minutes to complete!

Survey Prize: At the end of the survey, you will be able to enter a draw for a chance to win prizes with a total value of

€250.

Confidentiality: The survey is completely anonymous, and the results can only be accessed and disseminated by the scientific researcher of the study, Mr Amin Rezaei. All data collected from this survey will be used for scientific research purposes only.

Withdrawal: Your participation is completely voluntary, and a participant can drop out of the study at any time, however as the data is anonymous this cannot be withdrawn. If you have any questions about this research or the management of the research data, please email rezaeim@tcd.ie.

Consent: Clicking on the "Next" button below indicates that you have read the information provided on this page and you voluntarily agree to participate. If you DO NOT wish to participate in the research study, please decline participation by clicking on the "Exit" button on the top right corner of this page to quit the survey.

Amin Rezaei
PhD Candidate, Civil Engineering - Transportation Engineering
Department of Civil, Structural & Environmental Engineering
Trinity College Dublin, the University of Dublin
Dublin, Ireland
Email: rezaeim@tcd.ie

Questions

1. How much have you heard about Autonomous Vehicles?

   ◯ Nothing at all ◯ Somewhat ◯ A great deal

2. On a scale from 1-5, how interested are you in driving an Autonomous Vehicle?

   ◯ Not interested ◯ Neither ◯ Very interested

3. Since Autonomous Vehicles could perform all driving operations, the owners/drivers could be able to spend their time doing some activities. So, if you have had an Autonomous Vehicle, how would you prefer to spend your time in the vehicle? (Please select the options with **the highest preferences**)

   ☐ Sleeping/resting and reading

   ☐ Enjoying the scenery

   ☐ Any social activities (TV, games, internet)

   ☐ Working

   ☐ Other (please specify)

4. How likely would you be to own an Autonomous Vehicle if you have been told that Autonomous Vehicles could only operate in some limited areas in the city and not everywhere around the country?

   ◯ Not at all likely ◯ Somewhat likely ◯ Extremely likely

5. How much do you think Autonomous Vehicles will be safer and more secure than human drivers?

   ◯ Not at all ◯ Somewhat ◯ Extremely

6. If you were to own an Autonomous Vehicle, how safe and secure would you feel if the Autonomous Vehicle had no steering wheel at all?

   ◯ Not at all ◯ Somewhat ◯ Extremely

7. How likely do you think an Autonomous Vehicle with a manual override control system would be more secure than an Autonomous Vehicle without such a system?

   ◯ Not at all ◯ Somewhat ◯ Extremely

8. If you were the passenger of an Autonomous Vehicle, how would you feel about the vehicle's safe and quick driving reactions in case of an unexpected driving incident?

◯ Not at all concerned ◯ Somewhat concerned ◯ Extremely concerned

9. Imagine you are a passenger of a Traditional vehicle and you see some pedestrians which might want to cross the road. How much would you be concerned in the following conditions?

	Not at all concerned	Somewhat concerned	Extremely concerned
You are travelling at night	◯	◯	◯
The road condition is slippery	◯	◯	◯
The vehicle is moving at the speed limit	◯	◯	◯

10. Now, imagine you are a passenger of an Autonomous Vehicle, and you see some pedestrians who might want to cross the road. How much would you be concerned in the following conditions?

	Not at all concerned	Somewhat concerned	Extremely concerned
You are travelling at night	◯	◯	◯
The road condition is slippery	◯	◯	◯
The vehicle is moving at the speed limit	◯	◯	◯

11. Did you know that Autonomous Vehicles will record travel data such as departure and arrival times, locations, trip routes, etc.?

◯ Yes ◯ No

12. How much would you be concerned about the privacy of your travel data such as departure and arrival times, locations, trip routes, etc.?

◯ Not at all concerned ◯ Somewhat concerned ◯ Extremely concerned

13. How much do you agree that Autonomous Vehicles should record travel data?

- ◯ Disagree
- ◯ Undecided
- ◯ Agree

14. If recording your data by Autonomous Vehicles was mandatory for vehicle navigation, with whom would you prefer to share those data? (Please select the options with **the highest preferences**)

- ☐ Car manufacturers
- ☐ Local/national transport authorities
- ☐ Local/national transport consultant companies
- ☐ Insurance companies
- ☐ Other (please specify)

15. How much would you be willing to accept liability in case of an accident if you were the owner/passenger of an Autonomous Vehicle?

- ◯ Nothing at all
- ◯ Somewhat
- ◯ A great deal

16. Since Autonomous Vehicles move with little or no human involvements, who do you think should accept **the highest liability** of the Autonomous Vehicle in case of an accident?

- ☐ National transport authorities
- ☐ Local traffic control centres
- ☐ Autonomous Vehicle manufacturers
- ☐ Insurance companies
- ☐ Autonomous Vehicle owners
- ☐ Other (please specify)

17. If you are interested in driving an Autonomous Vehicle, what would be the most interesting aspects of the vehicle which makes you buy them? (Please select the options with **the highest importance**)

- ☐ Safe driving
- ☐ Auto guidance and navigation for not being worried about finding directions
- ☐ Being fun and enjoying your free time when not driving
- ☐ Reduction of traffic congestion, queue, and delay
- ☐ Reduction of Vehicle Emissions and Fuel consumption
- ☐ Other (please specify)

18. How likely are you to purchase an Autonomous Vehicle once the technology is fully developed and tested?

◯ Not at all likely ◯ Somewhat likely ◯ Extremely likely

19. Since there is no previous experience of using Autonomous Vehicles and their practical impacts on people's lives, some users might prefer to wait and see Autonomous Vehicles' efficiency based on the early adopters' opinion about it. So, if you were going to purchase an Autonomous Vehicle, how likely would you be to wait to see the early adopters' opinion?

◯ Not at all likely ◯ Somewhat likely ◯ Extremely likely

20. If you were going to purchase an Autonomous Vehicle, how much would you be willing to pay in addition to the cost of the same vehicle in Traditional mode?

◯ Below 10% ◯ 10% - 20% ◯ Above 20%

21. How likely are you to purchase an Autonomous Vehicle if the cost was not an issue?

◯ Not at all likely ◯ Somewhat likely ◯ Extremely likely

22. On a scale from 1-5, how likely do you think an on-demand ridesharing service like Uber, Lyft, and Hailo provided via Autonomous Vehicles would be more efficient for you rather than owning an Autonomous Vehicle?

◯ Not at all likely ◯ Somewhat likely ◯ Extremely likely

23. If an on-demand ridesharing service like Uber, Lyft, and Hailo had been provided to you via Autonomous Vehicles, would you still purchase an Autonomous Vehicle?

◯ Yes ◯ No

24. What is your gender?

- ◯ Male
- ◯ Female
- ◯ Other

25. What is your age?

- ◯ 18 - 25 years old
- ◯ 26 - 35 years old
- ◯ 36 - 50 years old
- ◯ 50+ years old

26. Where is your county of residence?

[ ]

27. Do you possess a driving license?

- ◯ Yes
- ◯ No

28. Do you have a car?

- ◯ Yes
- ◯ No

29. How many cars do you have?

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5+

30. How old is your car?

- ◯ 0 - 2 years old
- ◯ 2 - 5 years old
- ◯ 5 - 7 years old
- ◯ 7 - 10 years old
- ◯ Above 10 years old

31. Do you own a mobile phone?

- ◯ Yes
- ◯ No

32. When did you buy your mobile phone?

- ◯ In the past 12 months
- ◯ 1 - 2 years ago
- ◯ 2 - 4 years ago
- ◯ 4 - 7 years ago
- ◯ More than 7 years ago

33. When you were buying your mobile phone, was it the latest version of its brand available in the market?

◯ Yes ◯ No

34. How much do you like the latest smart technologies?

◯ Nothing at all ◯ Somewhat ◯ A great deal

35. Do you have any other comments, questions, or concerns regarding the application of Autonomous Vehicles or this survey?

[ ]

36. If you'd like to be notified about the result of this survey, please provide an email address below. The information provided here will only be used to notify you of the results of the survey.

Email Address [ ]

B4. Breakdown of the responses regarding the initial perception of AVs – previous knowledge about AVs

		Heard about AV							
		Nothing at all		**Somewhat**		**A great deal**		**Total**	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	156	72.2	67	46.2	31	30.4	254	54.9
	Male	60	27.8	78	53.8	71	69.6	209	45.1
	Total	216	100.0	145	100.0	102	100.0	463	100.0
Age	18-35	4	1.9	3	2.1	2	1.9	9	1.9
	26-35	44	20.5	23	15.9	20	19.2	87	18.8
	36-50	95	44.2	67	46.2	41	39.4	203	43.8
	50+	72	33.5	52	35.9	41	39.4	165	35.6
	Total	215	100.0	145	100.0	104	100.0	464	100.0
	SD*	34	15.8	25	17.2	16	15.7	75	16.1
Car Ownership	Yes	166	77.6	166	77.6	166	77.6	166	77.6
	No	48	22.4	48	22.4	48	22.4	48	22.4
	Total	214	100.0	214	100.0	214	100.0	214	100.0
	SD*	59	27.6	59	27.6	59	27.6	59	27.6
Overall Results	**All**	**216**	**46.4**	**145**	**31.3**	**105**	**22.5**	**466**	**100**

* Standard deviation

B5. Breakdown of the responses regarding the initial perception of AVs – interest in driving AVs

		Interest in driving AVs							
		Not interested		**Neither**		**Very interested**		**Total**	
		N	%	N	%	N	%	N	%
Gender	Female	107	57.5	87	63.0	53	41.4	247	54.6
	Male	79	42.5	51	37.0	75	58.6	205	45.4
	Total	186	100.0	138	100.0	128	100.0	452	100.0
Age	18-35	4	2.1	2	1.5	2	1.6	8	1.8
	26-35	30	16.0	23	16.8	31	24.2	84	18.6
	36-50	86	46.0	62	45.3	54	42.2	202	44.7
	50+	67	35.8	50	36.5	41	32.0	158	35.0
	Total	187	100.0	137	100.0	128	100.0	452	100.0
	SD*	32	17.0	23	17.1	19	15.0	74	16.3
Car Ownership	Yes	152	82.2	110	80.3	102	79.7	364	80.9
	No	33	17.8	27	19.7	26	20.3	86	19.1
	Total	185	100.0	137	100.0	128	100.0	450	100.0
	SD*	60	32.2	42	30.3	38	29.7	139	30.9
Overall Results	**All**	**187**	**41.2**	**138**	**30.4**	**129**	**28.4**	**454**	**100**

* Standard deviation

B6. Breakdown of the responses regarding preference for spending time in AVs for participants' gender, age, and car ownership

	Gender				Age								Car ownership			
	Male		Female		18-25		26-35		36-50		50+		Yes		No	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Sleeping/ resting, reading																
Yes	60	28.6	87	33.2	7	77.8	29	33.3	77	37.2	35	20.6	114	29.8	34	38.2
No	150	71.4	175	66.8	2	22.2	58	66.7	130	62.8	135	79.4	268	70.2	55	61.8
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	45	21.4	44	16.8	2.5	27.8	14.5	16.7	26.5	12.8	50	29.4	77	20.2	10.5	11.8
Enjoying the scenery																
Yes	134	63.8	202	77.1	7	77.8	66	75.9	138	66.7	127	74.7	261	68.3	75	84.3
No	76	36.2	60	22.9	2	22.2	21	24.1	69	33.3	43	25.3	121	31.7	14	15.7
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	29	13.8	71	27.1	2.5	27.8	22.5	25.9	34.5	16.7	42	24.7	70	18.3	30.5	34.3
Any social activities (TV, games, internet)																
Yes	62	29.5	69	26.3	4	44.4	31	35.6	69	33.3	29	17.1	51	13.4	16	18.0
No	148	70.5	193	73.7	5	55.6	56	64.4	138	66.7	141	82.9	331	86.6	73	82.0
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	43	20.5	62	23.7	0.5	5.6	12.5	14.4	34.5	16.7	56	32.9	140	36.6	28.5	32.0
Working																
Yes	34	68.0	32	12.2	4	44.4	20	23.0	31	15.0	11	6.5	51	13.4	16	18.0
No	16	32.0	230	87.8	5	55.6	67	77.0	176	85.0	159	93.5	331	86.6	73	82.0
Total	50	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	9	18.0	99	37.8	0.5	5.6	23.5	27.0	72.5	35.0	74	43.5	140	36.6	28.5	32.0
Other answers																
Yes	25	11.9	23	8.8	0	0.0	5	5.7	20	9.7	23	13.5	40	10.5	7	7.9
No	185	88.1	239	91.2	9	100.0	82	94.3	187	90.3	147	86.5	342	89.5	82	92.1
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	80	38.1	108	41.2	4.5	50.0	38.5	44.3	83.5	40.3	62	36.5	151	39.5	37.5	42.1

* Standard deviation

B7. Breakdown of the responses about whether AVs would be safer and more secure than human drivers

		Not at all		Somewhat		Extremely		Total	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	127	62.6	78	54.2	51	44.0	256	55.3
	Male	76	37.4	66	45.8	65	56.0	207	44.7
	Total	203	100.0	144	100.0	116	100.0	463	100.0
Age	18-25	4	2.0	2	1.4	3	2.6	9	1.9
	26-35	36	17.7	26	17.9	24	20.7	86	18.5
	36-50	93	45.8	63	43.4	50	43.1	206	44.4
	50+	70	34.5	54	37.2	39	33.6	163	35.1
	Total	203	100.0	145	100.0	116	100.0	464	100.0
	SD*	34	16.6	24	16.6	18	15.2	75	16.2
Car Ownership	Yes	174	86.1	110	75.9	90	78.3	374	81.0
	No	28	13.9	35	24.1	25	21.7	88	19.0
	Total	202	100.0	145	100.0	115	100.0	462	100.0
	SD*	73	36.1	38	25.9	33	28.3	143	31.0
Overall Results	**All**	**205**	**44.0%**	**145**	**31.1%**	**116**	**24.9%**	**466**	**100%**

* Standard deviation

B8. Breakdown of the responses regarding Feeling safe and secure if AVs had no steering wheel

		Not at all		Somewhat		Extremely		Total	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	187	61.1	45	48.9	25	37.9	257	55.4
	Male	119	38.9	47	51.1	41	62.1	207	44.6
	Total	306	100.0	92	100.0	66	100.0	464	100.0
Age	18-25	4	1.3	4	4.3	1	1.5	9	1.9
	26-35	48	15.7	21	22.6	17	25.8	86	18.5
	36-50	139	45.4	37	39.8	29	43.9	205	44.1
	50+	115	37.6	31	33.3	19	28.8	165	35.5
	Total	306	100.0	93	100.0	66	100.0	465	100.0
	SD*	54	17.5	12	13.4	10	15.2	75	16.2
Car Ownership	Yes	253	83.2	72	77.4	50	75.8	375	81.0
	No	51	16.8	21	22.6	16	24.2	88	19.0
	Total	304	100.0	93	100.0	66	100.0	463	100.0
	SD*	101	33.2	26	27.4	17	25.8	144	31.0
Overall Results	**All**	**308**	**66.0**	**93**	**19.9**	**66**	**14.1**	**467**	**100**

* Standard deviation

B9. Breakdown of the responses about whether AVs with a manual override control system would be safer and more secure than an AV without such a system or not

		Not at all		Somewhat		Extremely		Total	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	56	67.5	61	55.5	141	52.2	258	55.7
	Male	27	32.5	49	44.5	129	47.8	205	44.3
	Total	83	100.0	110	100.0	270	100.0	463	100.0
Age	18-25	2	2.4	3	2.8	4	1.5	9	1.9
	26-35	16	19.3	22	20.2	48	17.6	86	18.5
	36-50	40	48.2	48	44.0	116	42.6	204	44.0
	50+	25	30.1	36	33.0	104	38.2	165	35.6
	Total	83	100.0	109	100.0	272	100.0	464	100.0
	SD*	14	16.6	17	15.4	45	16.5	75	16.2
Car Ownership	Yes	60	73.2	84	77.1	229	84.5	373	80.7
	No	22	26.8	25	22.9	42	15.5	89	19.3
	Total	82	100.0	109	100.0	271	100.0	462	100.0
	SD*	19	23.2	30	27.1	94	34.5	142	30.7
Overall Results	**All**	**83**	**17.8**	**111**	**23.8%**	**272**	**58.4%**	**466**	**100%**

* Standard deviation

B10. Breakdown of the responses regarding the concern about AVs' quick driving reaction in unexpected driving incidents

		Not at all concerned		Somewhat concerned		Extremely concerned		Total	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	90	62.9	83	58.0	85	48.6	258	56.0
	Male	53	37.1	60	42.0	90	51.4	203	44.0
	Total	143	100.0	143	100.0	175	100.0	461	100.0
Age	18-25	3	2.1	5	3.5	1	0.6	9	1.9
	26-35	27	19.0	25	17.5	34	19.2	86	18.6
	36-50	68	47.9	64	44.8	72	40.7	204	44.2
	50+	44	31.0	49	34.3	70	39.5	163	35.3
	Total	142	100.0	143	100.0	177	100.0	462	100.0
	SD*	24	16.7	23	15.8	29	16.5	75	16.2
Car Ownership	Yes	111	78.7	112	78.9	151	85.3	374	81.3
	No	30	21.3	30	21.1	26	14.7	86	18.7
	Total	141	100.0	142	100.0	177	100.0	460	100.0
	SD*	41	28.7	41	28.9	63	35.3	144	31.3
Overall Results	**All**	**143**	**30.9**	**144**	**31.0**	**177**	**38.1**	**464**	**100**

* Standard deviation

B11. Breakdown of the responses about adopting AVs if they could only operate in some limited areas in the city and not everywhere around the country

		Not at all likely		Somewhat likely		Extremely likely		Total	
		N	%	N	%	N	%	N	%
Gender	Female	182	57.6	53	58.2	24	40.0	259	55.5
	Male	134	42.4	38	41.8	36	60.0	208	44.5
	Total	316	100.0	91	100.0	60	100.0	467	100.0
Age	18-25	6	1.9	3	3.2	0	0.0	9	1.9
	26-35	49	15.6	24	25.8	14	23.3	87	18.6
	36-50	143	45.4	34	36.6	29	48.3	206	44.0
	50+	117	37.1	32	34.4	17	28.3	166	35.5
	Total	315	100.0	93	100.0	60	100.0	468	100.0
	SD*	54	17.2	12	13.2	10	17.2	76	16.2
Car Ownership	Yes	261	83.1	72	78.3	44	73.3	377	80.9
	No	53	16.9	20	21.7	16	26.7	89	19.1
	Total	314	100.0	92	100.0	60	100.0	466	100.0
	SD*	104	33.1	26	28.3	14	23.3	144	30.9
Overall Results	**All**	**317**	**67.4**	**93**	**19.8**	**60**	**12.8**	**470**	**100**

* Standard deviation

B12. Breakdown of the responses about previous knowledge that AVs might record travel data

		Previous knowledge					
		Yes		No		Total	
		N	%	N	%	N	%
Gender	Female	50	32.7	210	66.2	260	55.3
	Male	103	67.3	107	33.8	210	44.7
	Total	153	100.0	317	100.0	470	100.0
Age	18-25	2	1.3	7	2.2	9	1.9
	26-35	33	21.4	53	16.7	86	18.3
	36-50	66	42.9	141	44.5	207	43.9
	50+	53	34.4	116	36.6	169	35.9
	Total	154	100.0	317	100.0	471	100.0
	SD*	24	15.7	53	16.6	77	16.2
Car Ownership	Yes	132	86.8	248	78.2	380	81.0
	No	20	13.2	69	21.8	89	19.0
	Total	152	100.0	317	100.0	469	100.0
	SD*	56	36.8	90	28.2	146	31.0
Overall Results	**All**	**154**	**32.6**	**319**	**67.4**	**473**	**100**

* Standard deviation

B13. Breakdown of the responses regarding the concern about the privacy of AVs' travel data

		Not at all concerned		**Somewhat concerned**		**Extremely concerned**		**Total**	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	74	56.5	70	57.4	118	53.9	262	55.5
	Male	57	43.5	52	42.6	101	46.1	210	44.5
	Total	131	100.0	122	100.0	219	100.0	472	100.0
Age	18-25	4	3.1	2	1.6	3	1.4	9	1.9
	26-35	22	16.9	24	19.5	41	18.6	87	18.4
	36-50	59	45.4	50	40.7	98	44.5	207	43.8
	50+	45	34.6	47	38.2	78	35.5	170	35.9
	Total	130	100.0	123	100.0	220	100.0	473	100.0
	SD*	21	16.2	19	15.8	36	16.5	77	16.2
Car Ownership	Yes	108	83.1	93	76.9	181	82.3	382	81.1
	No	22	16.9	28	23.1	39	17.7	89	18.9
	Total	130	100.0	121	100.0	220	100.0	471	100.0
	SD*	43	33.1	33	26.9	71	32.3	147	31.1
Overall Results	**All**	**131**	**27.6**	**123**	**25.9**	**221**	**46.5**	**475**	**100**

* Standard deviation

B14. Breakdown of the responses about the agree/disagreements with the record travel data by AVs

		Disagree		**Undecided**		**Agree**		**Total**	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	85	55.6	100	57.5	71	52.6	256	55.4
	Male	68	44.4	74	42.5	64	47.4	206	44.6
	Total	153	100.0	174	100.0	135	100.0	462	100.0
Age	18-25	1	0.7	2	1.2	6	4.3	9	1.9
	26-35	30	19.7	31	17.9	24	17.4	85	18.4
	36-50	64	42.1	82	47.4	58	42.0	204	44.1
	50+	57	37.5	58	33.5	50	36.2	165	35.6
	Total	152	100.0	173	100.0	138	100.0	463	100.0
	SD*	25	16.3	30	17.3	21	15.0	75	16.2
Car Ownership	Yes	124	81.0	134	77.9	114	83.8	372	80.7
	No	29	19.0	38	22.1	22	16.2	89	19.3
	Total	153	100.0	172	100.0	136	100.0	461	100.0
	SD*	48	31.0	48	27.9	46	33.8	142	30.7
Overall Results	**All**	**153**	**32.9**	**174**	**37.4**	**138**	**29.7**	**465**	**100**

* Standard deviation

B15. Breakdown of the responses related to the groups or agency who should access to AVs' travel data (multiple responses allowed)

	Gender				Age								Car ownership			
	Male		Female		18-25		26-35		36-50		50+		Yes		No	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Car manufacturers																
Yes	82	39.0	92	35.1	5	55.6	36	41.4	79	38.2	55	32.4	141	36.9	31	34.8
No	128	61.0	170	64.9	4	44.4	51	58.6	128	61.8	115	67.6	241	63.1	58	65.2
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	23	11.0	39	14.9	0.5	5.6	7.5	8.6	24.5	11.8	30	17.6	50	13.1	13.5	15.2
Transport authorities																
Yes	95	45.2	112	42.7	6	66.7	33	37.9	94	45.4	73	42.9	160	41.9	45	50.6
No	115	54.8	150	57.3	3	33.3	54	62.1	113	54.6	97	57.1	222	58.1	44	49.4
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	10	4.8	19	7.3	1.5	16.7	10.5	12.1	9.5	4.6	12	7.1	31	8.1	0.5	0.6
Consultants																
Yes	44	21.0	43	16.4	3	33.3	12	13.8	40	19.3	33	19.4	70	18.3	17	19.1
No	166	79.0	219	83.6	6	66.7	75	86.2	167	80.7	137	80.6	312	81.7	72	80.9
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	61	29.0	88	33.6	1.5	16.7	31.5	36.2	63.5	30.7	52	30.6	121	31.7	27.5	30.9
Insurance companies																
Yes	77	36.7	119	45.4	2	22.2	33	37.9	85	41.1	75	44.1	149	39.0	46	51.7
No	133	63.3	143	54.6	7	77.8	54	62.1	122	58.9	95	55.9	233	61.0	43	48.3
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	28	13.3	12	4.6	2.5	27.8	10.5	12.1	18.5	8.9	10	5.9	42	11.0	1.5	1.7
Other answers																
Yes	20	9.5	12	4.6	0	0.0	6	6.9	13	6.3	14	8.2	30	7.9	3	3.4
No	190	90.5	249	95.4	9	100.0	81	93.1	193	93.7	156	91.8	351	92.1	86	96.6
Total	210	100.0	261	100.0	9	100.0	87	100.0	206	100.0	170	100.0	381	100.0	89	100.0
SD*	85	40.5	118.5	45.4	4.5	50.0	37.5	43.1	90	43.7	71	41.8	160.5	42.1	41.5	46.6

* Standard deviation

B16. Breakdown of the responses regarding the participants' willingness to accept AV's legal liability in accidents (multiple responses allowed)

		Nothing at all		Somewhat		A great deal		Total	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	155	57.4	79	58.5	28	42.4	262	55.6
	Male	115	42.6	56	41.5	38	57.6	209	44.4
	Total	270	100.0	135	100.0	66	100.0	471	100.0
Age	18-25	4	1.5	5	3.7	0	0.0	9	1.9
	26-35	47	17.4	27	19.9	13	19.7	87	18.4
	36-50	121	44.8	52	38.2	33	50.0	206	43.6
	50+	98	36.3	52	38.2	20	30.3	170	36.0
	Total	270	100.0	136	100.0	66	100.0	472	100.0
	SD*	45	16.8	20	14.4	12	18.1	76	16.2
Car Ownership	Yes	227	84.1	33	24.6	53	80.3	381	81.1
	No	43	15.9	101	75.4	13	19.7	89	18.9
	Total	270	100.0	134	100.0	66	100.0	470	100.0
	SD*	92	34.1	34	25.4	20	30.3	146	31.1
Overall Results	**All**	**271**	**57.2**	**137**	**28.9**	**66**	**13.9**	**474**	**100**

* Standard deviation

B17. Breakdown of the responses about the group or agency who should accept the highest legal liability of AVs in accidents

	Gender				Age								Car ownership			
	Male		Female		18-25		26-35		36-50		50+		Yes		No	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
National transport authorities																
Yes	35	16.7	31	11.8	0	0.0	10	11.5	38	18.4	18	10.6	54	14.1	12	13.5
No	175	83.3	231	88.2	9	100.0	77	88.5	169	81.6	152	89.4	328	85.9	77	86.5
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	70	33.3	100	38.2	4.5	50.0	33.5	38.5	65.5	31.6	67	39.4	137	35.9	32.5	36.5
Car manufacturers																
Yes	153	72.9	181	69.1	7	77.8	62	71.3	145	70.0	120	70.6	277	72.5	57	64.0
No	57	27.1	81	30.9	2	22.2	25	28.7	62	30.0	50	29.4	105	27.5	32	36.0
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	48	22.9	50	19.1	2.5	27.8	18.5	21.3	41.5	20.0	35	20.6	86	22.5	12.5	14.0
AV owners																
Yes	35	16.7	55	21.0	3	33.3	20	23.0	37	17.9	29	17.1	66	17.3	23	25.8
No	175	83.3	207	79.0	6	66.7	67	77.0	170	82.1	141	82.9	316	82.7	66	74.2
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	70	33.3	76	29.0	1.5	16.7	23.5	27.0	66.5	32.1	56	32.9	125	32.7	21.5	24.2
Traffic control centres																
Yes	35	16.7	24	9.2	1	11.1	10	11.5	28	13.5	20	11.8	49	12.8	10	11.2
No	175	83.3	238	90.8	8	88.9	77	88.5	179	86.5	150	88.2	333	87.2	79	88.8
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	70	33.3	107	40.8	3.5	38.9	33.5	38.5	75.5	36.5	65	38.2	142	37.2	34.5	38.8
Insurance companies																
Yes	49	23.3	55	21.0	1	11.1	21	24.1	43	20.8	40	23.5	82	21.5	22	24.7
No	161	76.7	207	79.0	8	88.9	66	75.9	164	79.2	130	76.5	300	78.5	67	75.3
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	56	26.7	76	29.0	3.5	38.9	22.5	25.9	60.5	29.2	45	26.5	109	28.5	22.5	25.3
Other answers																
Yes	6	2.9	8	3.1	0	0.0	1	1.1	6	2.9	7	4.1	8	2.1	6	6.7
No	204	97.1	254	96.9	9	100.0	86	98.9	201	97.1	163	95.9	374	97.9	83	93.3
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	99	47.1	123	46.9	4.5	50.0	42.5	48.9	97.5	47.1	78	45.9	183	47.9	38.5	43.3

B18. Breakdown of the responses about whether participants would wait to see the early adopters' opinion for buying AVs

		Not at all likely		Somewhat likely		Extremely likely		Total	
		N	%	N	%	N	%	N	%
Gender	Female	34	55.7	43	51.2	184	56.6	261	55.5
	Male	27	44.3	41	48.8	141	43.4	209	44.5
	Total	61	100.0	84	100.0	325	100.0	470	100.0
Age	18-25	0	0.0	3	3.6	5	1.5	8	1.7
	26-35	9	15.0	20	24.1	58	17.7	87	18.5
	36-50	32	53.3	39	47.0	135	41.3	206	43.8
	50+	19	31.7	21	25.3	129	39.4	169	36.0
	Total	60	100.0	83	100.0	327	100.0	470	100.0
	SD*	12	19.8	13	15.3	54	16.4	76	16.3
Car Ownership	Yes	51	83.6	62	73.8	267	82.4	380	81.0
	No	10	16.4	22	26.2	57	17.6	89	19.0
	Total	61	100.0	84	100.0	324	100.0	469	100.0
	SD*	21	33.6	20	23.8	105	32.4	146	31.0
Overall Results	**All**	**61**	**12.9**	**84**	**17.8**	**327**	**69.3%**	**472**	**100**

* Standard deviation

B19. Breakdown of the responses about purchasing AV once the technology is fully developed and tested

		Not at all likely		Somewhat likely		Extremely likely		Total	
		N	%	N	%	N	%	N	%
Gender	Female	148	62.7	64	53.8	50	42.7	262	55.5
	Male	88	37.3	55	46.2	67	57.3	210	44.5
	Total	236	100.0	119	100.0	117	100.0	472	100.0
Age	18-25	4	1.7	3	2.5	1	0.8	8	1.7
	26-35	36	15.3	24	20.2	27	22.9	87	18.4
	36-50	98	41.7	53	44.5	56	47.5	207	43.9
	50+	97	41.3	39	32.8	34	28.8	170	36.0
	Total	235	100.0	119	100.0	118	100.0	472	100.0
	SD*	40	17.2	19	15.6	20	16.6	77	16.3
Car Ownership	Yes	194	82.6	93	78.8	95	80.5	382	81.1
	No	41	17.4	25	21.2	23	19.5	89	18.9
	Total	235	100.0	118	100.0	118	100.0	471	100.0
	SD*	77	32.6	34	28.8	36	30.5	147	31.1
Overall Results	**All**	**237**	**50.0**	**119**	**25.1**	**118**	**24.9**	**474**	**100**

* Standard deviation

B20. Breakdown of responses about the most interesting aspects of the AVs, which make participants buy them

	Gender				Age								Car ownership			
	Male		Female		18-25		26-35		36-50		50+		Yes		No	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Safe driving																
Yes	107	51.0	120	45.8	6	66.7	42	48.3	101	48.8	79	46.5	172	41.3	55	61.8
No	103	49.0	142	54.2	3	33.3	45	51.7	106	51.2	91	53.5	244	58.7	34	38.2
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	416	100.0	89	100.0
SD*	2	1.0	11	4.2	1.5	16.7	1.5	1.7	2.5	1.2	6	3.5	36	8.7	10.5	11.8
Automatic guidance and navigation systems																
Yes	81	38.6	99	37.8	7	77.8	32	36.8	74	35.7	67	39.4	144	37.7	36	40.4
No	129	61.4	163	62.2	2	22.2	55	63.2	133	64.3	103	60.6	238	62.3	53	59.6
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	24	11.4	32	12.2	2.5	27.8	11.5	13.2	29.5	14.3	18	10.6	47	12.3	8.5	9.6
Being fun and enjoying the free time when not driving																
Yes	70	33.3	67	25.6	5	55.6	24	27.6	70	33.8	38	22.4	108	30.4	30	33.7
No	140	66.7	195	74.4	4	44.4	63	72.4	137	66.2	132	77.6	247	69.6	59	66.3
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	355	100.0	89	100.0
SD*	35	16.7	64	24.4	0.5	5.6	19.5	22.4	33.5	16.2	47	27.6	69.5	19.6	14.5	16.3
Reduction of traffic congestion, queue, and delay																
Yes	72	34.3	71	27.1	3	33.3	28	32.2	66	31.9	47	27.6	110	28.8	33	37.1
No	138	65.7	191	72.9	6	66.7	59	67.8	141	68.1	123	72.4	272	71.2	56	62.9
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	33	15.7	60	22.9	1.5	16.7	15.5	17.8	37.5	18.1	38	22.4	81	21.2	11.5	12.9
Reduction of emissions and fuel consumption																
Yes	85	40.5	116	44.3	5	55.6	37	42.5	88	42.5	72	42.4	221	81.5	39	19.5
No	125	59.5	146	55.7	4	44.4	50	57.5	119	57.5	98	57.6	50	18.5	161	80.5
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	271	100.0	200	100.0
SD*	20	9.5	15	5.7	0.5	5.6	6.5	7.5	15.5	7.5	13	7.6	85.5	31.5	61	30.5
Other answers																
Yes	11	5.2	13	5.0	0	0.0	4	4.6	6	2.9	14	8.2	17	4.5	6	6.7
No	199	94.8	249	95.0	9	100.0	83	95.4	201	97.1	156	91.8	365	95.5	83	93.3
Total	210	100.0	262	100.0	9	100.0	87	100.0	207	100.0	170	100.0	382	100.0	89	100.0
SD*	94	44.8	118	45.0	4.5	50.0	39.5	45.4	97.5	47.1	71	41.8	174	45.5	38.5	43.3

B21. Breakdown of the WTP for an AV in addition to the price of the same vehicle in the traditional mode

		Below 10%		10% - 20%		Above 20%		Total	
		N	%	N	%	N	%	N	%
Gender	Female	106	52.2	98	58.7	57	56.4	261	55.4
	Male	97	47.8	69	41.3	44	43.6	210	44.6
	Total	203	100.0	167	100.0	101	100.0	471	100.0
Age	18-25	3	1.5	1	0.6	4	4.0	8	1.7
	26-35	25	12.4	35	20.8	27	26.7	87	18.5
	36-50	77	38.1	75	44.6	55	54.5	207	43.9
	50+	97	48.0	57	33.9	15	14.9	169	35.9
	Total	202	100.0	168	100.0	101	100.0	471	100.0
	SD*	38	18.8	28	16.4	19	18.8	77	16.3
Car Ownership	Yes	167	83.1	142	84.5	72	71.3	381	81.1
	No	34	16.9	26	15.5	29	28.7	89	18.9
	Total	201	100.0	168	100.0	101	100.0	470	100.0
	SD*	67	33.1	58	34.5	22	21.3	146	31.1
Overall Results	**All**	**204**	**43.1**	**168**	**35.5**	**101**	**21.4**	**473**	**100**

* Standard deviation

B22. Breakdown of the responses regarding the purchasing likelihood of AV if the cost was not an issue

		Not at all likely		Somewhat likely		Extremely likely		Total	
		N	%	N	%	N	%	N	%
Gender	Female	108	60.7	75	63.0	79	45.7	262	55.7
	Male	70	39.3	44	37.0	94	54.3	208	44.3
	Total	178	100.0	119	100.0	173	100.0	470	100.0
Age	18-25	3	1.7	4	3.4	1	0.6	8	1.7
	26-35	25	14.0	26	22.0	36	20.7	87	18.5
	36-50	77	43.3	54	45.8	75	43.1	206	43.8
	50+	73	41.0	34	28.8	62	35.6	169	36.0
	Total	178	100.0	118	100.0	174	100.0	470	100.0
	SD*	32	17.7	18	15.2	28	16.2	76	16.3
Car Ownership	Yes	148	83.6	99	83.2	133	76.9	380	81.0
	No	29	16.4	20	16.8	40	23.1	89	19.0
	Total	177	100.0	119	100.0	173	100.0	469	100.0
	SD*	60	33.6	40	33.2	47	26.9	146	31.0
Overall Results	**All**	**179**	**37.9**	**119**	**25.2**	**174**	**36.9**	**472**	**100**

* Standard deviation

B23. Breakdown of the response about whether an on-demand ridesharing service of AVs would be more efficient than owning an AV

		Not at all likely		**Somewhat likely**		**Extremely likely**		**Total**	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	108	60.7	75	63.0	79	45.7	262	55.7
	Male	70	39.3	44	37.0	94	54.3	208	44.3
	Total	178	100.0	119	100.0	173	100.0	470	100.0
Age	18-25	3	1.7	4	3.4	1	0.6	8	1.7
	26-35	25	14.0	26	22.0	36	20.7	87	18.5
	36-50	77	43.3	54	45.8	75	43.1	206	43.8
	50+	73	41.0	34	28.8	62	35.6	169	36.0
	Total	178	100.0	118	100.0	174	100.0	470	100.0
	SD*	32	17.7	18	15.2	28	16.2	76	16.3
Car Ownership	Yes	148	83.6	99	83.2	133	76.9	380	81.0
	No	29	16.4	20	16.8	40	23.1	89	19.0
	Total	177	100.0	119	100.0	173	100.0	469	100.0
	SD*	60	33.6	40	33.2	47	26.9	146	31.0
Overall Results	**All**	**206**	**44.1**	**144**	**30.8**	**117**	**25.1**	**467**	**100**

* Standard deviation

B24. Breakdown of the responses about purchasing private AVs rather than an on-demand ridesharing service of AVs

		Purchasing private AVs					
		Yes		**No**		**Total**	
		N	**%**	**N**	**%**	**N**	**%**
Gender	Female	99	48.8	162	60.7	261	55.5
	Male	104	51.2	105	39.3	209	44.5
	Total	203	100.0	267	100.0	470	100.0
Age	18-25	2	1.0	6	2.3	8	1.7
	26-35	49	24.0	37	13.9	86	18.3
	36-50	90	44.1	117	44.0	207	44.0
	50+	63	30.9	106	39.8	169	36.0
	Total	204	100.0	266	100.0	470	100.0
	SD*	32	15.6	46	17.5	77	16.4
Car Ownership	Yes	167	82.3	213	80.1	380	81.0
	No	36	17.7	53	19.9	89	19.0
	Total	203	100.0	266	100.0	469	100.0
	SD*	66	32.3	80	30.1	146	31.0
Overall Results	**All**	**204**	**43.2**	**268**	**56.8**	**472**	**100**

* Standard deviation

B25. Breakdown of the responses regarding mobile phone ownership

		Owning a mobile phone					
		Yes		**No**		**Total**	
		N	**%**	**N**	**%**	**N**	**%**
Gender	Female	261	56.0	1	25.0	262	55.7
	Male	205	44.0	3	75.0	208	44.3
	Total	466	100.0	4	100.0	470	100.0
Age	18-25	8	1.7	1	20.0	8	1.7
	26-35	86	18.5	0	0.0	86	18.5
	36-50	207	44.4	0	0.0	207	44.4
	50+	165	35.4	4	80.0	165	35.4
	Total	466	100.0	5	100.0	466	100.0
	SD*	76	16.4	2	32.8	76	16.4
Car Ownership	Yes	89	19.1	0	0.0	89	19.0
	No	376	80.9	4	100.0	380	81.0
	Total	465	100.0	4	100.0	469	100.0
	SD*	144	30.9	2	50.0	146	31.0
Overall Results	**All**	**468**	**98.9**	**5**	**1.1**	**473**	**100**

* Standard deviation

B26. Breakdown of the responses about whether the mobile phone was the latest version of its brand available in the market when people were buying it

		Was it the latest version?					
		Yes		**No**		**Total**	
		N	**%**	**N**	**%**	**N**	**%**
Gender	Female	119	93.7	141	56.9	260	55.9
	Male	8	6.3	107	43.1	205	44.1
	Total	127	100.0	248	100.0	465	100.0
Age	18-25	6	2.8	3	1.2	9	1.9
	26-35	46	21.2	40	16.1	86	18.5
	36-50	91	41.9	114	45.8	205	44.0
	50+	74	34.1	92	36.9	166	35.6
	Total	217	100.0	249	100.0	466	100.0
	SD*	32	14.8	43	17.5	75	16.2
Car Ownership	Yes	166	77.2	209	83.9	375	80.8
	No	49	22.8	40	16.1	89	19.2
	Total	215	100.0	249	100.0	464	100.0
	SD*	59	27.2	85	33.9	143	30.8
Overall Results	**All**	**218**	**46.6**	**250**	**53.4**	**468**	**100**

* Standard deviation

B27. Breakdown of the responses about the time of purchasing the mobile phone

		In the past 12 months		1-2 years ago		2-4 years ago		4-7 years ago		More than 7 years ago		Total	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	107	60.8	92	52.9	49	62.8	8	38.1	6	35.3	262	56.2
	Male	69	39.2	82	47.1%	29	37.2	13	61.9	11	64.7	204	43.8
	Total	176	100.0	174	100.0	78	100.0	21	100.0	17	100.0	466	100.0
Age	18-25	2	1.1	4	2.3	3	3.8	0	0.0	0	0.0	9	1.9
	26-35	40	22.7	30	17.2	12	15.2	3	14.3	1	5.9	86	18.4
	36-50	85	48.3	81	46.6	28	35.4	7	33.3	6	35.3	207	44.3
	50+	49	27.8	59	33.9	36	45.6	11	52.4	10	58.8	165	35.3
	Total	176	100.0	174	100.0	79	100.0	21	100.0	17	100.0	467	100.0
	SD*	30	16.8	29	16.7	13	16.4	4	19.7	4	23.7	76	16.2
Car Ownership	Yes	143	81.3	144	83.2	60	76.9	15	71.4	14	82.4	376	80.9
	No	33	18.8	29	16.8	18	23.1	6	28.6	3	17.6	89	19.1
	Total	176	100.0	173	100.0	78	100.0	21	100.0	17	100.0	465	100.0
	SD*	55	31.3	58	33.2	21	26.9	5	21.4	6	32.4	144	30.9
Overall Results	**All**	**176**	**37.5**	**176**	**37.5**	**79**	**16.80**	**21**	**4.5**	**17**	**3.7**	**469**	**100**

* Standard deviation

B28. Breakdown of the responses regarding the interest in the latest smart technologies

		Nothing at all		Somewhat		A great deal		Total	
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender	Female	34	60.7	91	59.9	137	52.1	262	55.6
	Male	22	39.3	61	40.1	126	47.9	209	44.4
	Total	56	100.0	152	100.0	263	100.0	471	100.0
Age	18-25	1	1.8	2	1.3	6	2.3	9	1.9
	26-35	8	14.3	30	19.7	49	18.6	87	18.4
	36-50	24	42.9	71	46.7	112	42.4	207	43.9
	50+	23	41.1	49	32.2	97	36.7	169	35.8
	Total	56	100.0	152	100.0	264	100.0	472	100.0
	SD*	10	17.5	25	16.7	42	15.8	76	16.2
Car Ownership	Yes	47	83.9	121	80.7	213	80.7	381	81.1
	No	9	16.1	29	19.3	51	19.3	89	18.9
	Total	56	100.0	150	100.0	264	100.0	470	100.0
	SD*	19	33.9	46	30.7	81	30.7	146	31.1
Overall Results	**All**	**56**	**11.8**	**153**	**32.3**	**265**	**55.9**	**474**	**100**

* Standard deviation

B29. Model fitting for the impact of gender on individuals' interest in driving AVs

Model Fitting Information				
Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	224.432			
Final	66.801	157.632	4	**0**
Likelihood Ratio Tests				
Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	66.801	0	0	.
AVs are safer and more secure than human drivers	212.033	145.232	2	**0**
Gender	73.201	6.401	2	**0.041**
Goodness-of-Fit				
	Chi-Square	df	Sig.	
Pearson	16.895	6	**0.010**	
Deviance	17.323	6	0.008	
Pseudo R-Square				
Cox and Snell	Nagelkerke	McFadden		
0.298	**0.337**	0.163		

B30. Parameter estimates for the impact of gender on individuals' interest in driving AVs

Interested in Driving AV		**B**	**Std. Error**	**Wald**	**df**	**Sig.**	**Exp(β)**	**95% Confidence Interval for Exp(β)**	
								Lower Bound	**Upper Bound**
Interested in Driving AV[a]: Neither									
Intercept		-1.554	.279	31.009	1	.000			
AVs are safer and more secure than human drivers		**.482**	.088	30.095	1	**.000**	**1.619**	1.363	1.923
Gender	Female	**.367**	.243	2.282	1	**.131**	**1.444**	.897	2.325
	Male	**0**[b]	.	.	0	**.**	**.**	.	.
Interested in Driving AV: Very Interested									
Intercept		-3.137	.368	72.543	1	.000			
AVs are safer and more secure than human drivers		**1.041**	.103	101.976	1	**.000**	**2.831**	2.313	3.465
Gender	Female	**-.295**	.282	1.090	1	**.296**	**.745**	.428	1.295
	Male	**0**[b]	.	.	0	**.**	**.**	.	.

a. The reference category is: Not at all.
b. This parameter is set to zero because it is redundant.

B31. Model-fitting information for the impact of individuals' age on their interest in driving AVs

Model fitting information				
Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	357.334			
Final	202.542	154.792	10	**.000**
Likelihood Ratio Tests				
Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	202.542	.000	0	.
AVs are safer and more secure than human drivers	349.768	147.226	2	**.000**
Feeling safe and secure about AVs quick reaction in accidents	205.245	2.703	2	**.259**
Age	205.780	3.238	6	**.778**
Goodness-of-Fit				
	Chi-Square	df	Sig.	
Pearson	73.963	52	.024	
Deviance	76.316	52	.016	
Pseudo R-Square				
Cox and Snell	Nagelkerke	McFadden		
0.298	**0.337**	0.163		

B32. Parameter estimates for the impact of individuals' age on their interest in driving AVs

Interested in Driving AV		B	Std. Error	Wald	df	Sig.	Exp(β)	95% Confidence Interval for Exp(β)	
								Lower Bound	Upper Bound
Interested in Driving AV[a]: Neither									
Intercept		-.979	.348	7.897	1	.005			
AVs are safer and more secure than human drivers		**.493**	.089	30.390	1	**.000**	**1.636**	1.374	1.950
Feeling safe and secure about AVs quick reaction in accidents		**-.120**	.074	2.662	1	**.103**	**.887**	.768	1.024
Age	18-25	**-.494**	.930	.283	1	**.595**	**.610**	.099	3.775
	26-35	**.045**	.353	.017	1	**.898**	**1.047**	.524	2.091
	36-50	**-.083**	.270	.095	1	**.758**	**.920**	.542	1.563
	50+	**0**[b]	.	.	0	**.**	**.**	.	.
Interested in Driving AV[a]: Very Interested									
Intercept		-3.281	.472	48.221	1	.000			
AVs are safer and more secure than human drivers		**1.055**	.105	101.979	1	**.000**	**2.873**	2.341	3.526
Feeling safe and secure about AVs quick reaction in accidents		**-.055**	.092	.354	1	**.552**	**.947**	.791	1.133
Age	18-25	**-.242**	1.101	.049	1	**.826**	**.785**	.091	6.786
	26-35	**.590**	.400	2.171	1	**.141**	**1.803**	.823	3.950
	36-50	**.078**	.323	.059	1	**.808**	**1.082**	.574	2.038
	50+	**0**[b]	.	.	0	**.**	**.**	.	.

a. The reference category is: Not at all.
b. This parameter is set to zero because it is redundant.

B33. Model-fitting information for individuals' preferred activity in AVs

Model fitting information				
Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	56.844			
Final	37.515	19.329	4	**.001**
Likelihood Ratio Tests				
Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	37.515	.000	0	.
Gender	37.591	.077	1	**.782**
Age	55.865	18.351	3	**.000**
Goodness-of-Fit				
	Chi-Square	df	Sig.	
Pearson	8.801	3	.032	
Deviance	8.928	3	.030	
Pseudo R-Square				
Cox and Snell	Nagelkerke	McFadden		
0.040	**0.057**	0.033		

B34. Parameter estimates for individuals' preferred activity in AVs

Interested in driving AV		**B**	**Std. Error**	**Wald**	**df**	**Sig.**	**Exp(β)**	**95% Confidence Interval for Exp(β)**	
								Lower Bound	**Upper Bound**
Sleeping/Resting, Reading[a]: Yes									
Intercept		-.979	.348	7.897	1	.005			
Gender	Female	**.058**	.209	.077	1	**.782**	**1.060**	.703	1.596
	Male	**0[b]**	.	.	0	.	.	.	.
Age	18-25	**2.416**	.843	8.219	1	**.004**	**11.206**	2.148	58.470
	26-35	**.601**	.302	3.959	1	**.047**	**1.824**	1.009	3.297
	36-50	**.811**	.240	11.426	1	**.001**	**2.250**	1.406	3.600
	50+	**0[b]**	.	.	0	.	.	.	.

a. The reference category is: No.
b. This parameter is set to zero because it is redundant.

B35. Model fitting of the AVs' safe and secure operation compared to human drivers

Model Fitting Information				
Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	559.802			
Final	345.349	214.452	20	**.000**
Likelihood Ratio Tests				
Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept				
Feeling safe and secure about AVs quick reaction in accidents	349.602	4.253	2	**.119**
Feeling safe and secure in an AV with manual control	383.655	38.306	2	**.000**
Feeling safe and secure in an AV without a steering wheel	470.953	125.603	2	**.000**
Gender	347.910	2.560	2	**.278**
Age	351.540	6.191	6	**.402**
Number of cars	360.323	14.974	6	**.020**
Goodness-of-Fit				
	Chi-Square	df	Sig.	
Pearson	318.338	270	.023	
Deviance	251.611	270	.783	
Pseudo R-Square				
Cox and Snell	Nagelkerke	McFadden		
.454	**.517**	.286		

B36. Parameter estimates of AVs' safe and secure operation compared to human drivers

AVs are safer and more secure than human drivers		**B**	**Std. Error**	**Wald**	**df**	**Sig.**	**Exp(β)**	**95% Confidence Interval for Exp(β)**	
								Lower Bound	**Upper Bound**
AVs are safer and more secure than human drivers[a]: Somewhat									
Intercept		-4.89	0.709	47.571	1	0			
Feeling safe and secure about AVs quick reaction in accidents	Not at all	**-0.022**	0.089	0.062	1	**0.804**	**0.978**	0.822	1.165
	Somewhat	**0.569**	0.115	24.428	1	**0**	**1.767**	1.41	2.214
	Extremely	**1.081**	0.187	33.254	1	**0**	**2.948**	2.041	4.257
Gender	Female	**-0.318**	0.301	1.119	1	**0.29**	**0.728**	0.404	1.312
	Male	**0[b]**	.	.	0	.	.	.	.
Age	18-25	**-19.025**	4443.74	0	1	**0.997**	**0.004**	0	.
	26-35	**-0.6**	0.431	1.944	1	**0.163**	**0.549**	0.236	1.276
	36-50	**-0.137**	0.319	0.185	1	**0.667**	**0.872**	0.466	1.63
	50+	**0[b]**	.	.	0	.	.	.	.
Number of Cars	1	**1.182**	0.343	11.888	1	**0.001**	**3.261**	1.665	6.386
	2	**0.854**	0	.	1	.	**2.349**	2.349	2.349
	3	**-16.832**	2900.084	0	1	**0.995**	**0.004**	0	.
	5+	**0[b]**	.	.	0	.	.	.	.
AVs are safer and more secure than human drivers[a]: Extremely									
Intercept		11.533	3681.455	0	1	0.998			
Feeling safe and secure about AVs quick reaction in accidents	Not at all	**0.219**	0.126	3.006	1	**0.083**	**1.244**	0.972	1.593
	Somewhat	**0.7**	0.166	17.792	1	**0**	**2.014**	1.455	2.788
	Extremely	**1.631**	0.201	65.986	1	**0**	**5.109**	3.447	7.573
Gender	Female	**-0.61**	0.391	2.429	1	**0.119**	**0.543**	0.252	1.17
	Male	**0[b]**	.	.	0	.	.	.	.
Age	18-25	**-2.545**	1.705	2.228	1	**0.136**	**0.078**	0.003	2.219
	26-35	**-0.382**	0.553	0.479	1	**0.489**	**0.682**	0.231	2.016
	36-50	**0.052**	0.414	0.016	1	**0.899**	**1.054**	0.468	2.373
	50+	**0[b]**	.	.	0	.	.	.	.
Number of cars	1	**-18.369**	3681.455	0	1	**0.996**	**0.001**	0	.
	2	**-18.786**	3681.455	0	1	**0.996**	**0.006**	0	.
	3	**-19.385**	3681.456	0	1	**0.996**	**0.003**	0	.
	5+	**0[b]**	.	.	0	.	.	.	.

a. The reference category is: Not at all.
b. This parameter is set to zero because it is redundant.

B37. Model fitting of how safe and secure would AVs be without a steering wheel

Model Fitting Information				
Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	597.247			
Final	359.427	237.820	16	**.000**
Likelihood Ratio Tests				
Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	359.427a	.000	0	.
Agree that AVs should record data	375.183	15.757	2	**.000**
Purchase AV when It is fully developed and tested	368.033	8.606	2	**.014**
AVs are safer and more secure than human Drivers	421.969	62.543	4	**.000**
Feeling safe and secure about AVs quick reaction in accidents	378.224	18.798	4	**.001**
Interested in driving AV	363.911	4.484	4	**.344**
Goodness-of-Fit				
	Chi-Square	df	Sig.	
Pearson	393.182	322	.004	
Deviance	274.556	322	.974	
Pseudo R-Square				
Cox and Snell	Nagelkerke	McFadden		
0.427	**0.519**	0.321		

B38. Parameter estimates of how safe and secure AVs would be without a steering wheel

Feeling safe and secure in an AV without a steering wheel		B	Std. Error	Wald	df	Sig.	Exp(β)	95% Confidence Interval for Exp(β)	
								Lower Bound	Upper Bound
Feeling safe and secure in an AV without a steering wheel[a]: somewhat likely									
Intercept		-2.105	0.666	9.996	1	0.002			
Agree that AVs should record data		**0.271**	0.127	4.562	1	**0.033**	**1.311**	1.023	1.681
Purchase AV when It is fully developed and tested		**0.267**	0.113	5.604	1	**0.018**	**1.306**	1.047	1.629
AVs are safer and more secure than human drivers	Not at all	**-2.385**	0.472	25.508	1	**0**	**0.092**	0.036	0.232
	Somewhat	**-0.833**	0.365	5.212	1	**0.022**	**0.435**	0.212	0.889
	Extremely	**0[b]**	.	.	0	**.**	**.**	.	.
Feeling safe and secure about AVs quick reaction in accidents	Not at all concerned	**-0.526**	0.425	1.532	1	**0.216**	**0.591**	0.257	1.359
	Somewhat concerned	**0.865**	0.333	6.733	1	**0.009**	**2.375**	1.236	4.566
	Extremely concerned	**0[b]**	.	.	0	**.**	**.**	.	.
Interested in driving AV	Not interested	**0.62**	0.467	1.759	1	**0.185**	**1.859**	0.744	4.646
	Neither	**0.458**	0.397	1.333	1	**0.248**	**1.581**	0.726	3.443
	Very interested	**0[b]**	.	.	0	**.**	**.**	.	.
Feeling safe and secure in an AV without a steering wheel[a]: Extremely likely									
Intercept		**-2.819**	0.92	9.381	1	0.002			
Agree that AVs should record data		**0.642**	0.172	13.939	1	**0**	**1.9**	1.356	2.661
Purchase AV when It is fully developed and tested		**0.363**	0.155	5.5	1	**0.019**	**1.438**	1.062	1.948
AVs are safer and more secure than human drivers	Not at all	**-3.788**	0.835	20.565	1	**0**	**0.023**	0.004	0.116
	Somewhat	**-2.397**	0.495	23.486	1	**0**	**0.091**	0.035	0.24
	Extremely	**0[b]**	.	.	0	**.**	**.**	.	.
Feeling safe and secure about AVs quick reaction in Accidents	Not at all concerned	**-0.579**	0.525	1.216	1	**0.27**	**0.56**	0.2	1.569
	Somewhat concerned	**-0.385**	0.46	0.702	1	**0.402**	**0.68**	0.276	1.675
	Extremely concerned	**0[b]**	.	.	0	**.**	**.**	.	.
Interested in driving AV	Not interested	**-0.718**	0.797	0.813	1	**0.367**	**0.488**	0.102	2.324
	Neither	**0.358**	0.515	0.483	1	**0.487**	**1.431**	0.521	3.927
	Very interested	**0[b]**	.	.	0	**.**	**.**	.	.

a. The reference category is: Not at all likely.
b. This parameter is set to zero because it is redundant.

B39. Model fitting for purchasing private AVs even if ridesharing AVs are provided

Model Fitting Information				
Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	252.830			
Final	146.241	106.589	4	**.000**
Likelihood Ratio Tests				
Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept				
AVs are safer and more secure than human drivers	148.350	2.109	1	**.146**
Feeling safe and secure in an AV without a steering wheel	153.102	6.860	1	**.009**
Interested in driving AV	181.546	35.304	1	**.000**
Gender	147.206	.965	1	**.326**
Goodness-of-Fit				
	Chi-Square	df	Sig.	
Pearson	59.525	42	.039	
Deviance	68.770	42	.006	
Pseudo R-Square				
Cox and Snell	Nagelkerke	McFadden		
0.216	**0.289**	0.178		

B40. Parameter estimates for purchasing private AVs even if ridesharing AVs are provided

Purchase AV even If ridesharing AV provided		**B**	**Std. Error**	**Wald**	**df**	**Sig.**	**Exp(β)**	**95% Confidence Interval for Exp(β)**	
								Lower Bound	**Upper Bound**
Yes[a]									
Intercept		-2.249	.297	57.251	1	.000			
AVs are safer and more secure than human drivers		**.128**	.088	2.127	1	**.145**	**1.137**	.957	1.351
Feeling safe and secure in an AV without a steering wheel		**.243**	.094	6.716	1	**.010**	**1.275**	1.061	1.532
Interested in driving AV		**.452**	.078	33.514	1	**.000**	**1.571**	1.348	1.831
Gender	Female	**-.218**	.222	.967	1	**.325**	**.804**	.520	1.242
	Male	**0**[b]	.	.	0	.	.	.	.

a. The reference category is: No.
b. This parameter is set to zero because it is redundant.

B41. Model fitting of the effects of gender and age on WTP for AVs

Model Fitting Information				
Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	363.203			
Final	299.295	63.908	12	**.000**
Likelihood Ratio Tests				
Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept				
Interested in driving AV	320.672	21.377	2	**.000**
Heard about AV	301.006	1.710	2	**.425**
Gender	301.936	2.640	2	**.267**
Age	333.469	34.173	6	**.000**
Goodness-of-Fit				
	Chi-Square	df	Sig.	
Pearson	137.788	104	.015	
Deviance	135.135	104	.022	
Pseudo R-Square				
Cox and Snell	Nagelkerke	McFadden		
0.133	**0.152**	0.068		

B42. Parameter estimates of the effects of gender and age on WTP for AVs

		B	**Std. Error**	**Wald**	**df**	**Sig.**	**Exp(β)**	**95% Confidence Interval for Exp(β)**	
								Lower Bound	**Upper Bound**
WTP for AV in addition to the price of TV[a]: 10% - 20%									
Intercept		-1.511	.344	19.336	1	.000			
Interested in driving AV		**.228**	.072	10.066	1	**.002**	**1.256**	1.091	1.446
Heard about AV		**.094**	.078	1.455	1	**.228**	**1.098**	.943	1.279
Gender	Female	**.373**	.241	2.389	1	**.122**	**1.452**	.905	2.328
	Male	**0[b]**	.	.	0	.	.	.	.
Age	18-25	**-.563**	1.184	.226	1	**.634**	**.569**	.056	5.798
	26-35	**.654**	.329	3.962	1	**.047**	**1.924**	1.010	3.665
	36-50	**.424**	.246	2.964	1	**.085**	**1.528**	.943	2.475
	50+	**0[b]**	.	.	0	.	.	.	.
WTP for AV in addition to the price of TV[a]: Above 20%									
Intercept		-3.028	.470	41.519	1	.000			
Interested in driving AV		**.374**	.088	18.111	1	**.000**	**1.454**	1.224	1.728
Heard about AV		**.005**	.096	.003	1	**.956**	**1.005**	.833	1.213
Gender	Female	**.060**	.291	.042	1	**.838**	**1.061**	.600	1.876
	Male	**0[b]**	.	.	0	.	.	.	.
Age	18-25	**2.186**	.905	5.839	1	**.016**	**8.897**	1.511	52.380
	26-35	**1.953**	.421	21.520	1	**.000**	**7.051**	3.089	16.093
	36-50	**1.613**	.356	20.501	1	**.000**	**5.018**	2.496	10.088
	50+	**0[b]**	.	.	0	.	.	.	.

a. The reference category is: WTP Below 10%.
b. This parameter is set to zero because it is redundant.

APPENDIX C: Copy of the Expert Survey

C1. Email Invitation Sent by the Researcher of this Study

Subject line: *first name of participant*, I need your expert opinion in my survey on AVs.
Dear *first name of participant* This is Amin, your LinkedIn connection, I'm running a **short expert survey** on the application of Autonomous Vehicles as part of my PhD research, and I need the experts' opinions. So, I'd be grateful if I could have your support in this matter. This short survey is designed in multiple-choice and check-box questions and will take you **less than 6 minutes** to complete. If you have any inquiry, please feel free to contact me through my email address at rezaeim@tcd.ie or my LinkedIn page. Thank you so much for your time and input in advance! **Please click here to take the survey now** If you experience problems opening the link, please copy and paste the following into your browser address bar: https://www.surveymonkey.com/r/AVs-Expert Amin Rezaei PhD Candidate, Civil Engineering - Transportation Engineering Department of Civil, Structural & Environmental Engineering Trinity College Dublin, the University of Dublin Dublin, Ireland Email: rezaeim@tcd.ie

C2. Expert Survey Questionnaire

Introduction

Dear Participant,

Thank you for participating in this survey. Your feedback is important. This survey forms part of a PhD study at Trinity College Dublin.

Aim: We're conducting research on the efficiency of **Autonomous Vehicles (AVs)** and their adoption in highway transport, and we would like to have your expert opinion about it.

The term "AVs" throughout the survey refers to **level 5 - Fully Autonomous Vehicles** without a steering wheel unless other levels are specified.

Survey length: This survey should take no longer than 6 minutes to complete!

Confidentiality: The survey is completely anonymous, and the results can only be accessed and disseminated by the scientific researcher of the study, Mr Amin Rezaei. All data collected from this survey will be used for scientific research purposes only.

Withdrawal: Your participation is completely voluntary, and a participant can drop out of the survey at any time. If you have any questions about this research or the management of the research data, please email rezaeim@tcd.ie.

Consent: Clicking on the "**Next**" button below indicates that you have read the information provided on this page and you voluntarily agree to participate. If you DO NOT wish to participate in the research study, please decline participation by clicking on the "**Exit**" button on the top right corner to quit the survey.

Thank you,

Amin Rezaei
PhD Candidate, Civil Engineering - Transportation Engineering
Department of Civil, Structural & Environmental Engineering
Trinity College Dublin, the University of Dublin

AVs' Impacts

1. What would be the most valuable outcome/s of the adoption of AVs?

- ☐ Safe driving
- ☐ Vehicle security
- ☐ Reduction of travel time
- ☐ Reduction of traffic congestion
- ☐ Fuel consumption and vehicle
- ☐ Other (please specify)

2. How do you think Autonomous Vehicles (AVs) will affect the following parameters?

	Substantially decrease	No impact	Substantially increase
Travel time	○	○	○
Traffic congestion: queue, delay, etc.	○	○	○
Road throughput	○	○	○
Fuel consumption and vehicle emissions	○	○	○
Road users' safety	○	○	○
Number of accidents	○	○	○
Severity of accidents	○	○	○

AVs' Concerns

3. What do you think would be the most significant concerns regarding the application of AVs?

- ☐ Safety concerns
- ☐ Security concerns (such as getting hacked and losing control of the AV)
- ☐ Privacy concerns such as sharing trip data with different agencies (insurance companies, manufacturers, etc.)
- ☐ Legal liabilities (in case of an accident
- ☐ Traffic issues such as congestions, queue, delay Fuel consumption and emission
- ☐ Other (please specify)

4. Which one of the following technical issues with an AV would be most concerning?

- ☐ Sensor failures and system shut down
- ☐ Incorrect understanding of the surrounding objects (humans, animals, and others)
- ☐ Getting restricted by factory-defined driving operations, i.e., AV drivers would not be as free as human drivers in driving actions such as speeding up/down, a sudden leave of a queue or merging traffic and some other
- ☐ Not being as good as human drivers in quick driving reactions (For example, some people believe AVs might not be quick enough to react when their leading vehicles suddenly reduce their speed)
- ☐ Other (please specify)

5. Which group/agency do you think should accept the highest liability in case of an accident involved with an AV?

- ☐ AV owners
- ☐ Insurance companies
- ☐ Legal authorities
- ☐ Local traffic control centers
- ☐ AV manufacturers
- ☐ Other (please specify)

Overall Opinion

6. Which one of the following statements best sums up your opinion regarding the future use of AVs on public roads?

- ○ The science and industry of the AVs are doing very well. So, I have no concern to adopt AVs.
- ○ I am concerned about safety, security and hacking threats but I'd like to try AVs.
- ○ A lot more investigations and preparation needed before AVs' adoption on public roads. So, I'm not opposed to AVs, but I don't adopt them until further investigations approve their safety, security and efficiency.
- ○ I am opposed to AVs ever being allowed on public roads in any condition.
- ○ Other (please specify)

7. If an on-demand ridesharing service like Uber, Lyft, and Hailo had been provided to you via AVs, how likely would you support it rather than the application of private AVs?

Not at all likely	Somewhat likely	Extremely likely
☆	☆	☆

8. If the emergence of AVs was inevitable, which type of the following AVs would you support?

- ○ An AV with a driving wheel and manual override control systems
- ○ An AV without a driving wheel
- ○ None

Demographic Questions

9. In what country do you currently reside?

10. How many years of experience do you have in your field?

- 1 – 3 years
- 3 – 5 years
- 5 – 10 years
- 10 – 20 years
- Above 20 years

11. What is your main area of expertise?

- Transportation (Eng./Planning/Modelling/Policy/Economics/etc.)
- Civil Engineering
- Electronic Engineering
- Computer Engineering
- Mechanical Engineering
- Behavioural and Social Sciences
- Other (please specify)

12. Where do you work for?

- Government
- Road authority
- Academia
- Private sector
- Other (please specify)

Feedback/Contact

13. Please share any other comments you have below:

14. If you would like to be notified about the result of this survey, please provide an email address.

Email Address

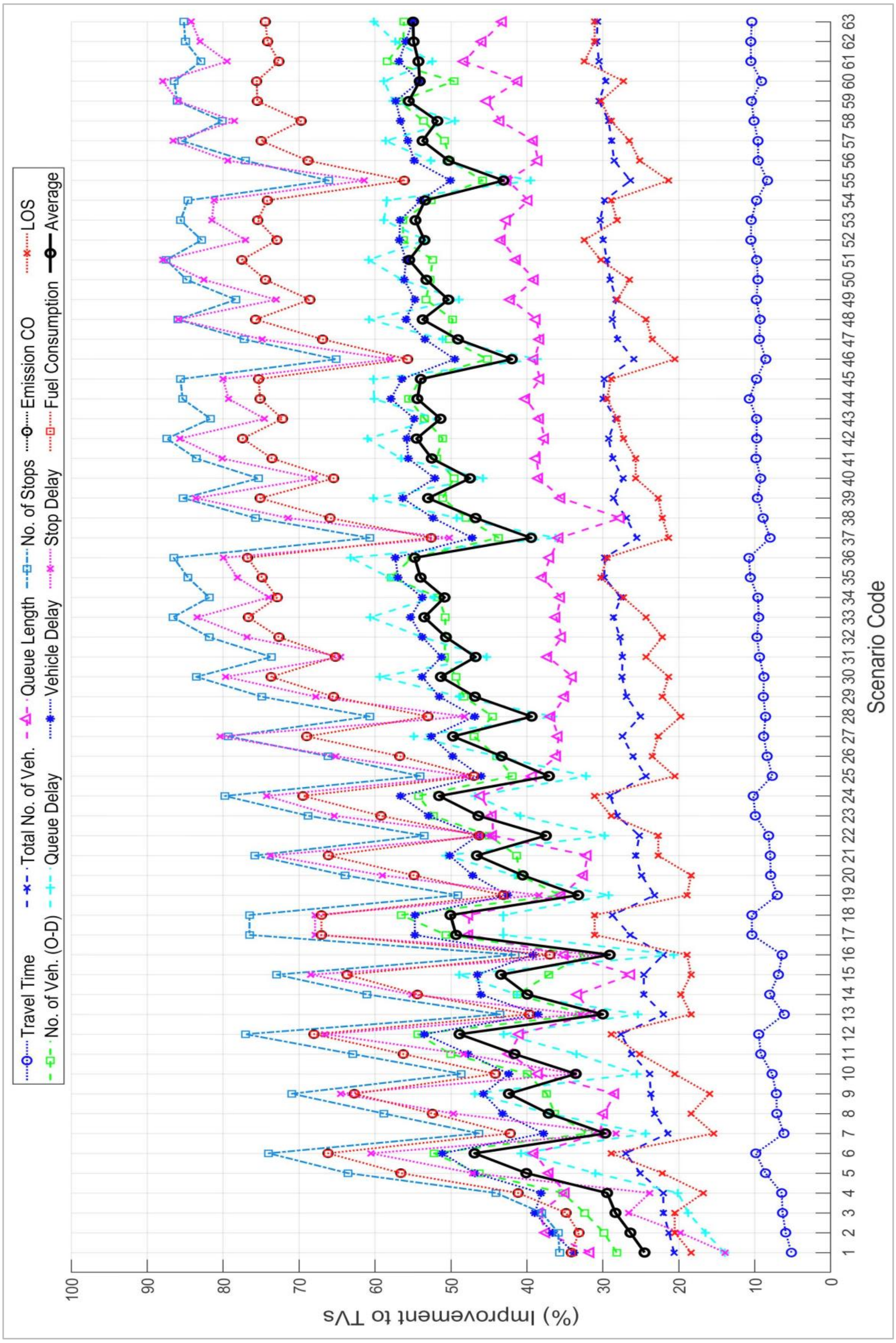
APPENDIX D: Result Tables Related to the Optimisation of Driving Behaviours

D1. Results of the simulation of 63 scenarios for the optimisation of CC0, CC1, and CC2

Scenario	Travel time from beginning to end	Vehicles from beginning to end	Total vehicles in the model	Queue delay	Queue length	Vehicle delay	Number of stops	Stop delay	Emission CO	Fuel consumption	LOS value	LOS index (range)
	hh:mm	Count	Count	hh:mm	km	hh:mm	Count	hh:mm	Ton.	Litre	1-6	A-F
TVs	02:17	1,139	34,931	01:23	2.46	01:18	1,112	00:17	2.18	117,821	3.70	C-D
1	02:10	1,460	42,132	01:12	1.68	00:51	715	00:14	1.43	77,582	3.02	C-D
2	02:09	1,479	42,368	01:10	1.54	00:49	713	00:13	1.45	78,767	2.94	B-C
3	02:08	1,508	42,626	01:08	1.51	00:47	689	00:12	1.42	76,776	2.94	B-C
4	02:08	1,541	42,634	01:07	1.60	00:48	622	00:13	1.28	69,330	3.08	C-D
5	02:05	1,666	43,693	00:57	1.55	00:41	405	00:09	0.94	51,133	2.88	B-C
6	02:03	1,734	44,362	00:49	1.50	00:38	289	00:06	0.74	39,841	2.63	B-C
7	02:08	1,503	42,416	01:03	1.71	00:48	597	00:12	1.26	68,100	3.13	C-D
8	02:07	1,553	43,032	00:52	1.72	00:44	458	00:08	1.03	56,035	3.02	C-D
9	02:07	1,565	43,206	00:44	1.76	00:42	323	00:06	0.81	43,918	3.11	C-D
10	02:06	1,594	43,264	01:02	1.51	00:44	571	00:11	1.21	65,790	2.94	B-C
11	02:04	1,709	44,083	00:55	1.42	00:40	412	00:08	0.95	51,516	2.77	B-C
12	02:04	1,758	44,577	00:47	1.45	00:36	255	00:05	0.70	37,657	2.63	B-C
13	02:08	1,508	42,620	01:02	1.68	00:47	628	00:11	1.31	71,105	3.02	C-D
14	02:06	1,609	43,534	00:49	1.64	00:42	433	00:07	0.99	53,692	2.97	B-C
15	02:07	1,562	43,523	00:42	1.81	00:41	301	00:05	0.79	42,786	3.02	C-D
16	02:08	1,509	42,626	01:06	1.60	00:47	650	00:12	1.37	74,266	3.00	C
17	02:04	1,716	44,160	00:54	1.39	00:38	377	00:07	0.93	50,123	2.69	B-C
18	02:02	1,783	44,970	00:47	1.29	00:35	261	00:05	0.72	38,819	2.55	B-C
19	02:07	1,545	43,029	00:59	1.59	00:44	566	00:10	1.24	67,036	3.00	C
20	02:06	1,605	43,634	00:49	1.66	00:41	401	00:07	0.98	53,177	3.02	C-D
21	02:06	1,610	43,904	00:41	1.67	00:38	269	00:04	0.74	39,910	2.86	B-C
22	02:05	1,651	43,729	00:58	1.36	00:41	517	00:09	1.17	63,322	2.86	B-C
23	02:03	1,735	44,746	00:49	1.36	00:36	347	00:05	0.89	48,044	2.63	B-C
24	02:03	1,757	45,077	00:44	1.32	00:33	225	00:04	0.66	35,946	2.55	B-C
25	02:06	1,617	43,431	00:56	1.49	00:42	511	00:08	1.15	62,474	2.94	B-C
26	02:05	1,640	44,024	00:47	1.57	00:39	376	00:06	0.94	50,967	2.83	B-C
27	02:05	1,674	44,511	00:37	1.58	00:36	230	00:03	0.67	36,537	2.86	B-C
28	02:05	1,646	43,684	00:53	1.55	00:41	437	00:08	1.02	55,331	2.97	B-C
29	02:05	1,689	44,325	00:42	1.60	00:37	279	00:05	0.75	40,689	2.88	B-C
30	02:05	1,701	44,531	00:34	1.62	00:36	183	00:03	0.57	31,014	2.91	B-C
31	02:04	1,718	44,506	00:45	1.54	00:38	293	00:06	0.76	40,988	2.80	B-C
32	02:03	1,717	44,622	00:38	1.59	00:36	202	00:04	0.60	32,233	2.88	B-C
33	02:04	1,717	44,926	00:33	1.57	00:34	149	00:02	0.51	27,482	2.80	B-C
34	02:04	1,727	44,581	00:40	1.58	00:36	202	00:04	0.59	31,953	2.69	B-C

35	02:02	1,798	45,347	00:35	1.52	00:33	171	00:03	0.55	29,613	2.58	B-C
36	02:02	1,767	45,323	00:30	1.55	00:33	150	00:03	0.51	27,361	2.61	B-C
37	02:06	1,637	43,856	00:53	1.58	00:41	437	00:08	1.03	55,842	2.91	B-C
38	02:04	1,686	44,334	00:42	1.78	00:37	270	00:04	0.74	40,156	2.88	B-C
39	02:03	1,721	44,929	00:33	1.58	00:34	164	00:02	0.54	29,314	2.86	B-C
40	02:04	1,704	44,483	00:45	1.51	00:37	274	00:05	0.75	40,708	2.75	B-C
41	02:03	1,730	44,959	00:36	1.50	00:34	183	00:03	0.58	31,158	2.75	B-C
42	02:03	1,721	45,149	00:32	1.53	00:34	140	00:02	0.49	26,593	2.69	B-C
43	02:03	1,748	44,819	00:40	1.52	00:35	204	00:04	0.61	32,774	2.66	B-C
44	02:02	1,772	45,390	00:33	1.47	00:32	163	00:03	0.54	29,303	2.61	B-C
45	02:03	1,754	45,348	00:33	1.52	00:33	160	00:03	0.54	29,076	2.63	B-C
46	02:05	1,654	43,995	00:51	1.50	00:39	388	00:07	0.96	52,189	2.94	B-C
47	02:04	1,711	44,727	00:41	1.52	00:36	253	00:04	0.72	38,994	2.83	B-C
48	02:04	1,706	44,973	00:32	1.50	00:34	156	00:02	0.53	28,599	2.80	B-C
49	02:03	1,746	44,796	00:42	1.42	00:35	241	00:04	0.68	37,021	2.66	B-C
50	02:04	1,740	45,069	00:36	1.50	00:34	169	00:03	0.56	30,147	2.72	B-C
51	02:03	1,736	45,221	00:32	1.44	00:34	139	00:02	0.49	26,471	2.58	B-C
52	02:02	1,780	45,393	00:39	1.39	00:33	191	00:03	0.59	31,911	2.50	B-C
53	02:02	1,781	45,541	00:34	1.41	00:33	160	00:03	0.53	28,928	2.66	B-C
54	02:03	1,738	45,338	00:34	1.48	00:35	171	00:03	0.56	30,431	2.63	B-C
55	02:05	1,661	44,142	00:50	1.41	00:38	377	00:06	0.95	51,675	2.91	B-C
56	02:04	1,710	44,892	00:39	1.51	00:35	255	00:03	0.68	36,741	2.77	B-C
57	02:04	1,718	45,011	00:34	1.50	00:34	162	00:02	0.54	29,469	2.72	B-C
58	02:03	1,750	45,145	00:42	1.39	00:33	221	00:03	0.66	35,666	2.63	B-C
59	02:02	1,786	45,590	00:35	1.34	00:33	155	00:02	0.53	28,879	2.58	B-C
60	02:04	1,704	45,277	00:34	1.45	00:35	151	00:02	0.53	28,765	2.69	B-C
61	02:02	1,804	45,589	00:39	1.27	00:33	190	00:03	0.59	32,218	2.50	B-C
62	02:02	1,780	45,689	00:35	1.33	00:34	167	00:02	0.56	30,465	2.55	B-C
63	02:02	1,779	45,657	00:33	1.40	00:35	165	00:02	0.56	30,113	2.55	B-C

D2. Improvement of each scenario compared with the results of the simulation of TVs



D3. Results of the simulation regarding the impact of CC0, CC1, and CC2 on queue length

Count	Scenario	Queue length	Improvement to TVs	CC0	CC1	CC2
1	61	1,271	48.2%	0.38	0.23	3.00
2	18	1,286	47.6%	0.75	0.23	4.00
3	24	1,324	46.1%	0.38	0.23	4.00
4	62	1,329	45.9%	0.38	0.23	2.00
5	59	1,344	45.3%	0.38	0.45	2.00
6	23	1,362	44.5%	0.38	0.45	4.00
7	22	1,363	44.5%	0.38	0.68	4.00
8	17	1,387	43.5%	0.75	0.45	4.00
9	58	1,387	43.5%	0.38	0.45	3.00
10	52	1,391	43.3%	0.75	0.23	3.00
11	63	1,395	43.2%	0.38	0.23	1.00
12	53	1,408	42.6%	0.75	0.23	2.00
13	55	1,410	42.6%	0.75	0.23	2.00
14	11	1,416	42.3%	1.13	0.45	4.00
15	49	1,421	42.1%	0.75	0.45	3.00
16	51	1,440	41.3%	0.75	0.45	1.00
17	60	1,445	41.1%	0.38	0.45	1.00
18	12	1,450	40.9%	1.13	0.23	4.00
19	44	1,470	40.1%	1.13	0.23	2.00
20	54	1,478	39.8%	0.75	0.23	1.00
Base	TV	2,455	-	1.50	0.90	4.00

D4. The frequency of factorial changes regarding the effect of CC0, CC1, and CC2 on queue length

CC-parameter	**CC0**			**CC1**			**CC2**		
Initial value	1.5			0.9			4		
Factorial change	-25%	-50%	-75%	-25%	-50%	-75%	-25%	-50%	-75%
Reduced value	1.13	0.75	0.38	0.68	0.45	0.23	3.00	2.00	1.00
Frequency	3	8	9	1	8	11	4	5	4
Total frequency	**20**			**20**			**13**		

D5. Results of the simulation regarding the impact of CC0, CC1, and CC2 on queue delay

Count	Scenario	Queue delay	Improvement to TVs	CC0	CC1	CC2
1	36	1,853	63.2%	1.50	0.23	1.00
2	42	1,967	61.0%	1.13	0.45	1.00
3	51	1,973	60.8%	0.75	0.45	1.00
4	48	1,976	60.8%	0.75	0.68	1.00
5	33	1,984	60.6%	1.50	0.45	1.00
6	45	2,004	60.2%	1.13	0.23	1.00
7	39	2,006	60.2%	1.13	0.68	1.00
8	63	2,008	60.1%	0.38	0.23	1.00
9	44	2,010	60.1%	1.13	0.23	2.00
10	30	2,048	59.3%	1.50	0.68	1.00
11	53	2,075	58.8%	0.75	0.23	2.00
12	60	2,075	58.8%	0.38	0.45	1.00
13	57	2,085	58.6%	0.38	0.68	1.00
14	54	2,094	58.4%	0.75	0.23	1.00
15	35	2,112	58.1%	1.50	0.23	2.00
16	59	2,135	57.6%	0.38	0.45	2.00
17	62	2,150	57.3%	0.38	0.23	2.00
18	41	2,189	56.6%	1.13	0.45	2.00
19	50	2,195	56.4%	0.75	0.45	2.00
20	27	2,273	54.9%	0.38	0.90	1.00
Base	TV	5,038	-	1.50	0.90	4.00

D6. The frequency of factorial changes regarding the impact of CC0, CC1, and CC2 on queue delay

CC-parameter	CC0			CC1			CC2		
Initial value	1.5			0.9			4		
Factorial change	-25%	-50%	-75%	-25%	-50%	-75%	-25%	-50%	-75%
Reduced value	1.13	0.75	0.38	0.68	0.45	0.23	3.00	2.00	1.00
Frequency	5	5	6	4	7	8	0	7	13
Total frequency	16			19			20		

D7. Results of the simulation regarding the impact of CC0, CC1, and CC2 on the number of stops

Count	Scenario	Number of Stops	Improvement to TVs	CC0	CC1	CC2
1	51	139	87.5%	0.75	0.45	1.00
2	42	140	87.4%	1.13	0.45	1.00
3	33	149	86.6%	1.50	0.45	1.00
4	36	150	86.5%	1.50	0.23	1.00
5	60	151	86.4%	0.38	0.45	1.00
6	59	155	86.1%	0.38	0.45	2.00
7	48	156	86.0%	0.75	0.68	1.00
8	45	160	85.6%	1.13	0.23	1.00
9	53	160	85.6%	0.75	0.23	2.00
10	57	162	85.4%	0.38	0.68	1.00
11	44	163	85.3%	1.13	0.23	2.00
12	39	164	85.3%	1.13	0.68	1.00
13	63	165	85.2%	0.38	0.23	1.00
14	62	167	85.0%	0.38	0.23	2.00
15	50	169	84.8%	0.75	0.45	2.00
16	35	171	84.6%	1.50	0.23	2.00
17	54	171	84.6%	0.75	0.23	1.00
18	30	183	83.5%	1.50	0.68	1.00
19	41	183	83.5%	1.13	0.45	2.00
20	61	190	82.9%	0.38	0.23	3.00
Base	TV	1,112	-	1.50	0.90	4.00

D8. The frequency of factorial changes regarding the impact of CC0, CC1, and CC2 on the number of stops

CC-parameter	CC0			CC1			CC2		
Initial value	1.5			0.9			4		
Factorial change	-25%	-50%	-75%	-25%	-50%	-75%	-25%	-50%	-75%
Reduced value	1.13	0.75	0.38	0.68	0.45	0.23	3.00	2.00	1.00
Frequency	5	5	6	4	7	9	1	7	12
Total frequency	**16**			**20**			**20**		

D9. Results of the simulation regarding the impact of CC0, CC1, and CC2 on stop delay

Count	Scenario	Stop delay	Improvement to TVs	CC0	CC1	CC2
1	51	00:02:05	87.9%	0.75	0.45	1.00
2	60	00:02:05	87.9%	0.38	0.45	1.00
3	57	00:02:19	86.6%	0.38	0.68	1.00
4	48	00:02:26	85.9%	0.75	0.68	1.00
5	59	00:02:26	85.9%	0.38	0.45	2.00
6	42	00:02:28	85.7%	1.13	0.45	1.00
7	63	00:02:44	84.2%	0.38	0.23	1.00
8	39	00:02:50	83.6%	1.13	0.68	1.00
9	33	00:02:52	83.4%	1.50	0.45	1.00
10	62	00:02:56	83.0%	0.38	0.23	2.00
11	50	00:03:01	82.5%	0.75	0.45	2.00
12	53	00:03:12	81.5%	0.75	0.23	2.00
13	54	00:03:15	81.2%	0.75	0.23	1.00
14	27	00:03:23	80.4%	0.38	0.90	1.00
15	41	00:03:26	80.1%	1.13	0.45	2.00
16	45	00:03:27	80.0%	1.13	0.23	1.00
17	36	00:03:28	79.9%	1.50	0.23	1.00
18	30	00:03:31	79.7%	1.50	0.68	1.00
19	61	00:03:33	79.5%	0.38	0.23	3.00
20	56	00:03:34	79.4%	0.38	0.68	2.00
Base	TV	00:17:17	-	1.50	0.90	4.00

D10. The frequency of factorial changes regarding the impact of CC0, CC1, and CC2 on stop delay

CC-parameter	**CC0**			**CC1**			**CC2**		
Initial value	1.5			0.9			4		
Factorial change	-25%	-50%	-75%	-25%	-50%	-75%	-25%	-50%	-75%
Reduced value	1.13	0.75	0.38	0.68	0.45	0.23	3.00	2.00	1.00
Frequency	4	5	8	5	7	7	1	5	13
Total frequency	**17**			**19**			**19**		

D11. Results of the simulation regarding the impact of CC0, CC1, and CC2 on fuel consumption and CO emissions

Count	Scenario	Emission	Fuel consumption	Improvement to TVs	CC0	CC1	CC2
1	51	0.49	26,471	77.5%	0.75	0.45	1.00
2	42	0.49	26,593	77.4%	1.13	0.45	1.00
3	36	0.51	27,361	76.8%	1.50	0.23	1.00
4	33	0.51	27,482	76.7%	1.50	0.45	1.00
5	48	0.53	28,599	75.7%	0.75	0.68	1.00
6	60	0.53	28,765	75.6%	0.38	0.45	1.00
7	59	0.53	28,879	75.5%	0.38	0.45	2.00
8	53	0.53	28,928	75.4%	0.75	0.23	2.00
9	45	0.54	29,076	75.3%	1.13	0.23	1.00
10	44	0.54	29,303	75.1%	1.13	0.23	2.00
11	39	0.54	29,314	75.1%	1.13	0.68	1.00
12	57	0.54	29,469	75.0%	0.38	0.68	1.00
13	35	0.55	29,613	74.9%	1.50	0.23	2.00
14	63	0.56	30,113	74.4%	0.38	0.23	1.00
15	50	0.56	30,147	74.4%	0.75	0.45	2.00
16	54	0.56	30,431	74.2%	0.75	0.23	1.00
17	62	0.56	30,465	74.1%	0.38	0.23	2.00
18	30	0.57	31,014	73.7%	1.50	0.68	1.00
19	41	0.58	31,158	73.6%	1.13	0.45	2.00
20	52	0.59	31,911	72.9%	0.75	0.23	3.00
Base	TV	2.18	117,821	-	1.50	0.90	4.00

D12. The frequency of factorial changes regarding the impact of CC0, CC1, and CC2 on fuel consumption and CO emissions

CC-parameter	**CC0**			**CC1**			**CC2**		
Initial value	1.5			0.9			4		
Factorial change	-25%	-50%	-75%	-25%	-50%	-75%	-25%	-50%	-75%
Reduced value	1.13	0.75	0.38	0.68	0.45	0.23	3.00	2.00	1.00
Frequency	5	6	5	4	7	9	1	7	12
Total frequency	**16**			**20**			**20**		

D13. Results of the simulation regarding the impact of CC0, CC1, and CC2 on LOS

Count	Scenario	LOS	Improvement to TVs	CC0	CC1	CC2
1	52	2.50	32.4%	0.75	0.23	3.00
2	61	2.50	32.4%	0.38	0.23	3.00
3	18	2.55	31.1%	0.75	0.23	4.00
4	24	2.55	31.1%	0.38	0.23	4.00
5	62	2.55	31.1%	0.38	0.23	2.00
6	63	2.55	31.1%	0.38	0.23	1.00
7	35	2.58	30.3%	1.50	0.23	2.00
8	51	2.58	30.3%	0.75	0.45	1.00
9	59	2.58	30.3%	0.38	0.45	2.00
10	36	2.61	29.5%	1.50	0.23	1.00
11	44	2.61	29.5%	1.13	0.23	2.00
12	6	2.63	28.9%	1.13	0.23	4.00
13	12	2.63	28.9%	1.13	0.23	4.00
14	23	2.63	28.9%	0.38	0.45	4.00
15	45	2.63	28.9%	1.13	0.23	1.00
16	54	2.63	28.9%	0.75	0.23	1.00
17	58	2.63	28.9%	0.38	0.45	3.00
18	43	2.66	28.1%	1.13	0.23	3.00
19	49	2.66	28.1%	0.75	0.45	3.00
20	17	2.69	27.3%	0.75	0.45	4.00
Base	TV	3.70	-	1.50	0.90	4.00

D14. The frequency of factorial changes regarding the impact of CC0, CC1, and CC2 on LOS

CC-parameter	**CC0**			**CC1**			**CC2**		
Initial value	1.5			0.9			4		
Factorial change	-25%	-50%	-75%	-25%	-50%	-75%	-25%	-50%	-75%
Reduced value	1.13	0.75	0.38	0.68	0.45	0.23	3.00	2.00	1.00
Frequency	5	6	7	0	6	14	5	4	5
Total frequency	**18**			**20**			**14**		

APPENDIX E: Simulation Results of TVs and AVs in Various Traffic Conditions of the Year

E1. Number of TVs under various time-intervals of the simulation model of a test month (May. 4th)

Run	Data collection points	Simulation time-intervals*						
		Warm-up	Recorded for evaluation					
		0 - 600	600-1200	1200-1800	1800-2400	2400-3000	3000-3600	3600-4200
1	1-4	**	887	827	841	827	874	889
1	5-8	**	956	977	964	965	945	910
1	9-12	**	985	1171	1231	672	871	690
1	13-16	**	1282	1274	994	943	1074	800
1	17-20	**	1355	1165	1248	980	1131	1000
1	21-24	**	1364	1081	1075	1106	1094	1075
1	25-28	**	876	849	855	844	842	884
2	1-4	**	820	870	872	825	877	918
2	5-8	**	919	910	994	957	962	976
2	9-12	**	1109	1204	1186	587	983	402
2	13-16	**	1246	1188	895	1069	876	792
2	17-20	**	1199	1191	1082	1040	1097	1084
2	21-24	**	1097	1097	1150	1095	1090	1220
2	25-28	**	846	862	872	830	874	876
3	1-4	**	870	834	854	853	885	876
3	5-8	**	932	974	958	949	981	919
3	9-12	**	1098	1232	1011	794	894	629
3	13-16	**	1220	1225	902	1103	747	802
3	17-20	**	1199	1298	946	1055	1173	1183
3	21-24	**	1102	1116	1188	1243	1212	1180
3	25-28	**	860	827	867	840	903	859
4	1-4	**	861	842	831	817	925	835
4	5-8	**	921	1019	946	944	925	870
4	9-12	**	986	1146	1181	819	784	750
4	13-16	**	1232	1179	1193	923	666	942
4	17-20	**	1451	982	1061	1094	984	1078
4	21-24	**	1172	1092	1074	1114	1220	1272
4	25-28	**	898	836	800	850	926	850
5	1-4	**	898	858	838	863	861	890
5	5-8	**	874	1032	1002	937	1005	835
5	9-12	**	1132	1253	981	799	715	741
5	13-16	**	1302	1040	985	1169	925	924
5	17-20	**	1139	1339	1149	1118	1045	1136
5	21-24	**	1131	1268	1083	1115	1113	1080
5	25-28	**	871	864	854	857	849	874
6	1-4	**	845	832	861	890	909	841
6	5-8	**	914	936	957	982	995	1007

6	9-12	**	1049	1286	1070	805	754	740
6	13-16	**	1252	1094	1015	968	920	984
6	17-20	**	1177	1226	1069	1226	1056	1056
6	21-24	**	1173	1247	1091	1101	1144	1261
6	25-28	**	831	836	862	883	894	851
7	1-4	**	853	915	878	837	831	843
7	5-8	**	912	994	1032	983	969	843
7	9-12	**	1031	1297	1077	749	719	817
7	13-16	**	1361	1350	729	1201	623	971
7	17-20	**	1304	1283	894	1112	1036	1035
7	21-24	**	1145	1051	1122	1075	1124	1105
7	25-28	**	844	932	875	841	829	843
8	1-4	**	858	885	851	864	846	839
8	5-8	**	960	964	1013	961	992	956
8	9-12	**	1128	1204	957	897	740	683
8	13-16	**	1308	1320	912	857	868	896
8	17-20	**	1307	1088	1108	1090	1119	1062
8	21-24	**	1145	1194	1078	1148	1246	1226
8	25-28	**	869	896	850	845	844	836
9	1-4	**	876	880	860	811	860	854
9	5-8	**	927	999	1034	940	950	900
9	9-12	**	1035	1132	1067	787	845	976
9	13-16	**	1252	1291	891	1060	721	1042
9	17-20	**	1313	1256	927	1180	1024	1122
9	21-24	**	1190	1124	1111	1207	1099	1054
9	25-28	**	875	888	845	840	856	860
10	1-4	**	840	854	852	852	923	877
10	5-8	**	902	957	999	960	949	858
10	9-12	**	1102	1184	1096	763	881	606
10	13-16	**	1290	1282	787	959	836	945
10	17-20	**	1197	1119	1115	1128	1133	1097
10	21-24	**	1258	1190	1130	1174	1179	1143
10	25-28	**	838	843	846	861	911	883
11	1-4	**	906	855	841	869	855	819
11	5-8	**	930	1016	1007	989	946	874
11	9-12	**	981	1131	1249	779	764	870
11	13-16	**	1289	1230	982	1165	1230	670
11	17-20	**	1247	1400	1330	949	1073	1168
11	21-24	**	1309	1376	1083	1194	1246	1181
11	25-28	**	879	884	847	843	865	844
12	1-4	**	787	887	891	866	847	857
12	5-8	**	937	889	1030	984	982	974
12	9-12	**	1011	1223	1001	927	770	727
12	13-16	**	1288	1308	792	1052	783	1096
12	17-20	**	1258	1222	958	1250	1119	1208
12	21-24	**	1143	1175	1232	1252	1174	1214
12	25-28	**	801	897	853	875	867	845
13	1-4	**	813	843	876	932	862	830
13	5-8	**	918	922	964	976	1024	933
13	9-12	**	1107	1267	908	854	869	628

13	13-16	**	1268	1189	1086	1021	944	755
13	17-20	**	1376	1225	1084	1034	1043	1040
13	21-24	**	1331	1095	1097	1077	1146	1270
13	25-28	**	817	849	860	906	874	864
14	1-4	**	890	892	816	847	886	828
14	5-8	**	931	988	991	923	960	828
14	9-12	**	1138	1260	915	774	715	882
14	13-16	**	1161	1318	874	948	914	1198
14	17-20	**	1198	1070	1130	1398	1142	1058
14	21-24	**	1265	1158	1120	1347	1037	1207
14	25-28	**	887	866	824	847	885	846
15	1-4	**	867	852	852	890	806	898
15	5-8	**	912	1002	955	964	1011	780
15	9-12	**	1124	1150	1126	788	741	742
15	13-16	**	1217	1294	985	1089	989	889
15	17-20	**	1259	1330	1259	949	1019	1034
15	21-24	**	1293	1179	1071	1101	1191	1129
15	25-28	**	863	858	831	904	812	895

* The time interval 0-600 (seconds of the simulation time) represents the time-interval used for filling up the road network
** Not recorded for evaluations

E2. Simulation of TVs in 10 peak traffic conditions in the peak month (May)

MAY-Peak	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-04th	03:10:56	1,354	41,778	02:27:31	4	02:08:58	1,426	00:30:19	2.61	141,364	4.53
AM-09th	03:10:29	1,340	41,621	02:24:31	4	02:07:34	1,415	00:29:57	2.58	138,697	4.44
AM-10th	03:08:21	1,397	41,770	02:19:15	4	02:02:05	1,333	00:29:42	2.48	134,219	4.36
AM-11th	03:10:36	1,336	41,411	02:25:43	4	02:06:35	1,398	00:30:37	2.56	138,879	4.42
AM-16th	03:09:41	1,350	41,450	02:22:11	4	02:05:11	1,368	00:29:14	2.50	135,152	4.47
AM-17th	03:11:15	1,353	41,888	02:27:48	4	02:09:01	1,434	00:30:40	2.62	141,902	4.47
AM-24th	03:11:08	1,325	41,247	02:25:19	4	02:08:24	1,391	00:30:26	2.51	135,683	4.42
AM-25th	03:08:13	1,357	41,290	02:19:08	4	02:00:46	1,313	00:28:05	2.43	131,607	4.39
AM-30th	03:08:53	1,378	41,668	02:18:55	4	02:03:27	1,340	00:29:11	2.48	134,333	4.39
AM-31st	03:08:59	1,430	42,422	02:24:24	4	02:04:52	1,402	00:29:10	2.57	139,343	4.39
Average	**03:09:51**	**1,362**	**41,655**	**02:23:28**	**4.03**	**02:05:41**	**1,382**	**00:29:44**	**2.53**	**137,118**	**4.43**

E3. Simulation of AVs in 10 peak traffic conditions in the peak month (May)

MAY-Peak	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-04th	02:46:04	2,179	50,714	00:54:08	2	00:55:30	205	00:02:10	0.67	36,441	3.14
AM-09th	02:46:38	2,121	50,387	00:53:43	2	00:55:33	206	00:02:11	0.68	36,701	3.19
AM-10th	02:43:54	2,229	50,599	00:49:21	2	00:50:56	186	00:01:49	0.64	34,414	3.06
AM-11th	02:44:40	2,185	50,377	00:52:29	2	00:53:54	200	00:02:01	0.66	36,010	3.06
AM-16th	02:43:45	2,171	50,347	00:50:31	2	00:52:13	191	00:01:55	0.64	34,523	2.97
AM-17th	02:47:32	2,155	50,721	00:55:51	2	00:57:46	216	00:02:16	0.70	37,703	3.22
AM-24th	02:45:36	2,144	50,291	00:53:20	2	00:54:11	204	00:02:06	0.67	36,187	3.14
AM-25th	02:42:44	2,186	50,111	00:49:31	2	00:50:39	187	00:01:47	0.64	34,431	2.94
AM-30th	02:44:16	2,217	50,443	00:51:20	2	00:52:25	194	00:01:58	0.65	35,148	3.06
AM-31st	02:45:47	2,237	51,032	00:55:00	2	00:56:08	210	00:02:15	0.68	36,763	3.11
Average	**02:45:06**	**2,182**	**50,502**	**00:52:31**	**2**	**00:53:56**	**200**	**00:02:03**	**1**	**35,832**	**3.09**

E4. Simulation of TVs in 10 normal traffic conditions in peak month (May)

Normal conditions in May	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
PM-02nd	02:34:55	1,169	33,391	01:02:12	1.16	00:51:05	483	00:12:10	1.08	58,367	3.19
PM-03rd	02:36:07	1,207	33,924	01:03:58	1.17	00:53:25	500	00:12:50	1.11	60,155	3.33
PM-09th	02:35:30	1,215	33,861	01:03:13	1.14	00:53:01	503	00:12:31	1.09	59,174	3.31
PM-11th	02:35:10	1,282	34,423	01:03:24	1.11	00:52:33	502	00:12:36	1.11	60,374	3.33
PM-15th	02:32:30	1,180	33,279	00:59:09	1.06	00:48:01	467	00:11:28	1.04	56,447	3.19
PM-16th	02:33:37	1,161	33,308	01:01:39	1.11	00:49:20	480	00:11:58	1.07	57,729	3.28
PM-18th	02:34:12	1,215	33,709	01:01:45	1.10	00:50:43	477	00:11:55	1.07	58,089	3.31
PM-23rd	02:35:01	1,198	33,661	01:01:33	1.11	00:51:49	482	00:12:29	1.09	59,222	3.36
PM-25th	02:36:10	1,252	34,054	01:02:55	1.16	00:53:34	483	00:12:42	1.08	58,275	3.44
PM-30th	02:33:53	1,196	33,753	01:01:57	1.09	00:50:26	494	00:11:58	1.11	59,897	3.33
Average	**02:34:43**	**1,208**	**33,736**	**01:02:11**	**1.12**	**00:51:24**	**487**	**00:12:16**	**1.09**	**58,773**	**3.31**

E5. Simulation of AVs in 10 normal traffic conditions in the peak month (May)

Normal conditions in May	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
PM-02nd	02:05:37	1,726	39,070	00:05:13	0.08	00:05:36	18	00:00:29	0.19	10,353	1.64
PM-03rd	02:07:53	1,664	38,278	00:06:11	0.05	00:07:47	24	00:00:34	0.20	11,027	1.97
PM-09th	02:07:56	1,769	39,996	00:06:18	0.08	00:07:42	24	00:00:30	0.21	11,602	1.83
PM-11th	02:08:45	1,865	40,370	00:08:00	0.07	00:08:34	28	00:00:39	0.23	12,211	1.92
PM-15th	02:05:41	1,686	38,963	00:04:46	0.04	00:05:46	18	00:00:30	0.19	10,453	1.64
PM-16th	02:05:11	1,708	39,247	00:04:24	0.02	00:05:29	16	00:00:30	0.19	10,290	1.67
PM-18th	02:06:14	1,711	39,663	00:05:32	0.06	00:06:12	19	00:00:29	0.20	10,788	1.72
PM-23rd	02:05:23	1,777	39,828	00:04:58	0.01	00:05:41	18	00:00:29	0.20	10,588	1.72
PM-25th	02:06:38	1,873	40,353	00:05:30	0.04	00:06:39	20	00:00:29	0.20	11,004	1.78
PM-30th	02:07:13	1,736	39,649	00:06:03	0.05	00:07:12	23	00:00:33	0.21	11,333	1.86
Average	**02:06:39**	**1,752**	**39,542**	**00:05:41**	**0.05**	**00:06:40**	**21**	**00:00:31**	**0.20**	**10,965**	**1.78**

E6. Simulation of TVs in 10 off-peak traffic conditions in the peak month (May)

Off-peak conditions in May	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-01st	01:53:17	1,866	29,441	00:00:00	0.00	00:01:19	0	00:00:00	0.11	6,042	1.00
AM-06th	02:05:30	1,807	33,072	00:13:49	0.29	00:12:22	79	00:02:33	0.31	16,621	1.86
PM-06th	02:19:52	1,789	35,798	00:38:31	0.66	00:32:15	256	00:06:46	0.68	36,838	2.89
AM-07th	02:00:02	1,771	32,313	00:05:58	0.17	00:07:16	37	00:01:13	0.21	11,469	1.56
AM-13th	02:07:52	1,766	33,350	00:17:12	0.33	00:15:02	97	00:03:06	0.35	18,959	2.14
AM-14th	01:54:48	1,948	31,077	00:00:35	0.02	00:02:32	5	00:00:09	0.13	7,012	1.11
AM-20th	02:12:46	1,765	34,124	00:25:42	0.47	00:20:48	159	00:04:43	0.48	26,182	2.50
AM-21st	01:59:07	1,930	32,300	00:03:57	0.13	00:06:35	25	00:00:56	0.18	9,837	1.47
AM-27th	02:09:37	1,856	34,136	00:21:28	0.39	00:17:41	125	00:03:50	0.41	22,295	2.19
AM-28th	01:58:29	1,860	31,671	00:03:21	0.11	00:06:07	22	00:00:53	0.17	9,392	1.42
Average	**02:04:08**	**1,836**	**32,728**	**00:13:03**	**0.26**	**00:12:12**	**81**	**00:02:25**	**0.30**	**16,465**	**1.81**

E7. Simulation of AVs in 10 off-peak traffic conditions in the peak month (May)

Off-peak conditions in May	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-01st	02:00:00	1,818	29,258	00:00:00	0.00	00:00:03	0	00:00:00	0.10	5,601	1.00
AM-06th	02:00:03	1,992	34,464	00:00:03	0.00	00:00:08	0	00:00:01	0.12	6,674	1.00
PM-06th	02:01:51	2,337	39,927	00:01:56	0.00	00:02:08	5	00:00:15	0.16	8,528	1.28
AM-07th	02:00:02	1,857	32,933	00:00:03	0.00	00:00:08	0	00:00:01	0.12	6,393	1.00
AM-13th	02:00:05	2,018	35,235	00:00:08	0.00	00:00:14	0	00:00:02	0.13	6,844	1.00
AM-14th	02:00:01	1,920	30,980	00:00:01	0.00	00:00:04	0	00:00:00	0.11	5,931	1.00
AM-20th	02:00:11	2,135	36,828	00:00:16	0.00	00:00:22	0	00:00:03	0.13	7,212	1.00
AM-21st	02:00:01	2,004	32,691	00:00:01	0.00	00:00:05	0	00:00:00	0.12	6,268	1.00
AM-27th	02:00:14	2,162	36,423	00:00:18	0.00	00:00:23	1	00:00:03	0.13	7,115	1.00
AM-28th	02:00:01	1,912	31,979	00:00:01	0.00	00:00:05	0	00:00:00	0.11	6,123	1.00
Average	**02:00:15**	**2,016**	**34,072**	**00:00:17**	**0.00**	**00:00:22**	**1**	**00:00:03**	**0.12**	**6,669**	**1.03**

E8. Simulation of TVs in 10 peak traffic conditions in the normal month (September)

Peak conditions in Sep.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-4th	03:07:55	1,389	41,309	02:17:39	3.85	02:00:03	1,300	00:28:34	2.42	131,261	4.42
AM-7th	03:09:08	1,267	40,146	02:19:38	3.82	02:00:29	1,305	00:29:24	2.44	131,979	4.44
AM-8th	03:09:00	1,342	41,004	02:19:05	3.93	02:03:09	1,345	00:29:31	2.47	133,622	4.42
AM-11th	03:07:06	1,370	40,949	02:15:34	3.68	01:58:16	1,280	00:28:01	2.37	128,519	4.33
AM-12th	03:08:03	1,354	41,274	02:16:36	3.76	02:01:27	1,317	00:28:59	2.42	130,942	4.42
AM-13th	03:08:37	1,397	41,586	02:17:09	3.82	02:01:52	1,330	00:29:13	2.45	132,574	4.44
AM-14th	03:08:00	1,401	41,792	02:18:26	3.78	02:01:26	1,330	00:29:05	2.45	132,606	4.28
AM-19th	03:07:43	1,393	41,441	02:15:51	3.69	02:00:31	1,326	00:29:13	2.41	130,407	4.39
AM-20th	03:10:55	1,318	41,203	02:22:53	4.02	02:07:09	1,395	00:30:21	2.53	137,245	4.50
AM-21st	03:09:49	1,308	40,681	02:20:33	3.93	02:04:35	1,366	00:30:29	2.47	133,527	4.53
Average	**03:08:38**	**1,354**	**41,139**	**02:18:20**	**3.83**	**02:01:54**	**1329**	**00:29:17**	**2.443**	**132268.2**	**4.42**

E9. Simulation of AVs in 10 peak traffic conditions in the normal month (September)

Peak conditions in Sep.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litre)	LOS value (1-6)
AM-4th	02:42:51	2,211	50,117	00:49:16	1.93	00:50:21	187	00:01:51	0.64	34,679	3.06
AM-7th	02:43:20	2,046	48,893	00:49:51	2.07	00:52:34	195	00:01:51	0.65	35,347	3.00
AM-8th	02:44:07	2,147	49,816	00:50:24	1.93	00:51:56	191	00:01:52	0.64	34,892	3.06
AM-11th	02:42:01	2,178	49,543	00:49:56	1.85	00:49:52	191	00:01:52	0.64	34,777	2.94
AM-12th	02:43:30	2,184	50,105	00:48:28	1.95	00:50:05	183	00:01:45	0.63	34,125	2.97
AM-13th	02:42:18	2,285	50,682	00:48:14	1.88	00:48:09	178	00:01:48	0.62	33,798	3.00
AM-14th	02:45:21	2,151	50,083	00:51:54	2.04	00:53:12	200	00:02:02	0.67	36,123	3.11
AM-19th	02:43:35	2,227	50,252	00:48:46	1.91	00:51:06	185	00:01:53	0.64	34,519	3.03
AM-20th	02:44:02	2,186	50,297	00:52:22	2.14	00:53:02	200	00:01:52	0.66	35,883	2.97
AM-21st	02:43:44	2,141	49,767	00:50:35	1.94	00:52:50	194	00:01:55	0.65	35,390	3.03
Average	**02:43:29**	**2,176**	**49,956**	**00:49:59**	**1.96**	**00:51:19**	**190**	**00:01:52**	**0.64**	**34953**	**3.02**

E10. Simulation of TVs in 10 normal traffic conditions in the normal month (September)

Normal conditions in Sep.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-7th	02:30:26	1,196	31,828	00:56:44	0.96	00:45:00	406	00:10:41	0.90	48,540	3.17
AM-10th	02:38:33	1,745	37,707	00:56:08	1.18	00:48:22	412	00:10:05	1.00	54,320	3.31
AM-13th	02:29:44	1,237	33,434	00:55:32	0.98	00:43:15	407	00:10:38	0.95	51,362	3.08
AM-14th	02:29:32	1,247	33,579	00:54:02	0.10	00:44:00	405	00:10:13	0.94	50,801	3.22
AM-19th	02:33:06	1,202	33,439	01:00:07	1.09	00:48:22	435	00:11:39	0.96	53,923	3.33
AM-20th	02:28:15	1,271	33,513	00:51:28	0.95	00:41:31	367	00:09:38	0.89	47,968	3.17
AM-21st	02:29:44	1,270	33,918	00:54:20	0.96	00:44:43	403	00:10:16	0.95	51,695	3.14
AM-22nd	02:29:53	1,385	34,596	00:55:01	0.96	00:44:58	412	00:10:34	0.95	53,263	3.25
AM-25th	02:27:19	1,322	33,720	00:50:47	0.94	00:40:11	381	00:09:27	0.89	48,405	3.00
AM-26th	02:29:16	1,208	33,269	00:53:25	1.00	00:43:24	393	00:10:12	0.92	50,025	3.17
Average	**02:30:35**	**1,308**	**33,900**	**00:54:45**	**0.91**	**00:44:23**	**402**	**00:10:20**	**0.94**	**51030**	**3.18**

E11. Simulation of AVs in 10 normal traffic conditions in the normal month (September)

Normal conditions in Sep.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-7th	02:04:47	1,799	39,537	00:03:59	0.02	00:05:00	15	00:00:27	0.19	10,126	1.67
AM-10th	02:08:29	2,512	43,543	00:09:12	0.03	00:08:29	28	00:00:28	0.24	12,729	1.72
AM-13th	02:04:43	1,747	38,877	00:03:51	0.01	00:04:49	14	00:00:27	0.18	9,893	1.56
AM-14th	02:04:25	1,768	38,956	00:03:56	0.01	00:04:39	14	00:00:30	0.18	9,841	1.64
AM-19th	02:05:36	1,745	39,394	00:04:18	0.03	00:05:37	16	00:00:26	0.19	10,270	1.67
AM-20th	02:05:05	1,784	38,755	00:03:31	0.01	00:05:02	14	00:00:27	0.18	9,812	1.72
AM-21st	02:05:12	1,798	39,431	00:04:36	0.03	00:05:22	17	00:00:31	0.19	10,425	1.61
AM-22nd	02:04:54	1,992	40,171	00:04:08	0.01	00:04:54	14	00:00:27	0.19	10,125	1.58
AM-25th	02:02:53	1,838	38,861	00:02:30	0.01	00:03:08	8	00:00:20	0.16	8,895	1.42
AM-26th	02:04:10	1,695	38,654	00:03:18	0.01	00:04:19	12	00:00:24	0.18	9,574	1.53
Average	**02:05:01**	**1,868**	**39,618**	**00:04:20**	**0.02**	**00:05:08**	**15**	**00:00:27**	**0.19**	**10169**	**1.61**

E12. Simulation of TVs in 10 off-peak traffic conditions in the normal month (September)

Off-peak conditions in Sep.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-2nd	02:13:31	1,736	34,026	00:27:40	0.51	00:22:04	169	00:04:51	0.51	27,627	2.58
AM-3rd	02:20:11	1,740	35,271	00:37:55	0.58	00:33:00	239	00:06:41	0.66	35,746	2.97
AM-9th	02:14:45	1,719	33,954	00:28:24	0.56	00:23:08	171	00:05:04	0.51	27,613	2.56
AM-10th	02:03:44	1,944	33,120	00:08:54	0.26	00:10:53	55	00:01:59	0.25	13,794	1.72
AM-16th	02:11:45	1,788	34,056	00:24:06	0.47	00:19:33	142	00:04:14	0.45	24,561	2.36
AM-17th	02:17:02	1,644	33,659	00:32:35	0.61	00:27:08	203	00:05:46	0.58	31,177	2.83
AM-23rd	02:12:39	1,875	34,184	00:25:58	0.48	00:20:23	161	00:04:40	0.48	26,154	2.31
AM-24th	02:19:39	1,741	34,897	00:38:04	0.69	00:30:43	245	00:06:41	0.66	35,615	2.81
AM-30th	01:57:46	1,941	32,218	00:02:43	0.10	00:00:19	41	00:02:48	0.17	9,076	1.36
PM-23rd	02:14:08	1,789	34,226	00:27:41	0.54	00:22:41	168	00:05:07	0.51	27,359	2.50
Average	**02:12:31**	**1,792**	**33,961**	**00:25:24**	**0.48**	**00:20:59**	**159**	**00:04:47**	**0.48**	**25872**	**2.40**

E13. Simulation of AVs in 10 off-peak traffic conditions in the normal month (September)

Off-peak conditions in Sep.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-2nd	02:00:14	1,966	35,786	00:00:18	0.00	00:00:27	1	00:00:04	0.13	7,066	1.00
AM-3rd	02:01:38	2,267	39,547	00:02:16	0.00	00:02:04	6	00:00:17	0.16	8,606	1.31
AM-9th	02:00:17	2,113	37,017	00:00:24	0.00	00:00:33	1	00:00:05	0.13	7,303	1.03
AM-10th	02:00:02	2,124	34,099	00:00:02	0.00	00:00:06	0	00:00:01	0.12	6,541	1.00
AM-16th	02:00:13	2,130	36,644	00:00:18	0.00	00:00:25	1	00:00:03	0.13	7,170	1.00
AM-17th	02:00:38	2,079	37,233	00:00:58	0.00	00:00:58	2	00:00:09	0.14	7,571	1.11
AM-23rd	02:00:16	2,230	36,830	00:00:19	0.00	00:00:26	1	00:00:03	0.13	7,163	1.00
AM-24th	02:00:38	2,230	38,900	00:01:41	0.00	00:01:44	4	00:00:12	0.15	8,163	1.22
AM-30th	02:00:01	1,983	32,453	00:00:01	0.00	00:00:05	0	00:00:00	0.12	6,228	1.00
PM-23rd	02:00:17	2,190	37,121	00:00:24	0.00	00:00:31	1	00:00:04	0.13	7,268	1.00
Average	**02:00:25**	**2,131**	**36,563**	**00:00:40**	**0.00**	**00:00:44**	**2**	**00:00:06**	**0.13**	**7308**	**1.07**

E14. Simulation of TVs in 10 peak traffic conditions in the off-peak month (February)

Peak conditions in Feb.	**Travel time (hh:mm:ss)**	**# Vehicles (O-D)**	**# Vehicles (total)**	**Queue delay (hh:mm:ss)**	**Queue length (km)**	**Vehicle delay (hh:mm:ss)**	**Stops (num)**	**Stop delay (hh:mm:ss)**	**CO emission (tons)**	**Fuel consumption (litres)**	**LOS value (1-6)**
AM-1st	03:05:56	1,434	41,830	02:16:12	4.00	01:56:55	1,282	00:27:56	2.41	130,471	4.53
AM–3rd	03:05:01	1,437	41,520	02:15:25	4.00	01:54:50	1,243	00:27:32	2.34	126,826	4.44
AM–7th	03:06:55	1,388	41,062	02:13:06	4.00	01:57:41	1,248	00:28:23	2.33	126,187	4.36
AM–9th	03:08:28	1,368	41,511	02:18:17	4.00	02:02:37	1,337	00:28:46	2.45	132,674	4.42
AM–14th	03:03:59	1,386	40,815	02:06:22	3.00	01:50:30	1,178	00:26:07	2.23	120,658	4.47
AM–15th	03:06:48	1,394	41,093	02:13:46	4.00	01:58:19	1,289	00:28:21	2.36	127,762	4.47
AM–16th	03:07:38	1,408	41,798	02:19:08	4.00	02:00:34	1,317	00:28:36	2.43	131,681	4.42
AM–17th	03:05:32	1,384	40,911	02:12:21	4.00	01:54:05	1,218	00:27:14	2.29	124,129	4.39
AM–21st	03:05:44	1,452	41,523	02:13:25	4.00	01:55:21	1,246	00:27:42	2.33	126,276	4.39
AM–27th	03:05:06	1,425	41,216	02:14:31	4.00	01:53:42	1,230	00:27:19	2.32	125,374	4.39
Average	**03:06:07**	**1,408**	**41,328**	**02:14:15**	**3.90**	**01:56:27**	**1259**	**00:27:48**	**2.35**	**127204**	**4.43**

E15. Simulation of AVs in 10 peak traffic conditions in the off-peak month (February)

Peak conditions in Feb.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-1st	02:41:43	2,277	50,595	00:47:14	1.81	00:47:33	173	00:01:47	0.61	32,958	3.00
AM–3rd	02:41:20	2,246	50,149	00:48:16	1.72	00:48:34	178	00:01:43	0.61	33,263	2.92
AM–7th	02:43:56	2,167	49,641	00:48:28	1.98	00:49:33	180	00:01:52	0.63	34,035	2.94
AM–9th	02:43:13	2,210	50,382	00:50:08	1.89	00:49:47	185	00:01:55	0.64	34,436	3.03
AM–14th	02:41:12	2,113	48,968	00:45:56	1.81	00:46:54	170	00:01:39	0.6	32,480	2.89
AM–15th	02:42:44	2,185	49,742	00:48:02	1.89	00:47:56	178	00:01:48	0.63	33,904	3.03
AM–16th	02:42:31	2,231	50,444	00:49:52	1.79	00:50:15	187	00:01:54	0.63	34,322	3.06
AM–17th	02:41:32	2,198	49,556	00:48:18	1.67	00:48:57	183	00:01:55	0.63	33,902	2.94
AM–21st	02:42:07	2,223	50,002	00:47:58	1.84	00:49:06	178	00:01:48	0.62	33,473	2.97
AM–27th	02:40:28	2,216	49,812	00:46:41	1.70	00:47:11	173	00:01:44	0.60	32,735	2.83
Average	**02:42:05**	**2,207**	**49,929**	**00:48:05**	**1.81**	**00:48:35**	**179**	**00:01:48**	**0.62**	**33551**	**2.96**

E16. Simulation of TVs in 10 normal traffic conditions in the off-peak month (February)

Normal conditions in Feb.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
PM-1st	02:28:40	1,220	33,083	00:52:04	1.00	00:42:05	388	00:09:56	0.92	49,815	3.11
PM-14th	02:30:21	1,210	33,377	00:54:42	1.00	00:43:59	399	00:10:33	0.94	51,024	3.14
PM-15th	02:28:26	1,208	33,257	00:51:40	1.00	00:41:57	379	00:09:52	0.90	48,977	3.11
PM-17th	02:30:40	1,350	34,142	00:53:59	1.00	00:45:52	395	00:10:45	0.95	51,212	3.28
PM-20th	02:26:18	1,289	33,653	00:49:19	1.00	00:39:04	361	00:09:02	0.86	46,832	3.00
PM-21st	02:09:59	1,596	33,137	00:18:01	0.00	00:17:13	112	00:03:30	0.39	20,930	2.25
PM-22nd	02:28:36	1,334	33,845	00:52:31	1.00	00:41:24	371	00:10:03	0.89	48,047	3.11
PM-23rd	02:30:35	1,296	33,920	00:55:53	1.00	00:45:32	421	00:10:59	0.97	52,559	3.14
PM-24th	02:28:47	1,483	35,348	00:52:58	1.00	00:44:08	397	00:10:02	0.94	51,022	3.19
PM-28th	02:26:06	1,225	33,224	00:48:46	1.00	00:38:50	353	00:09:04	0.84	45,233	3.00
Average	**02:26:51**	**1,321**	**33,699**	**00:48:59**	**0.90**	**00:40:00**	**358**	**00:09:23**	**0.86**	**46565**	**3.03**

E17. Simulation of AVs in 10 normal traffic conditions in the off-peak month (February)

Normal conditions in Feb.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
PM-1st	02:03:18	1,731	38,417	00:02:46	0.00	00:03:29	10	00:00:22	0.17	9,111	1.47
PM-14th	02:03:12	1,740	38,843	00:02:53	0.00	00:03:31	10	00:00:22	0.17	9,231	1.47
PM-15th	02:02:48	1,723	38,682	00:02:32	0.00	00:03:06	8	00:00:20	0.17	8,939	1.42
PM-17th	02:03:18	1,961	39,841	00:03:18	0.00	00:03:38	10	00:00:22	0.17	9,420	1.47
PM-20th	02:03:06	1,785	38,717	00:02:39	0.00	00:03:21	9	00:00:20	0.17	8,987	1.50
PM-21st	02:03:53	1,801	39,198	00:03:27	0.00	00:04:03	12	00:00:23	0.18	9,531	1.50
PM-22nd	02:03:54	1,859	39,119	00:03:23	0.00	00:04:11	12	00:00:27	0.18	9,535	1.53
PM-23rd	02:04:33	1,848	39,518	00:03:59	0.00	00:04:48	14	00:00:28	0.18	9,982	1.56
PM-24th	02:04:49	2,081	40,738	00:03:55	0.00	00:05:05	14	00:00:25	0.19	10,212	1.69
PM-28th	02:03:10	1,698	38,228	00:02:37	0.00	00:03:30	9	00:00:22	0.17	9,025	1.50
Average	**02:03:36**	**1,823**	**39,130**	**00:03:09**	**0.00**	**00:03:52**	**11**	**00:00:23**	**0.18**	**9397**	**1.51**

E18. Simulation of TVs in 10 off-peak traffic conditions in the off-peak month (February)

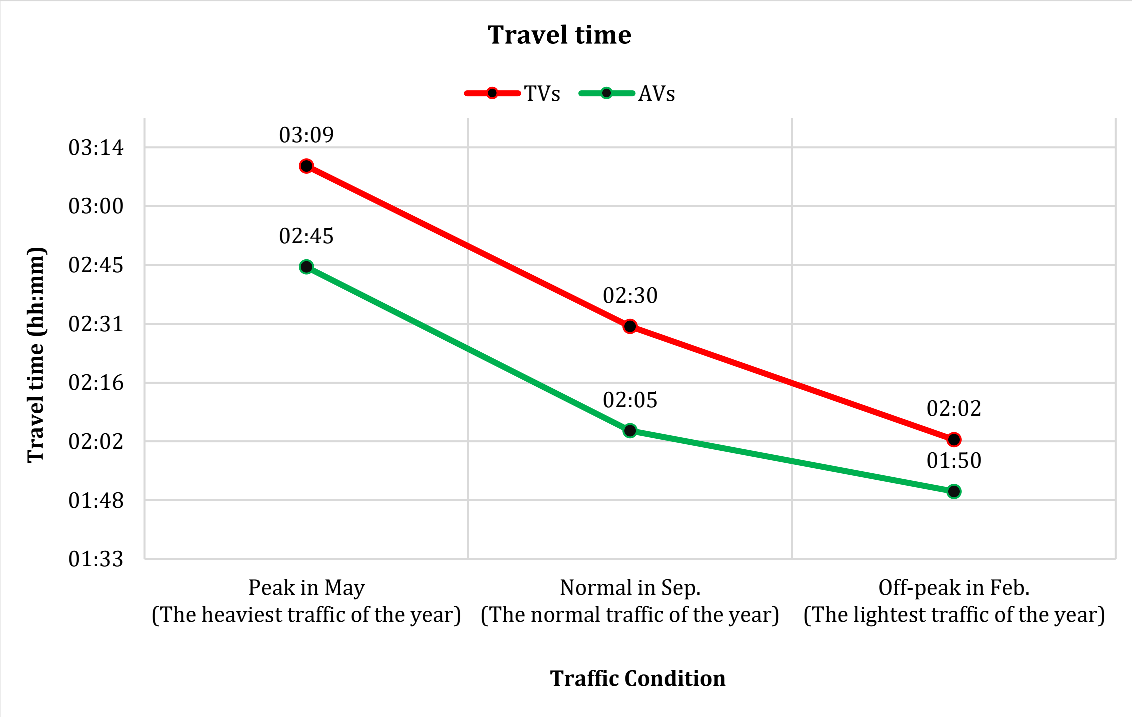
Off-peak conditions in Feb.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-4th	02:02:05	1,797	32,393	00:07:18	0.00	00:09:32	49	00:01:41	0.24	12,850	1.72
PM-4th	02:18:10	1,847	35,268	00:36:44	1.00	00:28:10	237	00:06:38	0.64	34,475	2.69
AM-5th	01:52:56	1,719	27,947	00:00:00	0.00	00:01:09	0	00:00:00	0.11	5,745	1.00
AM-11th	02:04:00	1,867	33,011	00:10:02	0.00	00:10:54	61	00:02:03	0.26	14,295	1.83
AM-12th	01:53:04	1,805	28,823	00:00:00	0.00	00:01:14	0	00:00:00	0.11	5,929	1.00
PM-12th	02:17:00	1,958	35,931	00:34:40	1.00	00:27:11	219	00:06:00	0.62	33,424	2.78
AM-18th	02:07:20	1,810	33,106	00:14:53	0.00	00:14:20	89	00:02:58	0.33	17,874	2.03
AM-19th	01:54:13	1,850	30,202	00:00:21	0.00	00:02:13	2	00:00:06	0.12	6,490	1.08
AM-25th	02:06:23	1,792	3,303	00:14:33	0.00	00:13:29	84	00:02:41	0.32	17,355	1.97
AM-26th	01:53:09	1,812	28,829	00:00:02	0.00	00:01:17	0	00:00:00	0.11	5,918	1.00
Average	**02:02:50**	**1,826**	**28,881**	**00:11:51**	**0.20**	**00:10:57**	**74**	**00:02:13**	**0.29**	**15436**	**1.71**

E19. Simulation of AVs in 10 off-peak traffic conditions in the off-peak month (February)

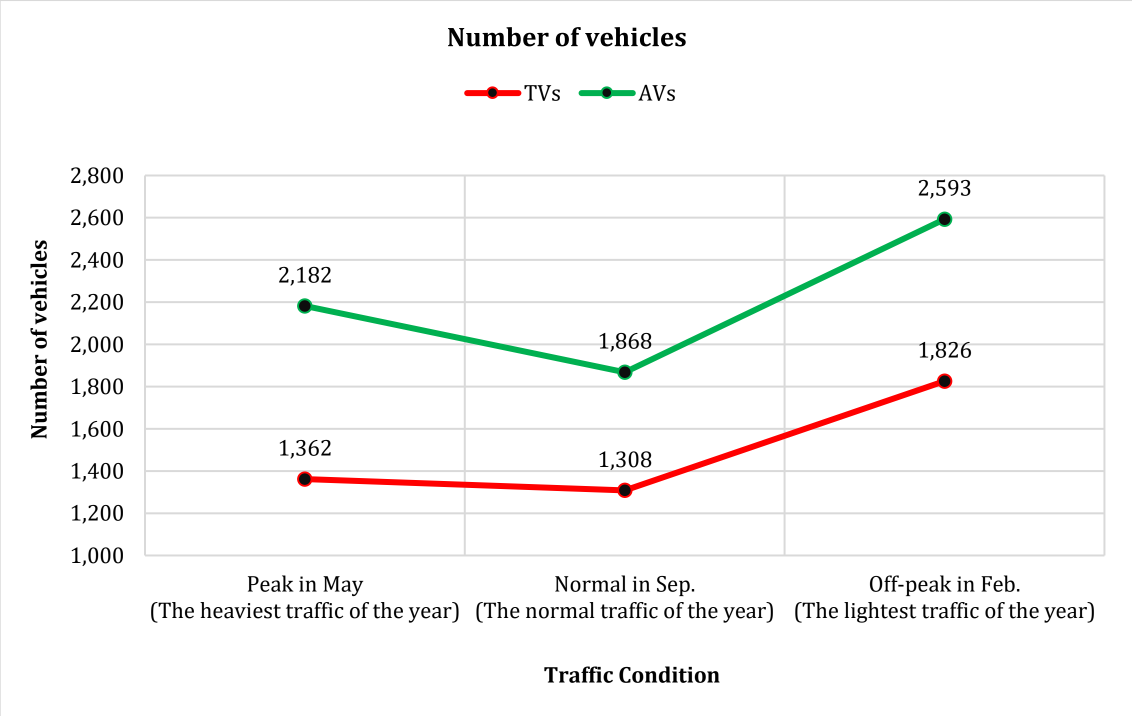
Off-peak conditions in Feb.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
AM-4th	02:00:02	1,929	33,167	00:00:01	0.00	00:00:06	0	00:00:00	0.12	6,381	1.00
PM-4th	02:00:44	2,337	39,003	00:00:56	0.00	00:01:02	2	00:00:08	0.14	7,805	1.11
AM-5th	02:00:00	1,669	27,768	00:00:00	0.00	00:00:03	0	00:00:00	0.10	5,334	1.00
AM-11th	02:00:03	2,049	34,189	00:00:02	0.00	00:00:08	0	00:00:01	0.12	6,582	1.00
AM-12th	02:00:00	1,754	28,643	00:00:00	0.00	00:00:03	0	00:00:00	0.10	5,501	1.00
PM-12th	02:01:01	2,459	39,534	00:01:16	0.00	00:01:17	3	00:00:10	0.15	8,047	1.17
AM-18th	02:00:03	2,039	34,716	00:00:04	0.00	00:00:09	0	00:00:01	0.12	6,700	1.00
AM-19th	02:00:01	1,819	30,085	00:00:00	0.00	00:00:04	0	00:00:00	0.11	5,791	1.00
AM-25th	02:00:03	2,011	34,948	00:00:04	0.00	00:00:11	0	00:00:01	0.13	6,786	1.00
AM-26th	00:29:25	7,200	28,658	00:00:00	0.00	00:00:03	0	00:00:00	0.10	5,476	1.00
Average	**01:51:08**	**2,527**	**33,071**	**00:00:14**	**0.00**	**00:00:19**	**1**	**00:00:02**	**0.12**	**6440**	**1.03**

APPENDIX F: Comparison of TVs and AVs in the Heaviest Traffic, Normal Traffic, and Lightest Traffic Conditions of the Year

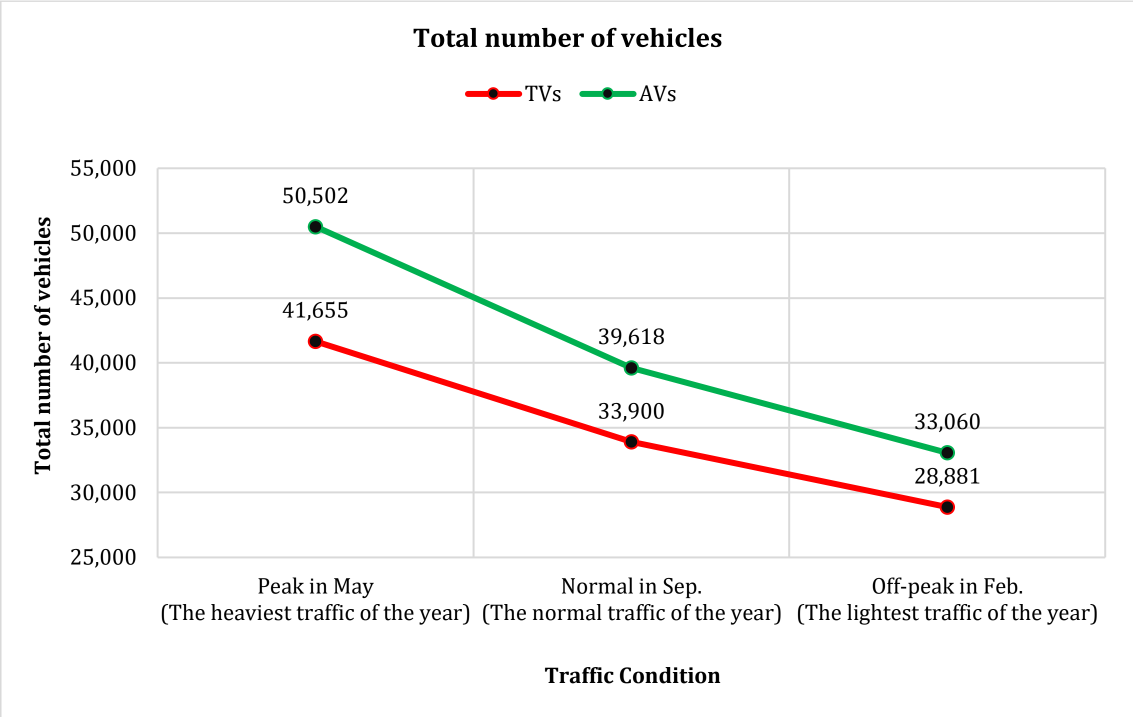
F1. Travel time for TVs and AVs in various traffic conditions of the year



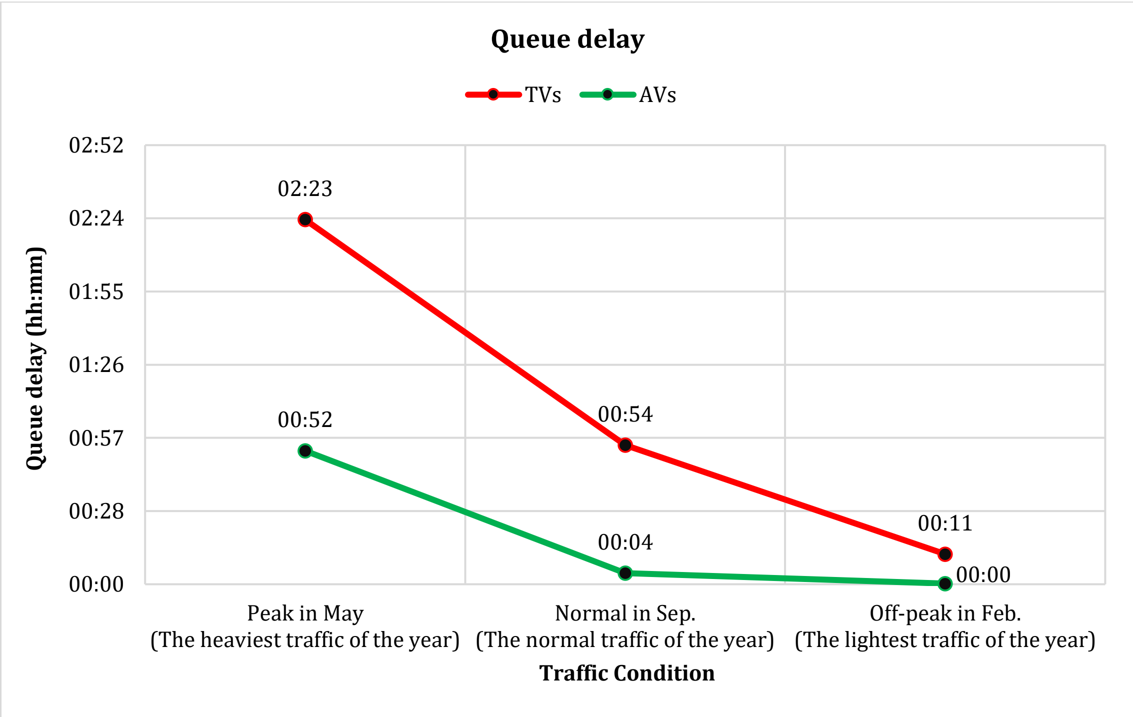
F2. Number of vehicles TVs and AVs in various traffic conditions of the year



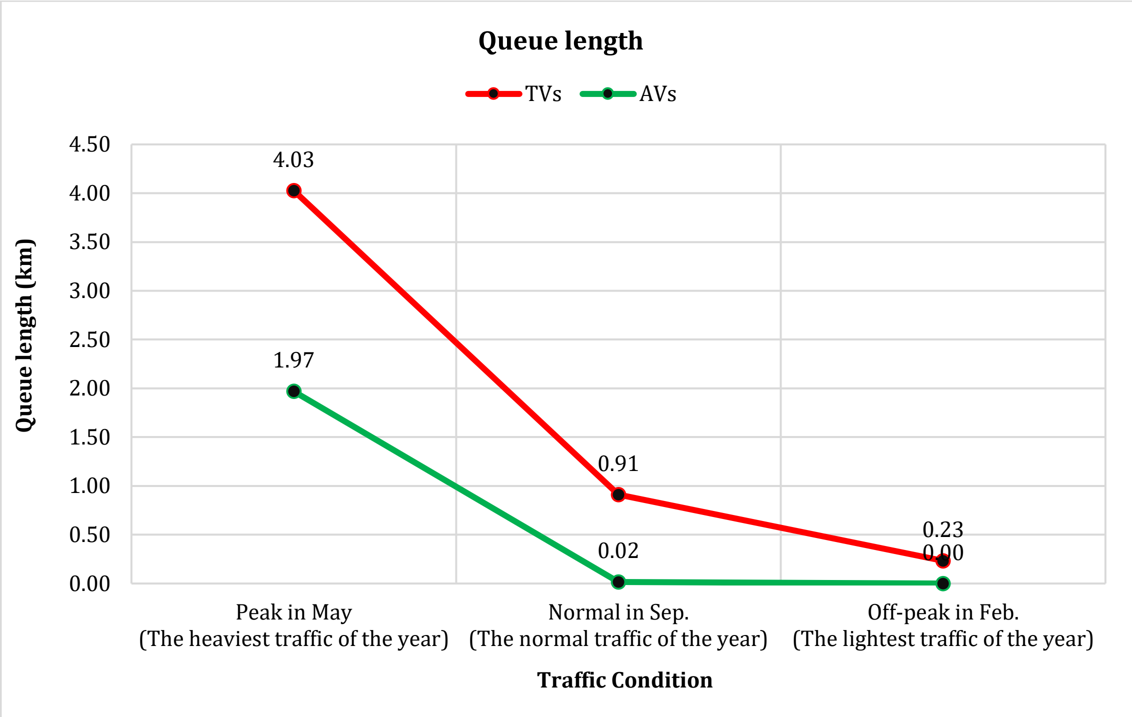
F3. Total number of vehicles TVs and AVs in various traffic conditions of the year



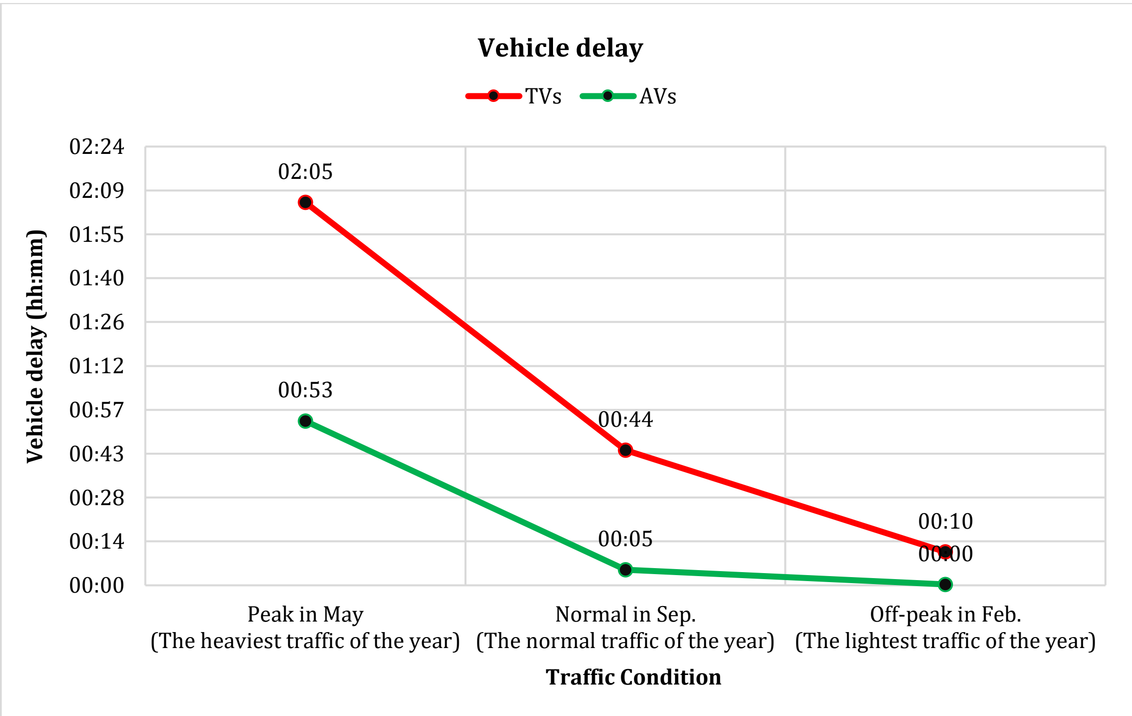
F4. Queue delay for TVs and AVs in various traffic conditions of the year



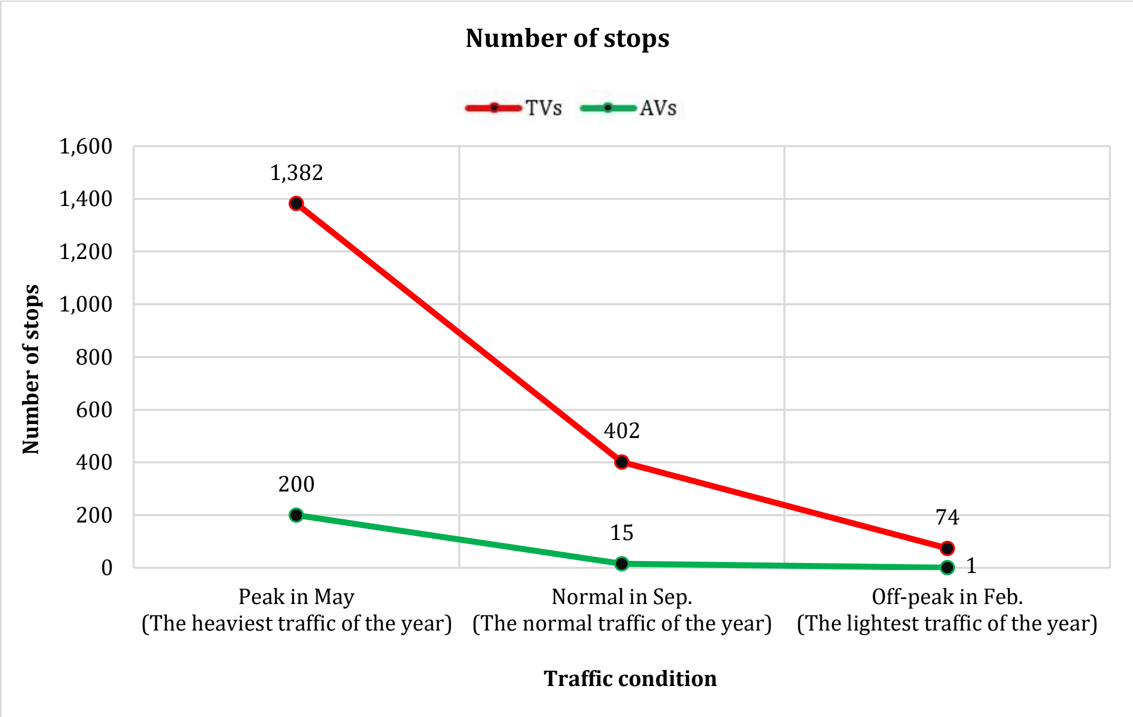
F5. Queue length for TVs and AVs in various traffic conditions of the year



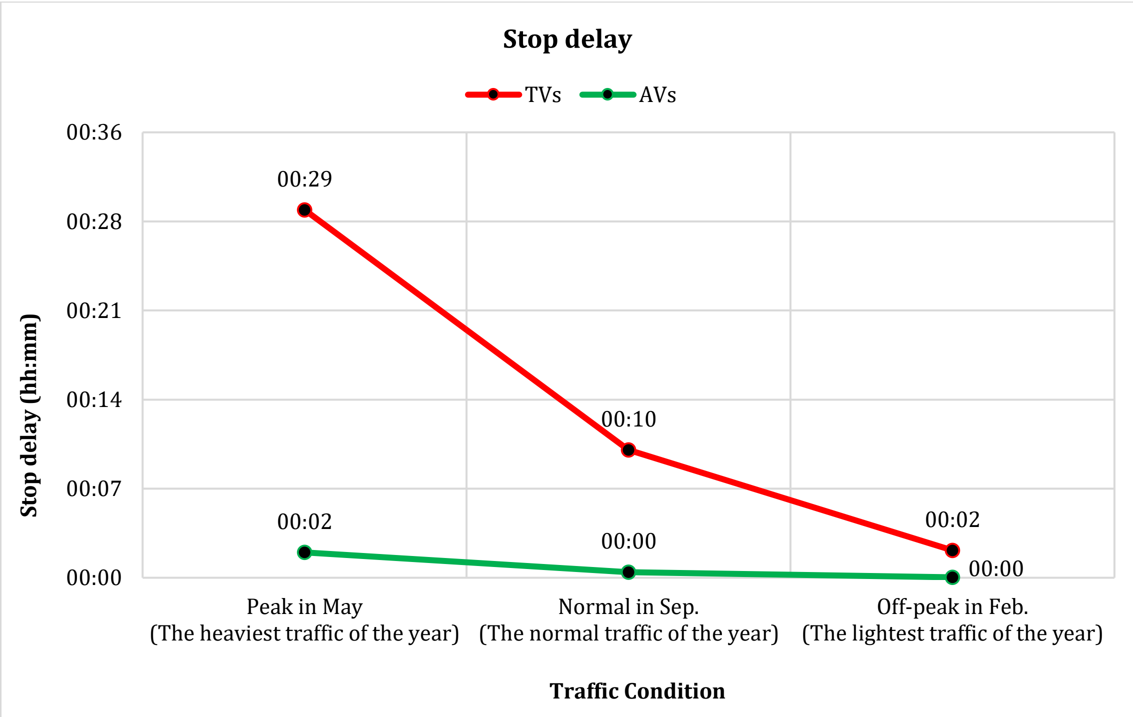
F6. Vehicle delay for TVs and AVs in various traffic conditions of the year



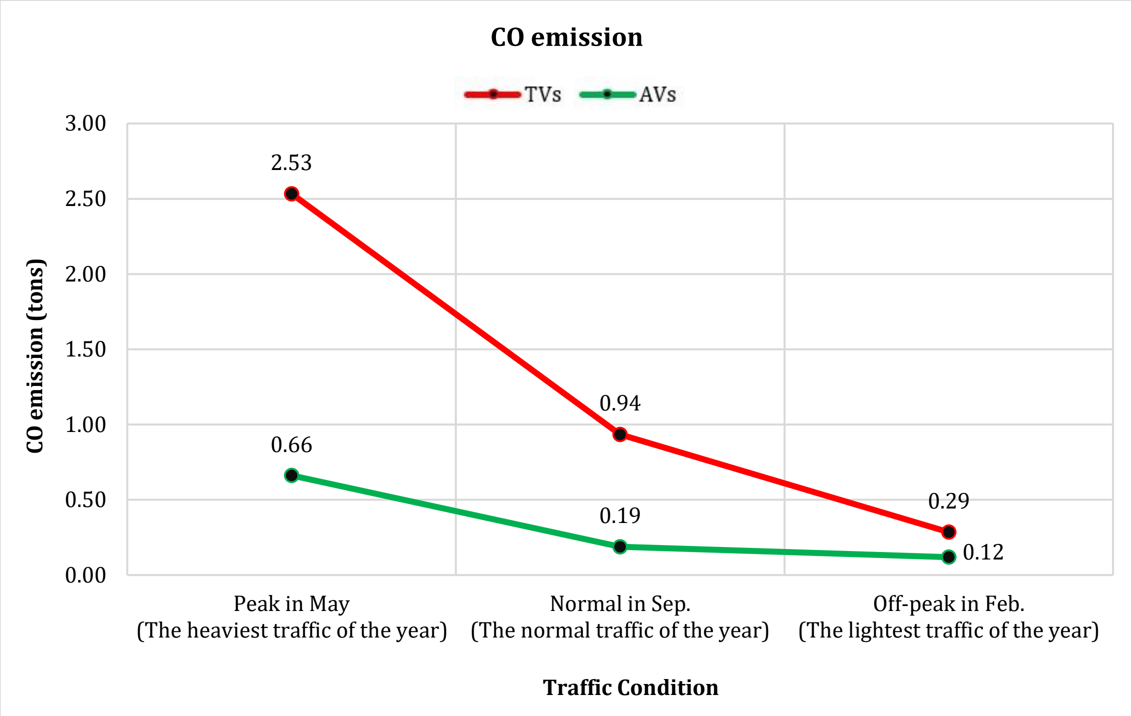
F7. Number of stops for TVs and AVs in various traffic conditions of the year



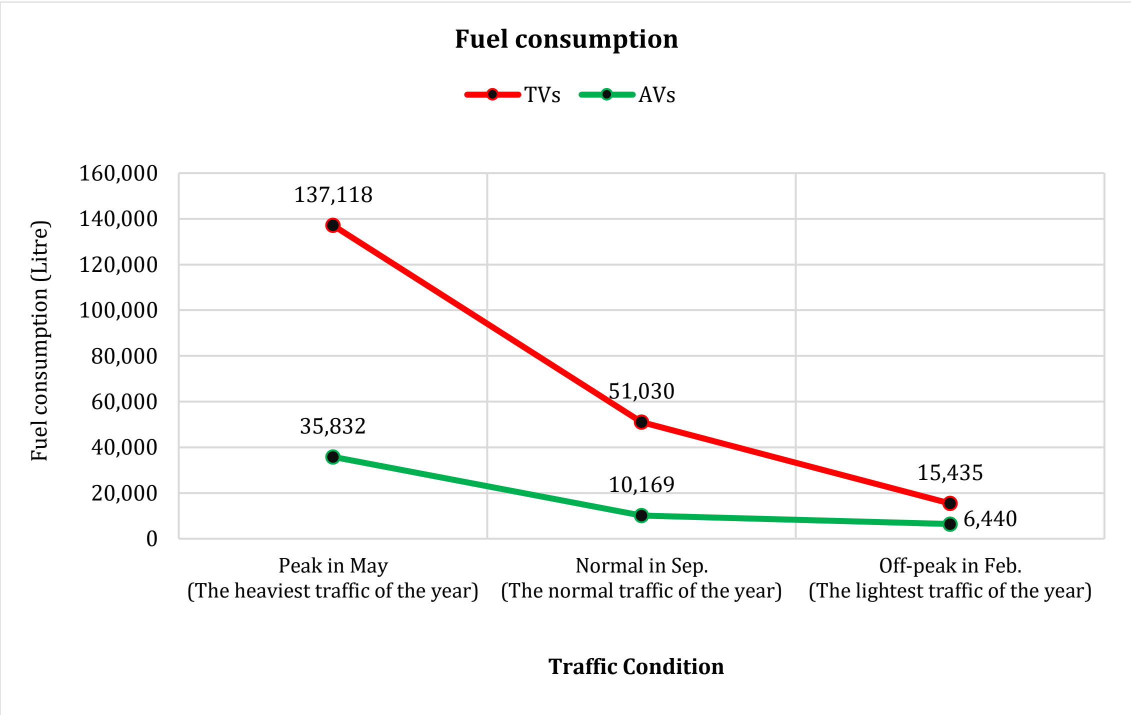
F8. Stop delay for TVs and AVs in various traffic conditions of the year



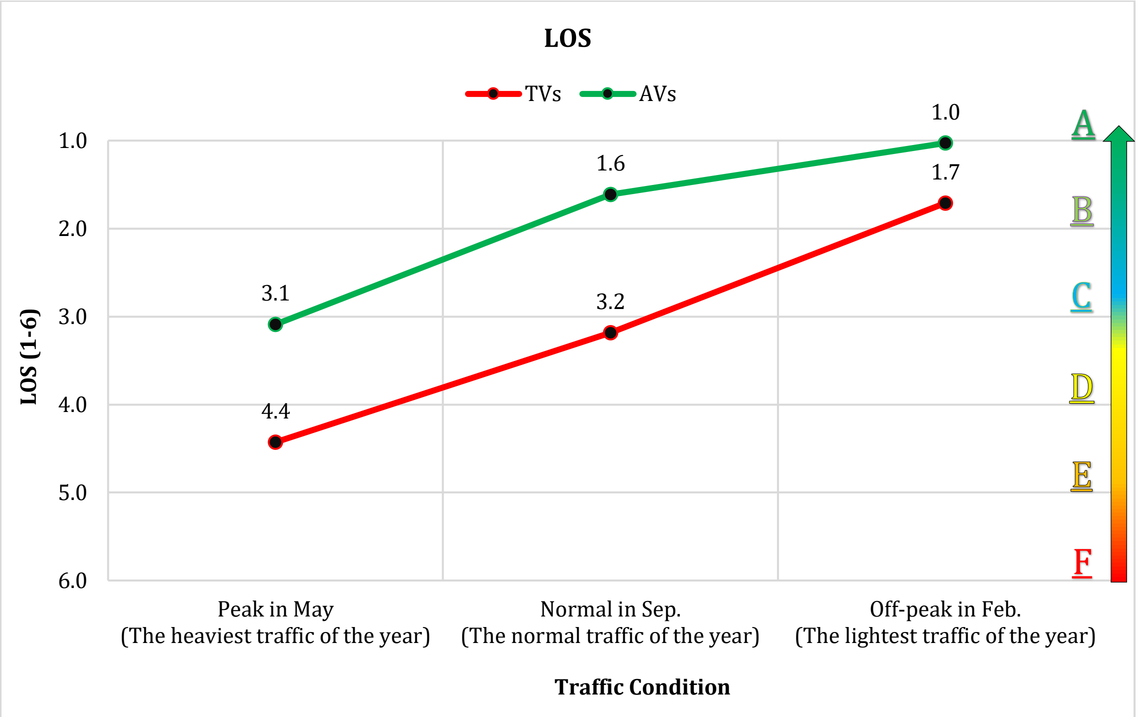
F9. CO emission for TVs and AVs in various traffic conditions of the year



F10. Fuel consumption for TVs and AVs in various traffic conditions of the year



F11. LOS for TVs and AVs in various traffic conditions of the year



APPENDIX G: Results of the Simulation of AVs with Driving Behaviours Defined by PTV

G1. Simulation of AVs with aggressive driving behaviour mode set by PTV

Normal traffic condition in Sep.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
07-Sep	02:00:14	1,891	40,047	00:00:11	0.00	00:00:46	0	00:00:01	0.15	7,968	1.00
10-Sep	02:00:27	2,708	44,701	00:00:18	0.00	00:01:08	1	00:00:01	0.16	8,774	1.11
13-Sep	02:00:14	1,821	39,268	00:00:10	0.00	00:00:45	0	00:00:01	0.14	7,820	1.00
14-Sep	02:00:14	1,840	39,404	00:00:10	0.00	00:00:44	0	00:00:01	0.15	7,866	1.00
19-Sep	02:00:15	1,846	39,933	00:00:11	0.00	00:00:48	0	00:00:01	0.15	7,971	1.00
20-Sep	02:00:15	1,855	39,120	00:00:10	0.00	00:00:44	0	00:00:01	0.14	7,772	1.00
21-Sep	02:00:21	1,894	39,976	00:00:14	0.00	00:00:56	1	00:00:01	0.15	7,995	1.00
22-Sep	02:00:15	2,060	40,530	00:00:10	0.00	00:00:45	0	00:00:01	0.15	8,025	1.00
25-Sep	02:00:12	1,883	39,104	00:00:09	0.00	00:00:39	0	00:00:01	0.14	7,729	1.00
26-Sep	02:00:13	1,763	39,050	00:00:10	0.00	00:00:43	0	00:00:01	0.14	7,805	1.00
Average	**02:00:16**	**1,956**	**40,113**	**00:00:11**	**0.00**	**00:00:48**	**0**	**00:00:01**	**0.15**	**7,972**	**1.01**

G2. Simulation of AVs with normal driving behaviour mode set by PTV

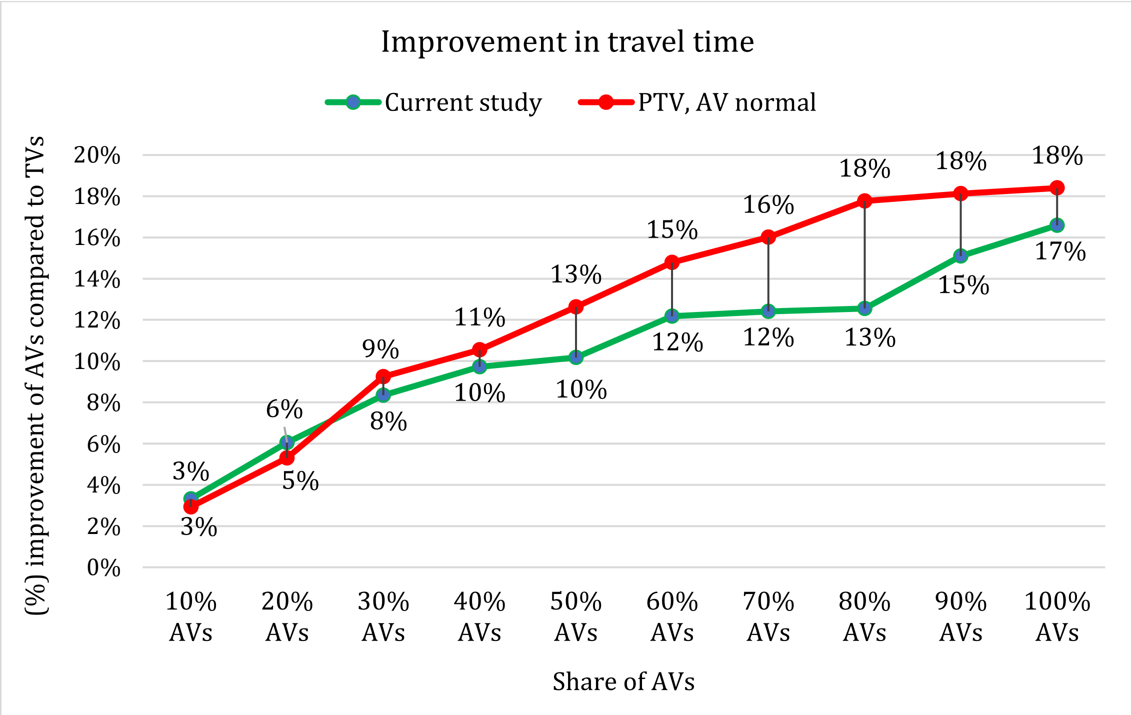
Normal traffic condition in Sep.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
07-Sep	02:08:12	1,702	39,293	00:00:50	0.00	00:06:21	5	00:00:18	0.16	8,843	1.53
10-Sep	02:03:45	2,590	44,291	00:00:37	0.00	00:03:19	3	00:00:09	0.17	9,129	1.22
13-Sep	02:06:44	1,664	38,670	00:00:54	0.00	00:05:38	6	00:00:20	0.16	8,743	1.50
14-Sep	02:07:03	1,679	38,822	00:00:41	0.00	00:05:24	4	00:00:15	0.16	8,619	1.42
19-Sep	02:06:18	1,698	39,295	00:00:50	0.00	00:05:08	5	00:00:17	0.16	8,701	1.44
20-Sep	02:05:18	1,723	38,638	00:00:35	0.00	00:04:19	4	00:00:13	0.15	8,364	1.39
21-Sep	02:09:08	1,688	39,160	00:00:51	0.00	00:06:57	5	00:00:18	0.16	8,884	1.53
22-Sep	02:07:31	1,869	39,862	00:00:41	0.00	00:05:50	4	00:00:15	0.16	8,787	1.47
25-Sep	02:05:04	1,754	38,655	00:00:31	0.00	00:04:13	3	00:00:12	0.15	8,307	1.39
26-Sep	02:03:15	1,679	38,725	00:00:29	0.00	00:02:55	3	00:00:10	0.15	8,206	1.22
Average	**02:06:14**	**1,805**	**39,541**	**00:00:42**	**0.00**	**00:05:00**	**4**	**00:00:15**	**0.16**	**8,658**	**1.41**

G3. Simulation of AVs with cautious driving behaviour mode set by PTV

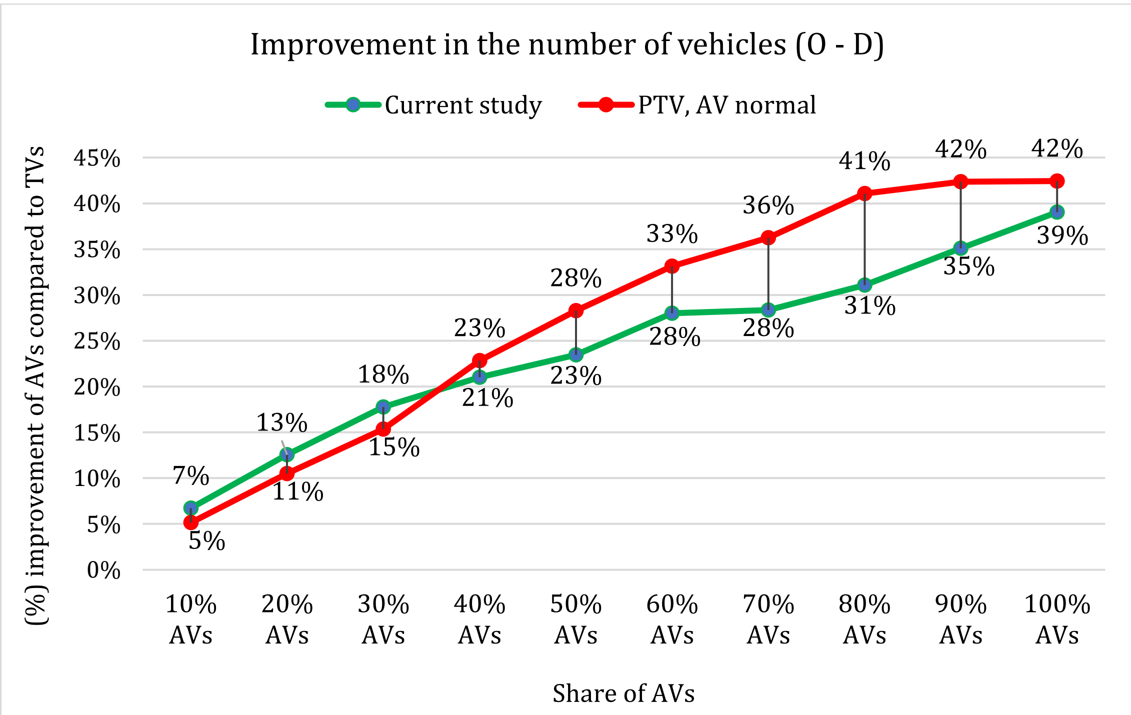
Normal traffic condition in Sep.	Travel time (hh:mm:ss)	# Vehicles (O-D)	# Vehicles (total)	Queue delay (hh:mm:ss)	Queue length (km)	Vehicle delay (hh:mm:ss)	Stops (num)	Stop delay (hh:mm:ss)	CO emission (tons)	Fuel consumption (litres)	LOS value (1-6)
07-Sep	02:22:20	1,393	32,336	01:22:04	2.00	01:01:37	142	00:33:33	0.39	21,229	4.39
10-Sep	02:25:17	1,934	36,027	01:16:10	2.00	00:58:04	136	00:29:42	0.39	21,357	4.42
13-Sep	02:20:59	1,354	31,940	01:17:54	2.00	00:58:39	136	00:31:33	0.38	20,631	4.22
14-Sep	02:21:55	1,363	32,167	01:17:15	2.00	00:57:50	132	00:31:12	0.37	20,208	4.28
19-Sep	02:20:49	1,426	31,762	01:11:47	2.00	00:50:11	119	00:27:16	0.34	18,666	3.72
20-Sep	02:20:19	1,413	32,114	01:14:42	2.00	00:55:40	129	00:29:30	0.37	19,928	4.28
21-Sep	02:20:58	1,432	32,477	01:16:34	2.00	00:58:27	135	00:31:07	0.38	20,529	4.39
22-Sep	02:21:22	1,551	33,269	01:13:04	2.00	00:55:55	129	00:29:06	0.37	20,209	4.33
25-Sep	02:20:18	1,445	32,328	01:09:40	2.00	00:52:33	121	00:27:24	0.35	19,201	4.42
26-Sep	02:21:40	1,325	31,973	01:14:07	2.00	00:55:47	128	00:29:28	0.37	19,875	4.28
Average	**02:21:36**	**1,464**	**32,639**	**01:15:20**	**2.00**	**00:56:28**	**131**	**00:29:59**	**0.37**	**20,183**	**4.27**

APPENDIX H: Comparison of the Results of the TV–AV Shared Road of This Study with the TV–AV Shared Road of PTV

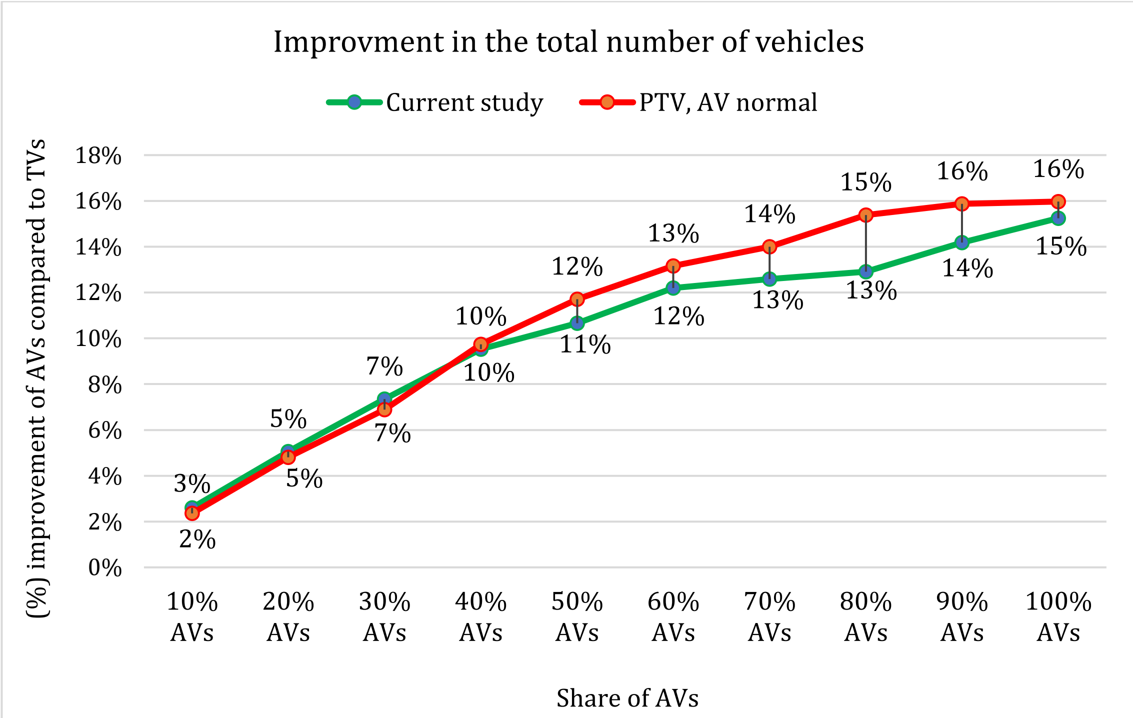
H1. Improvement in travel time of the shared road compared with 100% TVs



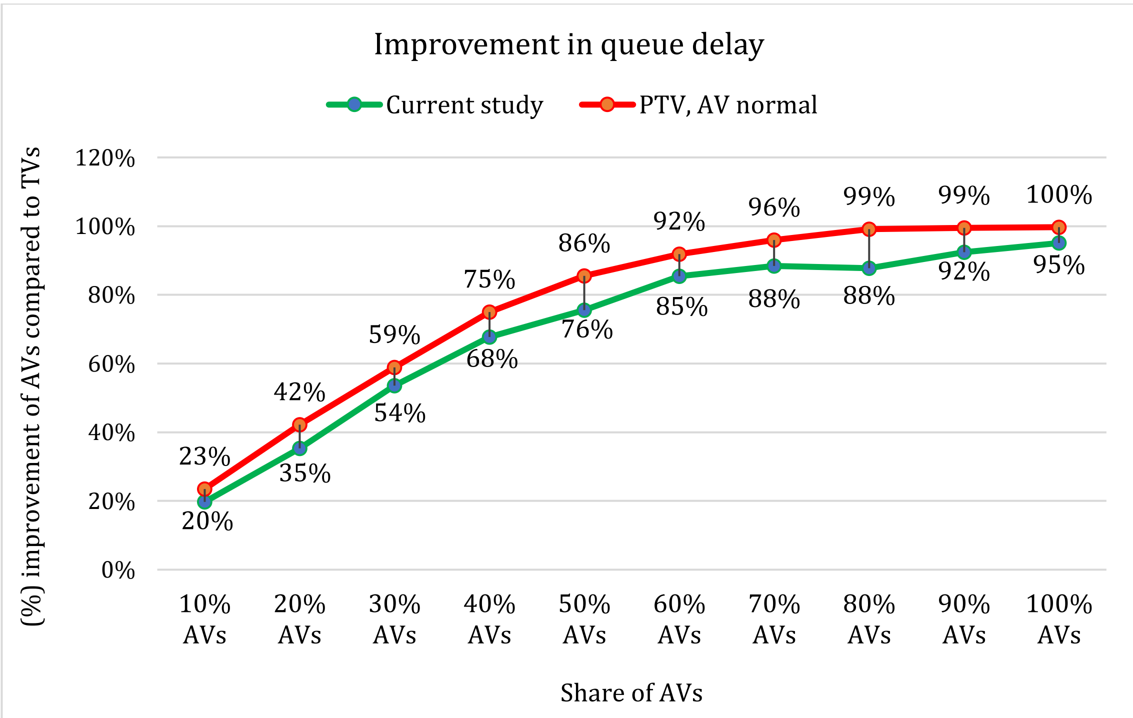
H2. Improvement in the number of vehicles (O-D) of the shared road compared with 100% TVs



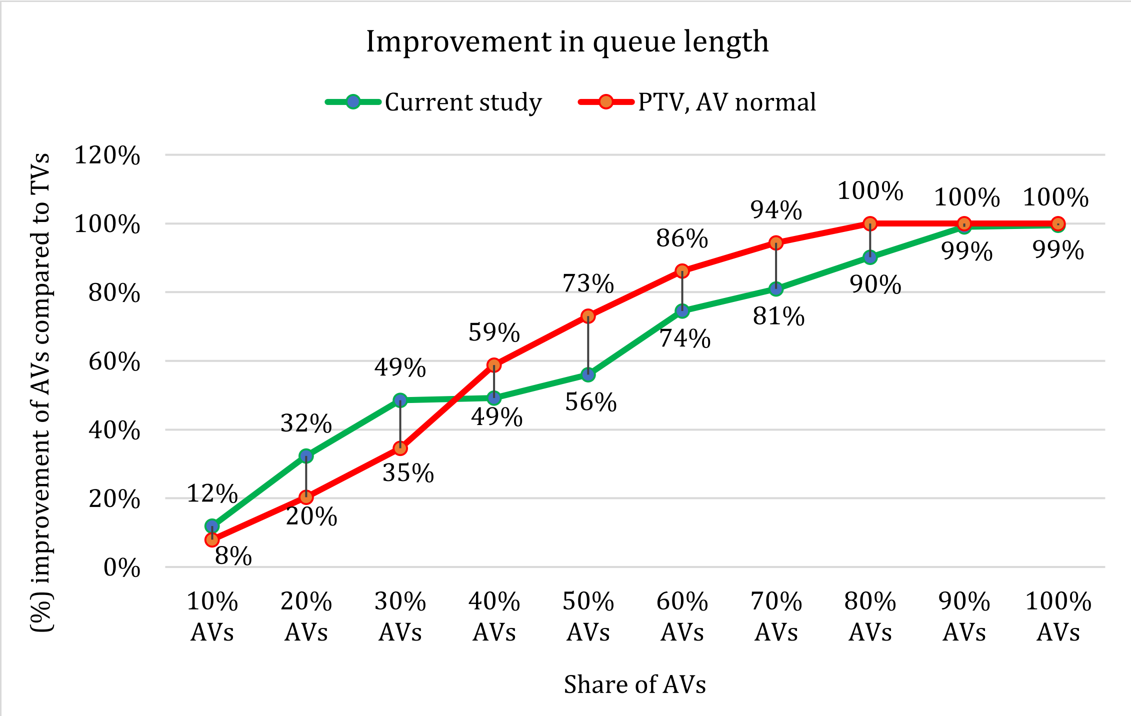
H3. Improvement in the total number of vehicles in the shared road compared with 100% TVs



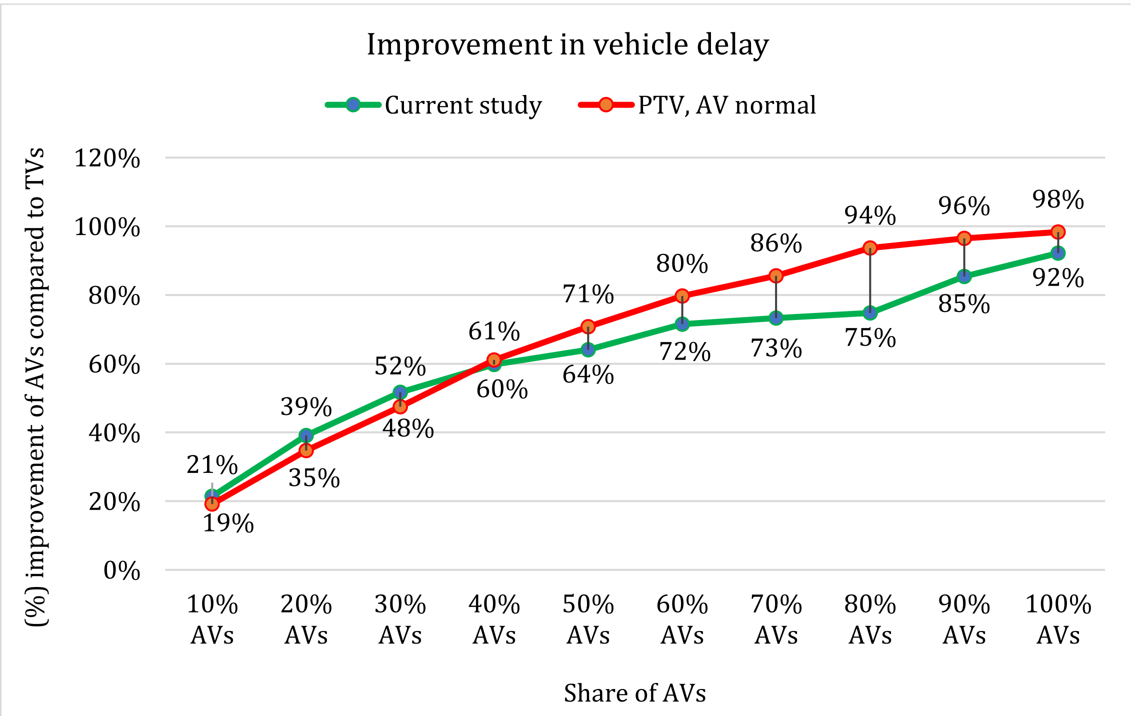
H4. Improvement in queue delay of the shared road compared with 100% TVs



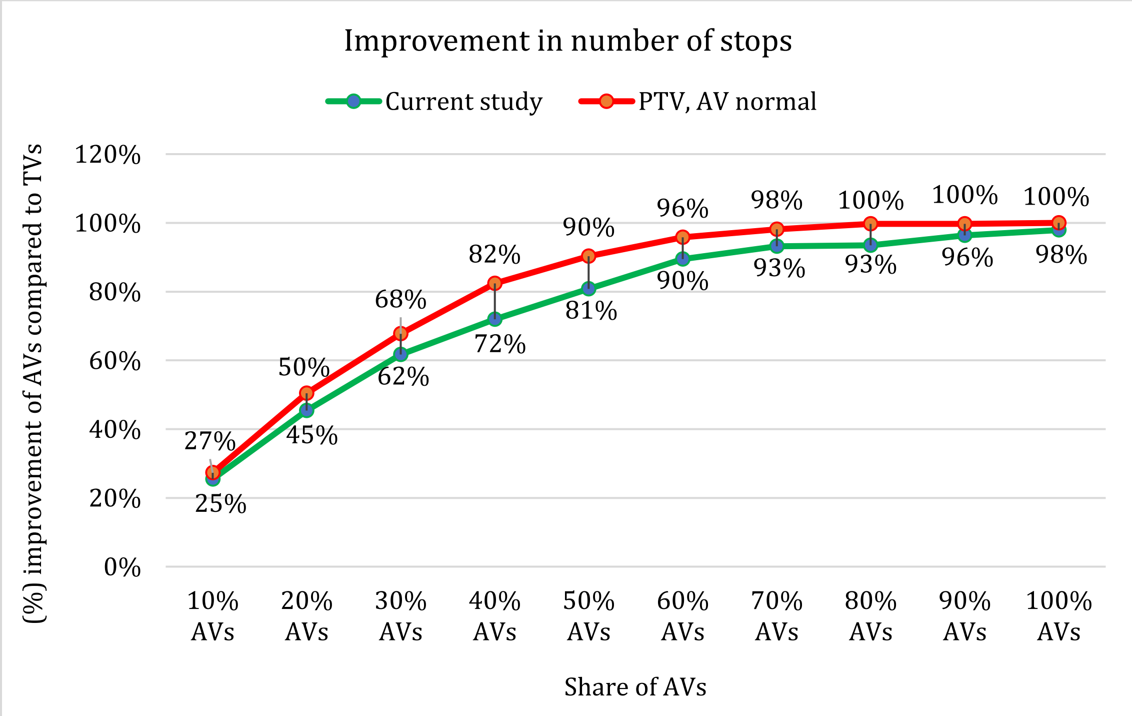
H5. Improvement in queue length of the shared road compared with 100% TVs



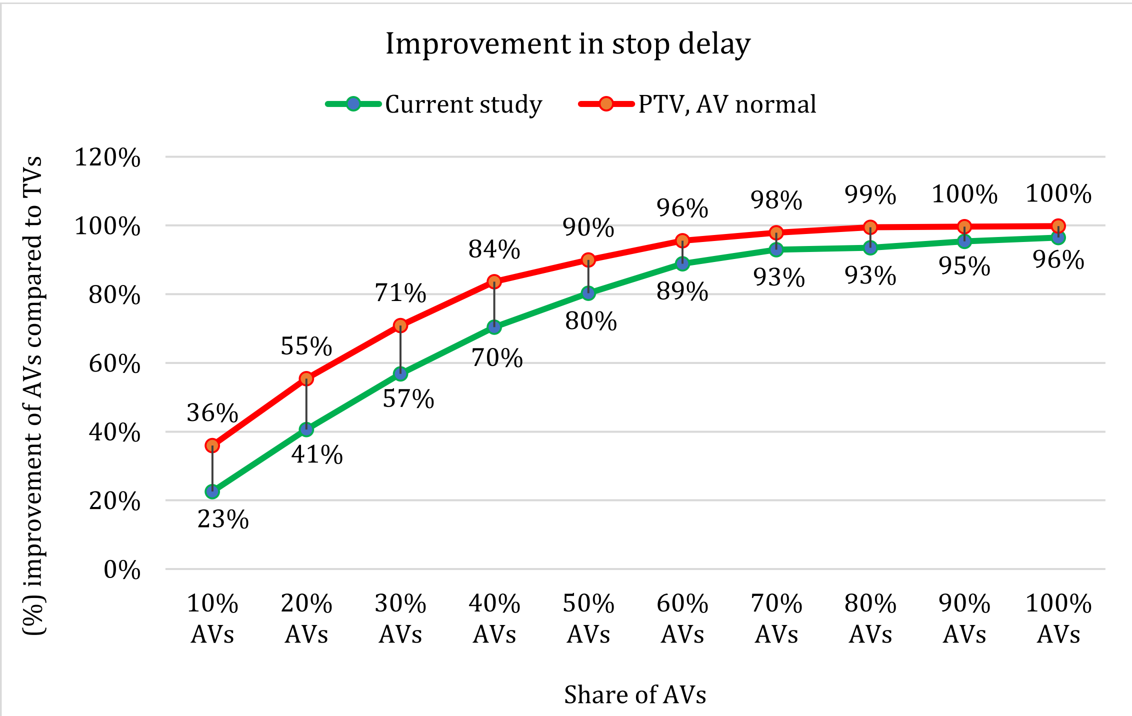
H6. Improvement in vehicle delay of the shared road compared with 100% TVs



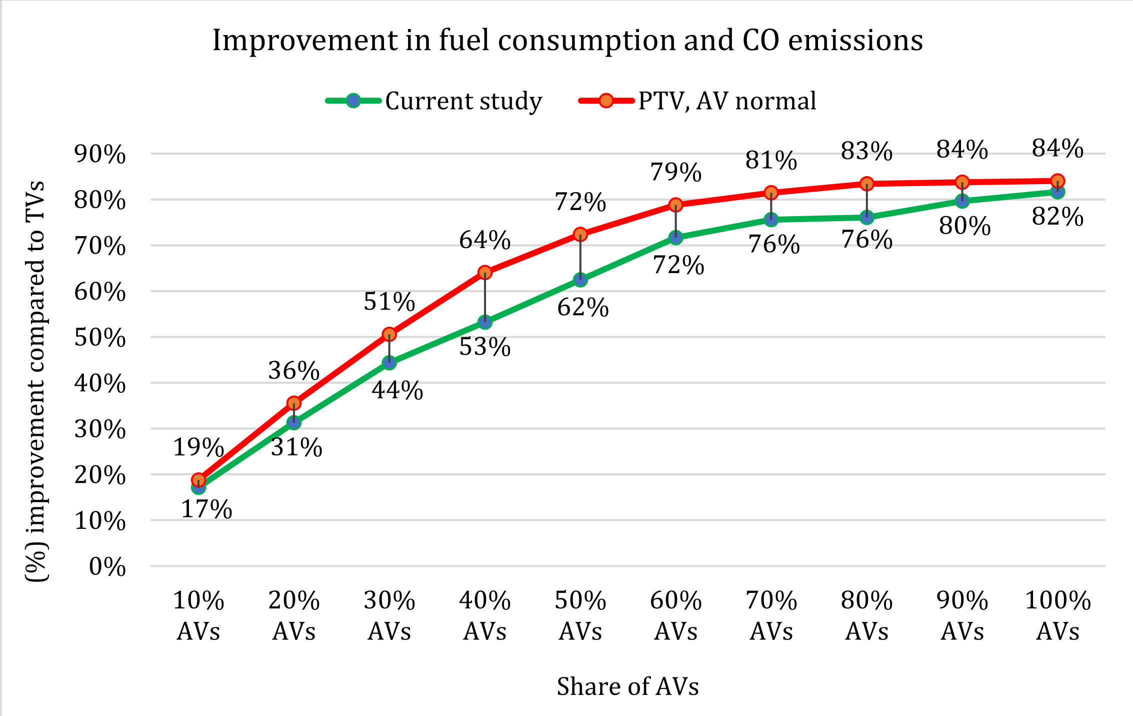
H7. Improvement in number of stops of the shared road compared with 100% TVs



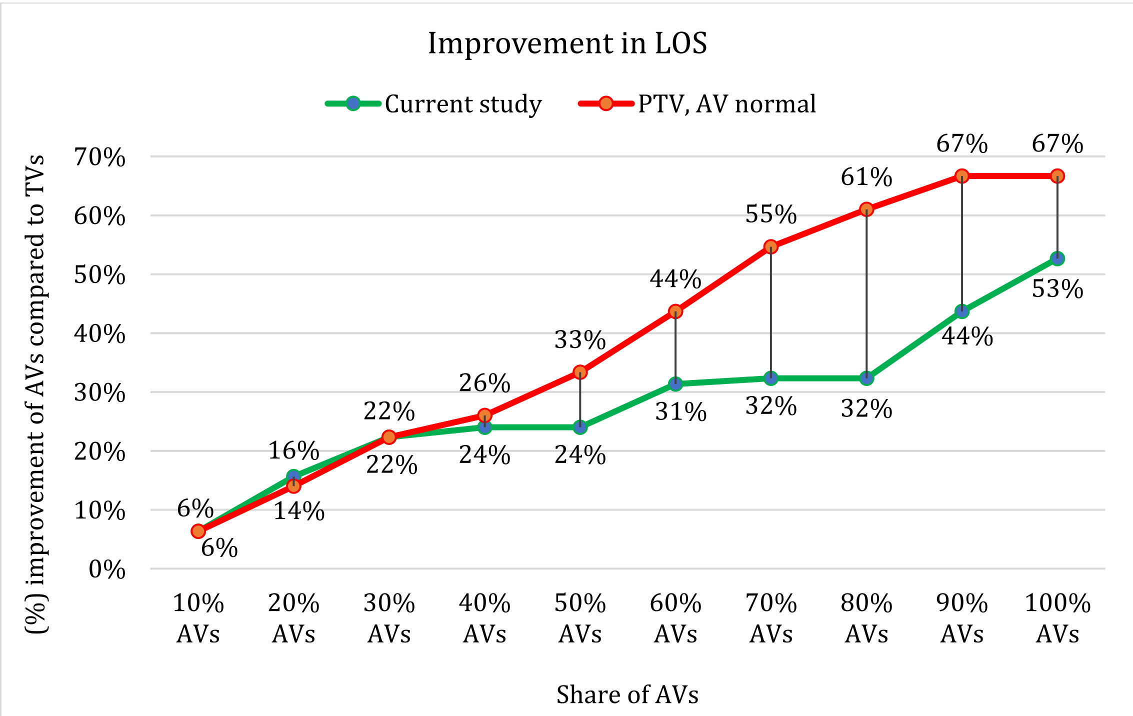
H8. Improvement in stop delay of the shared road compared with 100% TVs



H9. Improvement in fuel consumption and CO emissions of the shared road compared with 100% TVs



H10. Improvement in LOS of the shared road compared with 100% TVs



H11. The average improvement of the shared road compared with 100% TVs