The long-term impacts of cooperative, connected, and automated mobility on passenger transport

Deliverable D6.4 – WP6 – PU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824361.

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Work Package 6, Deliverable D6.4

Please refer to this report as follows:
Chaudhry, A., Sha, H., Haouari R., Zach, M., Papazikou, E., Boghani, H.C., Singh, M., Gebhard, S., Zwart, R.d., Mons, C., Weijermars, W., Hula, A., Roussou, J., Richter, G., Hu, B., Thomas, P., Quddus, M., Morris, A. (2021). *The long-term impacts of cooperative and automated cars, Deliverable D6.4 of the H2020 project LEVITATE.

Project details:	
Project start date: **Duration:** **Project name:**	01/12/2018 42 months LEVITATE – Societal Level Impacts of Connected and Automated Vehicles
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	This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824361.

Deliverable details:	
Version: **Dissemination level:** **Due date:** **Submission date:**	Final PU (Public) 31/10/2021 06/11/2021

* The original title of this deliverable was “The long-term impact, cost and benefits of cooperative and automated passenger transport”. The title has been revised to better reflect the current terminology used in this field of research.

Lead contractor for this deliverable:
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Revision history

Date	Version	Reviewer	Description
27/10/2021	Preliminary draft 1	Veronika Prändl-Zika	Review round 1 – accepted with reservation
26/10/2021	Preliminary draft 1	Apostolos Ziakopoulos	Review round 1 – Fully accepted
05/11/2021	Final draft	Pete Thomas (LOUGH), Vanessa Millar (LOUGH)	
06/11/2021	Final deliverable	Andrew Morris – Loughborough University ➔ EC	

Legal disclaimer

List of abbreviations

ACC	Adaptive Cruise Control
AIT	Austrian Institute of Technology
AMOD	Automated Mobility-On-Demand
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CATS	Connected and Automated Transport Systems
CAV	Connected and Autonomous Vehicle
CBD	Central Business District
CC	City centre
CCAM	Cooperative, Connected and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
CO2	Carbon dioxide
CV	Connected Vehicle
DRS	Dynamic Ride Sharing
ERP	Expected Penetration Rate
ERTRAC	European Road Transport Research Advisory Council
ESC	Eco-Speed Control
EU	European Union
EV	Electric Vehicle
FHWA	Federal Highway Administration
FOT	Field Operation Testing
GLOSA	Green Light Optimal Speed Advisory
HDV	Human Driven Vehicles
HGV	Heavy Goods Vehicle
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
IC	Inner city
IDM	Intelligent Driver Model
IP	Intra peripheral
ldm	Longest distance mode
LGV	Large Goods Vehicles
MOD	Mobility-On-Demand
MPR	Market Penetration Rate
mUoM	Marginal utility of money
NHTSA	National Highway Traffic Safety Administration
NOx	Nitrogen oxides
NRC	National Research Council

PCU	Passenger car unit
PM	Particulate Matter
PST	Policy Support Tool
RCRI	Rear-End Crash Risk Index
RUP	Road use pricing
SAE	Society of Automotive Engineers
SAV	Shared Autonomous Vehicle
SD	System Dynamics
SPAT	Signal Phase and Timing Information
SRG	Stakeholder Reference Group
SSAM	Surrogate Safety Assessment Model
SUC	Sub-use Case
TERCRI	Time Exposed Rear-end Crash Risk Index
TET	Time Exposed Time-to-collision
TIT	Time Integrated Time-to-collision
TTC	Time to Collision
UC	Use Case
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to everything
VHT	Vehicle Hours Travelled
VKT	Vehicle Kilometres Travelled
VMT	Vehicle Miles Travelled
VRPPDTW	Vehicle Routing Problem with Pickup and Delivery with Time Window
VTTI	Virginia Tech Transportation Institute
VTTS	Value of travel time saved
WTS	Willingness to share
XP	Extra peripheral

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Executive summary

The aim of the LEVITATE project is to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives. As part of this work the LEVITATE project seeks to forecast societal level impacts of cooperative, connected, and automated mobility (CCAM).

This report aims to provide an analysis of the long-term impacts of CCAM on a variety of passenger transport related policy interventions, termed as sub-use cases (SUC) in this document. The long-term impacts analysed include demand for parking spaces, road safety, energy efficiency, emissions, public health, accessibility in transport, and commuting distances. Based on the review of scientific literature, industrial/political roadmaps, discussions with city officials and industry professionals, and backcasting city dialogues, a list of key policy interventions (SUC) was developed to be tested through different methods. These include road use pricing, provision of dedicated lanes on urban highways, parking space regulations, parking price policies, automated ridesharing, and green light optimal speed advisory (GLOSA) system. The methodologies for analysing the impacts of the studied interventions were selected based on their feasibility and adequacy in examining the long-term impacts.

For assessing the road safety impacts, qualitative and quantitative analyses have been used. The qualitative study was based on a literature review and consultation with experts within the LEVITATE consortium to estimate direct/indirect impacts on road safety. The quantitative analysis combines microscopic simulation, the Surrogate Safety Assessment, and a probabilistic method to identify the potential crash rates used as a safety indicator within this project. The microscopic simulation method was also used to estimate the emissions of passenger cars in this report. System dynamic models were used to estimate the impact on commuting distances and parking spaces. The latter was also conducted from the Delphi panel, which, in addition, was used to assess the impacts on energy efficiency, public health, and finally on accessibility in transport.

Except Road Use Pricing analysed only through system dynamics and Delphi methods, all other sub-use cases were modelled through microscopic simulation method using large-scale calibrated and validated models of different cities including Manchester network for dedicated lanes, automated ridesharing and GLOSA, Leicester network for parking space regulations, and Santander model for testing parking price policies.

Connected and automated vehicles (CAV) deployment was tested from 0 to 100% with 20% increments under baseline scenario (increasing CAVs only with no other policy intervention) and with various sub-use cases (policy interventions). The behaviours of CAVs were defined based on an extensive literature review performed as part of the LEVITATE project. Two types of CAVs were included in the analysis, 1st Generation CAVs and second Generation CAVs, where 2nd generation CAVs were assumed to have improved driving characteristics and enhanced sensing and cognitive capabilities, which will lead to shorter time gaps as compared to 1st generation CAVs and human-driven vehicles.

Overall, the results from several policy interventions tested under passenger transport provided valuable insights about their implications and long-term impacts. Regarding the impact on demand for parking, the findings were mixed and depended on the assessment methods and studied interventions. The system dynamics modelling results showed increase in demand for parking with increasing MPR of automated vehicles. Under various parking space regulation schemes, it was found that the replacement of on-street parking with driving lanes can further increase the requirement for parking space significantly in the long term (at high MPRs). Suitable Parking price and road use pricing policies were found to be beneficial in reducing parking spaces according to the system dynamic model. The majority of experts opinions in this regard also showed similar findings under Delphi study. The system dynamics model also indicated that commuting distance would only slightly increase with the introduction of automated vehicles and with the implementation of each policy intervention presented within this deliverable.

The road safety assessment estimates a decrease in crash rates related to car-car crashes as well as crashes involving vulnerable road users. With regards to car-car crash rates, a slight increase at lower market penetration rate (MPR) (20%-40%) for dedicated lanes, parking price policies and automated ridesharing policy interventions was predicted to happen due to interactions between human-driven vehicles and automated vehicles.

The Delphi study results regarding the energy efficiency, emissions, public health, and accessibility in transport indicate that increasing MPR of automated vehicles will, in general, have a positive impact, while the effects of different policy interventions were found to be either dependent on the policy measure considered under every SUC, MPR of automated vehicles, or both. In this regard, the Delphi study findings indicated potentially significant benefits due to automated ride-sharing services on energy efficiency, public health and accessibility in transport. Overall, the results hold important messages for city governments to manage potential consequences due to the introduction of CAVs in the transport system. The findings from different assessment methods exhibit that increasing MPR of CAVs alone may not have positive impacts and the right policy decisions are critical for mitigating the potentially adverse impacts particularly during the transition phase.

1 Introduction

1.1 LEVITATE

Societal **Lev**el **I**mpacts of Connec**t**ed and **A**utoma**t**ed Vehicl**e**s (LEVITATE) is a European Commission supported Horizon 2020 project with the objective to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives.
Specifically LEVITATE has four key objectives:

1. To establish **a multi-disciplinary methodology** to assess the short, medium, and long-term impacts of CCAM on mobility, safety, environment, society, and other impact areas. Several quantitative indicators will be identified for each impact type
2. To develop a range of **forecasting and backcasting** scenarios and baseline conditions relating to the deployment of one or more mobility technologies that will be used as the basis of impact assessments and forecasts. These will cover three primary use cases – automated urban shuttle, passenger cars and freight services.
3. To apply the methods and **forecast the impact of CCAM** over the short, medium, and long term for a range of use cases, operational design domains and environments and an **extensive range of mobility, environmental, safety, economic and societal indicators**. A series of case studies will be conducted to validate the methodologies and to demonstrate the system.
4. To incorporate the established methods within a **new web-based policy support tool** to enable city and other authorities to forecast impacts of CCAM on urban areas. The methods developed within LEVITATE will be available within a toolbox allowing the impact of measures to be assessed individually. A Decision Support System will enable users to apply backcasting methods to identify the sequences of CCAM measures that will result in their desired policy objectives.

1.2 Work package 6 and deliverable 6.4 within LEVITATE

The Work Package 6 (WP6) considers the specific case of passenger cars which are used across the transport system, so forecasting of impacts involved the use on urban, rural and highway infrastructure.

Forecasting will be based on the methodology developed in WP3 and the scenarios developed in WP4 to identify and test specific scenarios regarding the impacts of CATS on urban transport. More specifically, the objectives of Work Package 6 (WP6) are:

- To identify how each area of impact (safety, mobility, environment, economy, and society) will be affected by the transition of conventional passenger cars into Connected and automated vehicles with focus on the transition towards higher levels of automation. Impacts on traffic will be considered cross cutting the other dimensions.
- To assess the short-, medium-, and long-term impacts, benefits, and costs of cooperative and automated driving systems for passenger cars,
- To test interactions of the examined impacts in passenger cars, and

- To prioritise considerations for a public policy support tool to help in decision making.

The purpose of Deliverable 6.4 is to present the long-term impacts of cooperative, connected, and automated driving in passenger transport. The exact impacts of interest and how to measure these have been defined in WP3 and WP4. The specific nature of long-term context has been defined in T6.1 (Boghani et al., 2019). The main approaches to forecast the long-term impacts are simulation modelling, system dynamics, Delphi, or classical statistical models. In deliverable 6.4, focus has been given to wider impacts including those on demand for parking, energy efficiency, environment, safety, public health, inequality in transport, and commuting distances.

Table 1.1 presents an overview of the list of impacts considered in the PST for WP6, along with a short description and the unit of measurement. Highlighted are those handled in this deliverable.

Table 1.1: Overview of the impacts in WP6. Highlighted are the long-term impacts for this deliverable.

Impact	Description	Method
Short term impacts / direct impacts		
Travel time	Average duration of a 5Km trip inside the city centre	Mesoscopic simulation/ Microscopic simulation/Delphi
Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel	Delphi
Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)	Delphi
Medium term impacts / systemic impacts		
Congestion	Average delays to traffic (seconds per vehicle-kilometre) as a result of high traffic volume	Microscopic simulation
Amount of travel	Person kilometres of travel per year in an area	Mesoscopic simulation/Microscopic simulation/Delphi
Modal split using public transport	% of trip distance made using public transportation	Mesoscopic simulation/ System dynamics/Delphi
Modal split using active travel	% of trip distance made using active transportation (walking, cycling)	Mesoscopic simulation/ System dynamics/Delphi
Shared mobility rate	% of trips made sharing a vehicle with others	Delphi
Vehicle utilisation rate	% of time a vehicle is in motion (not parked)	Delphi
Vehicle occupancy	average % of seats in use	Delphi
Long term impacts / wider impacts		

Road safety	Number of traffic conflicts per vehicle-kilometre driven (temp. until crash relation is defined).	Road safety method
Parking space	Required parking space in the city centre per person (m2/person)	System dynamics/Delphi
Energy efficiency	Average rate (over the vehicle fleet) at which propulsion energy is converted to movement	Delphi
NOX due to vehicles	Concentration of NOx pollutants as grams per vehicle-kilometre (due to road transport only)	Microscopic simulation
CO2 due to vehicles	Concentration of CO2 pollutants as grams per vehicle-kilometre (due to road transport only)	Microscopic simulation
PM10 due to vehicles	Concentration of PM10 pollutants as grams per vehicle-kilometre (due to road transport only)	Microscopic simulation
Public health	Subjective rating of public health state, related to transport (10 points Likert scale)	Delphi
Accessibility in transport	The degree to which transport services are used by socially disadvantaged and vulnerable groups including people with disabilities (10 points Likert scale)	Delphi
Commuting distances	Average length of trips to and from work (added together)	System dynamics

2 Sub-use cases (SUC)

Sub-use case (SUC) in this deliverable refers to subcategory (policy intervention) under passenger car use-case developed to study the quantifiable impacts of CCAM on passenger transport. From the stakeholder reference group (SRG) workshop, detailed in D 6.1 (Boghani et al., 2019), consultation was obtained from the experts from city administrations and industry on the generation and prioritization of the sub-use cases. Within LEVITATE, this list has been prioritized and refined within subsequent tasks in the project to inform the interventions and scenarios related to passenger transport. In turn, these SUCs will be included in the LEVITATE Policy Support Tool (PST).

The prioritisation of the sub-use cases mainly took these three input directions into account:

- Scientific literature: Indicating the scientific knowledge and the available assessment methodologies for the sub-use cases. However, this might not be directly linked to their importance / relevance for practice.
- Roadmaps: Indicating the relevance of sub-use cases from the industrial/ political point of view, independent of available scientific methodologies.
- SRG Workshop: Containing first-hand feedback for the sub-use cases but might only reflect the opinions of organisations and people who participated.
- Results of the backcasting city dialogues conducted in LEVITATE WP4 for Vienna, Greater Manchester and Amsterdam (Zach, Sawas, Boghani, & de Zwart, 2019; Papazikou et al., 2020)

Considering the input from all three sources, six key sub-use cases have been defined within WP6, which are as follows:

1) Road use pricing (RUP)
2) Provision of dedicated lanes for AVs on urban highways
3) Parking price policies
4) Parking space regulation
5) Automated ride sharing, and
6) Green Light Optimal Speed Advisory (GLOSA)

2.1 Road use pricing (RUP)

The term road-use pricing refers to charges for the use of infrastructure, including distance and time-based fees, road tolls and various charges with the scope to discourage the access or long-stay of vehicles within an area.

Within LEVITATE the two different price charging schemes are considered as defined above for all passenger vehicles for a commercial mixed traffic zone. Here, "dynamic toll" is to be understood as a toll with dependency on occupancy (empty km or car sharing), time (system entry time), and space (road class or/and zone) while the unit pricing for those parameters could be fixed per respective unit (e.g., peak-hours/off-peak hours, km, persons). Differently, the "static toll" refers to a fixed fee or tax paid by users to enter a tolling area.

The road use pricing has raised significant interest and attention during the dialogue with cities and stakeholders, who made apparent that they would like to investigate both pricing models/options in order to adopt the optimum policy according to their priorities and their city vision.

In the initial list of interventions to explore there was also a differentiation in tolls between the human driven and fully automated vehicles. However, after the dialogue with the cities' representatives, it became clear that their *vision focuses on the reduction of any private motorised vehicle in their city centre*, rendering the toll variance meaningless.

2.1.1 Literature review

Existing urban systems

Existing road-use pricing systems concern a specific highway or highway network, or a well-defined city centre area. The major city systems in operation include London, Singapore, Stockholm and Milan. The charge can be modified during peak-hours or increased congestion. The performance of each system depends heavily on their specificities. Table 2.1 the characteristics of the road-charging schemes in these four cities.

Table 2.1 Characteristics of existing road-use pricing schemes (IEA/OECD, 2009)

Town	Name	Date implemented	Scheme type	Area (km²)	Operating hours	Price	Enforcement system
Singapore	Electronic road pricing	1975	Cordon ring (in)	7	Mo-Sa 7.00 - 22.00	Gantry / time dependent EUR 0 to 1.5	Radiofrequencies + cameras
London	Congestion charge	2003	Cordon ring (in)	40	Mo-Fr 7.00-18.30	Flat rate, GBP 8/day	CCTV cameras
Stockholm	Congestion tax	2006 (became permanent in 2007)	Cordon ring (in and out)	35	Mo-Fr 6.30-18.30	EUR 1 to 2/crossing depending on time of day	Laser + cameras
Milan	Ecopass	2008 (temporary through end of 2009; extension possible)	Cordon ring (in)	8	Mo-Fr 7.30-19.30	EUR 2 to 10/day	Digital cameras

In terms of the impact of such policies, they decrease congestion as they affect the amount of traffic and also, the vehicle travel. Other beneficial impacts concern emissions drop, CO_2 emissions reductions and safety (Transport for London, 2007; Eliasson, Hultkrantz, Nerhagen & Rosqvistk, 2009). It is generally supported that implementation of cordon schemes of congestion pricing in large urban areas could have a beneficial and wider impact in the society (IEA/OECD, 2009).

2.1.2 Political sensitivity of the sub-use case and implications

Road-use or congestion pricing schemes have faced opposition and protests, it has been criticised as not equitable, with negative effects in the economy of neighbourhoods and on retail businesses, or as another tax. Nevertheless, economists mostly agree on the economic viability of the intervention to reduce congestion and control traffic in the city centre (Kopp & Prud'Homme, 2010; Anas & Lindsey, 2011; Croci, 2016).

Within the LEVITATE project outcomes from the mesoscopic simulation on this intervention are disseminated via deliverables D6.2 (Haouari et al. 2021) and D6.3 (Sha et al. 2021) for short-term and medium-term impact assessment. Emphasis will be given wherever appropriate within the deliverables or case study documents that they are only case studies to see the effects of road use pricing intervention in those cities, and not necessarily their intention or decision to implement such intervention.

The road use pricing has raised significant interest and attention during the dialogue with cities and stakeholders, who made apparent that they would like to investigate both pricing models/options in order to adopt the optimum policy according to their priorities and their city vision.

2.1.3 Implementation

The method identified as most applicable to derive conclusions on changing mobility behaviour that is caused by variation of mobility pricing schemes, is an agent based macroscopic mobility simulation of activity chains with an underlying calibrated choice model. This method has been applied previously to investigate RUP measures at several implementation sites:

- Meyer de Freitas, Schuemperlin, and Balać (2016): Different toll levels in Zurich were simulated until a reduction of 20% vehicle kilometres travelled was reached.
- Kaddoura and Kickhöfer (2014): Application of road pricing to the MATSim Sioux Fall scenario.
- Simoni, Kockelman, Gurumurthy, and Bischoff (2019): The authors applied road pricing strategies in combination with AV vehicles.

Further assumptions made to investigate the SUC's scenarios for tolling imposed on the inner-city region of the overall model area, are detailed in D6.2 (Haouari et al. 2021). These assumptions allow for consideration of both static pricing upon toll-area entry as well as dynamic pricing depending on the travelled distance within the toll-area.

2.2 Provision of dedicated lanes on urban highways

According to Connected Automated Driving Roadmap from ERTRAC (2019), Dedicated AV Lane is a lane where vehicle(s) with specific automation level(s) are allowed but the area is not confined (it would be segregated in that case). It is envisaged that where a dedicated public transport lane is in operation, the dedicated AV lane would be integrated with the dedicated public transport lane, allowing both types of vehicles.

The results from the SRG meeting and findings from recent literature suggest that certain policies and regulations can directly influence the adoption of CAVs such as, road use pricing, parking fee, dedicated lanes, price of owning and operating car and many more. Within the LEVITATE Project the policy intervention of CAV dedicated lanes is thoroughly investigated as a sub-use case. The main objectives of this sub-use case included:

- Determining the minimum market penetration rate required for a dedicated lane to be a viable option
- Investigating the optimal configuration for dedicated CAV lanes, and
- Finding the societal level impacts of dedicated CAV lanes

2.2.1 Literature review

The review of literature on CAV dedicated lanes in this deliverable has been focused on learning their long-term and wider level impacts. The long-term impacts studied within LEVITATE project include changes in demand for parking, emissions, safety, public health, inequality in transport, and commuting distances.

Recently, a conceptual framework for design and operation of dedicated lanes on motorways, accounting for changes in driver behaviour, traffic flow performance, safety, and environment and the existing gaps in literature was designed by Rad, Farah, Taale, van Arem, and Hoogendoorn (2020) Their research focused on dedicated lanes which are an "existing lane of the motorway dedicated only for fully or partially automated vehicles with or without connectivity," or existing lanes which have been modified, but does not include expansion of an existing motorway or new infrastructure including a dedicated lane. The authors also provided a review of existing state of literature regarding the impact of dedicated lanes on traffic performance, a comparison of different access types of dedicated lanes, utilization policies of dedicated lanes, separation of managed lanes, plus behavioural adaptation of manual drivers and CAV drivers. The review identified several gaps in the current state of knowledge, as shown Figure 2.1, particularly in terms of understanding relations between dedicated lane design, MPR of C/AVs, utilisation policy, driver behaviour, traffic efficiency, safety, and environment.

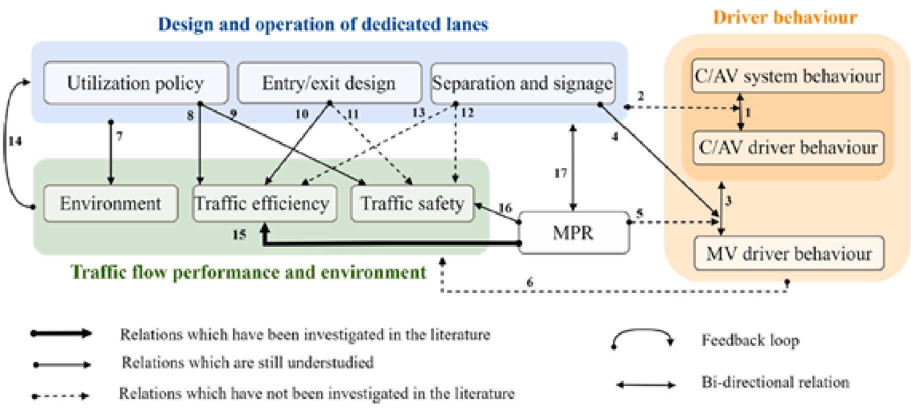


Figure 2.1: Conceptual framework for the relations between the design and operation of dedicated lanes, driver behaviour, traffic flow performance and the environment (Rad et al., 2020)

Previous studies have made efforts to analyse the safety impacts of CAV dedicated lanes, through surrogate safety measures, for safe deployment of CAVs in the transport system. In this regard, Chai, Rodier, Song, Zhang, and Jaller (2020) investigated the safety effects with varying CAVs penetration rates with External Driver Model for modelling the CAVs behaviours. PTV VISSIM platform was used to model the dedicated lane on a 7 km segment of four-lane Ninghu Freeway in China. The speed limit on this freeway is 120 km/h for passenger cars and 80 km/h for trucks. CAV platooning control algorithm was designed with intelligent driver behaviour model (IDM) for modelling the driver behaviour of CAVs. The researchers also analysed the safety impacts due to presence of freight vehicles in the traffic stream. Three scenarios were tested (0,1 and 2 exclusive lanes) with varying traffic demands (2000-8000 veh/h) and composition (truck proportion and CAV penetration rates). The author used TTC (Time to Collision), Time Exposed Time-to-collision (TET) and Time Integrated Time-to-collision (TIT) to build a relationship between simulation data and longitudinal safety. Rear-End Crash Risk Index (RCRI) was used to determine the rear end crashes. Lateral safety (e.g., angle and sideswipe crash risk) was evaluated by analysing the number of lane change conflicts (LCC) using the Surrogate Safety Assessment Model (SSAM) (Pu, Joshi, & Energy, 2008). The study concluded that one dedicated lane can improve the safety in low volume scenarios. Whereas for high volume demand two exclusive lanes provide more safety. Moreover, the presence of HGVs can significantly worsen the longitudinal safety in low MPRs.

In this regard, Rahman and Abdel-Aty (2018) have also attempted to assess the longitudinal safety of managed lane Connected Vehicle (CV) platoons on a busy congested expressway. The IDM and platooning concept were used for defining CV behaviours. For this study, an expressway in Florida with 17 weaving segments was used in IDM. A comparison of the implementation of (i) managed-lane CV platoons and (ii) all-lane CV platoons with a non-CV scenario was undertaken. Five safety measures were used as indicators for safety evaluation, which were (i) standard deviation of speed, (ii) time exposed time-to-collision (TET), (iii) time integrated time-to-collision (TIT), (iv) time exposed rear-end crash risk index (TERCRI), and (v) sideswipe crash risk (SSCR). Both CV approaches were found to significantly improve the longitudinal safety compared to the non-CV scenario. And the managed-lane CV platoons significantly outperformed all lanes CV platoons in terms of all five surrogate safety measures.

The review of existing literature performed by Rad et al (2020) clearly indicate lack of knowledge on overarching performance of CAVs dedicated lanes considering combined aspects of design, operation, driver behaviours, traffic efficiency, safety, and environment.

2.3 Parking price policies

Parking price is one of the key factors for deciding personal vehicle as a mode of transportation. Statistics show that there are around 30 million cars in Great Britain and the number is increasing every year (Department of Transport, 2017). As the number of cars increases, the need for parking spaces will increase. As the parking spaces may not always be available, policymakers want to reduce the demand for parking spaces as well as low occupancy cars. This is one of the reasons for implementing the parking prices (Institute for Transport Studies, 2019).

Autonomous vehicles do not need to park near the destination or park at all, and could hence solve the problem of parking. Identifying the importance of such policies, various parking pricing schemes, influencing parking behaviours, have been tested within LEVITATE project to analyse wider level impacts. As the autonomous vehicles do not require parking then they could do one of the following actions: i). roam around until the passenger needs them again ii). go back to origin and park outside, iii). There could be an intermediate situation (balanced scenario) where some vehicles return to the parking, and some remain in the network. Within this deliverable, the impacts of these parking price policies have been analysed on a variety of domains including demand for parking spaces, safety, emissions, energy efficiency, public health, inequality in transport, and commuting distances.

2.3.1 Literature Review

Since parking price plays a major role in choosing to use personal vehicles, parking price policies can have direct impact on network performance, safety, and emissions. It is known from early studies that parking can significantly affect traffic safety (Humphreys, Wheeler, Box, & Sullivan, 1979) and, in this regard, importance of implementing traffic safety management measures have been highlighted in recent studies as well Cao et al. (2017). The parking price is one of the measures agencies take to control the traffic demand (Kelly & Clinch, 2006). Further, the effect of autonomous vehicles on safety is one of the major concerns to the researchers, and many research efforts are continuing in this direction. To examine the effects of various urban form elements on vehicle travel and carbon emissions, Frank, Greenwald, Kavage, and Devlin (2011) used detailed data on several urban form characteristics. According to their findings, increasing parking costs from $0.28 to $1.19 per hour (50th to 75th percentile) lowered Vehicle miles travelled (VMT) by 11.5% and emissions by 9.9%. Furthermore, Litman (2021) specifies that the parking price could reduce the potentially large number of conflicts leading to higher safety.

Mei, Feng, Kong, Zhang, & Chen (2020) study showed that the reduced parking costs can increase the traffic congestion and the total distance travelled. Authors have also demonstrated that a 1$ increase in parking price can reduce the trips from 1.5 to 2 times (Harvey & Deakin, 1998). Similarly, other studies have demonstrated that a 10% increase in the parking price would reduce the parking demand on an average to 3% (Kelly & Clinch, 2006; Gillen, 1977; Kulash, 1974). Hence, the parking prices could potentially reduce the congestion, vehicle miles travelled (VMT), emissions and other externalities (Alavi, 2016).

The findings from the above literature suggest that the parking price policies can potentially benefit in many ways by improving traffic flow and safety and reducing emissions and demand for parking spaces.

2.4 Parking space regulations

On-street parking is the most common parking prototype comprising all paid and unpaid parking activities along the roadside in urban cities (Biswas, Chandra, & Ghosh 2017). It allows drivers to park their vehicles close to their destination and share the same road width with other vehicles moving on the street (Prakash, Bandyopadhyaya, & Sinha, 2020). On-street parking has some natural contributions to the economy. However, the negative effects have drawn attention from governmental bodies and academic institutions in terms of causing congestion, capacity reduction, and increasing road traffic accidents. Theoretically, the introduction of autonomous vehicles offers the potential to improve road safety and reduce the urban space requirements for roads and parking, which opens new opportunities to create more space for high-quality and liveable area (González-González, Nogués, & Stead, 2019, 2020).

2.4.1 Literature Review

Within this deliverable, the focus on this sub-use case has been given to study the wider impacts of various parking space regulations such as those related to environment, safety, demand for parking, public health, energy efficiency, inequality in transport, and commuting distances. Accordingly, the literature review is directed towards the findings from previous studies on the corresponding indicators.

Besides the impact on road capacity and congestion, on-street parking can potentially cause safety hazards and increases the risk to vulnerable road users (Prakash et al., 2020; Biswas et al., 2017). In a complex urban environment, drivers must monitor movements surrounded, i.e., vehicles, pedestrians, and other road users. Parked vehicles, therefore, increase the uncertainty, mental load, and potential risk associated with the road environment, such as parked cars may obstruct the view of the road ahead and make it more difficult to see pedestrians crossing the road (Edquist, Rudin-Brown, & Lenné, 2012). Several studies found that the child injury on the urban roads might have a strong relationship with the on-street parking (Martin, 2012; Schwebel, Davis & O'Neal, 2012; DiMaggio & Durkin, 2001) because of their limited ability to judge an oncoming vehicle with decreased visibility due to parked cars (Biswas et al. 2017).

With regard to demand for parking spaces, various research studies indicated that the introduction of autonomous vehicles has the potential to reduce the urban space requirements for roads and parking (Lyon et al., 2017; Cavoli, Phillips, Cohen, & Jones 2017; Anderson, et al., 2016; Chapin et al., 2016; Fagnant, Kockelman, & Bansal, 2015), and creating more space for the high-quality, liveable area (González-González et al., 2020, 2019) , especially in the context of shared autonomous vehicles (SAVs) (Othman, 2021). Consequently, a large number of existing parking spaces will be gradually removed, replaced, or converted to be used for other purposes, such as green and recreational spaces (Xia et al., 2021; Milakis, Arem & Wee, 2017; Chapin et al., 2016).

In this regard, automated ride-sharing services can play a vital role. Multiple studies have investigated the potential impacts of shared autonomous vehicles (SAVs), indicating their capability to significantly reduce car ownership due to the sharing concept, resulting in a reduction in parking spaces and land use (Othman, 2021; Xia et al., 2021; Martinez & Viegas, 2017; Milakis et al., 2017; Anderson et al., 2016; Alessandrini, Cattivera, Holguin, & Stam, 2014; Fagnant & Kockelman, 2015; Zhang & Guhathakurta, 2017). A recent study conducted by Xia et al. (2021) reviewed the current research on urban public parking spaces under the scenario of SAVs and proposed four key issues which involved: (a) how much to renew, (b) when to renew, (c) what to renew and (d) how to update. The main finding was that a large number of the parking spaces would be renovated and transformed for other uses in the SAV era.

A report conducted by International Transport Forum (ITF, 2015) investigated the microsimulation of the SAVs in the city of Lisbon, Portugal. The results showed that under a fully shared automated vehicle fleet scenario, both on-street and off-street parking spaces could be significantly reduced between 84% and 94%. A similar finding by Zhang, Guhathakurta, Fand, and Zhang (2015) used an agent-based simulation model to quantify space saving. The results indicated that the parking space required for the participating clients could be reduced by over 90% once the SAV system is implemented. The results also indicated that the amount of the urban parking spaces saved could be converted to more sustainable designs, such as more green, open, and human-oriented spaces.

A study by Silva, Földes, and Csiszár (2021) investigated the transformation between SAVs and urban spaces. The authors applied the method of building scenarios in a case study in Budapest, Hungary. The results indicated that almost 83% of the parking demand could be reduced and renovated for other purposes. The results also showed that SAVs could significantly minimise air pollution caused by parking infrastructure up to 45%.

Zhang and Guhathakurta (2017) proposed a discrete event simulation (DES) model based on the real transportation network with calibrated link-level travel speeds and a travel demand origin-destination matrix. The study attempted to examine the impact of SAVs on urban parking land use in the city of Atlanta, Georgia. The results revealed that nearly 5% of parking land could be reduced by the SAV system at a 5% market penetration level. The results also indicated that each SAV could emancipate more than 20 parking spaces in the city.

A number of studies attempted to predict the impacts of on-street parking using a traffic simulation approach, especially in the context of autonomous vehicles (such as Chai et al., 2020; ITF, 2018; Biswas et al., 2017). A study Chai et al. (2020) used the SUMO traffic model and local travel activity data to simulate AV parking scenarios in the central business district (CBD) of San Francisco. In the study, three scenarios have been simulated: (a) demand for drop-off and pick-up travel versus parking; (b) the supply of on-street and off-street parking; and (c) the total demand for parking and drop-off and pick-up travel due to an increase in the cost to travel. The results showed that the shift from parking trips to drop-off and pick-up trips improves traffic flow due to reduced parking search time and more efficient use of parking spaces. The results also indicated that over-allocation of drop-off and pick-up spaces could further increase CO_2 emissions from vehicles that get stuck in traffic congestion and suggested such convention of parking spaces to drop-off and pick-up spaces must be street specific and dynamic over-time to adjust to the changes in AV market shares.

A study conducted by ITF (2018) provided a modelling exercise to quantify the impact of re-allocating curb space from parking to pick-up and drop-off zones for passengers and freight in an area of the central business district (CBD) of Lisbon, Portugal. The results showed that the curb-release lay-bys have a better fit between the supply and demand for pick-up/drop-off capacity and have a significant reduction in queuing and resulting delays. The results also suggested that city councils should consider how to dynamically manage the spaces from the street to the curb over the course of the day.

Overall, the findings from the previous researchers indicated that on-street parking can cause some negative impacts on traffic performance and safety hazards to road users in the urban areas. In addition to reducing the requirements for public parking spaces, the introduction of connected and automated vehicles is predicted to mitigate safety hazards due to on-street parking manoeuvres as well as can potentially provide environmental benefits with suitable on-street parking regulation.

2.5 Automated ride sharing

Ridesharing is a conventional model where the private car is shared via pre-arranged journeys. Ridesharing is pre-arranged within, for example, neighbourhoods, the wider community, the workplace, informally via ride-matching websites and dedicated applications.

Sharing taxis has been done informally at taxi stands by identifying similar destinations via 'word of mouth'. However, app-based taxi sharing is an emerging business model where the user can call a taxi via the app and share it with others if they wish to. Ride matching is handled by optimising algorithms and matched ride options are available to users via the apps. CCAM can play a significant role in this model as connectivity will enhance the taxi sharing options, and automated vehicles are speculated to reduce taxis' costs.

However, it is important to identify that micro-transit services and on-demand mini-bus services can be operated along fixed or flexible routes based on demand. These are usually commercial services, and the number of seats is usually greater than taxis. This option seems to overlap with the urban shuttle sub-use cases within the LEVITATE project and does not seem to be a passenger car sub-use case.

Out of the possible options, it has been recognised that automated taxi sharing is the fastest emerging business and is already in operation in many cities worldwide. Considering the suitability under the passenger transport use case, automated taxi sharing was taken forward as one of the sub-use cases within this work package.

Understanding the potential changes in mobility, access to travel, modal split due to automated ride-sharing services within LEVITATE deliverables D 6.2 (Haouari et al. 2021) and D 6.3 (Sha et al. 2021), the analysis has been further expanded in this deliverable to identify broader level effects of such services in long term as outlined under section 1.2. These include impacts on environment, safety, energy efficiency, public health, inequality in transport, and commuting distances.

2.5.1 Literature review

The emergence of autonomously driven vehicles holds great promise for the future of on-demand shared mobility services. On-demand mobility services, such as car-sharing, ride-hailing, ride pooling gained increased popularity over the past few years. Due to becoming increasingly common travel solution, such mobility services are causing a dramatic change in the mobility behaviour of the users, especially in urban areas. On-demand mobility services can positively impact transportation, land use, environment, and road safety, and combining them with the emergent technology of autonomously driven vehicles could amplify these benefits.

In this regard, a comprehensive review of relevant studies in the field of Shared Autonomous Vehicles (SAVs) was by Narayanan, Chaniotakis, and Antoniou (2020). The authors discussed SAV services from different aspects, including service typology, characteristics, modelling, and potential impacts. A comparison of the studies over the years was also undertaken and further showed the change in impacts due to certain variables. For example, a decrease was found in the potential of SAVs to reduce parking requirements between 2015 and 2018. Data detail, accessibility, and reliability were identified as some of the main challenges of using the current tools to estimate the need for shared services. It also appeared to be the case that shared services will lead to a modal shift from public transport, and so SAVs would need to be integrated efficiently with public transport in the future. The authors also reported that assumptions within the previous studies are often based on current travel data rather than being based on future projections. In order to realistically understand the impacts of introducing SAVs, scenarios need to be based on plausible assumptions that may occur in the future. From the review, the main areas where there is a lack of research includes fleet size, elasticity, short-term car sharing systems, dynamics pricing, social equity, and public health.

It is also important to predict what could be the potential impacts of shared autonomous mobility services on travel behaviour and land use. In this context, Soteropoulos, Berger, and Ciari (2019) presented their findings through a review of the SAV modelling and simulation approaches. The review found that shared AV fleets could have positive impacts, reducing vehicles numbers and parking spaces, as well as vehicle hours travelled (VHT). However, there could also be a potential for a small increase in inner city population. The results also suggested that in rural areas, a greater number of vehicles may be needed to replace the current fleet due to more empty rides.

With regard to extra vehicles miles (VMT) travelled Fagnant et al. (2015) investigated the potential implications of a virtual shared autonomous fleet in an area of Austin, Texas 12 x 24mile in size. The authors assumed that a 1.3% share of the total regional trips are going to be served by SAVs and performed the simulation using MATSIM dynamic traffic simulation software under different traffic conditions during the daytime using 5-minute departure time windows. They concluded that 1 SAV have a replacement rate of approximately 9.3 while being able to maintain a good level of service and having an average of 1 minute user wait times. The results also revealed a reduction in parking demand by around 8 vehicle parking space per SAV. In terms of distance travelled, the results showed the new service generate around 8% VMT due to pick-up and relocation empty trips. The results also showed that in spite of the additional VMT, SAV deployment will probably have a positive impact on emission and air quality since SAVs are supposed to be modelled as environment-friendly vehicles with a high turnover rate and less cold starts.

Oh et al. (2020) studied the potential impacts of AMOD (Automated Mobility-On-Demand) on transportation in Singapore using activity and agent-based simulation (on the demand side and on the supply side, plus their interactions), and using a model of Singapore in 2030. The scenarios and performance measures used in the study included mode availability (all existing modes such as walking, car, car-pooling, bus, cycling etc, plus MOD and AMOD-single and shared), pricing (75%, 100% & 125% of existing taxis), fleet sizing and performance measures such as demand patterns (mode shares/shifts), network performance (vehicle km travelled, trip times, Travel Time Index) and AMOD service metrics (request satisfaction rates, vehicle utilization, average waiting times). The main findings were that AMOD use is likely to be greater than existing MOD and taxi services, but there was found to be an increase in Vehicle Kms Travelled of up to 17% when there was moderate adoption of AMOD and total vehicle ownership was not capped. The fleet size needed to serve AMOD demand across an island the size of Singapore would range from 27500 to 43200, which is more than an on-demand or taxi fleet.

In order to identify the overarching advantages and disadvantages Lokhandwala and Cai, (2018) analysed taxi sharing using agent-based modelling, with New York city taxis being used as the example for this study. A comparison of traditional taxis with shared automated taxis was undertaken. A potential fleet size reduction of 59% could be achieved from the switch to shared automated taxis from traditional taxis without any significant increase in wait time for occupants. The main benefits highlighted were increase occupancy rates, reduced travel distances, reduced carbon emissions and increased system flexibility. One disadvantage highlighted was that a reduced fleet size caused by dynamic ride sharing could lead to taxis focusing on higher demand areas, so some areas would be left with limited services, particularly in the suburbs.

The effects of trip densities and parking limitations on shared autonomous fleet performance was the focus of the study by Yan, Kockelman, and Gurumurthy (2020). MATSim is used to micro-simulate the 7-county Minneapolis – Saint Paul region of Minnesota, USA. Various trip densities (2%, 5%, 20% of total trips), parking constraints (kerb parking everywhere, kerb parking restricted) and fleet parameters (SAVs per traveller) are investigated, with and without DRS being enabled. With DRS, SAV Vehicles Per Miles Travelled reduced by 17% with 'empty' VMT being reduced by 26%. Parking restrictions led to a greater VMT (by 8%). Also, SAVs were found to potentially perform better in regions with a high population density and trip density with shorter trip lengths. External trips and commercial trips were not included in this study, and both could contribute to VMT and congestion, so this may slightly limit the validity of the result found.

Automated shared services are also expected to have a strong impact on demand for parking and air pollution as indicated through some of the literature already presented under section 2.4.1. As an example, the study of Silva et al. (2021) estimated the reduction in demand for parking spaces to reach up to 83% whereas decrease in air pollution was indicated to be up to 45%.

Overall, the findings of the literature presented above identifies various strategies through which benefits of shared autonomous services can be maximised. In this regard, fleet size, willingness to share, and characteristics of the service area can play a key role in maintaining the potential for positive benefits. Some areas where more research is needed include, fleet size, elasticity, short-term car sharing systems, dynamics pricing, social equity and public health, travel costs, and perception of time in ridesharing.

2.6 Green light optimal speed advisory (GLOSA)

Road transport entails undoubtedly benefits to the society but does not come without externalities. The negative effects on the environment and the society include traffic crashes, pollution, and congestion (Santos, Behrendt, Maconi, Shirvani, & Teytelboym, 2010). Congestion entails interrupted flow, lower speeds, larger travel times and delays. This has an environmental impact as when a vehicle faces delays on the road, with multiple stops and waiting in the traffic lights, due to mostly speed alterations and frequent acceleration and deceleration manoeuvres, the fuel consumption and pollution is increasing.

In recent years, technological achievements have rendered vehicle wireless communications available. Connected vehicle technology includes vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication and has several safety and mobility applications (Radivojevic, Stevanovic, & Stevanovic 2016). As traffic information becomes accessible, connected vehicles are able to adapt their behaviour according to traffic conditions and this adaptation can contribute to beneficial changes in traffic flow and emissions (Masera, Imprialou, Budd, & Morton, 2019). One emerging vehicle to infrastructure application that intends to improve emissions through optimizing traffic flow on signalized road networks is the Green Light Optimal Speed Advisory (GLOSA). An overview of GLOSA system application is demonstrated in Figure 2.2.

Green Light Optimal Speed Advisory (GLOSA) is a Day 1 C-ITS signage application, enabled by the C-ITS service "Signalised Intersections". The application utilises traffic signal information and the current position of the vehicle to provide a speed recommendation in order for the drivers to pass the traffic lights during the green phase and therefore, reduce the number of stops, fuel consumption and emissions. The distance to stop, the plans for signal timing and the speed limit profile for the area are taken into account to calculate the speed recommendation displayed to the driver. GLOSA service is provided through ETSI G5 into the on-board computer of the vehicle or via mobile network into a smartphone app.

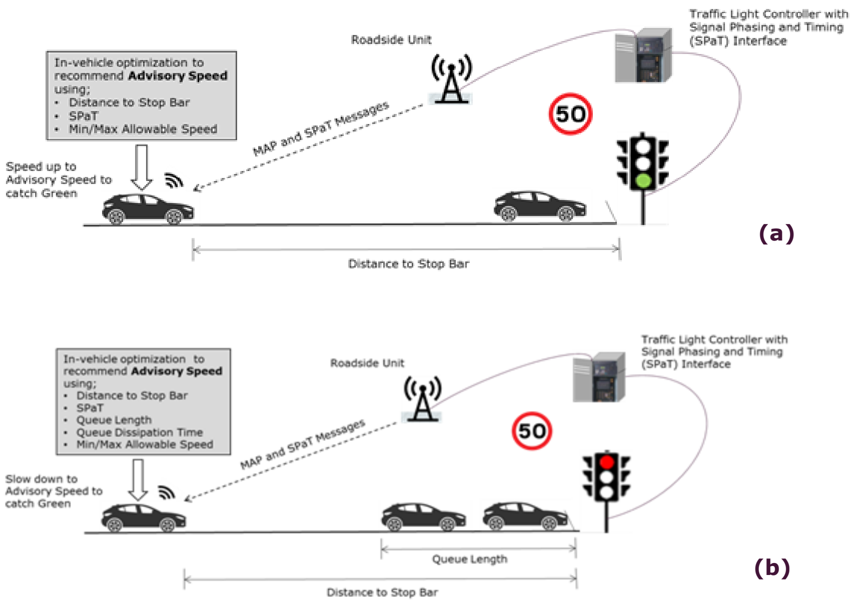


Figure 2.2: GLOSA system and application overview: (a) Communication initiated when current phase is Green, (b) Communication initiated when current phase is Red

In the era of CAVs, it would be useful for cities, various stakeholders, and transport planners to assess the societal impacts of such an application in an urban area and attempt to evaluate the benefits in relation to the relevant costs.

2.6.1 Literature review

Within this deliverable, an effort was made to review the previous studies investigating the impact of GLOSA system and similar technologies on wider impacts related to environment, safety, and fuel consumption.

The literature review on GLOSA system within this deliverable was directed to identify current knowledge and gaps on long term benefits and disbenefits of such technologies. With regard to previous studies exploring the impacts of GLOSA system, Mellegård and Reichenberg (2019) provided a review of 64 publications between 2006 and 2019 investigating GLOSA (Figure 2.3). Most based their findings on simulation, with a much smaller amount using real-world methods (e.g., pilots, FOTs). The on-board GLOSA algorithm was proposed as the main solution in the majority of the studies, with less proposing the whole system and/or predicting signal changes as the solution. The focus was on the equipped vehicle in most studies, as opposed to fellow road users or other societal issues. In terms of impacts, many of the studies looked at the effect of varying traffic levels on GLOSA effectiveness. No publications examined drivers' ability to follow the advised speed. Travel time increases, as well as decreases, were seen across the 64 studies.

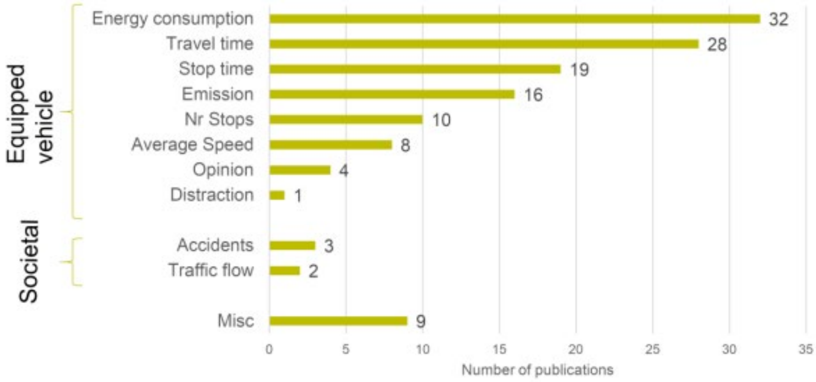


Figure 2.3: Overview of the effects/impacts evaluated across the 64 papers (from Mellegård and Reichenber, 2019)

Xia et al (2012) investigated the effects of eco-approach technology which uses Signal Phase and Timing (SPaT) on fuel consumption and CO_2 emissions. Both field operation testing (FOT) and simulation were carried out in this study. The FOT took place at Richmond Field Station in California, USA, with the test loop being 307m. The speed of (30 seconds green, 3s yellow, 27s red). There were 292 runs where the driver was given speed recommendations ('informed') and 260 runs where drivers were given no information ('uninformed'). The simulation study had a similar set-up to the FOT, with the same intersection being used in the simulation. Both FOT and simulation studies found that the informed driver saved around 13.6% fuel compared with the uninformed drivers, which means around 14% fuel and CO2 savings could be achieved using the eco-approach method. The main causes of these savings were due to early slowing down and not having to stop at the intersection. And as part of this, it was also observed that being more fuel efficient did not lead to any major increases in travel time.

Chen, Rakha, Loulizi, El-Shawarby, & Almannaa (2016) look at implementation issues regarding the application of Eco-Speed Control (ESC) systems. Field trials were undertaken at the Virginia Smart Road at VTTI (USA), which is 3.5km in length and contains a four-way signalised two-lane highway. 192 trips were undertaken using four participants and both uphill and downhill approaches to the intersection were included. Reductions in average fuel consumption levels (D6.4) and travel times (D6.2) were found to be in the range of 17.4% and 8.4%, respectively.

Another study focusing on heavy-duty trucks (Wang et al, 2019), undertook field operation trials in the City of Carson, California, USA, on a test area which consisted of six signalised intersections equipped with communication modules. which looked at acceleration and deceleration scenarios showed that a connected eco-driving system could result in around 9% and 4% savings in fuel respectively

A study performed by Karabag (2019) analysed the effect of GLOSA on emissions, using the VISSIM and MOVES simulation models. Two intersections on a section of road in the city of Tallahassee, Florida, USA, are used in the simulations. Both delay (D6.2) and pollutant emissions (D6.4) were found to reduce significantly when GLOSA is utilised in the simulations, with emissions reducing by between 30 and 51%, stop delay by 84% and number of stops by 88%.

The potentials and limitations of GLOSA systems in realistic large-scale simulations were investigated by Eckhoff, Halmos, and German (2013). This study mainly looked at environmental-related impacts (e.g. emissions) but also analysed impacts on waiting times and the number of stops. The simulation framework Veins was used, coupling OMNeT++ and the traffic simulator SUMO. An area of Munich was used to develop the simulation, and four levels of traffic density were investigated in the study, two were in free flow, one was in semi-free flow, flow, and one was in synchronised flow. CO2 emissions were lowered by up to 11.5% in low traffic densities, waiting times by 17% and amount of stops potentially by around 6%. But in heavier traffic conditions, some issues were detected, such as longer waiting times higher CO2 emissions for non-equipped vehicles.

Gajananan et al (2013) used an integrated traffic, driving and communication simulator to investigate the effects of GLOSA on emissions, travel times and stopped times. GLOSA introduction led to a reduction in all 3 of these areas (40-68% reduced stopped times, 10-16% reduced travel times, 8-20% reduced CO2 emission). Lebre et al. (2015), have also reported reductions in travel time through a simulation study under experimental and real traffic conditions.

Previous studies have also reported that benefits on GLOSA system can be achieved if used with fixed time signal controllers. For instance, Stevanovic, Stevanovic, and Kergaye (2013), who used VISSIM simulation model of 5-intersection corridor in the US while testing fixed and actuated signal timings, found improvement in travel time, number of stops, and fuel consumption under fixed timings, but not under actuated operation. Under fixed-time controllers, the authors also reported improvement in traffic performance with higher MPR and increased frequency of GLOSA system activation. Signal retiming/optimization before implementing GLOSA was suggested as increasing the benefits from such an application.

There are relatively fewer studies in literature exploring the safety impacts of GLOSA. In this regard, Stevanovic et al. (2013) has performed surrogate safety assessment on arterials due to implementation of GLOSA system. An urban corridor segment including 5 intersections, in Salt Lake City, UT, was modelled using VISSIM simulation model. Various signal control schemes including actuated, optimized, fixed-timing as well as actuated were tested with GLOSA application. Vehicular conflicts were analysed through microsimulation trajectories post-processed through FHWA's surrogate safety assessment model (SSAM). The results showed reduction in number of conflicts under fixed-time controller operation. Further reduction was found under optimised signal timings under pretimed signals. In terms of types of conflicts, the results showed considerable decrease in rear-end conflicts whereas the number of lane-change conflicts were found to increase with GLOSA application. The study also indicated increased conflicts under mixed fleet scenarios due to increased disruptions in the traffic.

Overall, findings from the previous studies indicate reduction in emissions and fuel consumption with the implementation of GLOSA system under fixed-time signal operation, considering vehicles comply with the speed advisory messages. However, percentage reduction reported was found to vary across the existing literature. A limited literature was found on safety impacts of GLOSA or similar systems; however, the available evidence suggest potential reduction in rear-end crashes with the application of GLOSA on pre-timed signals.

3 Methods

The types of impacts that are presented in Deliverable 3.1: A taxonomy of potential impacts of connected and automated vehicles at different levels of implementation (Elvik et al.,2019) have been estimated and forecast using appropriate assessment methods, such as traffic simulation, system dynamics and Delphi panel method. For example, traffic simulation can directly provide short-term impacts. Therefore, it was used to forecast short-term impacts to be able to develop relationships that can infer dose (in terms of introduction of sub-use case) and response (selected impact). Traffic simulation also provides further input to assess medium-term impacts by processing those results appropriately to infer such impacts. System level analysis (such as by tools found within system dynamics) can provide measure of long-term impacts. For the sake of simplicity and applicability of assessment methods, it is assumed that for the appropriate level of automation, adequate infrastructure exists. It is also assumed that the pure technological obstacles for the sub-use cases in consideration are solved. All these results relating to the relationships between sub-use cases, impacts and any intermediate parameters will be provided to WP8 of LEVITATE, which concerns the development of the LEVITATE Policy Support Tool (PST). The results will be integrated within the PST modules and functionalities so that impact assessment can be carried out by the user.
An overview of the methods used to estimate the long-term impacts in this deliverable is presented in Table 3.1.

Table 3.1: Overview of the methods used to estimate long-term impacts of connected and automated vehicles under WP6

Sub-use Cases	Methods		
	Microscopic Simulation	System Dynamics	Delphi
Road use pricing (RUP)		✓	✓
Provision of dedicated lanes on urban highways	✓		✓
Parking price policies	✓	✓	✓
Parking space regulations	✓	✓	✓
Automated ride sharing	✓	✓	✓
Green Light Optimal Speed Advisory (GLOSA)	✓		✓

3.1 Microscopic simulation

Traffic simulation has been widely applied to estimate the potential impacts of connected and automated vehicles. As identified in LEVITATE Deliverable on Impact Assessment Methods (Elvik et al., 2020), many studies have used microsimulation technique to estimate the potential impacts of CATS on traffic performance indicators. It is envisaged that the microsimulation approach can be used to calculate the direct impacts of CAVs. In most cases, a commercially available traffic microsimulation tool (such as AIMSUN, VISSIM, Paramics or SUMO) is used along with an external component. The microsimulation tool is applied to represent the infrastructure and creates the traffic in the predefined road system, while the external component aims to simulate the CATS functionalities.

Within WP6, the traffic microsimulation method is used to model and analyse the sub-use cases of dedicated lanes, parking space management, GLOSA, and automated ridesharing. AIMSUN Next Microsimulation tool has been used in all the sub-use cases, utilising calibrated and validated city networks, including Manchester and Leicester in the UK and Santander in Spain. CAV functionalities/behaviours were modelled by adjusting a wide spectrum of parameters in the simulation framework. All CAVs were modelled as electric while HDVs as non-electric vehicles.

Two types of CAVs (1st Generation CAVs and 2nd Generation CAVs) were modelled to analyse WP6 sub-use cases, details of which are provided in the following section. The deployment of CAVs was tested from 0 to 100% MPR with 20% increments as shown in Table 3.2. Simulations were run for the peak hours with each simulation scenario consisting of 10 replications.

Table 3.2: CAV Deployment scenarios

Type of Vehicle	CAV Deployment Scenarios							
	100-0-0	80-20-0	60-40-0	40-40-20	20-40-40	0-40-60	0-20-80	0-0-100
Human-Driven Vehicle - passenger vehicle	100%	80%	60%	40%	20%	0%	0%	0%
1st Generation (Cautious) CAV - passenger vehicle	0%	20%	40%	40%	40%	40%	20%	0%
2nd Generation (ambitious) CAV - passenger vehicle	0%	0%	0%	20%	40%	60%	80%	100%
Human-Driven LGV	100%	80%	40%	0%	0%	0%	0%	0%
LGV-AV	0%	20%	60%	100%	100%	100%	100%	100%
Human-Driven HGV	100%	80%	40%	0%	0%	0%	0%	0%
HGV-AV	0%	20%	60%	100%	100%	100%	100%	100%

3.1.1 Modelling of CAVs behaviours

Two types of CAVs were considered in this study:1st Generation CAVs and 2nd Generation CAVs. Both types are assumed to be fully automated vehicles with level 5 automation. The main idea behind modelling these two types is based on the assumption that technology will advance with time. Therefore, 2nd Gen CAVs will have improved sensing and cognitive capabilities, decision making, driver characteristics, and anticipation of incidents etc. In general, the main assumptions made on CAVs characteristics are as follows:

- 1st Generation: limited sensing and cognitive ability, long gaps, early anticipation of lane changes than human-driven vehicles and longer time in give way situations.
- 2nd Generation: advanced sensing and cognitive ability, data fusion usage, confidence in taking decisions, small gaps, early anticipation of lane changes than human-driven vehicles and less time in give way situations.

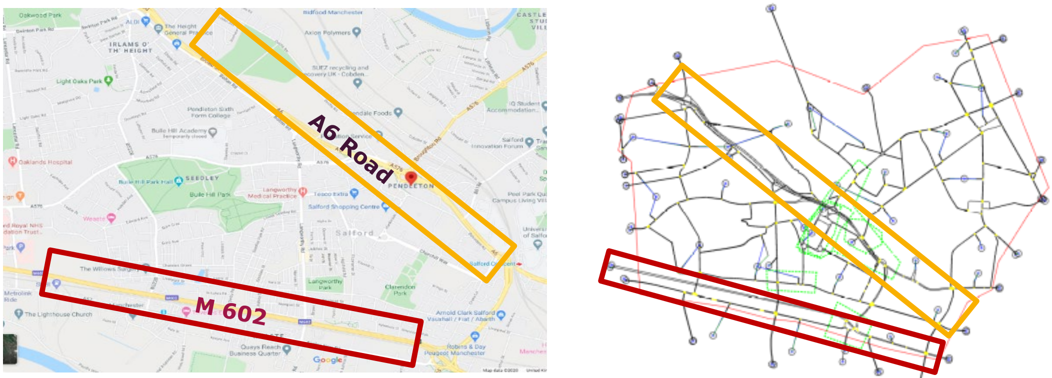
These characteristics were defined through various model parameters in AIMSUN Next including reaction time, time gap, acceleration and deceleration characteristics, parameters related to lane changing and over taking behaviour and several others. The default car-following model in AIMSUN is based on Gipps model (Gipps,1981,1986). Various parameters of the car-following model were adjusted to implement HDV and CAV behaviours. The assumptions on CAV parameters and their values were based on a comprehensive literature review, including both empirical and simulation-based studies (Cao et al., 2017; Eilbert, Berg, & Smith, 2019; Goodall & Lan, 2020; De Souza & Stern ,2021; Shladover, Su, & Lu ,2012), as well as discussions in meetings with various experts within the project. Some guidance on the behaviours was also obtained through studies on adaptive cruise control (ACC) and cooperative ACC (CACC) systems.

Traffic impact of CAVs were assessed in mixed traffic conditions that contain, in addition to passenger cars, freight and public transport (PT) vehicles. The automation of freight vehicles was also considered; however, due to limited knowledge on automation of freight vehicles, only a few parameters were adjusted to model the behaviours of freight CAVs.

3.1.2 Implementation based on SUC

3.1.2.1 Provision of dedicated lanes on urban highways

A calibrated and validated traffic microsimulation model of Manchester area (provided by Transport for Greater Manchester) was used for this sub-use case. In general, the model development and calibration involved details of road network in the study area, peak hour traffic demand, vehicle types, signal timing data, vehicular behaviour and lane usage, journey times, bus routes, stations, and timetable information. A comprehensive set of traffic counts was used to compare and validate the modelled flows with observed traffic counts. Modelled journey times were also compared and validated against observed journey times during the peak hours. This model provides a good foundation for the experiment as it includes a motorway and a major arterial road (M602 and A6, respectively) (Figure 3.1) which connect the centre of Manchester with the suburbs. The network consists of a 13 km^2 area with 308 nodes and 732 sections. The evening peak hour (1700 – 1800) traffic consists of 23226 car trips, 1867 light goods vehicles (LGV) trips, and 763 heavy goods vehicle (HGV) trips.



(a) (b)

Figure 3.1: The modelling area in the city of Manchester (a) and Manchester network in AIMSUN software (b)

Assumptions and parameters

The following assumptions have been made for this sub-use case:

- When introduced, the dedicated lane will be mandatory for CAVs and public transport (if applicable). That means that the CAVs are not allowed to travel in any other lane unless they cannot follow their route in any other way.
- The dedicated lane will be located either on motorway or A road in the Manchester Network.
- The A-road consists of several consecutive segments, which comprise of either two or three lanes. It is always assumed that one of these lanes is a dedicated lane, except in intersections when one cannot define a dedicated lane due to AIMSUN limitations.

Scenarios

In order to identify the most optimal strategy for providing dedicated lane which can potentially be most beneficial, the placement of dedicated lane was investigated under various scenarios including:

- Baseline scenario – AV implementation without a dedicated lane
- Scenario 1 – CAVs use a dedicated (innermost) lane in the motorway
- Scenario 2 – CAVs use a dedicated (innermost) lane in the motorway and the A-road
- Scenario 3 – CAVs use a dedicated (innermost) lane in the A-road.
- Scenario 4 – CAVs use a dedicated (outermost) lane in the A-road.

These scenarios were formulated in order to address the research questions, outlined under section 2.2.

In order to address the question of what is the minimum required market penetration rate for dedicated lanes to be a viable option, several mixed fleet combinations including human driven vehicles (HDVs) and CAVs with different market penetration rates were tested in each of the aforementioned scenario.

3.1.2.2 Parking price policies

A microsimulation model of Santander City was employed for this sub-use case (Figure 3.2). This city centre area model served the purpose of analysing the impact of various possible AV parking behaviours due to different parking price policies. The used network model contains 108 nodes (intersections) and 382 sections (one-way links). The study considers the evening peak hours (1900 - 2200) for analysis with an estimated traffic flow of 42337 private car trips.

Figure 3.2: The modelling area in Santander city (a) and in AIMSUN software (b)

This sub-use case refers to enforcing parking behaviour through different parking price policies. However, these behaviours can also be influenced by limiting parking spaces within a particular area. With automated vehicles, the widespread belief is that one would be able to command their highly automated vehicles to drive around with no occupants in them to avoid parking for a short duration. Four parking behaviours were considered for this sub-use case (Figure 3.3):

- Enter and park inside the area (baseline – consistent with the current situation),
- Enter, drop off passengers and return to origin to park (outside and inside included),
- Enter, drop off passengers and return to outside parking restriction area to park, and
- Enter and drive around (short stay)- the vehicle drops the passenger and drive around while waiting for the passenger to ride again

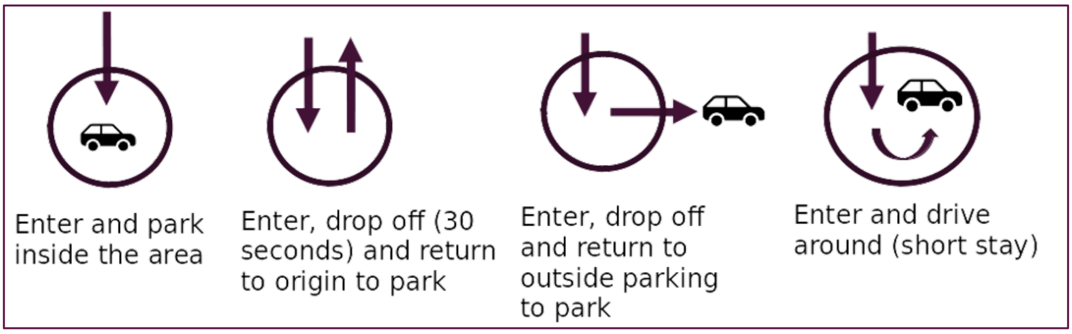


Figure 3.3: CAVs Parking behaviours

Different scenarios were considered based on the proportions of vehicles choosing these parking options (see Table 3.3). It should be noted that these percentages depend on parameters like the parking price which cannot be controlled directly in the microscopic simulation.

Table 3.3: Scenarios relating to the prevailing parking behaviours.

	Return to Origin %	Park Outside %	Drive around %	Park Inside %
Baseline	0%	0%	0%	100%
Case 1 (balanced)	22%	45%	20%	13%
Case 2 (Heavy drive around)	0%	0%	100%	0%
Case 3 (Heavy Return to origin and Park outside)	33%	67%	0%	0%

Assumptions

The following assumptions have been made for this sub-use case implementation:

- In the baseline scenario, it is assumed that sufficient spaces are available, and vehicles can park themselves inside without causing any disturbance to the traffic
- In the 'heavy drive around scenario', vehicles drop the passenger and drive around nearby
- In the case of 'heavy Return to origin and Park outside' vehicles do a mixed activity of parking outside and return origin
- The 'Balanced' scenario consists of a combination of all the parking choices available
- Simulations run for the peak hour with each simulation scenario consisting of 10 replications produce reliable results
- CAVs and classic vehicles can travel together without any requirement of dedicated lanes
- HGVs and LGVs are not present
- There exist only given parking options

Several possible compositions of modes (Human driven car, first generation AVs and second-generation AV) were considered for all scenarios for analysis (Table 3.2).

3.1.2.3 Parking space regulations

The study network used for this sub-use case is a traffic microsimulation model (developed using AIMSUN software) of the city of Leicester. The network consists of 10.2 km^2 area with 788 nodes and 1988 sections. Traffic during the lunch hour (1200-1300) consists of 23391 car trips, 3141 LGVs, and 16 HGVs trips. Due to having the city centre area, this model served the purpose of analysing various on-street parking space regulations. The Leicester city centre network is around 10.2km² and consists of 788 nodes and 1,988 sections. The traffic demand for passenger cars, LGVs and HGVs are 23 391 trips, 3 141 trips and 16 trips, respectively. The network is presented in Figure 3.4.

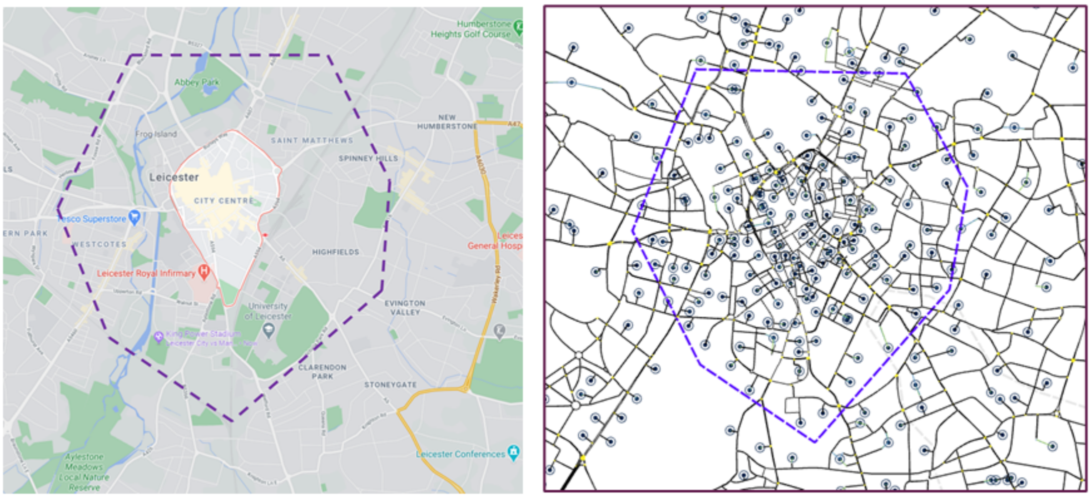


Figure 3.4: The Leicester city centre network in AIMSUN software

Scenarios

This specific network includes the city centre area only. For practical purposes to be more effective using simulation, on-street parking in the city centre has been divided into 4 parking zones, including a total of 52 streets with 138 parking bays as showed in Figure 3.5.

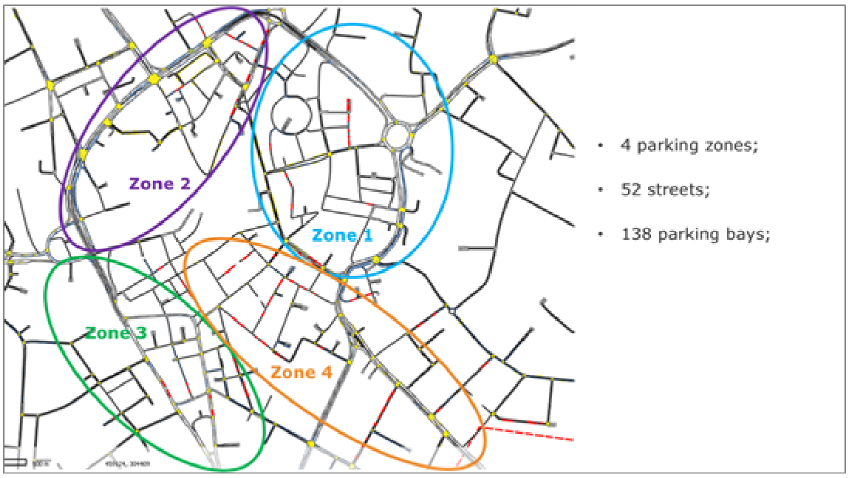


Figure 3.5: On-street parking zones in AIMSUN software

Within this SUC, six scenarios will be studied using microscopic simulation:

- Baseline scenario - CAV implementations without replacing the on-street parking intervention, CAV market penetration from 0% to 100% at 20% increments. Including a total of 52 streets with 138 parking bays for all 4 parking zones.

- Removing half of the on-street parking spaces - Scenarios based on the reduction of parking capacity, i.e., 50%. As described in the literature review section, the introduction of AVs offers the potential to reduce the urban spaces requirements for parking, the on-street parking spaces for 4 parking zones have been reduced to 28 streets and 79 parking bays, respectively.

- Replacing on-street parking spaces with driving lanes. In this scenario, on-street parking spaces will convert to driving lanes (shown in Figure 3.6).

- Replacing on-street parking spaces with cycling lanes. In this scenario, on-street parking spaces will convert to a dedicated cycle lane (shown in Figure 3.6), which means other vehicle types are not allowed to use the cycle lane. It should be noted that the cyclist behaviour has not been simulated in the modelling due to the limitation of the software.

- Replacing on-street parking spaces with pick-up and/or drop-off points (shown in Figure 3.7). The scenario assumes the AVs are shared AVs. As a result, after the vehicle pick-up or drop-off the passenger, the vehicle will exit the study area to return home or serve another customer. More detail of shared AVs can be found in automated ridesharing SUC.

- Replacing on-street parking spaces with public spaces. In this scenario, on-street parking spaces will convert to public spaces, e.g., green and recreational spaces (shown in Figure 3.6).

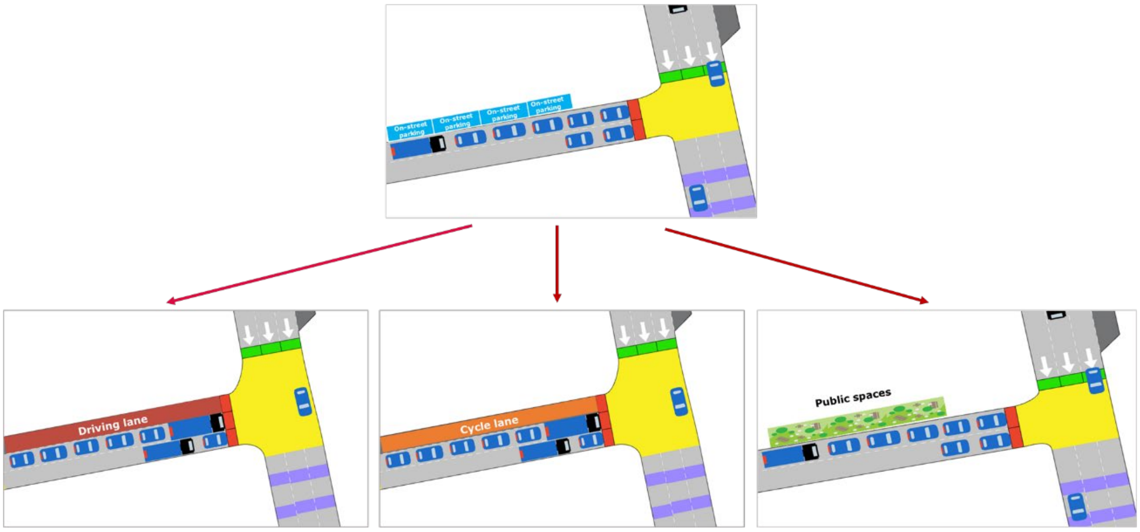


Figure 3.6: Replacing on-street parking with driving lane, cycle lane and public spaces

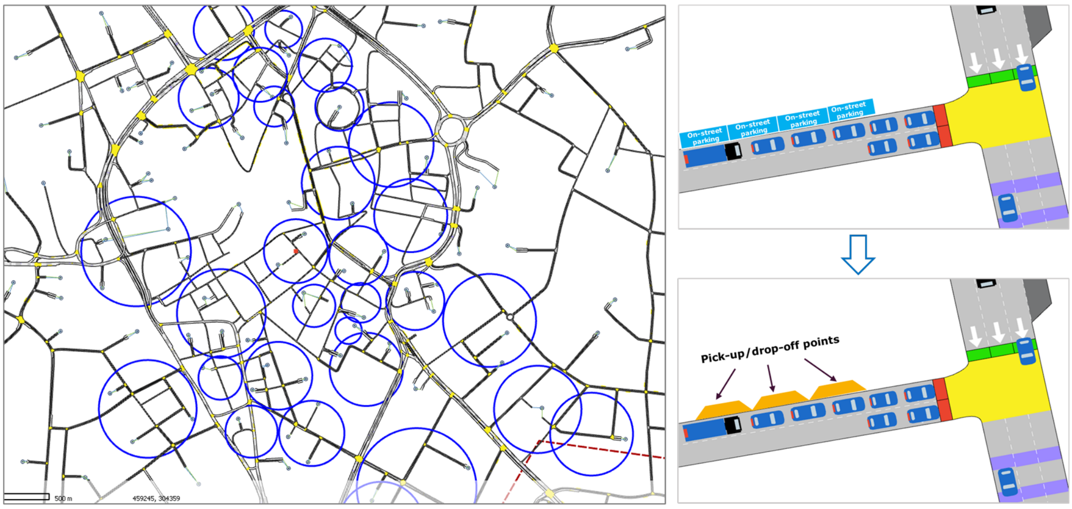


Figure 3.7: Replacing on-street parking with pick-up/drop-off points and the pick-up/drop-off locations in AIMSUN software

Assumptions

The following assumptions and limitations exist in this sub-use case implementation:

- Lunchtime rush hour is considered to be the most critical time period for this sub-use case,
- No residential parking is considered in the model,
- No changes have been considered in the disabled on-street parking bay,
- The pick-up/drop-off scenario was assumed to follow SAVs concept,
- On-street parking manoeuvre duration (blockage time) is assumed to be 30s with 20s deviation based on the previous literature (Chai et al., 2020; Chow, Rath, Yoon, Scalise, & Saenz, 2020; Fehr & Peers, 2018; Wijayaratna, 2015; Portilla*, Oreña, Berodia, & Díaz*, 2009),

- Cyclists are not modelled in the replacing on-street parking spaces with cycling lanes scenario due to the software limitation.

Modelling on-street parking manoeuvres

Within this sub-use case, the function of the periodic section incident has been applied to simulate the on-street parking manoeuvres (shown in Figure 3.8). It's a traffic incident that causes a lane blockage over a certain time period. This action creates random incidents and are placed randomly throughout the area i.e., street, parking bay (Transport Simulation Systems [TSS], 2021).

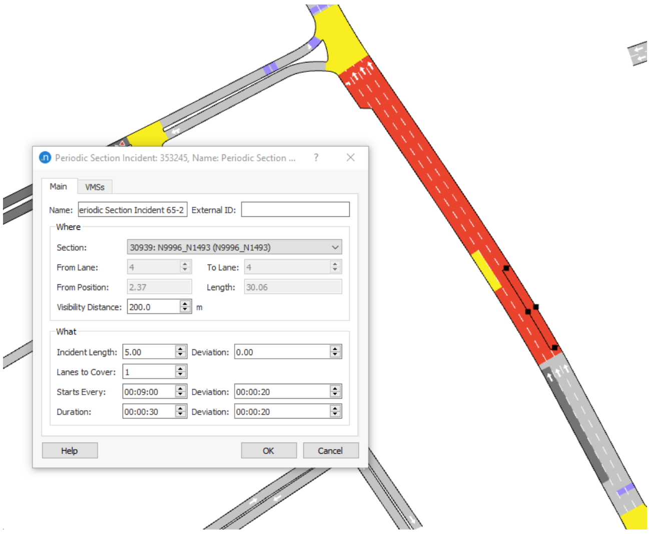


Figure 3.8 Screenshot of periodic section incident in AIMSUN Next

Figure 3.9 illustrates examples of the periodic section incident representing on-street parking on a single lane and a multi-lane road in the model using the AIMSUN Next simulation platform. The left image demonstrates the incident (on-street parking) happening on a single lane blocking the traffic over a certain time. The right image shows the incident happening on a multi-lane road where the following vehicle decides to change lane because of the leading vehicle making an on-street parking manoeuvre.

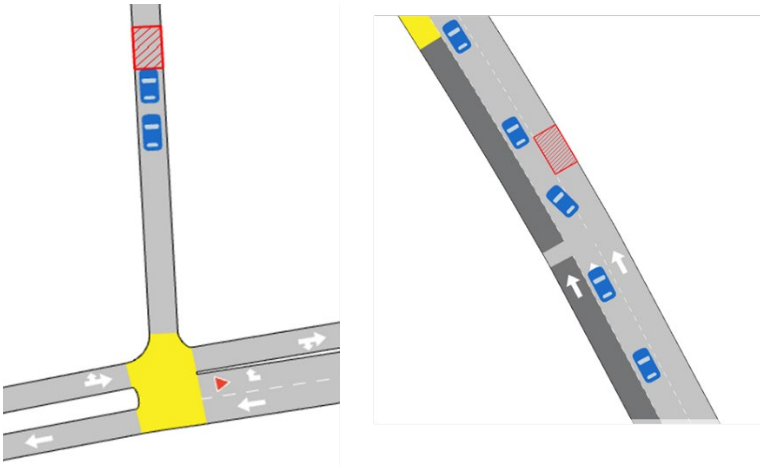


Figure 3.9 Periodic section incident on a single lane and multi-lane road in the model using in AIMSUN Next

3.1.2.4 Automated ride sharing

This sub-use case investigates the impacts of introducing autonomous shared vehicles (SAV) on the efficiency of transport systems. The proposed service combines free-floating car-sharing, ridesharing, and fully autonomous vehicles operating in Manchester (UK). With respect to operation, the proposed service is considered to provide on-demand trips where SAVs pick up passengers from their origins and drop them off at their destinations under time constraints.

In addition to passengers' origin, destination, departure, and arrival time, the SAV assignment in this sub-use case also considers the passengers' willingness to share (WTS) their rides with others which could depend on several factors such as increased travel and detour time (König & Grippenkoven, 2020), and the acceptance of sharing same vehicle with strangers (Lavieri & Bhat, 2019). The passengers' WTS has a significant impact on the efficiency of SAV service. For this reason, the impact due to this aspect is also investigated within this sub-use case.

The service introduced in this study is modelled by one of the well-known optimisation problems: the **Vehicle Routing Problem with Pickup and Delivery with Time Window (VRPPDTW)** (Mahmoudi & Zhou, 2016). With this optimisation process, trip-requests are matched to a SAV fleet (that was determined within the process), and optimised routes for SAVs are provided. The optimisation output served as an input for the AIMSUN Next Microsimulation tool to generate different KPIs to assess the impact of this service on mobility, safety, and environment. An overview of the modelling and implementation of this SUC is shown in Figure 3.10.

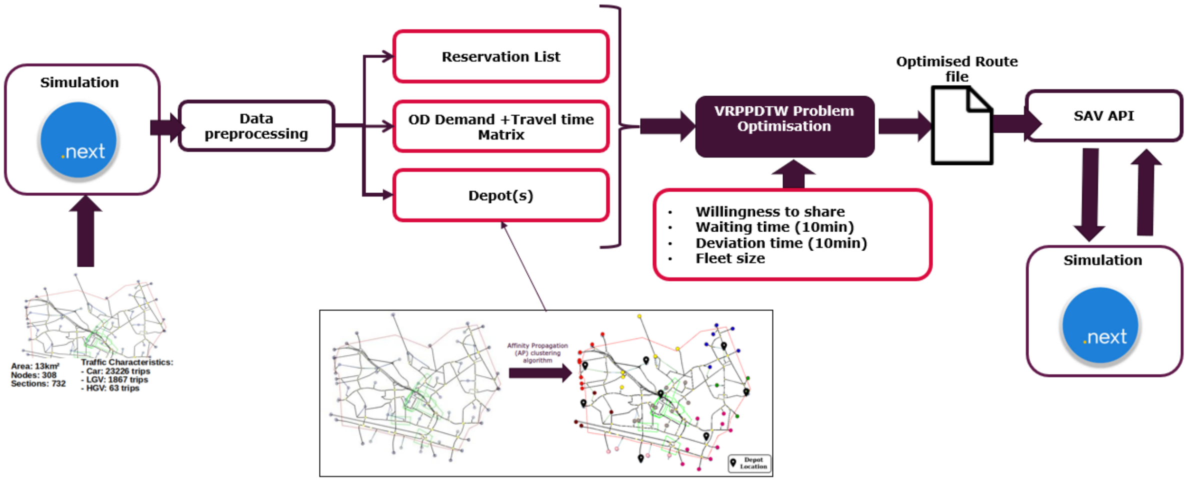


Figure 3.10: Overview of the modelling process of automate ridesharing SUC

Network model & data preparation

To illustrate the potential benefits of the proposed ride-sharing service, a calibrated and validated microsimulation model (developed using AIMSUN simulation platform) was used consisting of a 13km² area from the Great Manchester Area (UK) that contains 308 nodes and 732 road sections (Figure 3.11), and OD matrix of 58x58 centroids from the network. Traffic data of evening peak hours (1700 – 1800) was used, with an estimated traffic demand of 23 226 car trips, 1 867 large goods vehicles (LGV) trips, and 63 heavy goods vehicle (HGV) trips.

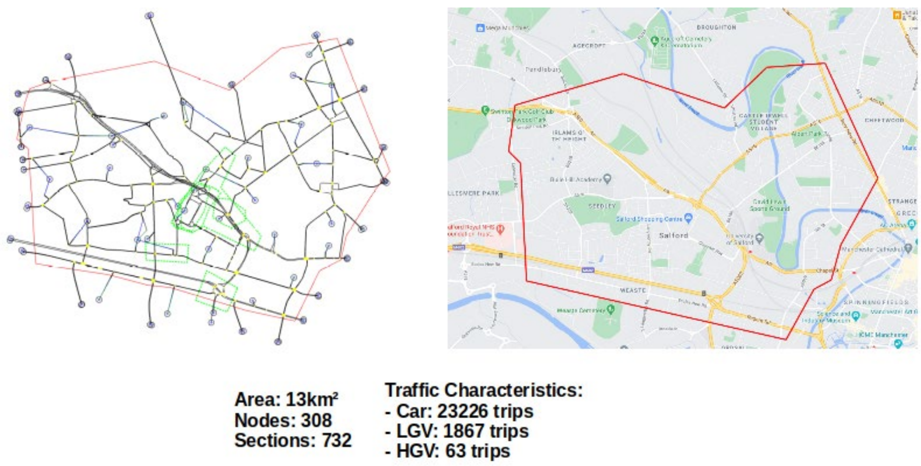


Figure 3.11: The Manchester network in AIMSUN software

As mentioned above, the proposed service is modelled as VRPPDTW problem, and to perform the optimisation process to solve this problem, a set of files have been extracted from the micro-simulation model of the study area:

- The Origin-Destination (OD) traffic demand matrix for personal car trips in the study area,
- A GIS file that contains the exact coordinates of the study area’s centroids,
- Travel Time matrix with values derived from the simulation of the original OD demand,
- A list of personal vehicle trips (trip ID, pickup centroid, drop off centroid, departure time, and arrival time) was also obtained from the simulation of the original OD demand.

These files hold data that will be used to generate input to the optimisation process, such as depots’ locations, trip requests, pick up and drop off time windows, etc.

It was assumed that demand for this new service will replace a share of personal vehicle demand. Through the simulation of the original OD demand matrix provided with the network model, a list of trips corresponding to the personal vehicles was obtained and used to select random candidate trips that this service will perform.

Google’s OR-Tools will be used to solve the VRPPDTW problem to assign routes for SAVs pickup and drop-off passengers. Each centroid in the network can be a pickup or drop-off location for several trips, which is not suitable for the OR-Tool solver that assumes each node can be visited only once and can be either a pickup or drop-off site. Therefore, to respond to this constraint, a dummy node was created for every passenger origin or destination with zero distance from the original location to distinguish pickup and drop-off nodes.

Every user of this new service has a preferred time window to be picked up from his/her origin and the desired time window for arrival at his/her destination. The departure and arrival times from the list of trip requests extracted from the simulation are used as lower bounds of pickup and arrival time windows. The upper bounds values are related to the passenger’s acceptable waiting time and detour from its original route (caused by ridesharing with others), and within this project, it was assumed that a passenger could tolerate waiting and detour time range from 5 min to 10 min. Instead of having fixed waiting and detour time values for all passengers, we applied a normal distribution to generate a set of values assigned to all passengers' trip requests.

Trip requests can be classified into individual or shared trips, depending on the passenger WTS. According to the literature, the acceptance of the shared trip option could be related to the user's approval of extra travel time associated with the pickup/drop-off of other passengers (König & Grippenkoven, 2020) and to his/her sensitivity toward sharing the same vehicle with other strangers (Lavieri & Bhat, 2019). To study the impact of the user's disposition to shared rides on the overall performances of the service and the network, we developed scenarios based on different aggregated levels of WTS. To facilitate the integration of this notation into the optimisation problem, it was assumed that a passenger is either willing or unwilling to share his/her ride. In other words, the passenger's decision will not be related to the value of time or money or even the number of other passengers sharing his ride. Passengers' preference for a shared ride was assigned randomly based on a predefined level of WTS. These preferences will be given as an input to Google's OR-Tools solver through a 1D array containing the demand corresponding to the number of passengers to be picked up or dropped off in each location. A positive value represents the demand at the pickup location, and a negative value represents the demand at drop-off location. If a passenger is willing to share his/her ride, the demand will be equal to the capacity of the SAV, which is assumed to be equal to regular 4-seater car; otherwise, the demand will be equal to one.

Depots allocation

Depots and charging station locations are critical factors in deploying a ride-sharing service. In this study, the Affinity Propagation clustering algorithm (Frey & Dueck, 2007) is used to determine the depots' locations. In contrast to other traditional clustering algorithms, such as K-means, the AP algorithm does not require inputting the number of clusters in advance. It determines the optimal number of clusters and their exemplars (clusters' centres) based on a message-passing procedure where all data points are considered as exemplars and exchange messages between them concerning their attractiveness and their availability to associate with other data points until an optimal set of exemplars and clusters emerges (Givoni & Frey,2009).

The affinity propagation algorithm was implemented using python's Scikit-learn package and executed with 1 000 maximum iterations taking the exact centroids' location in the Manchester network model and their corresponding total trip demand from the original OD matrix. As shown in Figure 3.12 eight clusters were determined by the algorithm, i.e., eight depots assigned to the nearest centroid from the exemplar of each cluster.

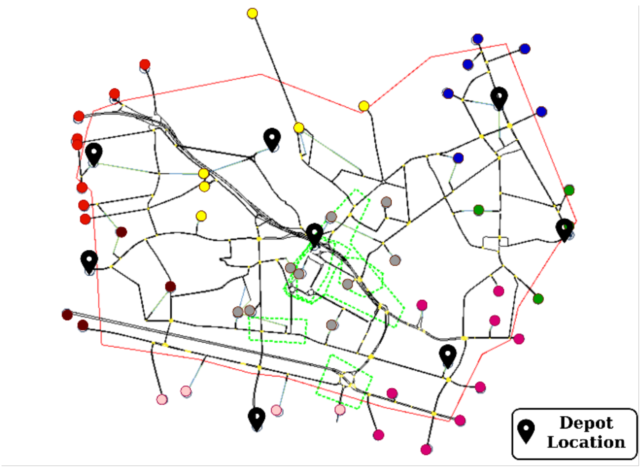


Figure 3.12: Allocation of SAV service depots based on Affinity Propagation clustering algorithm

Optimisation process

The following input data was given to Google's OR-Tools solver to solve the modelled VRPPDTW:

- The travel time matrix with values derived from the simulation of the original OD demand,
- The initial fleet size,
- The 1D demand array,
- The capacity of a SAV (4-seater car),
- The list of pick-up and drop-off pairs,

- The list of pick-up and arrival time windows, and
- The depots' locations.

The analysis was performed for the afternoon peak hour period (1700-1800). It was assumed that the SAVs were not required to return to their depots, but instead, they ended their routes at their last drop-off location, which was represented by the arbitrary ending depot location, which had zero distance from every other centroid. Regarding the initial fleet size, a SAV fleet equal to the served demand was assumed to be parked at each depot to ensure that every trip request is assigned to a SAV.

The maximum travel time for each SAV was set to one hour to ensure that SAVs finished their optimised routes within the simulation period. Moreover, a limit of 1 000 solutions was set for every scenario to prevent the solver from running indefinitely due to the size of the optimised problem, while sufficient investigation of the solution space will take place.

Scenarios & assumptions

Within this sub-use case, the impact of automated ride sharing is studied under the scenarios resulting from the combination of different rates of demand that will be served by SAVs and the percentage of travellers willing to share their rides (WTS) (Table 3.4).

Table 3.4: studied scenarios under automated ridesharing SUC

Scenarios	SAV demand	Willingness to share
Baseline (No policy intervention)	-	-
Scenario1	5%	20%
Scenario2		50%
Scenario3		80%
Scenario4		100%
Scenario5	10%	20%
Scenario6		50%
Scenario7		80%
Scenario8		100%
Scenario9	20%	20%
Scenario10		50%
Scenario11		80%
Scenario12		100%

For all scenarios, deployment of CAVs in the network was tested from 0% to 100% in 20% increments with the two types of CAVs presented in section 3.1.1.

The SAV capacity considered in this SUC is four passengers, and the SAV fleet composition includes 1st and 2nd Generation CAVs. The presence of each type is based on its market penetration rate defined in Table 3.2.

The following assumptions have been made for this sub-use case implementation:
- All CAVs and SAVs are EVs
- The battery capacity can support full-day operations for each SAV
- Parking spaces are enough for all SAVs in each station

- The pick-up and drop-off locations and behaviour will not be addressed in this sub-use case
- Preference for ridesharing is presented as a parameter with two statuses (Yes, No)
- Cancellation of assigned SAV is not allowed
- An SAV request refers to one traveller

Optimisation results

Table 3.5 shows the optimisation results for the different scenarios studied within this SUC. The results indicate that the fleet size required to replace conventional personal vehicle trips gradually decrease as more passengers are willing to share their rides. The decrease in the number of required SAVs is associated with an increase in the number of vehicles conventional that one SAV can replace.

Table 3.5: Optimisation results for automated ride sharing service

Demand to be served	Trips to be served	Willingness to share	Optimal SAV Fleet size	SAV Replacement Rate *
5%	1134	20%	645	1,8
		50%	570	2,0
		80%	490	2,3
		100%	435	2,6
10%	2239	20%	1154	1,9
		50%	1009	2,2
		80%	839	2,7
		100%	720	3,1
20%	5070	20%	2391	2,1
		50%	2067	2,5
		80%	1694	3,0
		100%	1436	3,5
(*): Number of personal vehicles replaced by one shared AV (SAV)				

Regarding travelled distance, Figure 3.13 shows that a higher willingness to share reduced the total and empty travelled distance covered by the SAV fleet in all scenarios. The results also revealed that with higher demand, the distance will be gradually increased. This increase is obtained not just because of serving more passengers but also because of the empty repositioning trips that SAVs need to perform to pick up passengers that represent a significant share of the overall trips, as seen in Figure 3.14.

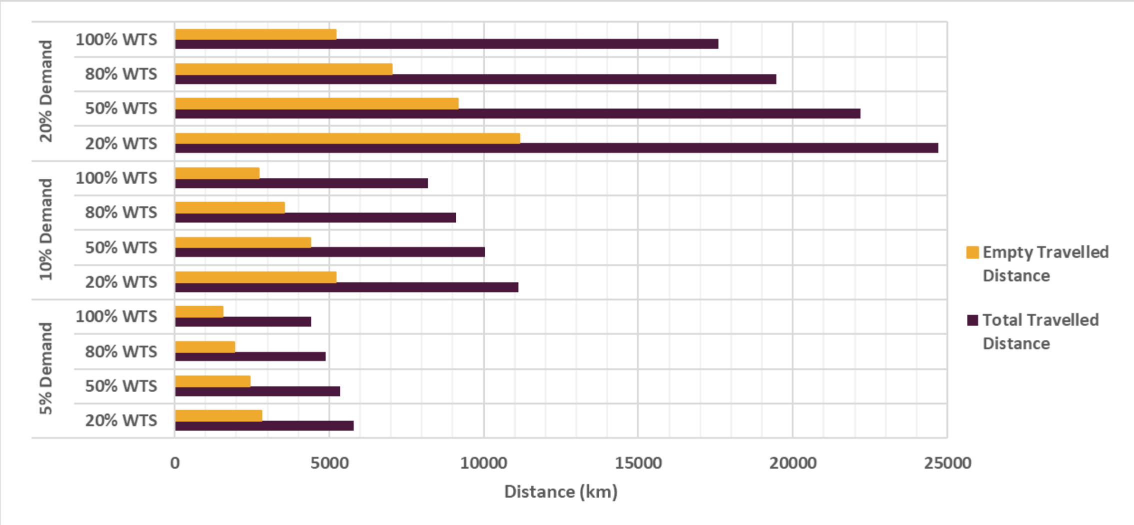


Figure 3.13: Total distance travelled by the shared autonomous vehicle (SAV) fleet in kilometres with different served demand and passengers willingness to share (WTS) percentages

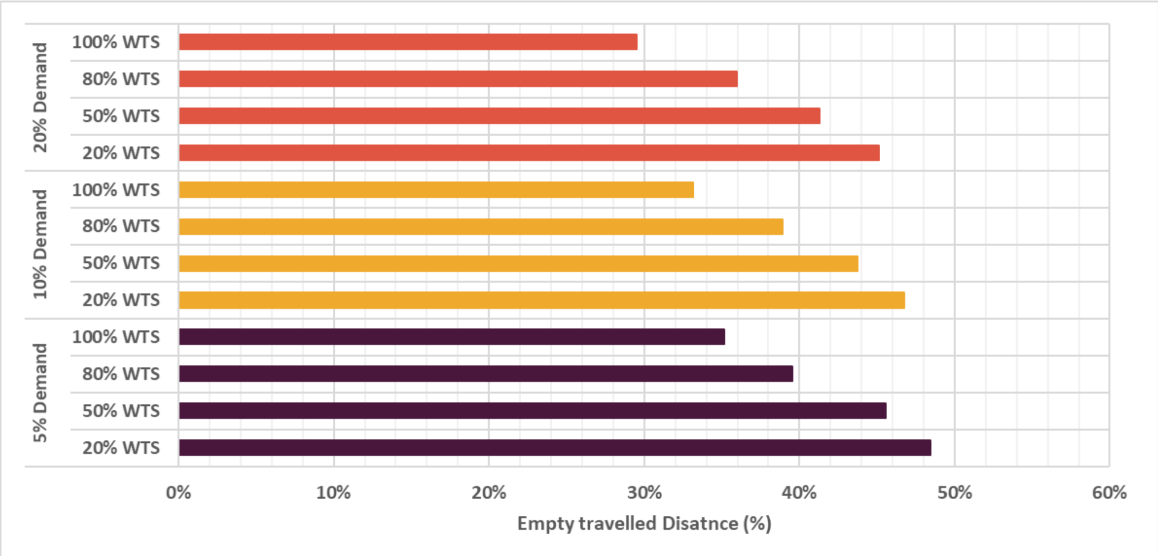


Figure 3.14: Percentage of empty distance travelled by the entire SAV fleet

3.1.2.5 Green Light Optimal Speed Advisory (GLOSA)

The traffic microsimulation model that is used for this sub-use case was provided by Transport for Greater Manchester. The model of Greater Manchester provides a sufficiently large and complex transport network with signalised intersections and other various road sections, rendering it suitable for the specific experiment. For implementing GLOSA, a corridor near the Salford area was selected in Manchester including three signalized intersections (Figure 3.15) where the distance between first and second intersection is around 400m whereas that between second and third intersection is around 800m. The impact of GLOSA was analysed under fixed time coordinated traffic control at these study locations signals.

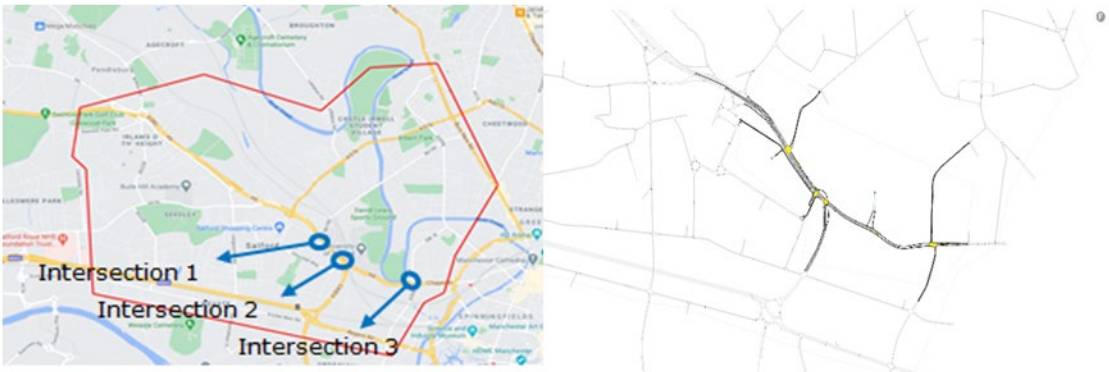


Figure 3.15: Test corridor in Manchester network for GLOSA application

The test scenarios on GLOSA implementation and CAV deployment are as follows:

- Baseline scenario – No GLOSA, CAV market penetration from 0% to 100% in 20% increments.
- Scenario 1 – GLOSA on intersection 1,
- Scenario 2 – GLOSA on intersections 1 and 2, and
- Scenario 3 – GLOSA on intersection 1, 2 and, 3.

Simulations were performed for the peak hours on baseline and all three analysis scenarios with CAV deployment as shown in Table 3.2. The analysed impacts included:

- Travel Time
- Delays
- Number of Stops
- Emissions
- Total Conflicts (Safety Impacts)

The following assumptions were made in the frame of GLOSA application.

1) The quality of communication between signals and vehicles is ideal and all messages are delivered successfully and without delay,
2) All the drivers accept and comply with the recommended speed,
3) GLOSA is applied at each simulation step, and
4) Only CAVs will have the capability to communicate with traffic signal controllers.

Simulations were run for the peak hours performing 10 replications under each scenario.

GLOSA algorithm

GLOSA Algorithm was developed based on reviewing some of the previously developed algorithms in literature (Stevanovic et al, 2013) with modifications as deemed adequate for the test network. The key steps describing the functionality are shown in Table 3.6.

Table 3.6: Steps involved in GLOSA system operation

Step 1. GLOSA system in vehicle searches for a traffic signal controller downstream
Step 2. If a traffic signal controller downstream is detected, go to step 3, else go to step 1
Step 3. GLOSA system in vehicle collects data on vehicle position and speed

Step 4. Get Map Data Message (MAP) information about the lane and turning restrictions. (GLOSA application generates geometry from MAP message to determine the vehicular position and determine the corresponding lane number)
Step 5. Calculate vehicle's distance to stop bar at the intersection approach
Step 6. Determine the existing queue length at the current moment
Step 7. Collect current signal phase and timing information (SPAT) from the controller at the current moment for corresponding lane of the approach at the intersection.
Step 8. Calculate the time required to arrive at the intersection
Step 9. Determine the phase at the arrival time
-If the current phase is Green, check if vehicle is arriving at Green? If yes, go to step 10, If not go to step 11.
-If the current phase is Red check if vehicle is arriving at Green. If yes, go to step 10, if not go to step 14.
Step 10. Vehicle is arriving at Green. Send advisory message to maintain current speed
Step 11. Vehicle is not arriving at green. Calculate advisory speed to arrive at current green phase
Step 12. Is advisory speed ≤ speedMax and advisory speed ≥speed Min, If yes go to step 13, else go to step 14
Step 13. speed upto advisory speed
Step 14. Calculate the advisory speed to arrive at junction on next green phase by using current queue length and queue dissipation time.
Step 15. If the advisory speed ≥speed Min and advisory speed ≤ speedMax (where speedMin=50% speed limit), If yes go to step 16, else go to step 17
Step 16. Slow down to speedMin
Step 17. Exit (vehicle will have to stop

Before applying the GLOSA algorithm on the test network, the impact of activation distance and frequency of GLOSA was analysed. The activation distance was kept to 400m while GLOSA was applied on each time step. Minimum speed threshold was kept as 50% of speed limit following the suggestions provided in some previous studies (Katsaros, Kernchen, Dianati, & Rieck,2011, Masera et al.,2019) while upper limit was kept as speed limit +5mph.

3.2 System dynamics

System dynamics (SD) is a mathematical modelling technique which can be used to understand the dynamic (nonlinear) behaviour of complex systems over time using stocks, flows, feedback loops, table functions and time delays. In modelling terms, systems dynamics models are continuous simulation models in which a system may be represented as a causal loop or stock flow diagram. The relationships between different variables can be expressed as general quantitative forms. Those variables which are interrelated connect through feedback loops which respond to the system conditions. This modelling approach provides the flexibility to modelers to add larger number of parameters or influencing factors in the model as compared to other conventional methods.

System Dynamics in LEVITATE is used as a supplementary approach, in order to investigate several longer-term impacts which cannot be covered by other methods: the modal split (for use of public transport as well as active modes, these were presented in D6.3), the demand for public parking space and the (average) commuting distance. The later ones are both covered within this deliverable. In particular, for the commuting distance, no other method is providing results.

In the following, a summary of the used base model – across all SUC – is given, followed by detailed information on the data used, the definition of zones and the calibration of the model. Finally, the implementation of the WP6 specific sub-use case in the system dynamics model is described.

3.2.1 Description of the base model

The basic system dynamics model used in LEVITATE can be considered as three sub-models which are interacting with each other, as depicted in Figure 3.16:

- At the core, the Transport Model is modelling the *travel demand and trips* (based on segmentation of the target area into geographical zones and the mode of transport). Both the change of total demand and the shift between several modes are influenced by the generalized costs. *Total modal split* is the most important impact variable calculated in this model.
- In order to generate and drive the demand, a precise *population* model has been implemented (segmentation into age groups, zone and income groups). Further this model is used to calculate the *average commuting distance* impact variable.
- Finally, the use of *public space* is modelled on zone level, distinguishing between parking space, driving lanes and other purposes. The *relative demand for parking space* is calculated in this model.

The generalized costs for travelling are composed by four influencing variables in the following way:

$$Generalized\ Costs = Travel\ Costs + Travel\ Time * Value\ of\ Travel\ Time - Attractiveness$$

Obviously, lower generalized costs might result from changes in any of these four variables, and lead to an increase in corresponding trips. Such changes in the model are caused by:

a) Increasing AV penetration rate – the variable considered as the main parameter in LEVITATE to investigate the development over time
b) Specific sub-use cases (SUC) considered on top of increasing AV penetration rate

Despite the simplicity of the described model, certain impacts can be assessed in a quantitative way, due to following features of the model:

- The system exhibits multiple (balancing) *feedback loops*, both within the sub-models and between them: Higher share of private car trips, for example, will increase the relative demand for parking space in an area, leading to higher parking search time and consequently higher generalized costs which, resulting in decreasing demand.
- While on high level of aggregation compared to micro-simulation and mesoscopic simulation approaches, the model is segmented with respect to geographic zones, age and income groups. This allows for calculation of much more specific dependencies than considering only the average (aggregated) values of all system variables.
- Finally, the model has been fed with data to calibrate the system against the current behaviour (i.e., the case of no automation), showing the observed modal split values (for the case of Vienna) – this is explained in more detail in the next section.

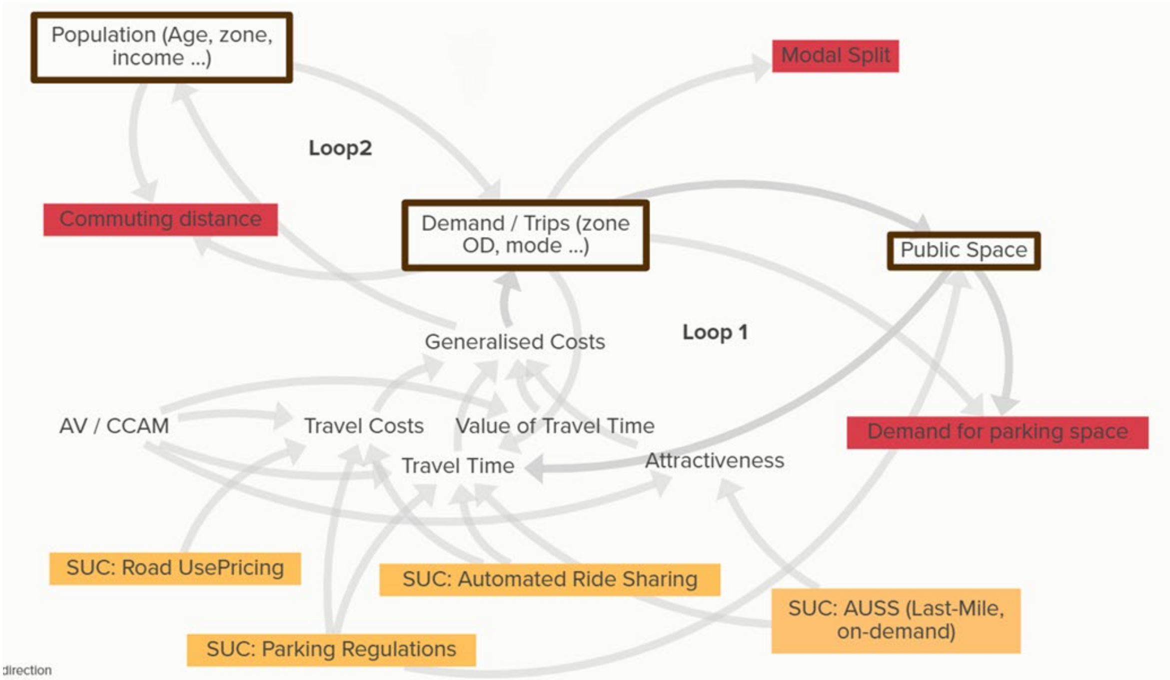


Figure 3.16: High level overview of the LEVITATE System Dynamics Model, showing main submodules (boxes), calculated impact variables (red) and implemented sub-use cases (yellow)

In order to document the assumed dependencies between variables in full detail, the Vensim[1] views for the main submodules are shown in Figures 3.17 to 3.19. These diagrams also show which of the key variables have been modelled as stock variables – which are essential for implementing a quantitative system dynamics model that can be simulated:

- The *population*, using the subscripts Age and Zone
- The number of *trips* as central model variable, using the subscripts Age, Origin Zone, Destination Zone and Mode
- Three forms of available *Public Space* – parking space, lane space and multi-functional / active modes – using the subscript Zone

[1] Vensim from Ventana Systems (https://vensim.com/) is the tool that has been used to implement the SD model.

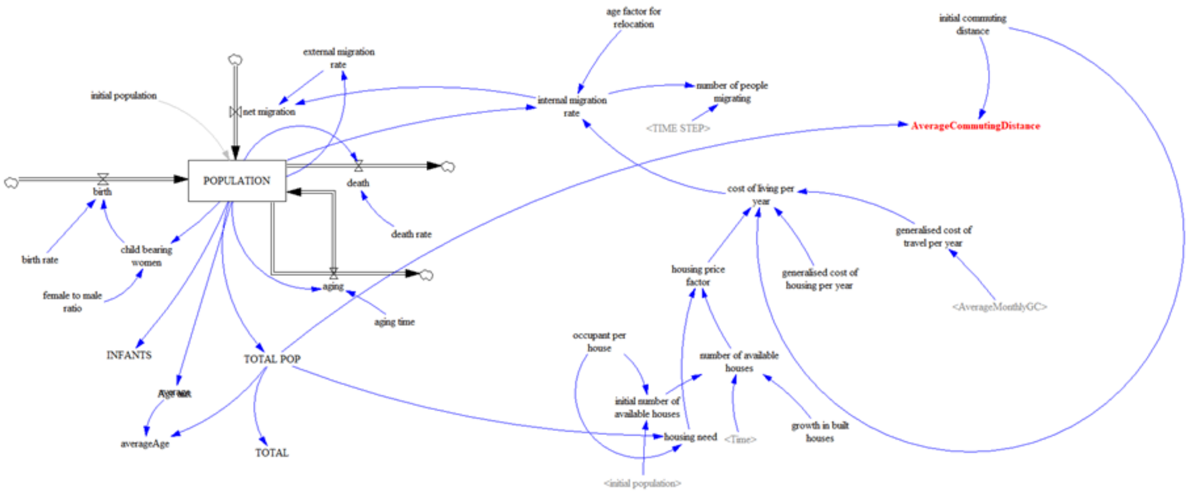


Figure 3.17: Detailed Vensim view of the population model

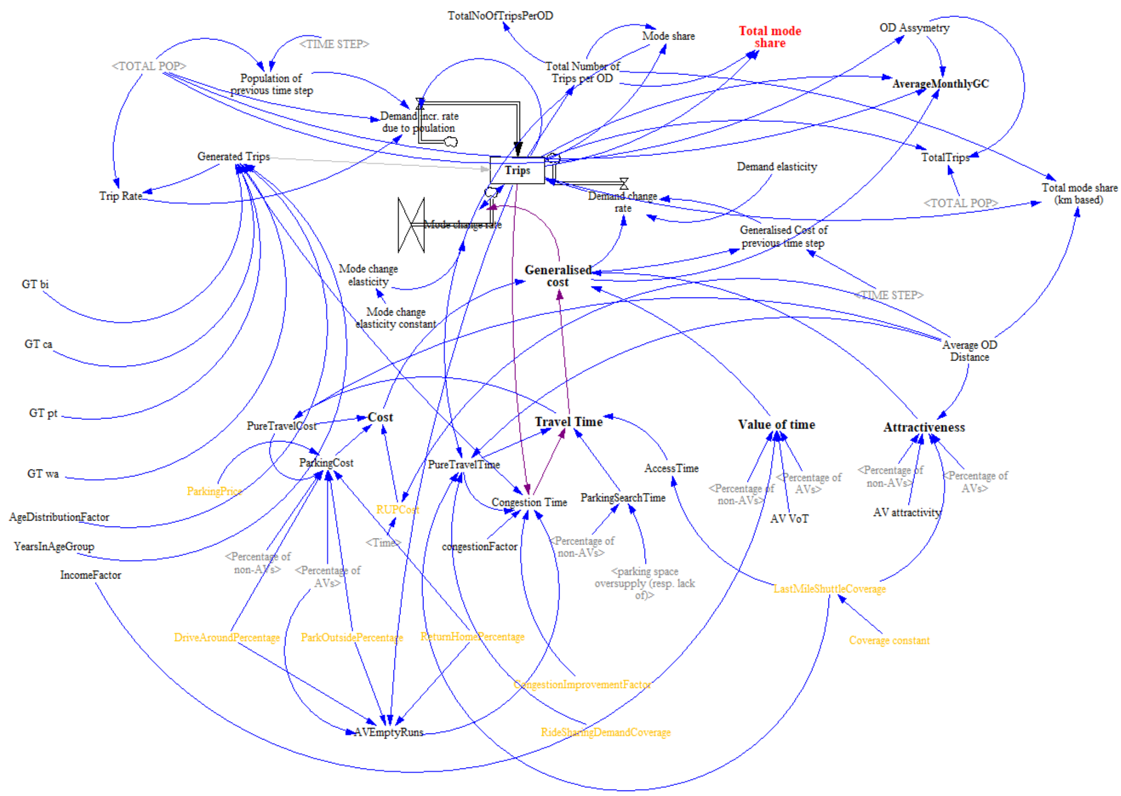


Figure 3.18: Detailed Vensim view of the transport model (Demand / Trips)

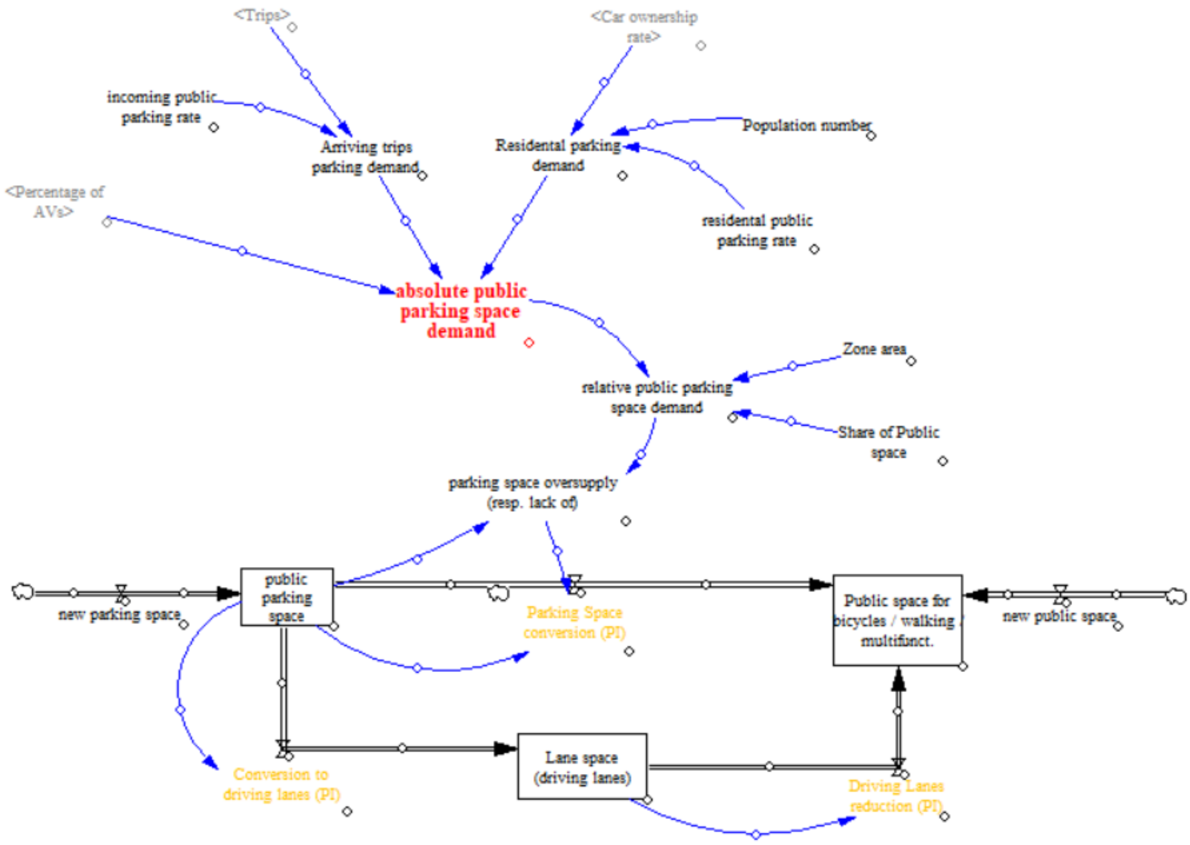


Figure 3.19: Detailed Vensim view of the public space model

3.2.2 Model data, zones, and calibration

The SUC scenarios were investigated in a SD model that is sharing the basic data on population, area, and trips with the MATSim model of Vienna, introduced in Deliverables D5.2 (Roussou, Oikonomou, Müller, Ziakopoulos, & Yannis, 2021) and D6.2 (Haouari et al., 2021). This model has been used for calibrating the SD model (providing the correct population structure, modal split etc.). Therefore, also the SD model covers Vienna and its wider surrounding area shown in Figure 3.20, serving as a prototypical example for a historically grown ("old" European) city. The area is segmented into roughly ring-shaped domains that lie concentric around the city centre. Borders between these domains are formed by major arterial (ring-)roads which are used to circumvent crossing through more densely populated areas towards the city centre.

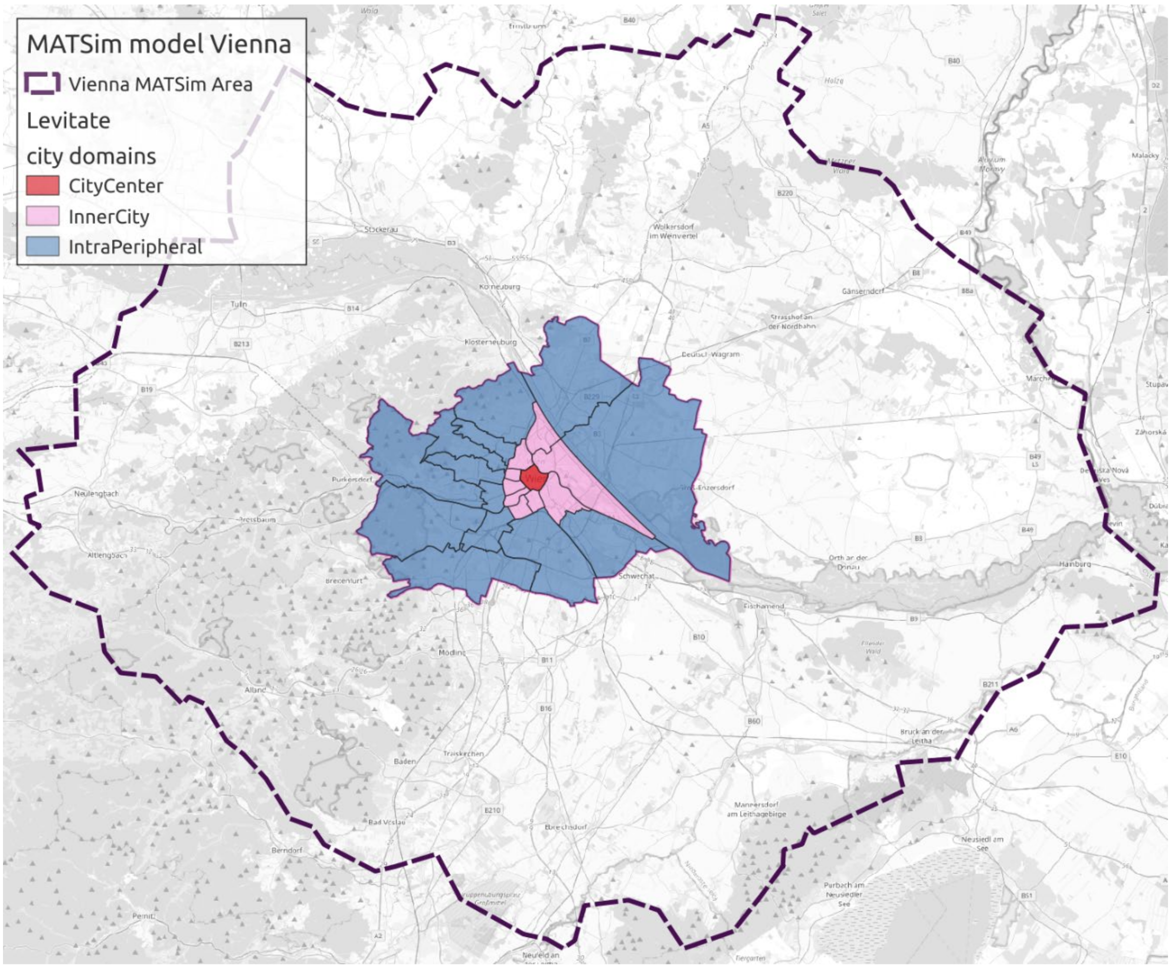


Figure 3.20: SD model total area overview (taken over from MATSim model). The colour-shaded domains within the model area cover the actual extent of the city of Vienna. The dashed line marks the wider model region surrounding the city.

A major assumption of the employed model is that such domain structures can be defined for most cities with a comparable structure and evolution. The four defined domains are:

1. **Zone 1 - City centre (CC)**: mostly reduced vehicle traffic areas, restricted entry is common
2. **Zone 2 - Inner city (IC)**: containing a densely populated belt around CC with lots of habitation areas
3. **Zone 3 - Intra peripheral (IP)**: domain outwards from IC up to the city limits which enclose the actual investigation area; habitation regions, some commercial, light industrial areas, larger recreational zones
4. **Zone 4 - Extra peripheral (XP)**: the remainder of the model area, defining the outer boundary and conditions for the inner investigation area

The calibrated system dynamics model in the absence of automation (AV penetration rate = 0) and any SUC / interventions (No Automation baseline) is very close to an equilibrium; the calculated impact variables stay constant over time and represent the current values.

3.2.3 Implementation of SUCs

In WP6, system dynamics has been used to cover following SUCs:

- Road use pricing (RUP)
- Parking price policies
- Parking space regulations
- Automated ride sharing

The integration of these SUCs into the SD model is highlighted in Figure 3.21. More precisely, the SUC related input parameters are based on assumptions as well as outputs from the microscopic simulation as specified in Table 3.7 below.

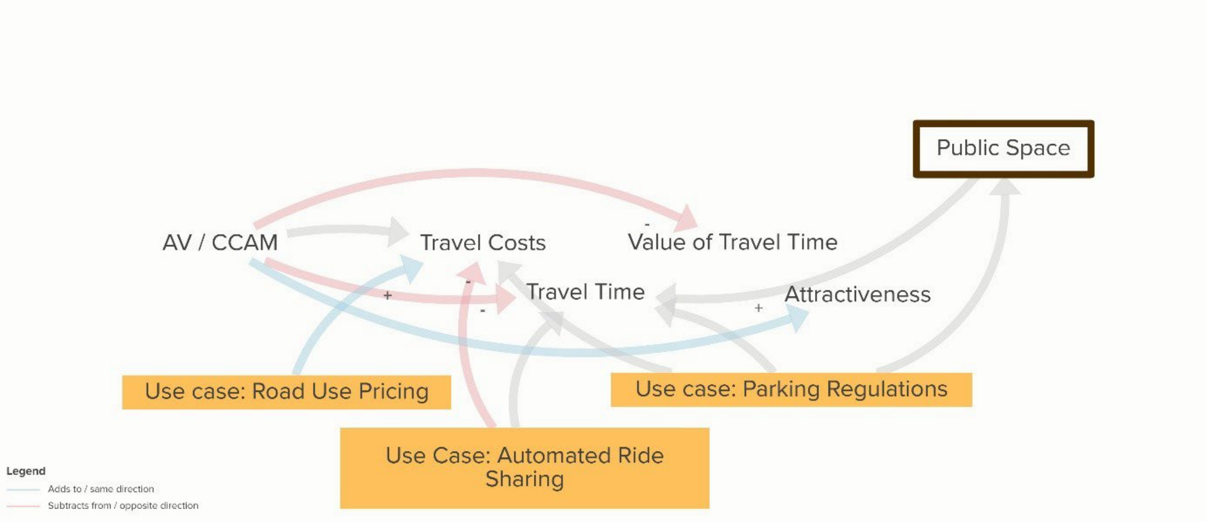


Figure 3.21: Implementation of WP6 SUCs in the SD model (red arrows reflect negative polarity, blue arrows positive polarity, and grey arrows unspecified polarity)

Table 3.7: SUC related input parameters in SD model

SUC	**Road Use Pricing**	**Parking Price**	**Replacing On-Street Parking**	**Automated Ride Sharing**
SD parameters (explicitly modelled)	Static toll (10 EUR) Toll area: zone 1 and 2	Average parking fee (5 EUR for balanced behaviour)	% Reduction of public parking space (50%) in zone 1/2	Percentage of passenger car demand served (20%) Willingness to share (100%)
Implicit inputs (microsimulation results)	(none)	% Driving around % Parking outside % Returning home	Changes in travel time / delay	Changes in travel time / delay

3.3 Delphi

3.3.1 Background of The Delphi method

The Delphi method is a process used to arrive at a collective, aggregate group opinion or decision by surveying a panel of experts. This concept was developed by the RAND Corporation for the military in order to forecast the effects of new military technology on the future of warfare, and then continued to make multiple practical applications of this method (Dalkey & Helmer, 1963). The Delphi methodology is based on a repetitive interview process in which the respondent can review his or her initial answers and thus change the overall information on each topic (Hsu & Sandford, 2007). This presupposes that the participants will be willing to not only give answers on the topics but also to repeat the interview in possibly more than two cycles. The Delphi method has three different dimensions: the exploratory Delphi aiming at the forecast of future events, the normative Delphi, in order to achieve policy consensus on goals and objectives within organisations or groups and the focus Delphi in order to gain feedback from stakeholders in some policy outcome (Garson, 2012). The Delphi method presents the following characteristics and features: anonymity of experts which assures free expression of opinions provided by the experts. This method helps to avoid social pressure from dominant or dogmatic individuals or even from the majority or minorities. At any point, experts can change their opinions or judgments without fear of being exposed to public criticism, providing controlled feedback as experts are informed about views of other experts who participate in the study (Profilidis & Botzoris, 2018).

3.3.2 The Delphi method within LEVITATE

Within LEVITATE, the Delphi method is used to determine all impacts that cannot be defined by the other aforementioned quantitative methods (traffic simulation, system dynamics, etc.). Initially, a long list of experts was identified for each use case (i.e., urban transport, passenger cars and freight transport), and contacted via an introductory mail asking them to express the willingness of participation. Those who responded positively participated in the main Delphi process, amounting to 70 experts in total (5 experts accepted to answer to 2 questionnaires). Experts come from various organisations such as research institutes, companies and universities (presented in Figure 3.22) where they have different job positions, such as directors, professors and managers (presented in Figure 3.23) and they come from different countries (presented in Figure 3.24).

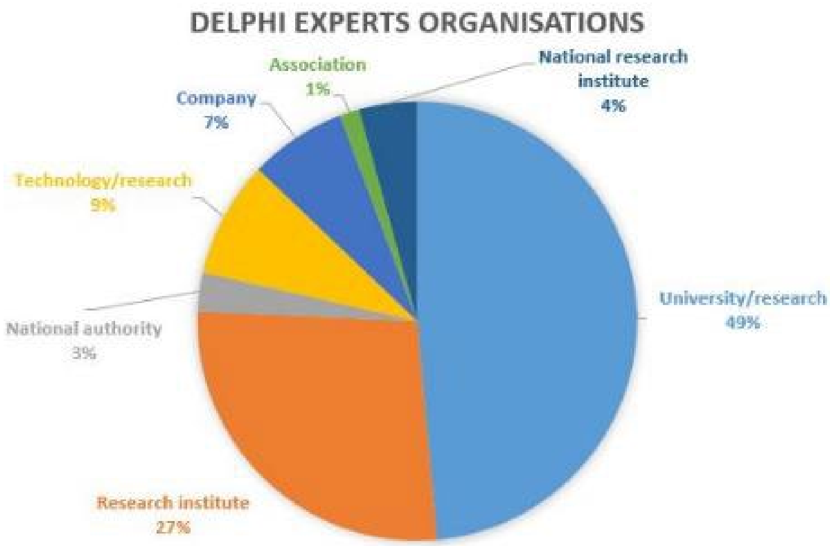


Figure 3.22: Delphi experts' organisations

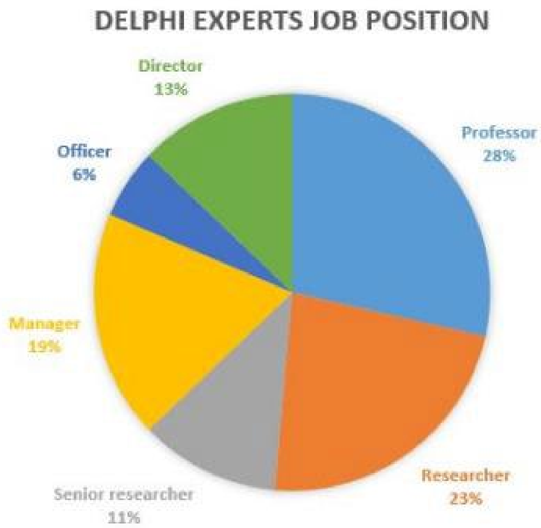


Figure 3.23: Delphi experts' job positions

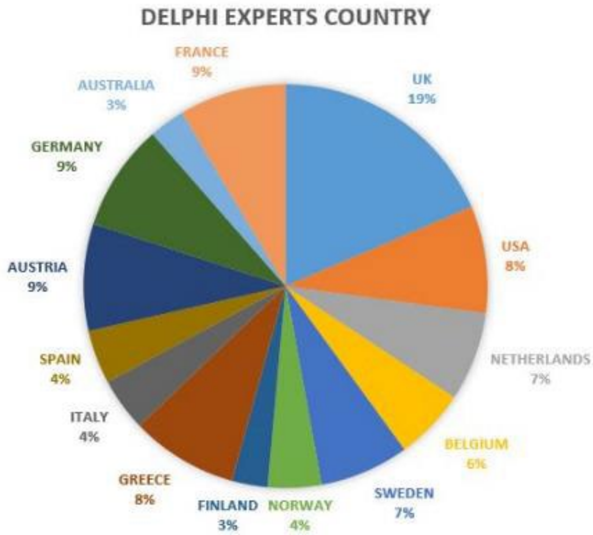
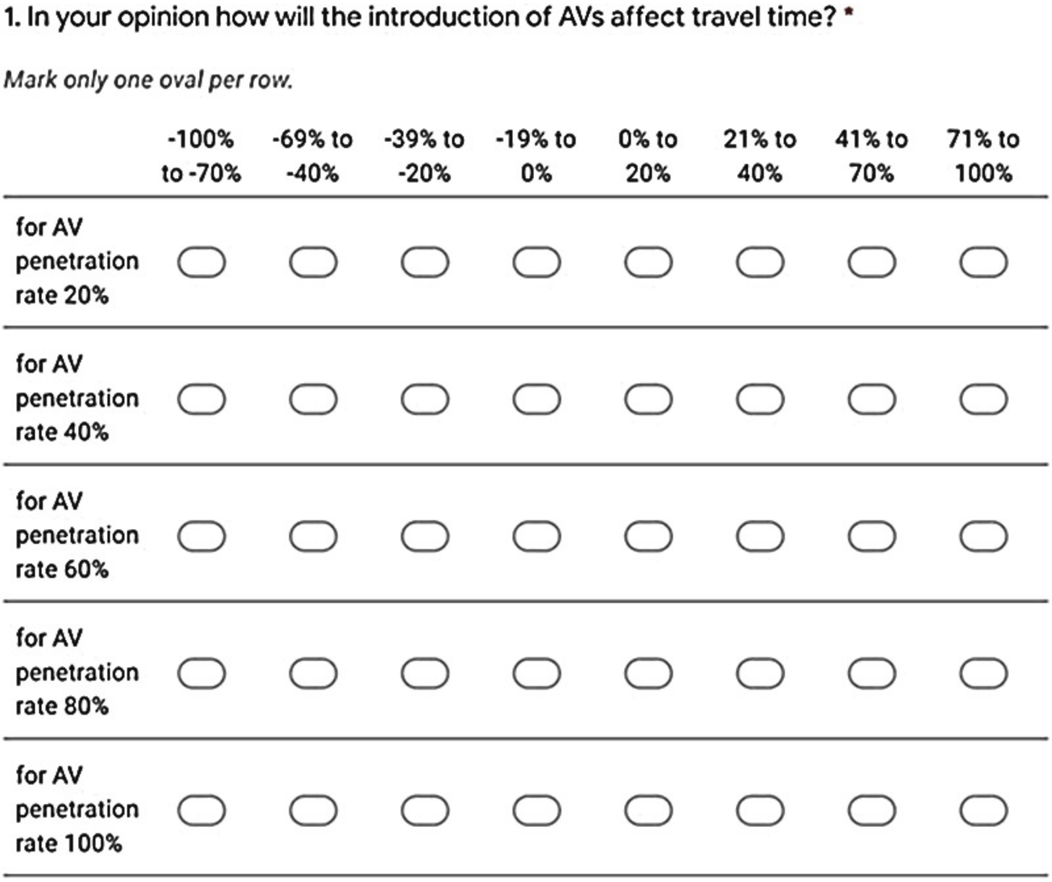


Figure 3.24: Delphi experts' countries

The Delphi method consisted of two rounds of e-mails. During the first round, experts received a questionnaire (30-45min duration) regarding a few (2-4) automation interventions related to automated urban transport, automated passenger cars or automated freight transport, as per their specific expertise. Before starting the questionnaire, they were asked to reply to the consent form accepting the use of the information they will add in the questionnaire. Then they were asked to evaluate the potential influence of the proposed interventions on different impact areas. Their answers were then analysed in order to create (anonymous) summary data for the different CCAM related interventions. These results were distributed with the second-round questionnaire and gave respondents the opportunity to reflect on the first-round outcomes before providing their answers again. In some cases, it led to respondents changing their first-round responses to something conforming more to the answers provided by other respondents.

In each first round questionnaire, experts were asked about the influence of automation related interventions on the proposed impacts for different connected & automated vehicle (CAV) market penetration rates. The CAV market penetration rates used are 0% (the baseline scenario), 20%, 40%, 60%, 80% and 100%, as defined by micro-simulation scenarios at the corresponding stage in the project; all methods have been using the same scenarios to achieve uniformity of the different results. The impacts included in the Delphi method are: travel time, vehicle operating cost, amount of travel, access to travel, modal split of travel using public transport, modal split of travel using active travel, shared mobility rate, vehicle utilization rate, vehicle occupancy, parking space, energy efficiency, public health and inequality in transport.

For each impact and each automation related scenario the participants were asked to indicate the percentage of change that the intervention would have for the mentioned CAV market penetration rates (Figure 3.25Figure 3.25). The percentages varied from -100% to +100% where the negative (minus sign) was either an improvement or a deterioration depending on the type of impact. For example, a negative effect on travel time would mean a reduction and thus an improvement, while on the other hand a negative percentage of change on public health would mean a deterioration.



1. In your opinion how will the introduction of AVs affect travel time? *

Mark only one oval per row.

	-100% to -70%	-69% to -40%	-39% to -20%	-19% to 0%	0% to 20%	21% to 40%	41% to 70%	71% to 100%
for AV penetration rate 20%								
for AV penetration rate 40%								
for AV penetration rate 60%								
for AV penetration rate 80%								
for AV penetration rate 100%								

Figure 3.25: Example Delphi question

Participants were divided in seven groups. Each group had a different questionnaire related to a specific type of interventions based on their expertise. Each questionnaire concerned 2-4 automation related interventions, including the baseline scenario where no policy intervention is applied except the introduction of CAVs in the urban environment. The questionnaire was also separated with size limitations in mind, as passenger cars would constitute an immense single questionnaire if their sub-use cases were considered all at once. For LEVITATE WP6:

- 10 experts participated in the first Delphi round for the parking regulations sub-use cases and 5 continued to the 2nd round.
- 10 experts participated in the 1st Delphi round for the parking behaviours sub-use cases and 6 continued to the 2nd round.
- 10 experts participated in the 1st Delphi round for the ridesharing and GLOSA sub-use cases and 6 continued to the 2nd round.
- 10 experts participated in the 1st Delphi round for the AV dedicated lanes sub-use cases and 6 continued to the 2nd round.
- 10 experts participated in the 1st Delphi round for the city toll sub-use cases and 7 continued to the 2nd round.

After the reception of the answers of the 1st Delphi round questionnaires, subsequent aggregation coding and analysis followed. For each intervention and each impact, a table was created: its rows represented the CAVs market penetration rates and the columns the different percentages of change (Table 3.8). All experts' answers were introduced in the table and then for each row (each CAVs market penetration rate) the percentage equal with the average of all answers was extracted.

Table 3.8: Example 1st round Delphi answers analysis

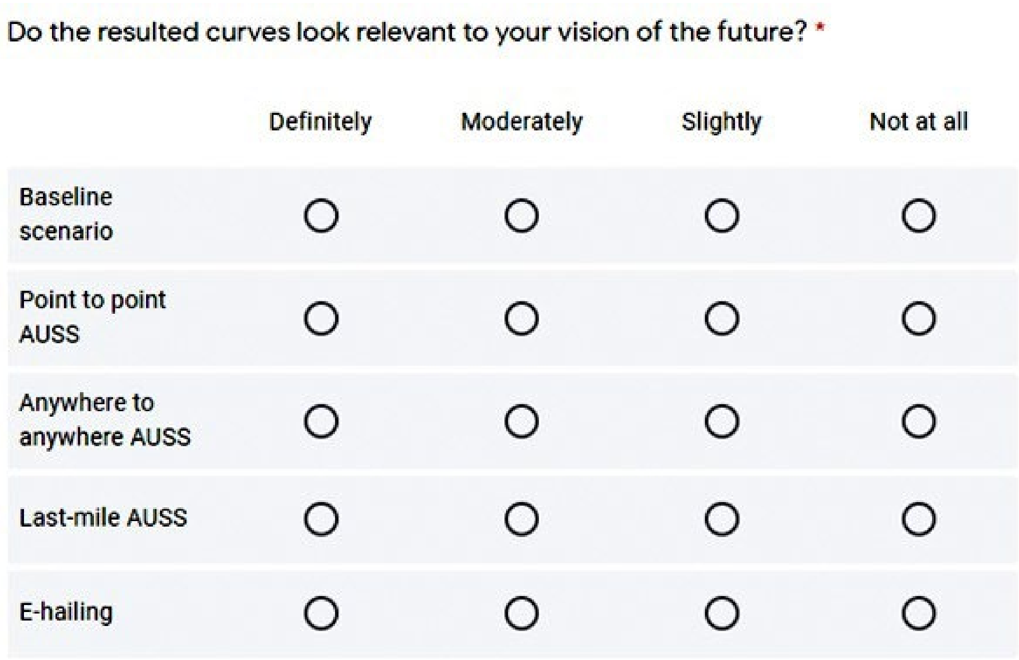
Centroids	-85%	-55%	-30%	-10%	10%	30%	55%	85%
AV MPR	-100% to -70%	-69% to -40%	-39% to -20%	-19% to 0%	0% to 20%	21% to 40%	41% to 70%	71% to 100%
20%	0	0	1	3	6	4	0	0
40%	0	0	0	3	6	2	3	0
60%	0	0	1	3	3	6	1	1
80%	0	0	3	4	1	2	4	0
100%	0	2	4	1	4	0	2	0

This percentage is the coefficient that will be used in the PST (Table 3.9). The conversion to percentage fluctuations ensures that the PST operates with different starting values provided either by default or by the user, to increase the flexibility and applicability of the tool.

Table 3.9: Example table PST coefficients

AV MPR	Aggregate change	PST coefficients
20%	2.75%	1.028
40%	-1.50%	0.985
60%	19.68%	1.197
80%	32.61%	1.326
100%	35.43%	1.354

Additionally, for each impact, a curve was created representing the values of the percentages for the different CAV market penetration rates. The resulting curves for all interventions and impacts were presented to the experts for the 2nd round of the Delphi, who were then asked whether they agreed with the 1st round results (Figure 3.26). They were given the opportunity to propose different percentages in case they disagreed. These suggestions were then incorporated in the final coefficients introduced in the LEVITATE PST through a weighted average scheme to make sure that each expert contributes equally.



Do the resulted curves look relevant to your vision of the future? *

	Definitely	Moderately	Slightly	Not at all
Baseline scenario	○	○	○	○
Point to point AUSS	○	○	○	○
Anywhere to anywhere AUSS	○	○	○	○
Last-mile AUSS	○	○	○	○
E-hailing	○	○	○	○

Figure 3.26: Example round 2 question

4 Long-term impacts

This part of the deliverable presents description and quantification of the long-term impacts of CCAM on passenger transport. In this regard, seven key impacts have been analysed under each sub-use case using an appropriate methodology as described under section 3. The impacts are as follows:

1. Demand for Parking
2. Road Safety (conflicts and crashes)
3. Energy Efficiency
4. Emissions
5. Public Health
6. Inequality in Transport
7. Commuting Distances

This section is organized based on the above listed long-term impacts, and each under each impact type, results from each sub-use case intervention have been presented and discussed.

4.1 Demand for parking

Parking space is considered as the required parking space in the city centre per person (m^2/person). The estimate of the impact of automation on Demand for Parking was made by using the system dynamics and Delphi methods.

4.1.1 Results from system dynamics

The System Dynamics model was used to forecast the impacts on parking demand due to increasing automation and several applicable interventions under WP6 including road-use pricing, parking regulations, parking price policies, and automated ride sharing, as shown in Figure 4.1. The impact is presented as relative demand, in percentage of public (street) space within the inner-city area (zone 2). With regard to increasing automation only (baseline), the results indicate an increase in demand for parking with increasing MPR, reaching more than 40% at full fleet penetration.

Implementation of parking space regulations of 50% on-street parking removal would lower the demand for parking as compared to baseline condition. Whereas conversion to driving lanes intervention would likely have an increased demand as compared to 50% parking space removal, due to encouraging higher number of vehicles on the road. In comparison with baseline, this policy will have lesser demand up to 50% fleet penetration and will gradually increase with higher levels of MPR.

Under parking pricing, policies providing balanced parking behaviours were analysed as it was found to be most suitable strategy through microsimulation analysis presented in D6.2. As expected, this policy intervention has significant impact; the relative demand for parking space stays constantly slightly above 20% with increasing MPR.

Road use pricing implementation was also found to reduce the demand for parking space significantly, very similar to the parking price policies.

Automated ride sharing services, considering 20% share of total demand and 100% willingness to share was not found to have any added demand for parking as compared to the baseline (Figure 4.1). This is because more people sharing rides would reduce the number of personal cars on the road. However, due to pick-ups, drop-offs, and waiting for passenger, the parking demand may not reduce either (w.r.t baseline curve), as indicated in Figure 4.1 below.

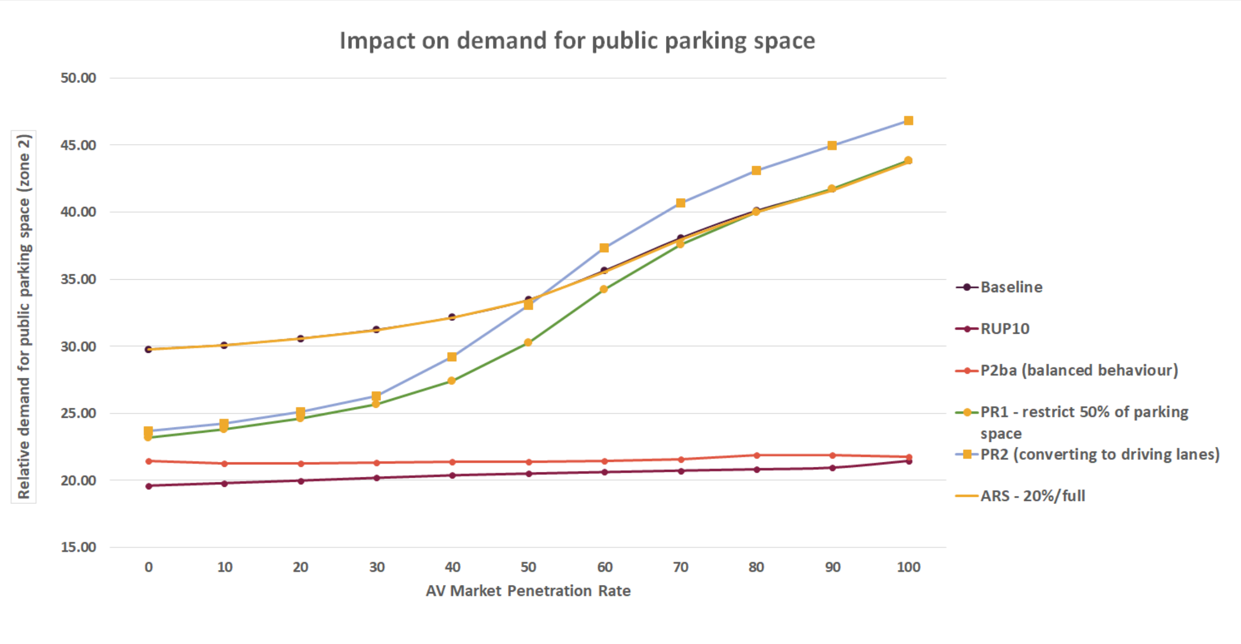


Figure 4.1: Impact of automation and different policy interventions on demand for Public Parking Space (RUP=road use pricing, P2ba=Parking behaviours under balanced scenario, PR1=remove 50% on-street parking spaces, PR2=replacing on-street parking with driving lane, ARS-20% full= Automated ride sharing with 20% demand and 100% willingness to share)

4.1.2 Results from Delphi

4.1.2.1 Road use pricing (RUP)

The general experts' opinion was that the introduction of AVs in the urban environment will progressively reduce (-36%) parking space required. The introduction of static and dynamic city tolls will not significantly affect parking space in the long term. Empty km pricing will affect the most the studied impact in the long term, among the other city toll scenarios, leading to a reduction of 11,2%.

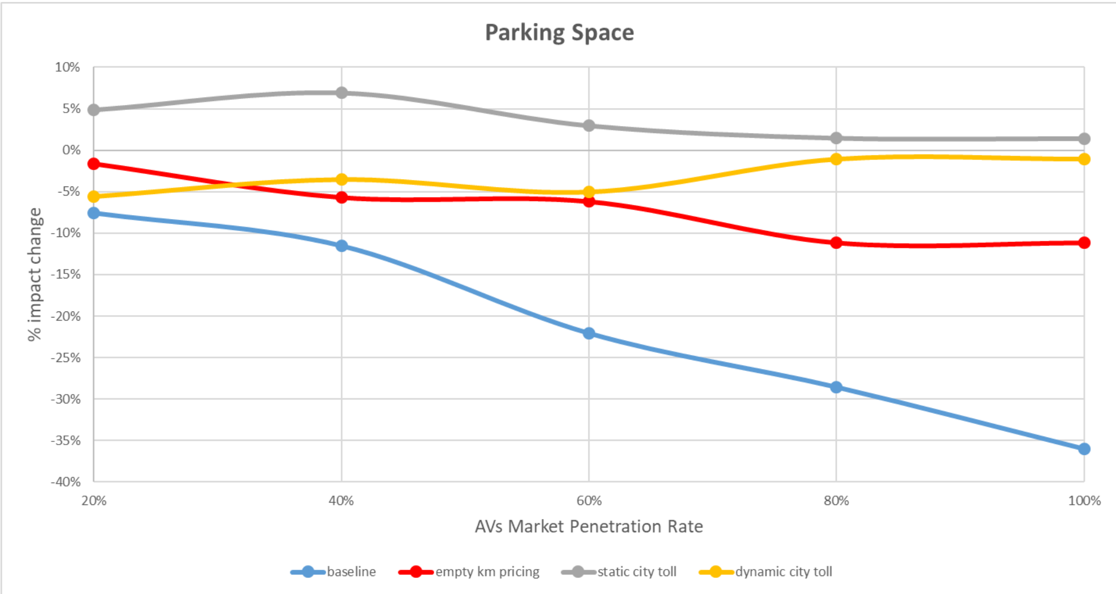


Figure 4.2: 1st round Delphi parking space results for the city toll scenarios

In the 2nd Delphi round questionnaires, the majority of experts stated that they definitely (14%) or moderately (43%-72%) agree with the resulted curves. Some experts slightly (14%-29%) or not at all agreed (0-14%) with the proposed trends and suggested that all scenarios will not significantly affect parking space required.

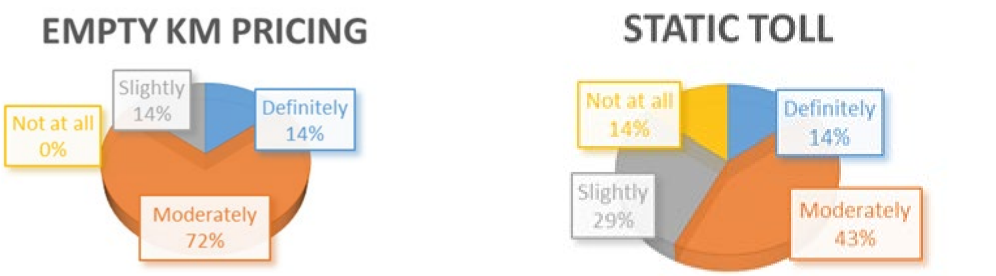


Figure 4.3: 2nd round Delphi parking space results for empty km pricing and static toll scenarios

Table 4.1: Final PST coefficients for parking space for the city toll scenarios

	Baseline		**Empty km pricing**		**Static toll**		**Dynamic toll**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	-6,1%	0,939	-1,6%	0,984	4,6%	1,046	-4,3%	0,957
40%	-9,6%	0,904	-5,4%	0,946	6,3%	1,063	-2,5%	0,975
60%	-18,9%	0,811	-5,8%	0,942	3,0%	1,030	-3,8%	0,962
80%	-24,6%	0,754	-10,5%	0,895	1,8%	1,018	-0,3%	0,997
100%	-31,2%	0,688	-10,5%	0,895	1,7%	1,017	-0,3%	0,997

4.1.2.2 Provision of dedicated lanes on urban highways

The general experts' opinion was that the introduction of AVs in the urban environment will negatively (-28,1%) affect parking space required. The introduction of AV dedicated lane on the outermost motorway lane and the introduction of a dynamically controlled motorway lane will not significantly affect parking space. On the other hand, the AV dedicated lane on the innermost motorway lane scenario as well as the AV dedicated lane on the outermost motorway lane and A-road will both reduce parking space by 10,6% in the long term.

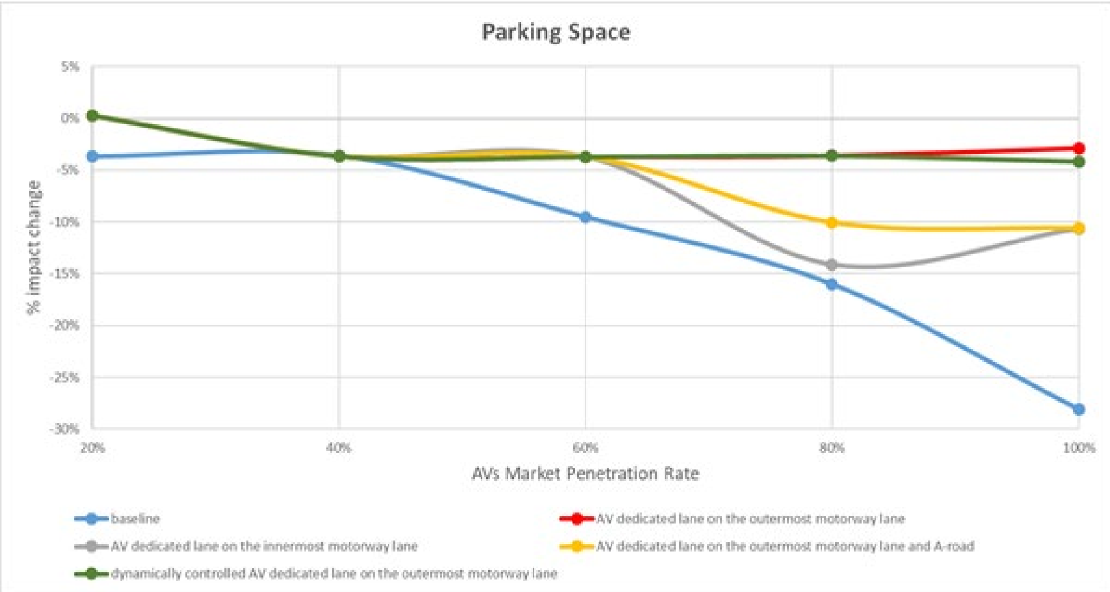


Figure 4.4; 1st round Delphi parking space results for the AV dedicated lanes scenarios

In the 2nd Delphi round questionnaires, all experts stated that they moderately agree with the resulted curves for the AV dedicated lane on the innermost motorway lane or on the outermost motorway lane and A-road. On the other hand, the majority of experts definitely (33%) or moderately (33%) agreed with the other scenarios. Two experts (33%) do not at all agree with the proposed curves and suggested that the baseline scenario, the AV dedicated lane on the outermost motorway lane scenario and the dynamically controlled AV dedicated lane scenario should have curves similar to the other the other AV dedicated lane scenarios.

Figure 4.5: 2nd round Delphi results AV dedicated lane on Baseline and innermost motorway lane

Table 4.2: Final PST coefficients for parking space for the AV dedicated lanes scenarios

	Baseline		**Outermost motorway lane**		**Innermost motorway lane**		**Outermost motorway lane and A-road**		**Dynamically controlled AV dedicated lane**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	-3,8%	0,962	-0,4%	0,996	0,3%	1,003	0,3%	1,003	-0,4%	0,996
40%	-3,7%	0,963	-3,8%	0,962	-3,7%	0,964	-3,7%	0,964	-3,8%	0,962
60%	-8,9%	0,911	-3,9%	0,961	-3,7%	0,963	-3,7%	0,963	-3,9%	0,961
80%	-14,6%	0,854	-3,8%	0,962	-14,1%	0,859	-10,1%	0,900	-3,8%	0,962
100%	-25,2%	0,748	-3,1%	0,969	-10,7%	0,894	-10,6%	0,894	-4,3%	0,957

4.1.2.3 Parking price policies

The general experts' opinion was that the introduction of CAVs parking behaviours will negatively affect parking space required. More precisely, the intervention that will have the biggest impact is CAVs parking inside the city centre, that will lead to a reduction of 41,2%. CAVs returning to origin, driving around and parking outside will reduce parking space by 19,7%, 36,2% and 12,2% respectively for 100% AVs market penetration rate. The introduction of AVs in the baseline scenario will lead to an 31,6% reduction of parking space in the long term.

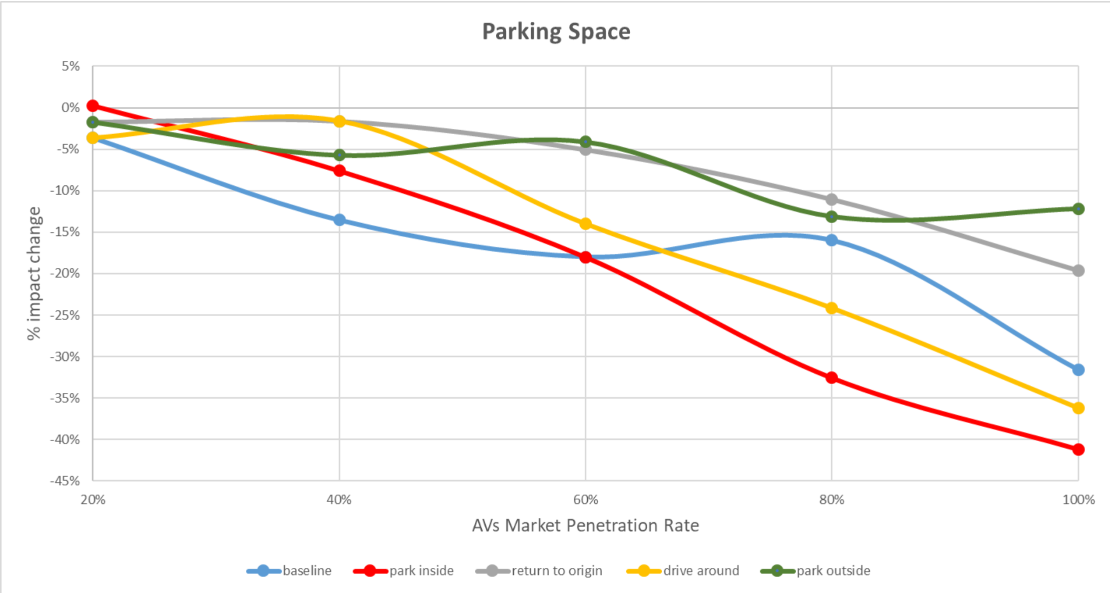


Figure 4.6: 1st round Delphi parking space results for the CAV parking price policies scenarios

The majority of the experts participating in the 2nd round stated that they agree definitely (50%) or moderately (17%-33%) with the resulted trends. One expert suggested that none of the studied sub-use cases will affect parking space regardless of the AVs market penetration rate.

Figure 4.7: 2nd round Delphi parking space results for baseline and parking inside scenarios

Table 4.3: Final PST coefficients for parking space for the CAV parking price policies scenarios

	Baseline		Park inside		Return to origin		Drive around		Park outside	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	-3,7%	0,963	-0,1%	0,999	-1,9%	0,981	-3,7%	0,963	-1,9%	0,981
40%	-13,0%	0,870	-7,0%	0,930	-1,8%	0,982	-1,8%	0,982	-5,7%	0,943
60%	-17,2%	0,828	-16,1%	0,839	-5,0%	0,950	-13,4%	0,866	-4,2%	0,958
80%	-15,3%	0,847	-28,8%	0,712	-10,7%	0,893	-23,0%	0,770	-12,6%	0,874
100%	-29,9%	0,701	-36,3%	0,637	-18,7%	0,813	-34,3%	0,658	-11,7%	0,883

4.1.2.4 Parking space regulations

general experts' opinion was that the introduction of parking regulations will reduce parking space required. Replacing on-street parking space with space for public use, with driving lanes or with pick-up/drop-off parking space will progressively reduce parking space required, reaching 29,6, 19,6% and 44,2% respectively for 100% AVs market penetration rate. The introduction of AVs in the baseline scenario will lead to an increase of 10% of the required parking space in the short term, but in the long term the impact of the baseline scenario on parking space will be inconsiderable.

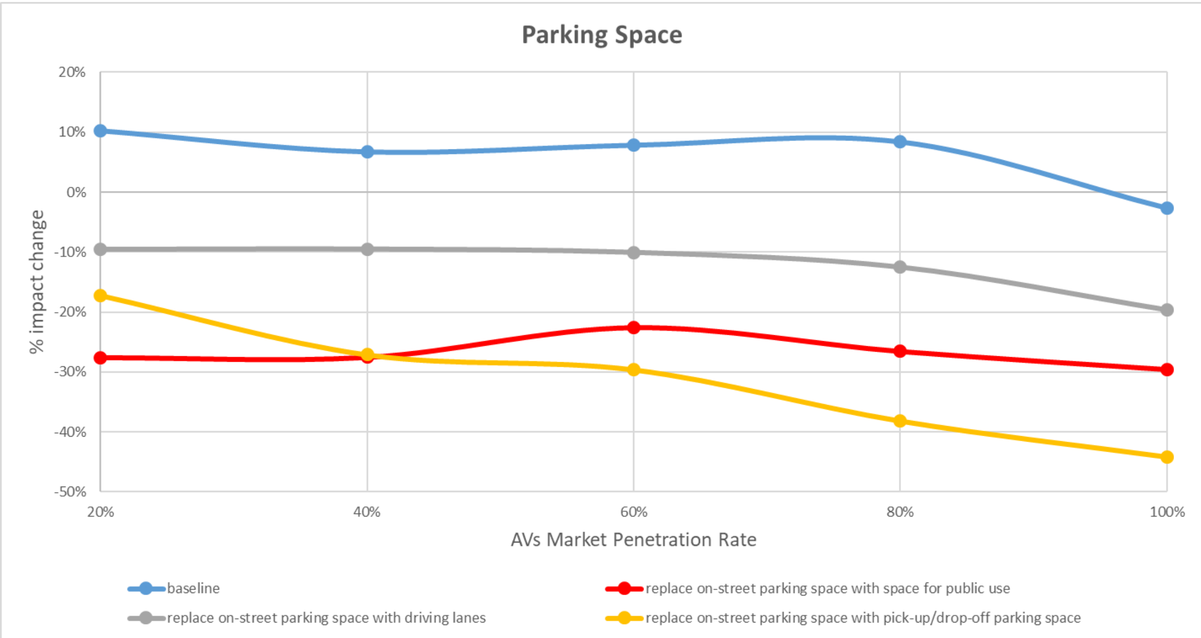


Figure 4.8: 1st round Delphi parking space results for parking space regulation scenarios

The majority of the experts participating in the 2nd round stated that they agree definitely (0%-60%) or moderately (40%-100%) with the resulted trends.

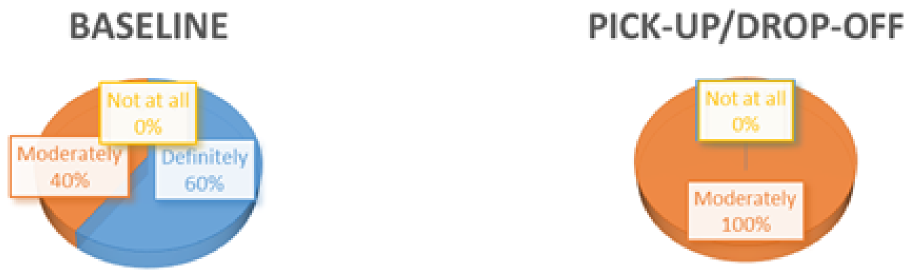


Figure 4.9: 2nd round Delphi parking space results for baseline and replacing on-street parking space with pick-up/drop-off locations

Table 4.4: Final PST coefficients for parking space for parking space regulation scenarios

	Baseline		Space for public use		Driving lanes		Pick-up/drop-off	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	10,2%	1,102	-27,6%	0,724	-9,6%	0,905	-17,2%	0,828
40%	6,7%	1,067	-27,6%	0,725	-9,5%	0,905	-27,1%	0,729
60%	7,8%	1,078	-22,6%	0,775	-10,1%	0,900	-29,6%	0,704
80%	8,4%	1,084	-26,6%	0,735	-12,5%	0,875	-38,2%	0,619
100%	-2,6%	0,974	-29,6%	0,704	-19,6%	0,804	-44,2%	0,559

4.1.2.5 Automated ride sharing

The general experts' opinion was that the introduction of AVs in the urban environment will progressively reduce (-36,6%) parking space required. The introduction of automated ridesharing will also reduce parking space required by 24,6%.

Figure 4.10: 1st round Delphi parking space results for the automated ridesharing

In the 2nd Delphi round questionnaires, the majority of experts definitely (0-16%) or moderately (67%) agreed with the resulted curves for the baseline and automated ridesharing scenarios.

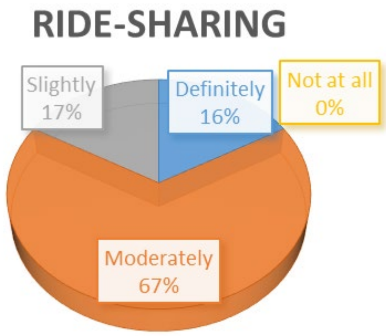


Figure 4.11: 2nd round Delphi parking space results for the automated ridesharing

Table 4.5: Final PST coefficients for parking space for the automated ridesharing

	Baseline		Automated ridesharing	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	0,7%	1,007	0,3%	1,003
40%	4,5%	1,045	-3,3%	0,967
60%	-11,1%	0,889	-12,2%	0,878
80%	-17,2%	0,828	-9,9%	0,901
100%	-31,7%	0,683	-23,0%	0,770

4.1.2.6 Green light optimal speed advisory (GLOSA)

The general experts' opinion was that the introduction of AVs in the urban environment will progressively reduce (-36,6%) parking space required. Regarding the GLOSA scenario, experts suggest that this scenario will not significantly affect parking space, proposing a general reduction (-3,7%) of the studied impact regardless of the AVs market penetration rate.

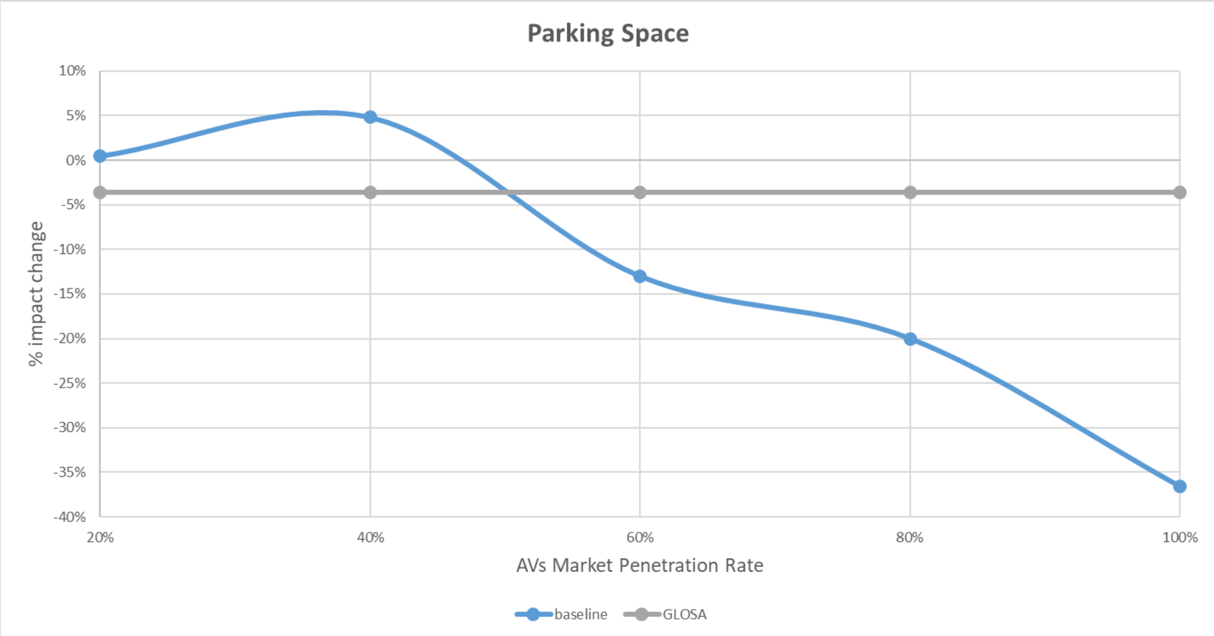


Figure 4.12: 1st round Delphi parking space results for GLOSA scenarios

In the 2nd Delphi round questionnaires, the majority of experts stated they slightly (50%) or not at all (17%) agreed with the 1st round results of the GLOSA scenario and suggested that this intervention will not at all affect the studied impact.

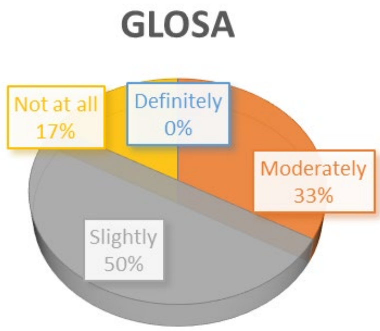


Figure 4.13: 2nd round Delphi parking space results for GLOSA

Table 4.6: Final PST coefficients for parking space for the automated ridesharing and GLOSA scenarios

	Baseline		**GLOSA**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	0,7%	1,007	-2,7%	0,973
40%	4,5%	1,045	-2,7%	0,973
60%	-11,1%	0,889	-2,7%	0,973
80%	-17,2%	0,828	-2,7%	0,973
100%	-31,7%	0,683	-2,7%	0,973

4.2 Road safety

Within LEVITATE, road safety impacts of both a general increasing penetration level of CAVs in the vehicle fleet as well as the more specific interventions studied in the SUCs are evaluated using multiple approaches. Because not all potential safety impacts could be quantified using simulation methods, a combination of literature review and consultation with experts within the LEVITATE consortium it was established where and how increasing automation is expected to have a direct/indirect effect on road safety. These results are summarized in Section 4.2.1. Second, the effects are quantified using microsimulation in AIMSUN (TSS, 2021) combined with the SSAM tool (Pu et al. 2008) which identifies potentially dangerous traffic interactions (traffic 'conflicts'). A prediction for the resulting change in car crashes is made for both a general baseline scenario (increasing penetration of CAVs) as well as the policy measure scenarios discussed in this Work Package. The crash predictions are described for each sub-use case in Section 4.2.2.

4.2.1 Expected road safety impacts

The expected road safety impacts of increasing penetration levels of Road safety is expected to be impacted by both a general increase in CAV penetration levels (baseline scenario) as well as the specific sub-use cases studied in WP6. These safety impacts are summarized in Figure 4.14 and discussed in more detail per sub-use case in the following sections.

General expected road safety impacts

The general introduction and increasing penetration levels of Connected and Automated Vehicles (CAVs) is expected to impact road safety in several direct and indirect ways. CAVs are expected to have a lower risk of being involved in a crash than human drivers, as they are expected to obey traffic rules, to not make mistakes that human drivers make, to have lower reaction times and to exhibit less variability in driving behaviour. On the other hand, some new potential risks might be introduced by automated vehicles, such as system failures, cyber security issues, and issues related to transition of control or mode confusion. In addition, some rebound/indirect effects can be expected, caused by changes in broader factors that in turn affect road safety. Examples of these indirect impacts include changes in road safety due to changes in total distance travelled, modal split, route choice and changes in the behaviour of other road users. For a more detailed discussion of the road safety impacts of increasing automation, see Weijermars et al (2021).

Direct impacts on driving behaviour

More specifically, regarding the interventions studied in this Work Package which focus on automated passenger vehicles, both direct effects on traffic interactions as well as indirect effects on travel behaviour are expected. An increased penetration rate of automated passenger cars, together with infrastructure changes (designated lanes & on-street parking) and GLOSA, are all expected to directly influence the driving behaviour of human drivers. Human drivers are, for example, expected to mimic the driving behaviours of automated vehicles. Research (Gouy, Wiedemann, Stevens, Brunett, & Reed, 2014; Yang, Wang, & Quddus, 2019) suggests that human drivers copy the shorter time headways used by CAVs when they are driving next to them, an effect which may be particularly strong in the case of a dedicated CAV lane parallel to human-driver lanes. Similarly, a driving simulator study (Preuk, Dotzauer, & Jipp, 2018) has shown that drivers mimicked the behaviour of GLOSA-equipped vehicles, including adopting shorter headways, when they had received detailed information about the system compared to drivers that only received general information or no information about the system. This can result in smoother traffic (with GLOSA) but also higher road safety risks when shorter headways are adopted. Due to humans' delayed response time compared to AVs, this copying behaviour might lead to more (severe) crashes thus reducing road safety.

Direct impacts on traffic flow

Both automated ride sharing and GLOSA are expected to affect the smoothness of traffic flow. Similarly, to the automated urban shuttles studied in Work Package 5 of LEVITATE, automated ride share vehicles are expected to make additional stops for pick-up and drop-off during the route. Without designated pick-up/drop-off spaces, it is likely that the vehicle will stop in one of the driving lanes, thereby impeding other traffic and causing additional congestion/lane-changing safety risks for other vehicles. GLOSA, on the other hand, is in theory expected to result in smoother traffic flow and therefore an improvement in traffic safety. However, simulation research (Stevanovic, Randivojevic, Stevanovic, Ostojic, & Kergaye, 2015) has shown that the number of conflicts only significantly decreases when GLOSA times are fixed, and the penetration rate is 100%. In addition, in some situations GLOSA-equipped vehicles might drive slower compared to human-driven vehicles when traffic is still mixed. Previous studies have linked speed differences between vehicles to increased crash rates (Aarts & Van Schagen, 2006), as well as irritation in human drivers, resulting in more aggressive and potentially dangerous driving behaviour (Adviesdienst Verkeer en Vervoer [AVV], 2001).

Direct impacts of infrastructure changes

Changes to infrastructure, on the other hand, can also influence driving behaviour. This includes the two infrastructural sub-use cases studied within this Work Package: the removal of on-street parking in exchange for other facilities, and the addition of dedicated automated vehicle lanes. Regarding the former, research has shown that human drivers adapt their behaviour when on-street parking spaces are occupied by driving closer to the centre of the road and by lowering their driving speed (Edquist, Rudin-Brown, & Lenné, 2012; Praburam & Koorey, 2015). However, Edquist et al.2012 found that, regardless of these behavioural adaptations, the crash risk was higher compared to when the on-street parking spaces were empty. Therefore, one might expect an increase in road safety when on-street parking is replaced. However, when less or no on-street parking is available, human drivers might exhibit other potentially dangerous behaviours like the aforementioned increased driving speed that has been linked to an increase in serious injuries and road deaths (SWOV, 2016), or dangerous manoeuvres to get into one of the remaining parking spaces.

Previous research (e.g., Favarò, Nader, Eurich, Tripp, & Varadaraju, 2017; Yu, Tak, Park, & Yeo, 2019; Shi, Li, Cai, Zhang, & Wu, 2020) as well as some of the simulation scenarios within LEVITATE show that some additional crash risks can come from mixing automated vehicle traffic with human-driven traffic, due to differences in driving styles (e.g., automated vehicles adopting shorter headways) and capabilities (e.g. human drivers' longer reaction times). Dedicated lanes for automated vehicles can help address this problem due to reducing interactions between human drivers and automated vehicles. However, depending on the distribution of automated and human-driven vehicles within the vehicle fleet, congestion may increase on one of the dedicated lanes. When CAV penetration rates are low, human-driven lanes are expected to get busier which might result in more conflicts and crashes in these lanes. When CAV penetration rates are high, the problem likely shifts to the dedicated lane. Dedicated lanes, especially when traffic congestion is high, can also lead to more complex merging and exiting situations. If the outermost lane is dedicated for automated vehicles, for example, and penetration rates are high, merging onto or exiting the highway can become more difficult for the remaining traffic.

Direct impacts on VRUs

Regarding the effects of these sub-use cases on vulnerable road users (VRUs) such as pedestrians and cyclists, the replacement of on-street parking with other facilities is expected to have the largest direct effect on VRUs due to its close proximity to walking and cycling facilities. A study by Biswas et al., 2017 also discussed road safety and presents some conflicting views on whether on-street parking impacts road safety negatively or not, while noting that a majority of road safety studies concludes on-street parking to have a negative impact. Concerning the effects on pedestrians in particular, it is noted that data from Great Britain (see also Department of Transport, 2015) suggests a contributing relation of on-street parking to car-pedestrian injury accidents in between 13 and 17% of cases.

Indirect impacts of automated passenger cars

Regarding indirect effects, road use pricing, parking policies, and automated ride sharing are all expected to have potential impacts on the total number of kilometres travelled as well as the modal split. An increase or decrease in the total number of kilometres travelled by all vehicles in the network affects the total exposure to risk and can subsequently, all else equal, lead to an increase or decrease in crashes. If such policies were to succeed in reducing the total kilometres driven by private human-driven passenger cars, through a reduction in travelled kilometres and/or a modal shift away from private motor vehicle use, a reduction in exposure to crash risk could be realized. If road use prices are used to make peak-hour, inner-city, or single occupancy travel more expensive, for example, then travellers may adjust how or when they travel and thus shift the risk (e.g., to other times of the day) or reduce the risk (e.g., through sharing rides/reducing trips). Similarly, automated ride sharing is expected to combine trips such that the total kilometres driven, and therefore the road safety risks, can be reduced. However, parking policies aimed at reducing or charging more for parking space in certain areas (e.g., city centres) may also result in an increase in kilometres driven if automated vehicles travel an extra distance after drop-off to reach a parking space.

General road safety impacts expected from increasing automation

- → Reduced traffic rule violations & instances of human error
- → Shorter reaction times than human drivers
- → Less variability in driving behaviour at full penetration (potentially more variability with low penetration/mixed traffic)
- → Slight mode shift from public transport to private transport expected, increasing exposure to safety risks: minimal impact on crash rate due to automation
- → Potential technological risks: system failures, cyber security issues, and issues with transition of control to human drivers / mode confusion at lower levels of automation

Road safety impacts expected from Automated passenger cars

- → Allows for policies which can shift the time/location/frequency of road safety risks due to the ability to park and pick up passengers autonomously
- → Potentially risky interactions between automated passenger cars and human-driven passenger cars
- → Human drivers may imitate more aggressive driving styles (i.e., shorter headways) of automated vehicles, leading to higher crash risk due to humans' longer reaction time

Dedicated AV lanes

- → Reduces risky interactions between human drivers and AVs
- → Can increase traffic in (non-)dedicated lane depending on AV penetration rate
- → Complex merging/ exiting interactions

Road use pricing

- → Can reduce km driven at certain times/locations depending on pricing scheme
- → Can disincentivize private car usage

Parking price policies

- → Increase in km driven if AVs travel farther to park rather than parking at destination
- → Can disincentivize private car usage

Parking space regulations

- → Potential reduction in conflicts with VRUs
- → Altered driving behaviour
- → Increase in km driven if AVs travel farther to park rather than parking at destination
- → Can disincentivize private car usage

Automated ride sharing

- → More pick-up/drop-offs can increase risky interactions
- → Reduction in total km driven
- → Shift from human-driven private car to shared automated taxis reduces human factor crash risks

Green Light Optimal Speed Advisory (GLOSA)

- → Smoother traffic flow at full GLOSA penetration
- → Potential speed differences with human drivers
- → GLOSA app: may be distracting/ imperfectly used by human drivers

Figure 4.14: Expected impacts of increasing automation, automated passenger cars, and the studied sub-use case interventions

4.2.2 Quantification of traffic safety impacts

The effects on road safety of increasing automation of the vehicle fleet together with the AUSS scenarios are quantified using microsimulation in AIMSUN combined with the Surrogate Safety Assessment Model (SSAM) (Pu et al., 2008) which identifies potentially dangerous traffic interactions (traffic 'conflicts'). SSAM, developed by the Federal Highway Administration (FHWA), uses trajectory files from the simulation to identify instances where vehicles in the network overstep threshold values of Time to Collision (TTC) and Post Encroachment Time (PET)[2], representing a potential crash-causing conflict. Using the theoretical probabilistic method developed by Tarko (2018), a prediction is made for the share of conflicts that result in a crash. These crash predictions are reported in the following sections for both a no-intervention baseline scenario (increasing penetration of automated vehicles) as well as the microsimulation sub-use case scenarios discussed in this Work Package: provision of dedicated lanes for AVs, parking price regulation, replacing on-street parking with other facilities, automated ride sharing and GLOSA. Because road use pricing has only been considered using mesosimulation, no crash rate predictions are available. Variations between the no-intervention results across sub-use cases can be explained by the different road networks used in the simulations.

The microsimulation software is limited to the simulation of motor vehicles on the road, and therefore does not simulate interactions involving vulnerable road users (VRUs) such as pedestrians and cyclists. As was discussed in Weijermars et al. (2021), increasing penetration levels of CAVs in general is expected to decrease fatalities among VRUs by more than 90% in case of 100% penetration. Because replacing on-street parking with other facilities is expected to have a larger impact on VRUs—due to their close proximity on the road, many interactions, and the potential of re-allocating road space to VRUs—additional effects on VRUs have been estimated for this sub-use case.

4.2.2.1 Provision of dedicated lanes on urban highways

The effects on road safety of increasing automation of the vehicle fleet together with a dedicated lane are quantified using microsimulation in AIMSUN combined with the SSAM tool which identifies potentially dangerous traffic interactions (traffic 'conflicts'). A prediction for the resulting change in car crashes is made for both a general baseline scenario as well as the dedicated lane implementation scenarios discussed in this Work Package:

1. No policy intervention (Baseline): increasing penetration of automated vehicles without dedicated lanes
2. Motorway & A-Roads: the leftmost (innermost) lanes in the motorway and the A-Road are dedicated to AVs.
3. Motorways only: the leftmost (innermost) lane in the motorway is dedicated to AVs.
4. A-Roads: rightmost lane is dedicated to AVs

2. The default values in AIMSUN for Time to Collision (TTC=1.5 s) and Post Encroachment Time (PET=5 s) are adopted for human-driven vehicles. Due to the quicker reaction times expected for automated vehicles, 1st generation AVs allow closer interactions (TTC= 1.0s) to be regarded as safe, and 2nd generation AVs can adopt the shortest headways (TTC= 0.5s).

5. <u>A-Roads: leftmost lane</u> is dedicated to AVs

The resulting crash rate predictions for the baseline and each scenario can be seen in Figure 4.15, in terms of percentage change from the starting point (100-0-0 scenario with 0% penetration rate). The crashes are normalised in terms of vehicle kilometres, in order to control for variations in traffic volume within simulated area. The results indicate that when penetration rates are very low (20% of the vehicle fleet is automated), a dedicated lane is predicted to result in up to 15% more crashes than the baseline (no dedicated lane) scenario. This can be explained in part due to the higher traffic intensities expected on non-automated lanes, which still make up 80% of the traffic volume. Similarly, at very high penetration rates a dedicated lane for automated vehicles loses its value and results in a slightly higher crash rate prediction than the baseline. When the vehicle fleets are more equally split, however, a small benefit can be seen of dedicated lanes when implemented on A-level roads.

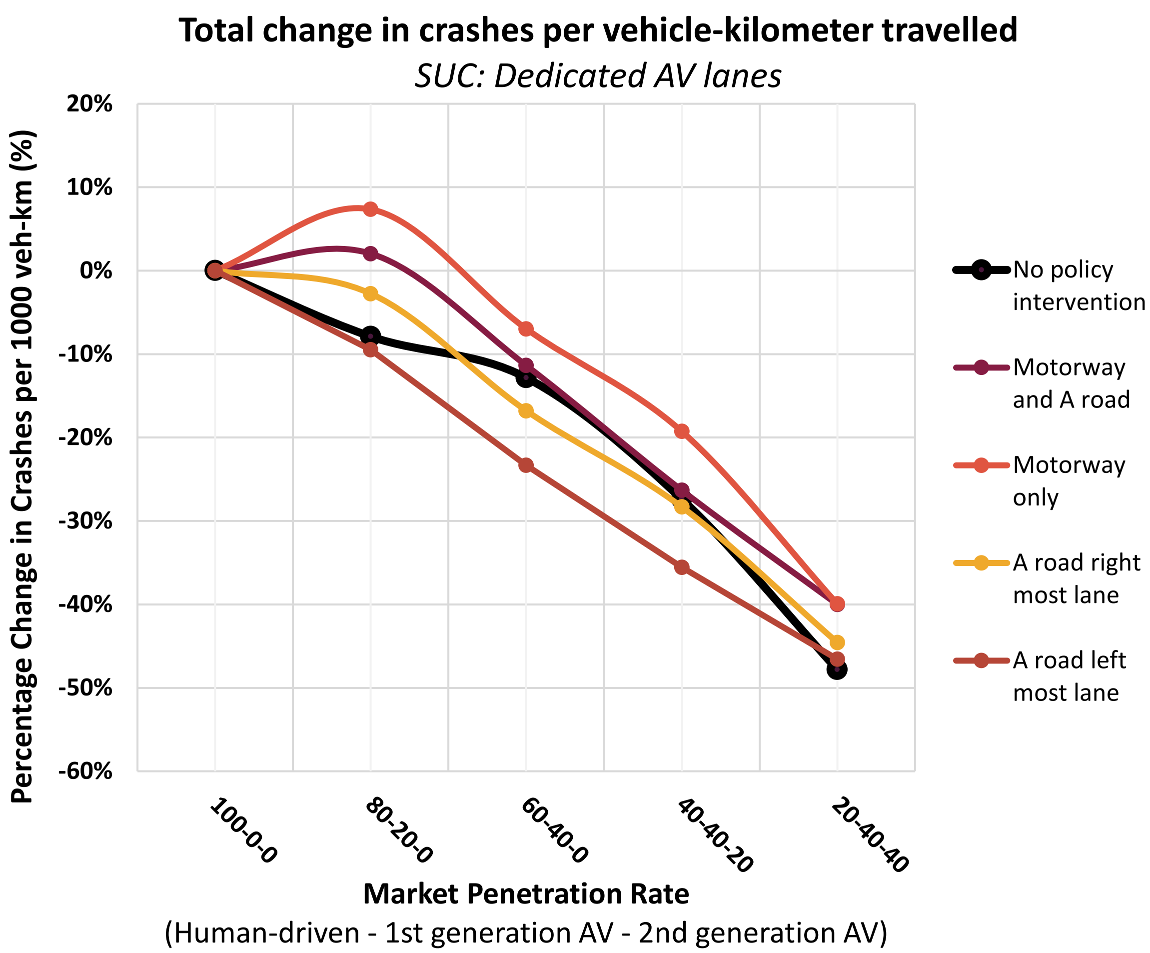


Figure 4.15: The impact of 4 dedicated AV lane scenarios on the predicted crash rate with increasing automation in the vehicle fleet, compared with a baseline scenario without dedicated lanes. Crash rate is reported in percentage change from the 100-0-0 scenario and simulated for the greater Manchester area.

4.2.2.2 Parking price policies

The effects on road safety of increasing automation of the vehicle fleet together with changing parking behaviours are quantified using microsimulation in AIMSUN combined with the SSAM tool which identifies potentially dangerous traffic interactions (traffic 'conflicts'). A prediction for the resulting change in car crashes is made for both a no policy intervention baseline scenario as well as the parking behaviour scenarios discussed in this Work Package:

1. <u>No policy intervention</u>: baseline scenario of increasing penetration of automated vehicles without changes to parking behaviour (cars park within central area)
2. <u>Drive-around scenario</u>: all cars drive around without parking until the passenger is ready to be picked up
3. <u>Balanced scenario</u>: cars park either inside centre (13%), return to origin (22%), drive outside centre to park (45%), or drive around until passenger is ready (20%)
4. <u>Return to origin and Park outside</u>: cars either return to origin (33%) or drive outside centre to park (67%)

The resulting crash rate predictions for the baseline and each scenario can be seen in Figure 4.16, in terms of percentage change from the starting point (100-0-0 scenario with 0% penetration rate). The crashes are normalised in terms of vehicle kilometres, in order to control for variations in traffic volume within the simulated area.

Generally, regardless of parking behaviour, automation among the vehicle fleet is expected to decrease crash rates at high penetration rates. At the highest penetration scenario (100% 2nd generation AVs), all four parking scenarios result in similar reductions in crash rates (55-67% reduction) compared to the starting point with only human-driven vehicles on the road. However, as is seen in several of the sub-use cases within LEVITATE, a temporary increase in crash rates is predicted at lower penetration rates when 20-40% of the vehicle fleet is automated. This is primarily due to interactions between human-driven vehicles and automated vehicles, which are expected to have different driving styles (e.g., 2nd gen automated vehicles adopting shorter headways) and different capabilities (e.g., human drivers' longer reaction times), which may lead to an initial increase in risks when many human drivers are still on the road.

This risk in mixed traffic is particularly visible in the "drive-around" scenario, where the automated vehicles cause additional congestion on the road—and therefore, additional opportunities for conflict—rather than parking to wait for their passengers. This additional congestion of 1st generation AVs circulating in the network combined with a still relatively high penetration of human-driven vehicles (60%) is expected to explain the peak in crashes predicted at the 60-40-0 penetration rate.

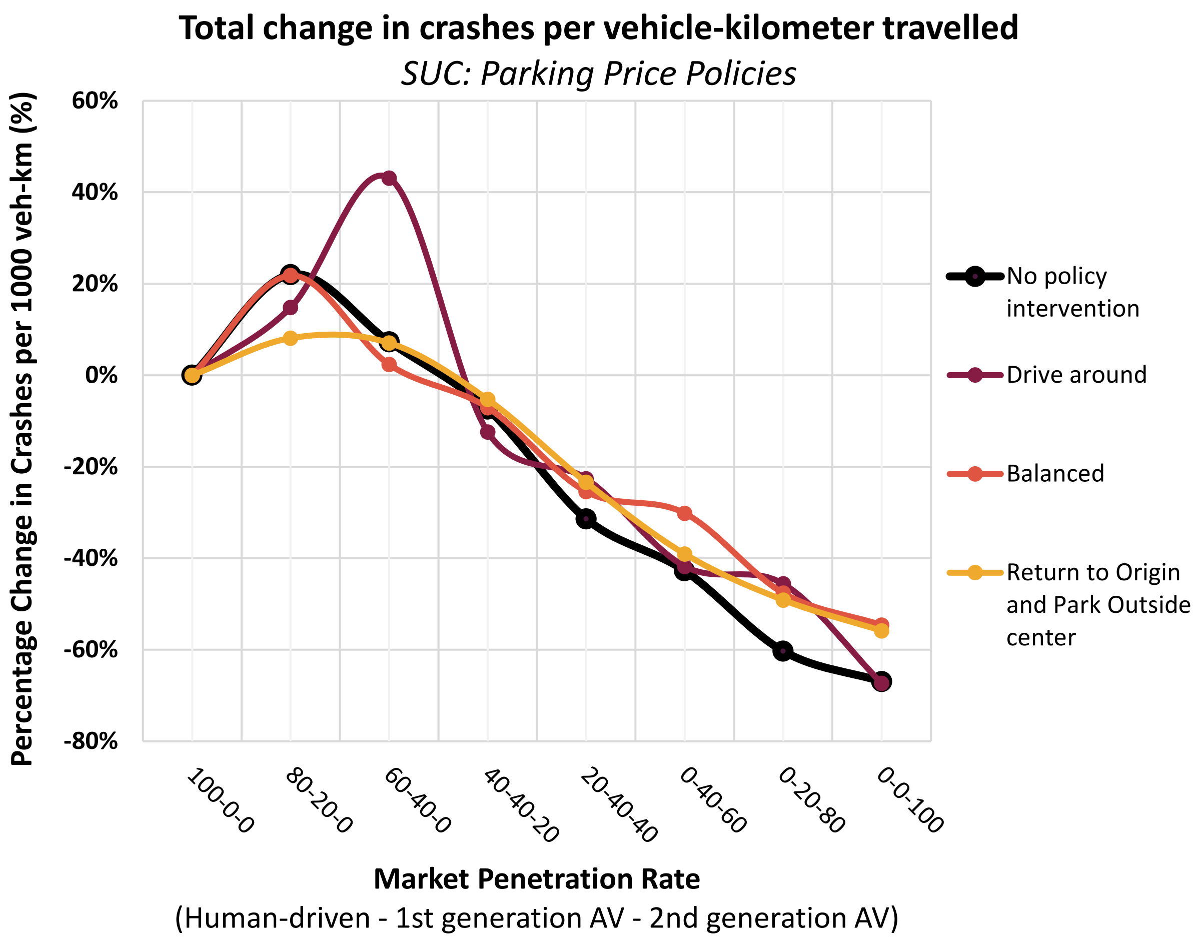


Figure 4.16: The impact of 3 parking price policies scenarios on the predicted crash rate with increasing automation in the vehicle fleet, compared with a baseline scenario without changes to parking behaviour. Crash rate is reported in percentage change from the 100-0-0 scenario and simulated for the Santander (ES) network.

4.2.2.3 Parking space regulations

The effects on road safety of increasing automation of the vehicle fleet together with replacing on-street parking with other facilities are quantified using microsimulation in AIMSUN combined with the SSAM tool which identifies potentially dangerous traffic interactions (traffic 'conflicts'). A prediction for the resulting change in car crashes is made for both a no policy intervention baseline scenario as well as the on-street parking replacement scenarios discussed in this Work Package:

1. No policy intervention: baseline scenario of increasing penetration of automated vehicles without a change to on-street parking
2. Remove half of on-street parking spaces: half of on-street parking spaces are removed without replacement
3. Replace with driving lanes: on-street parking is changed into an additional driving lane accessible to motor vehicle traffic
4. Replace with cycling lanes: on-street parking is changed into an additional cycling lane inaccessible to motor vehicle traffic (note: it is not possible to model cyclists in AIMSUN)

5. Replace with pick-up/drop-off points: on-street parking is changed into spaces for pick-up and drop-off of passengers used by shared AVs
6. Replace with public spaces: on-street parking is removed in favour of public space

The resulting crash rate predictions for this sub-use case can be seen in Figure 4.17. Overall, the scenarios in this sub-use case show negligible differences from the baseline scenario in which on-street parking remains. This suggests that the presence of on-street parking in the microsimulation does not account for a large portion of the predicted crashes. For all scenarios, a large reduction of over 90% is predicted in crash rates at full penetration of 2nd generation automated vehicles. This result, simulated for the Leicester network, shows a higher reduction in crash rates than on the other networks used in this Work Package, most likely due to differences in the network characteristics and vehicle fleet composition.

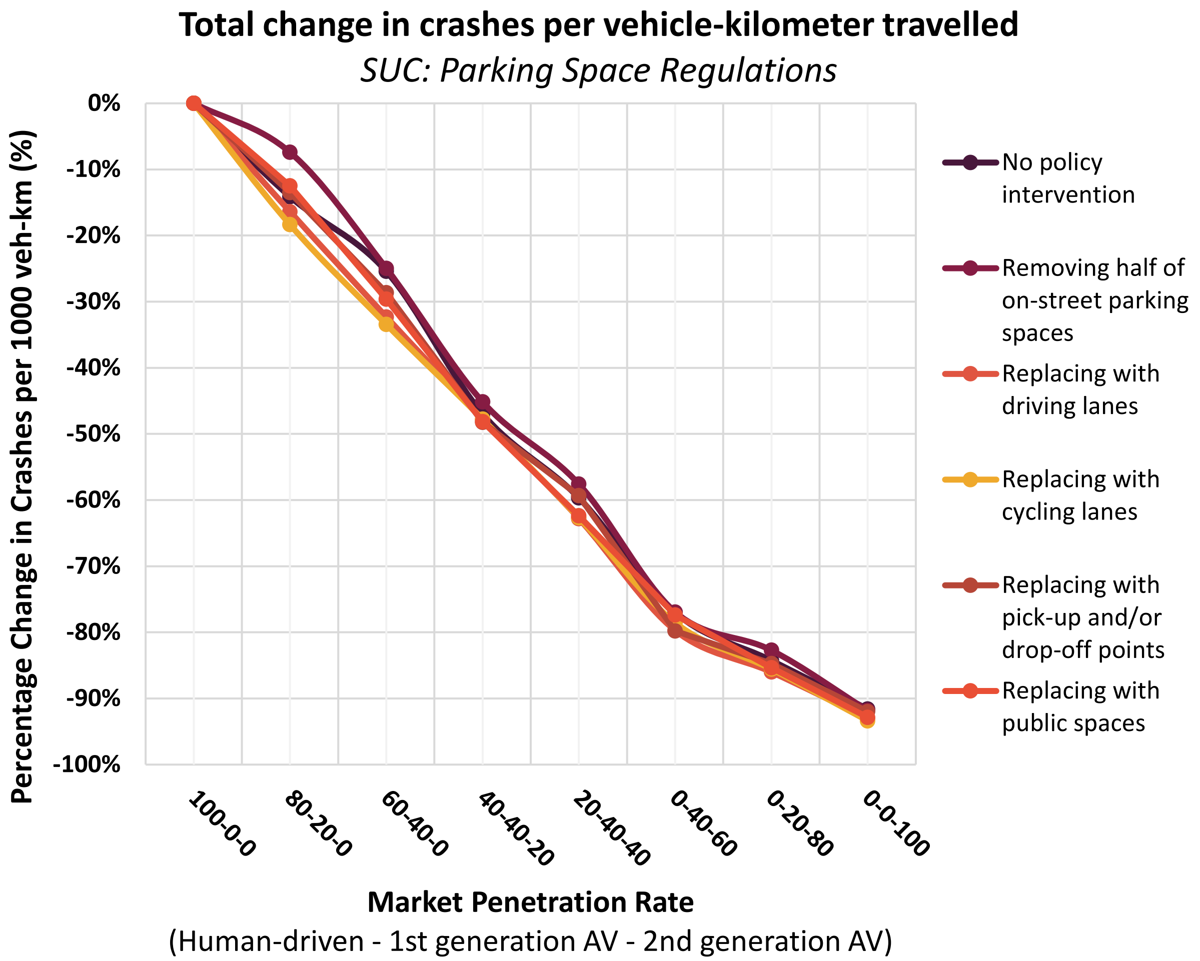


Figure 4.17: The impact of parking space regulations scenarios on the predicted crash rate with increasing automation in the vehicle fleet, compared with a baseline scenario without changes to parking behaviour. Crash rate is reported in percentage change from the 100-0-0 scenario and simulated for the Leicester (UK) city centre.

Impacts on VRUs

The replacement of on-street parking with cycling lanes or public space can be expected to have an impact on VRU accident numbers for various reasons.
The provision of cycling lanes in place of parking space would be expected to increase cyclist safety and several sources supporting this can be found (Lott & Lott, 1976; Smith et al., 2019; Pedroso, Angriman, Bellows, & Taylor, 2016), however, we note that these benefits are not found in all studies, see Mulvaney (2015).
Drop-off spots could affect pedestrian safety, via unexpected interactions between pedestrians and cyclists or cars (for instance through pedestrians getting out of a car and suddenly trying to cross the road).

The change in term of VRU risk would appear to be the elimination of the most common obstruction of view between pedestrians and motorized vehicles: the parked car. The study by Biswas et al., 2017 discussed road safety and presents some conflicting views on whether on-street parking impacts road safety negatively or not, while noting that a majority of road safety studies concludes on-street parking to have a negative impact. Concerning the effects on pedestrians in particular, it is noted that data from Great Britain (see also Department of Transport, 2015) suggests a contributing relation of on-street parking to car-pedestrian injury accidents in between 13 and 17% of cases. We aimed to find sources from other countries, to see if this share might apply more broadly to car-pedestrian accidents. See below for the final quantification within the project.

The impacts on VRU safety could be quantified using a constant reduction in VRU accidents by 17% for pedestrians, and 6% for cyclists. The estimate in Biswas et al, 2017 is consistent with Hungarian data in a study by Glász and Juhász (2017) (page 479): In this study, among "pedestrian at fault accidents" there were 373 attributed to "crossing behind an obstruction", which is a 17% share of the 2183 pedestrian-at-fault accident pool considered in this study. Since this affects mostly pedestrians and not cyclists, we also investigated how the effect on cyclists might be quantified in the same study. Indeed, the study by Glász and Juhász (2017) notes that 5.7% of cyclists were injured in "collisions with a parked vehicle", which we use as proxy for the effect on cyclists. Since the exact share of cyclist and pedestrian accidents among VRU accidents can vary strongly between cities and the PST does not reflect the exact split, it is difficult to give an exact estimate. A conservative estimate of a reduction of around 8% in unmotorized VRU at-fault accidents is thus assumed.

4.2.2.4 Automated ride sharing

The effects on road safety of increasing automation of the vehicle fleet together with an automated ride sharing system are quantified using microsimulation in AIMSUN combined with the SSAM tool which identifies potentially dangerous traffic interactions (traffic 'conflicts'). A prediction for the resulting change in car crashes is made for both a no policy intervention baseline scenario as well as the automated ride sharing scenarios discussed in this Work Package:

1. No policy intervention: baseline scenario of increasing penetration of automated vehicles without an automated ride sharing system
2. 5% demand for shared AVs: 5% of the total private vehicle travel demand (trips) is replaced by a shared AV trip, with a variable willingness to share the ride (20%, 50%, 80%, 100% of travellers)
3. 10% demand for shared AVs: 10% of the total private vehicle travel demand (trips) is replaced by a shared AV trip, with a variable willingness to share the ride (20%, 50%, 80%, 100% of travellers)
4. 20% demand for shared AVs: 20% of the total private vehicle travel demand (trips) is replaced by a shared AV trip, with a variable willingness to share the ride (20%, 50%, 80%, 100% of travellers)

The resulting crash rate predictions for this sub-use case can be seen in Figure 4.18 (a-c). At high penetration rates, all ride sharing scenarios as well as the baseline show a high reduction in crash rates. At 100% market penetration of 2nd generation automated vehicles, all scenarios are predicted to result in an 80-87% reduction in the total number of crashes per driven kilometre. For most scenarios, the addition of a ride sharing system is predicted to result in a slightly higher crash rate than the baseline, although the differences are small and appear to show some random variation. The additional conflict-causing interactions may be due to congestion caused when the automated vehicles stop for pick-up/drop-off. Neither the percentage of demand served nor the willingness of passengers to share trips show a clear relationship with the crash rate.

As is seen in several of the sub-use cases within LEVITATE, a temporary increase in crash rates is predicted at lower penetration rates when 20% of the vehicle fleet is automated. This is primarily due to interactions between human-driven vehicles and automated vehicles, which are expected to have different driving styles (e.g., automated vehicles adopting shorter headways) and different capabilities (e.g., human drivers' longer reaction times), which may lead to an initial increase in risks when many human drivers are still on the road.

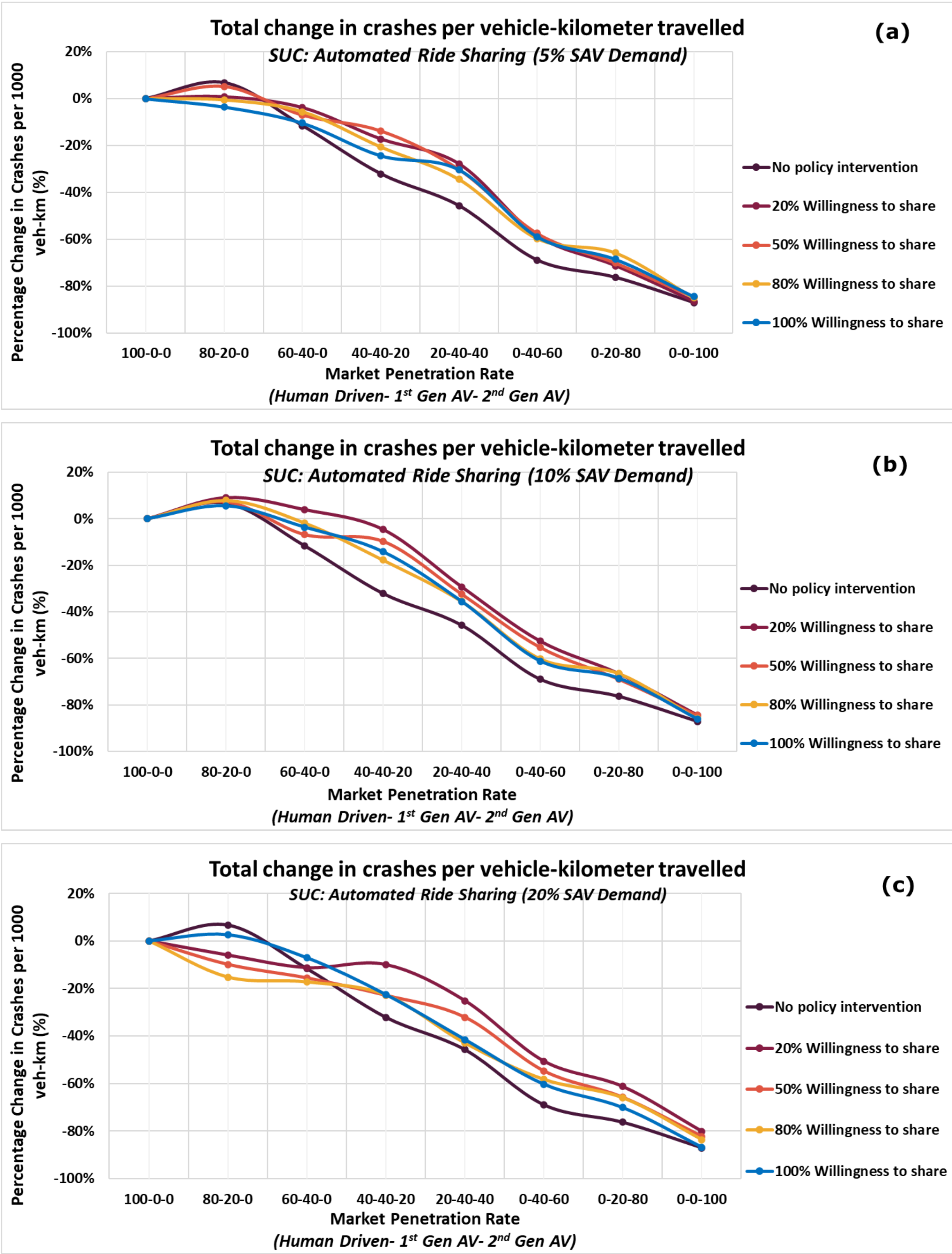


Figure 4.18: Impact of the automated ride sharing scenarios on the predicted crash rate with increasing automation in the vehicle fleet, compared with a baseline no policy intervention scenario without automated ride sharing. Crash rate is reported in percentage change from the 100-0-0 scenario and simulated for the Greater Manchester area (UK) network.

4.2.2.5 GLOSA

The effects on road safety of increasing automation of the vehicle fleet together with implementation of Green Light Optimal Speed Advisory (GLOSA) are quantified using microsimulation in AIMSUN combined with the SSAM tool which identifies potentially dangerous traffic interactions (traffic 'conflicts'). A prediction for the resulting change in car crashes is made for both a no policy intervention baseline scenario as well as the GLOSA scenarios discussed in this Work Package:

1. No policy intervention: baseline scenario of increasing penetration of automated vehicles without GLOSA
2. GLOSA on 1 intersection: GLOSA is implemented at 1 intersection in the network
3. GLOSA on 2 intersections: GLOSA is implemented at 2 intersections in the network
4. GLOSA on 3 intersections: GLOSA is implemented at 3 intersections in the network

The resulting crash rate predictions for this sub-use case can be seen in Figure 4.19.

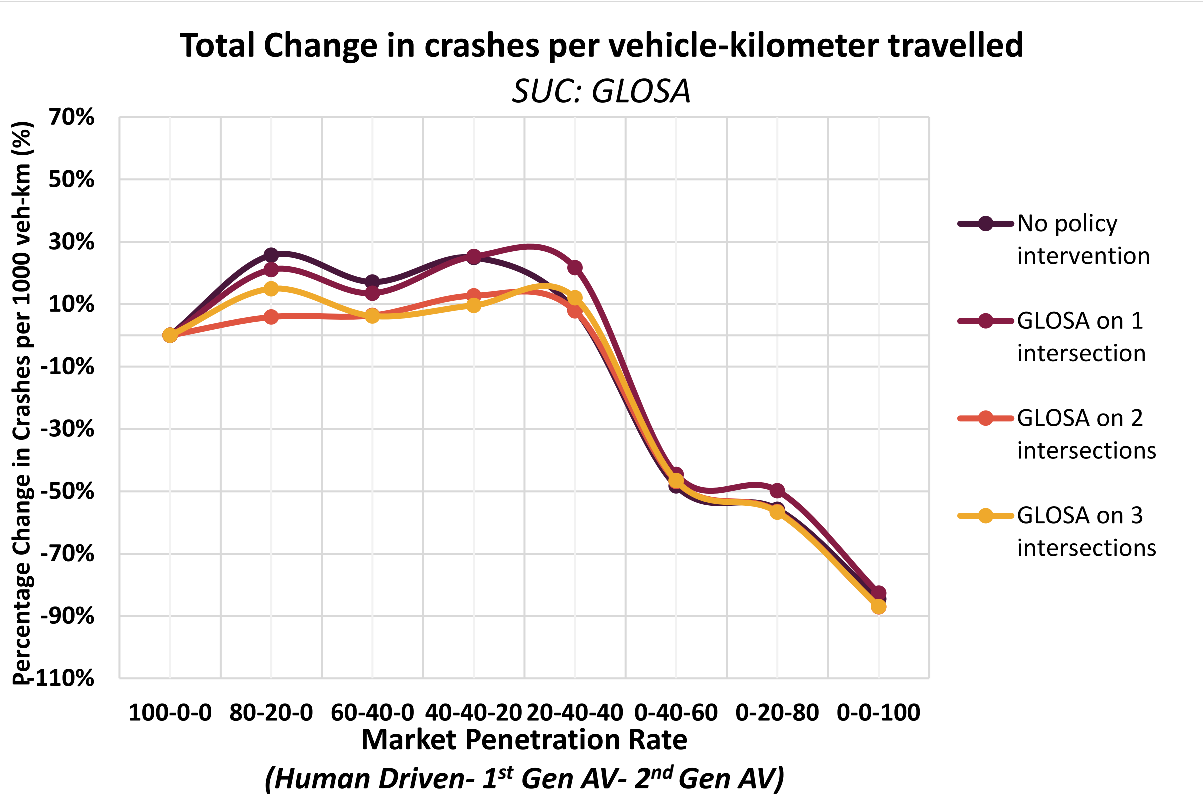


Figure 4.19: Impact of Green Light Optimal Speed Advisory (GLOSA) scenarios on the predicted crash rate with increasing automation in the vehicle fleet, compared with a baseline no policy intervention scenario without GLOSA Crash rate is reported in percentage change from 100-0-0 scenario and simulated for the Greater Manchester area (UK) network.

Under the No policy intervention (baseline) scenario, the results show an increase in crash rates at lower MPR scenarios with 1st and 2nd Generation CAVs. This could potentially be due to disruptions in the traffic stream caused by the inclusion of CAVs in the network, and the resulting interactions between human-driven vehicles and CAVs. Because human-driven vehicles and automated vehicles have different driving styles (e.g., different headways) and different capabilities (e.g., human drivers' longer reaction times), this may lead to an initial increase in risks when many human drivers are still on the road. As CAVs become a major part of the fleet composition in the higher MPR scenarios and human-driven vehicles are no longer present (from 0-40-60 scenario), a significant improvement in safety can be observed. Similar trends were also reported by an earlier study investigating the safety impacts of GLOSA system through surrogate safety assessment (Stevanovic et al.,2015).

With regard to safety impact due to GLOSA, a lower crash rate was found for the implementation of the GLOSA system at multiple intersections as opposed to a single intersection implementation. This difference is most prominent at scenarios with low MPR of 1st and 2nd Gen CAVs, suggesting that its implementation is particularly useful in mixed (human-driven and automated) traffic scenarios.

4.3 Energy efficiency

Energy efficiency is defined as the average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%). The impact on energy efficiency of the introduction of automation in the urban environment is calculated using the Delphi method.

4.3.1 Road use pricing (RUP)

According to the Delphi method results the introduction of city toll will improve energy efficiency. More precisely, dynamic city toll will increase by 15% the energy efficiency regardless of the AVs market penetration rate. Empty km pricing will lead in the long term to an increase of 10,3% of energy efficiency. Static city toll will increase energy efficiency 10,8% in the short term and 6,7% in the long term. The baseline scenario presents some fluctuations depending on the AVs market penetration rate, leading in the long term to an improvement of energy efficiency of 10,9% for 80% AVs market penetration rate.

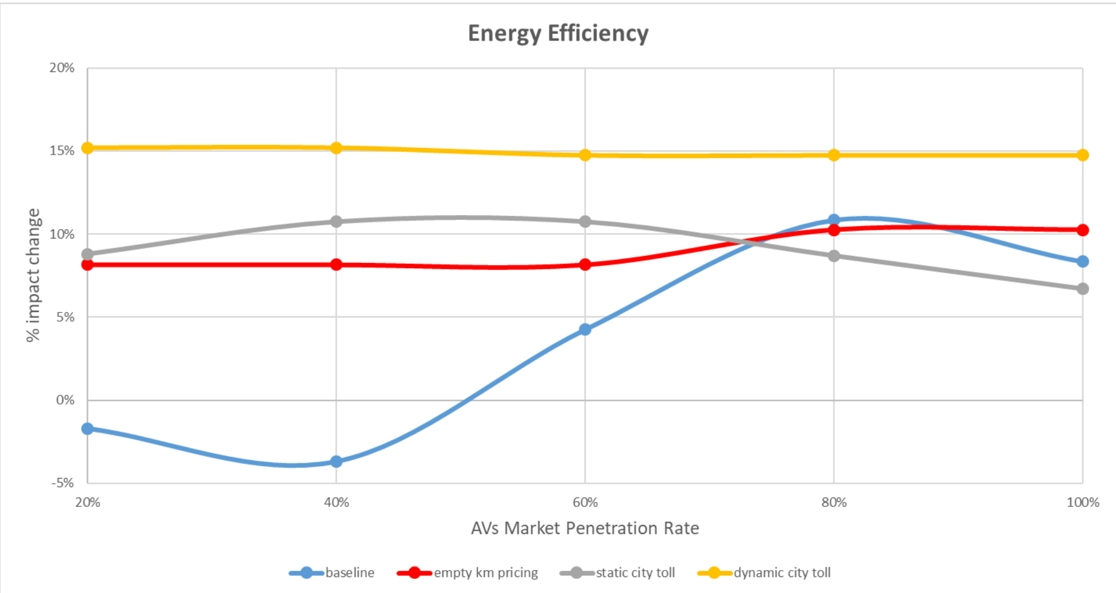


Figure 4.20: 1st round Delphi energy efficiency results for the city toll scenarios

In the 2nd Delphi round questionnaires, the majority of participants stated that they definitely (14%-29%) or moderately (57%) agree with the resulted curves. Some experts slightly (14%-29%) agreed with the proposed trends and suggested that all scenarios will not significantly affect energy efficiency, leading to a small reduction of -5%.

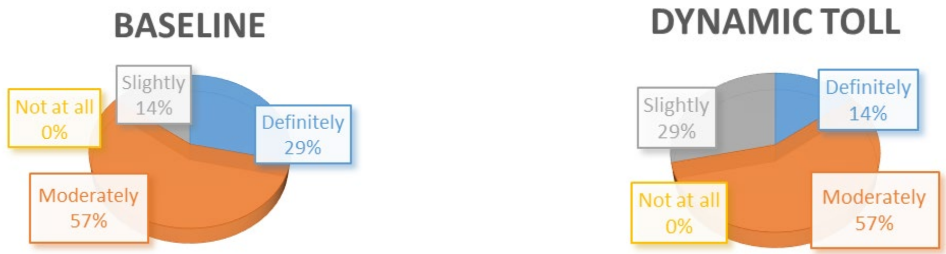


Figure 4.21: 2nd round Delphi energy efficiency results for baseline and dynamic city toll scenarios

Table 4.7: Final PST coefficients for energy efficiency for the city toll scenarios

	Baseline		**Empty km pricing**		**Static toll**		**Dynamic toll**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	-1,9%	0,981	6,9%	1,069	7,5%	1,075	13,1%	1,131
40%	-3,8%	0,962	6,9%	1,069	9,2%	1,092	13,1%	1,131
60%	3,7%	1,037	6,9%	1,069	9,2%	1,092	12,7%	1,127
80%	9,9%	1,099	8,8%	1,088	7,4%	1,074	12,7%	1,127
100%	7,6%	1,076	8,8%	1,088	5,6%	1,056	12,7%	1,127

4.3.2 Provision of dedicated lanes on urban highways

According to the Delphi method results the introduction of automation in the urban environment will not significantly improve energy efficiency. All scenarios present fluctuations depending on the AVs market penetration rate. The AV dedicated lane on the innermost motorway lane will improve energy efficiency the most, leading to an increase of 10,5% when AVs market penetration rate reaches 100%. Based on the 1st round answers, all other scenarios will slightly reduce energy efficiency in the short term but then improve energy in the long term only for AVs market penetration rate higher than 60%, leading to maximal increase of 6%.

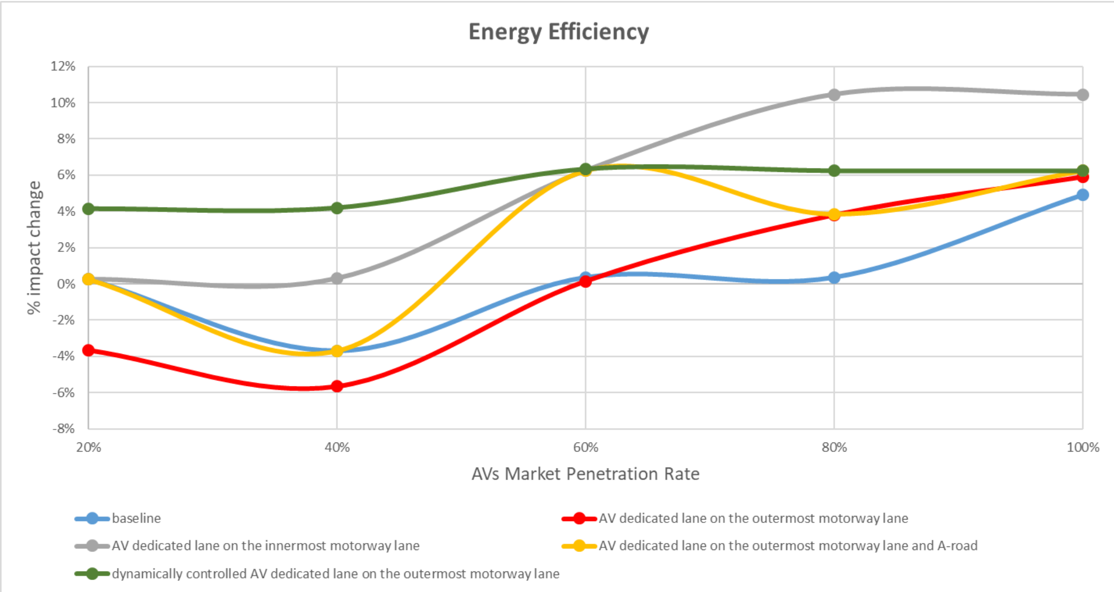


Figure 4.22: 1st round Delphi energy efficiency results for the AV dedicated lanes scenarios

In the 2nd Delphi round questionnaires, all experts stated that they definitely (33%) or moderately (67%) agree with the resulted curves for baseline scenario, the AV dedicated lane on the outermost motorway lane and the dynamically controlled AV dedicated lane. On the other hand, the majority of experts definitely (33%) or moderately (33-67%) agreed with the other scenarios. Two experts (33%) do not at all agree with the proposed curves and suggested that the AV dedicated lane on the outermost motorway lane and A-road scenario and the AV dedicated lane on the innermost motorway lane scenario should have curves similar to the other the other AV dedicated lane scenarios.

Figure 4.23: 2nd round Delphi energy efficiency results for baseline and AV dedicated lane on the innermost motorway lane

Table 4.8: Final PST coefficients for energy efficiency for the AV dedicated lanes scenarios

	Baseline		Outermost motorway lane		Innermost motorway lane		Outermost motorway lane and A-road		Dynamically controlled AV dedicated lane	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	0,3%	1,003	-3,7%	0,964	0,2%	1,002	0,2%	1,002	4,2%	1,042
40%	-3,7%	0,963	-5,7%	0,944	0,3%	1,003	-3,2%	0,968	4,2%	1,042
60%	0,3%	1,004	0,2%	1,002	5,5%	1,055	5,5%	1,055	6,4%	1,064
80%	0,3%	1,004	3,8%	1,038	9,1%	1,091	3,4%	1,034	6,3%	1,063
100%	4,9%	1,049	5,9%	1,059	9,1%	1,091	5,5%	1,055	6,3%	1,063

4.3.3 Parking price policies

According to the Delphi method results the introduction of automation in the urban environment will improve energy efficiency. The baseline scenario will improve energy efficiency the most, leading to an increase of 32,4% when AVs market penetration rate reaches 100%. Based on the 1st round answers, CAVs parking inside, returning to origin and parking outside will increase energy efficiency by 28,3%, 16,4% and 14,4% respectively. On the other hand, CAVs driving around will negatively affect energy efficiency, reaching -14,1% in the long term.

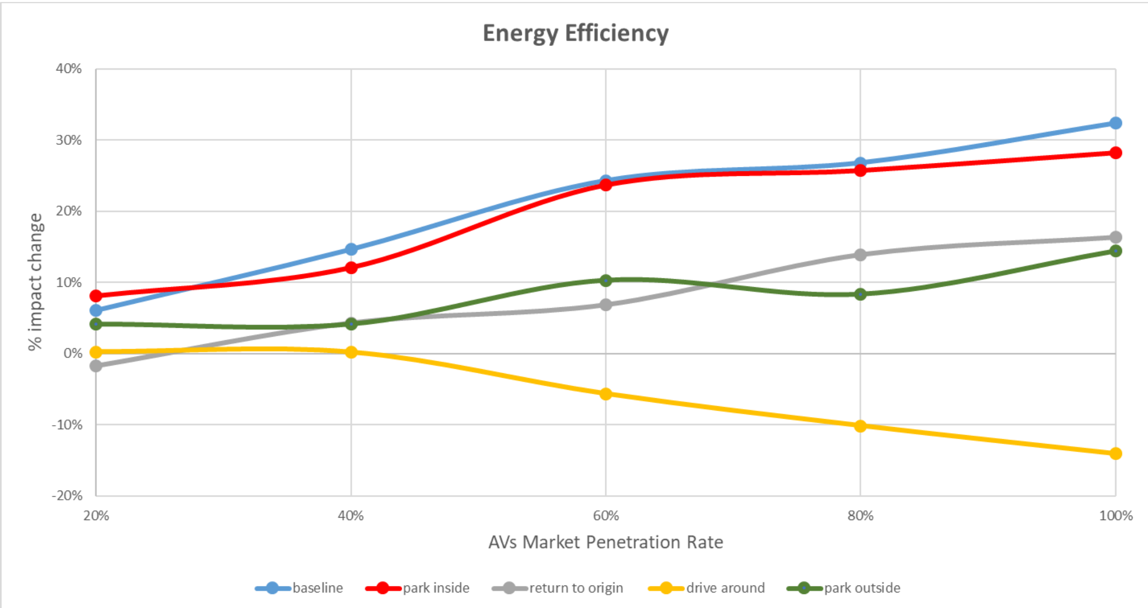


Figure 4.24: 1st round Delphi energy efficiency results for the CAV parking behaviour scenarios

In the 2nd round the majority of participants agreed definitely (50%) or moderately (33%) with the 1st round results. One expert suggested that the baseline scenario and CAVs parking inside will slightly improve the studied impact at an average of 5%. The same participant also proposed that the other scenarios will negatively affect energy efficiency at a percentage of -5% to -10%.

Figure 4.25: 2nd round Delphi energy efficiency results for baseline and CAVs driving around scenarios

Table 4.9: Final PST coefficients for energy efficiency for the CAV parking behaviour scenarios

	Baseline		**Park inside**		**Return to origin**		**Drive around**		**Park outside**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	6,0%	1,060	7,9%	1,079	-2,0%	0,980	-0,4%	0,996	3,6%	1,036
40%	14,0%	1,140	11,6%	1,116	3,7%	1,037	-0,4%	0,996	3,6%	1,036
60%	23,1%	1,231	22,5%	1,225	6,1%	1,061	-5,9%	0,941	9,3%	1,093
80%	25,4%	1,254	24,5%	1,245	12,7%	1,127	-10,1%	0,899	7,5%	1,075
100%	30,6%	1,306	26,8%	1,268	15,0%	1,150	-13,8%	0,862	13,2%	1,132

4.3.4 Parking space regulations

According to the Delphi method results the introduction of automation in the urban environment will improve energy efficiency. The baseline scenario will lead to an increase of 12,9% when AVs market penetration rate reaches 100%. Based on the 1st round answers, replacing on-street parking space with space for public will improve energy efficiency the most reaching an increase of 13,3% for 100% AVs market penetration rate. On the other hand, replace on-street parking space with driving lanes or with pick-up/drop-off will both negatively affect energy efficiency, reaching from -2,7% to -6,1%, and from -3,6% to -10,2% respectively.

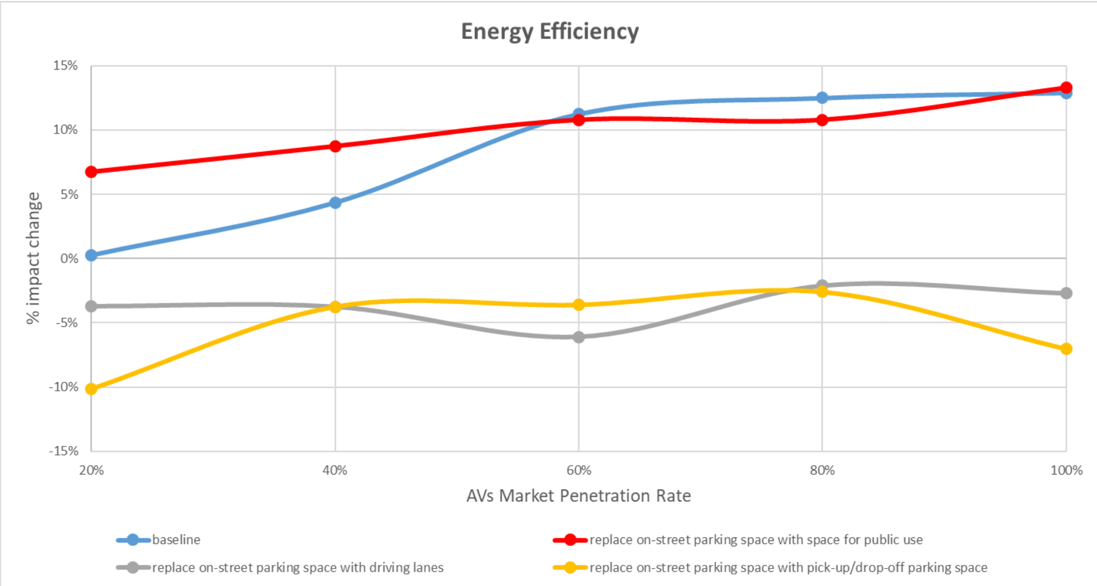


Figure 4.26: 1st round Delphi energy efficiency results for parking space regulation scenarios

In the 2nd round all the experts definitely (0%-60%) or moderately (40%-100%) agreed with the 1st round results.

Figure 4.27: 2nd round Delphi energy efficiency results for baseline and replacing on-street parking with driving lanes scenarios

Table 4.10: Final PST coefficients for energy efficiency for parking space regulation scenarios

	Baseline		**Space for public use**		**Driving lanes**		**Pick-up/drop-off**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	0,3%	1,003	6,8%	1,068	-3,7%	0,963	-10,2%	0,899
40%	4,4%	1,044	8,8%	1,088	-3,8%	0,963	-3,8%	0,963
60%	11,3%	1,113	10,8%	1,108	-6,1%	0,939	-3,6%	0,964
80%	12,5%	1,125	10,8%	1,108	-2,1%	0,979	-2,6%	0,974
100%	12,9%	1,129	13,3%	1,133	-2,7%	0,973	-7,1%	0,930

4.3.5 Automated ride sharing

According to the Delphi method results all scenarios will improve energy efficiency. Automated ridesharing and the baseline scenario will also progressively increase energy efficiency, reaching 21,8% and 15,2% respectively.

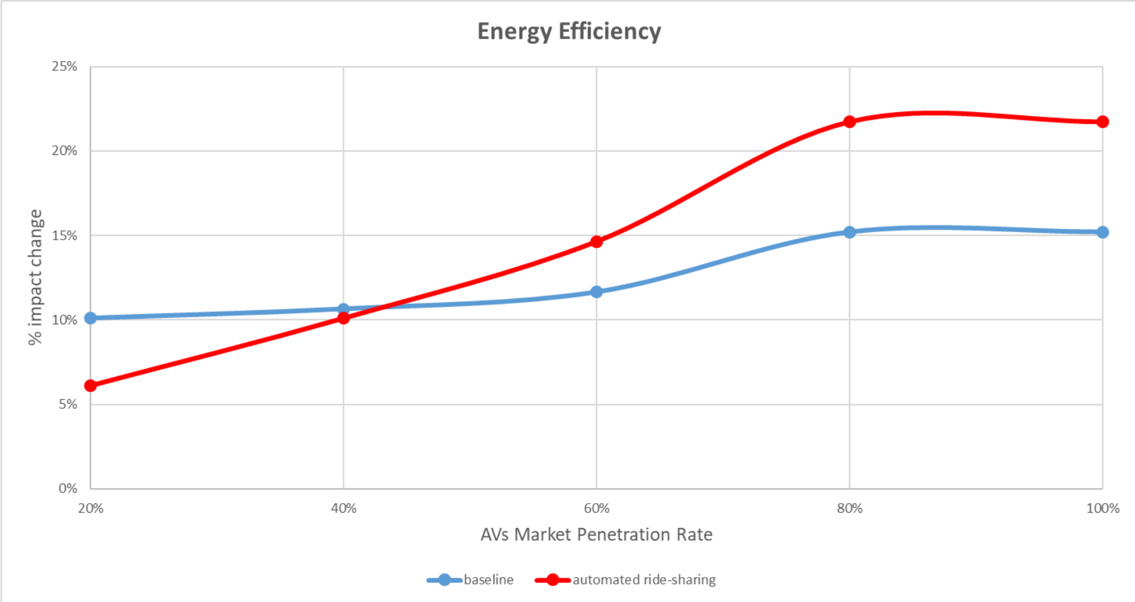


Figure 4.28: 1st round Delphi energy efficiency results for the automated ridesharing

In the 2nd Delphi round questionnaires, the majority of experts definitely (33%) or moderately (33%) agreed with the resulted curves. Two experts (33%) suggested that the proposed trends are overestimated and suggested an average increase of 5%-10% of energy efficiency for all scenarios.

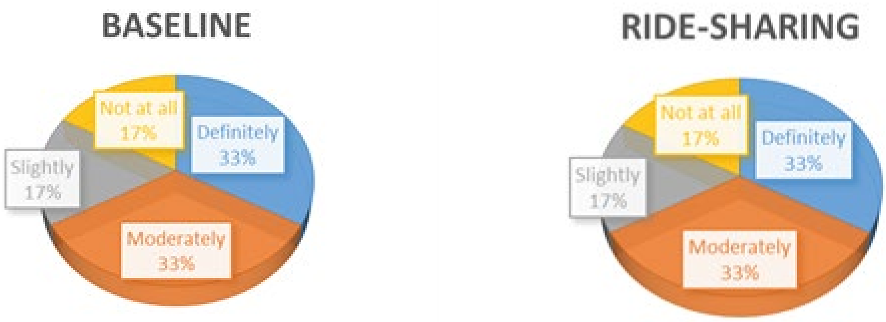


Figure 4.29: 2nd round Delphi energy efficiency results for baseline and automated ridesharing scenarios

Table 4.11: Final PST coefficients for energy efficiency for the automated ridesharing

	Baseline		**Automated ridesharing**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficient
20%	9,8%	1,098	6,3%	1,063
40%	10,3%	1,103	9,8%	1,098
60%	11,1%	1,111	13,8%	1,138
80%	14,2%	1,142	20,0%	1,200
100%	14,2%	1,142	20,0%	1,200

4.3.6 Green Light Optimal Speed Advisory (GLOSA)

According to the Delphi method results all scenarios will improve energy efficiency. More precisely, GLOSA will have the biggest impact on energy efficiency, leading to an increase of 31,2%. The baseline scenario will also progressively increase energy efficiency, reaching 15,2%.

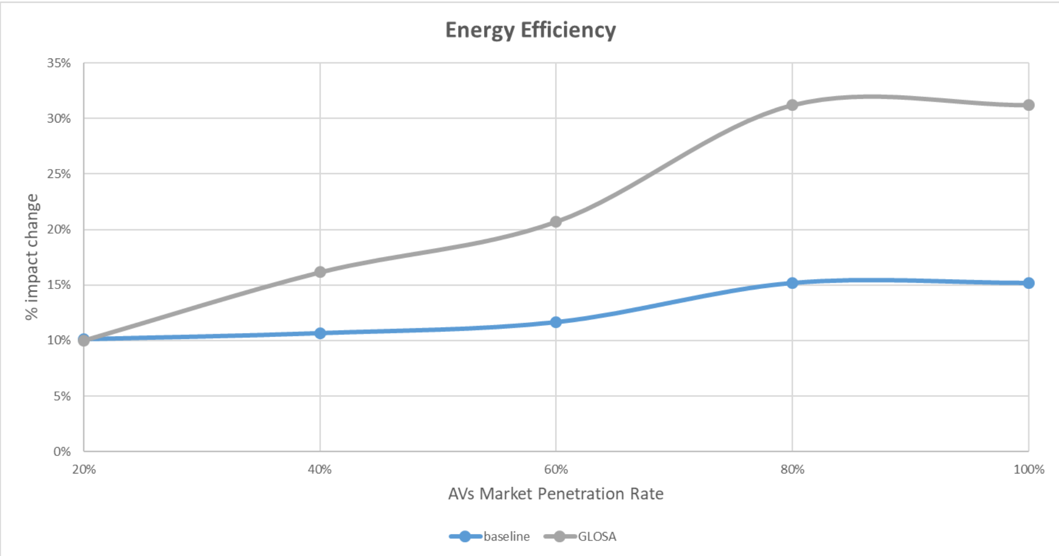


Figure 4.30: 1st round Delphi energy efficiency results for GLOSA scenarios

In the 2nd Delphi round questionnaires, the majority of experts definitely (33%) or moderately (33%) agreed with the resulted curves. Two experts (33%) suggested that the proposed trends are overestimated and suggested an average increase of 5%-10% of energy efficiency for all scenarios.

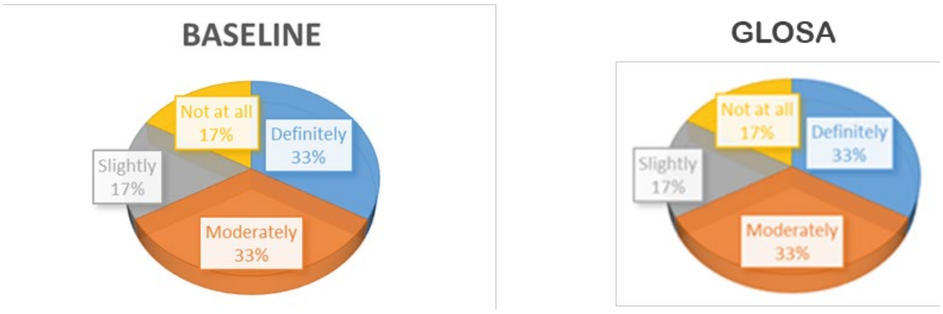


Figure 4.31: 2nd round Delphi energy efficiency results for baseline and GLOSA

Table 4.12: Final PST coefficients for energy efficiency for GLOSA scenarios

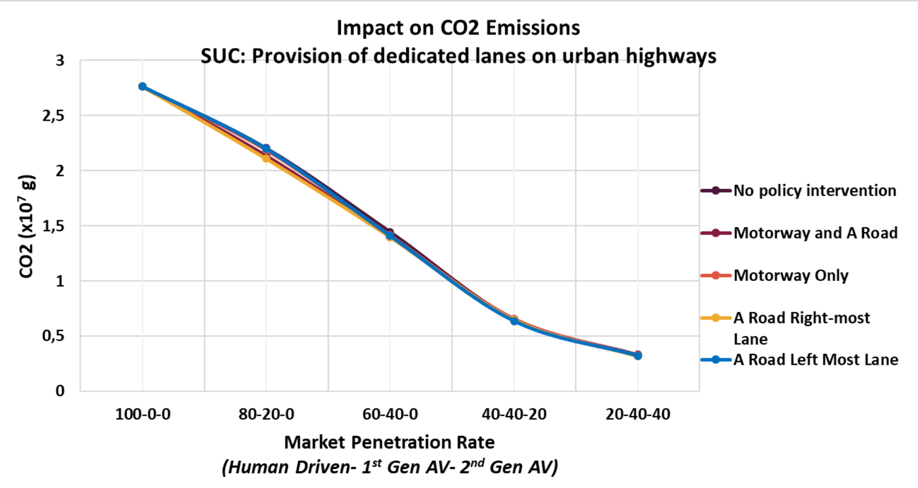
AV penetration rates	Baseline		GLOSA	
	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	9,8%	1,098	9,4%	1,094
40%	10,3%	1,103	14,8%	1,148
60%	11,1%	1,111	18,7%	1,187
80%	14,2%	1,142	27,9%	1,279
100%	14,2%	1,142	27,9%	1,279

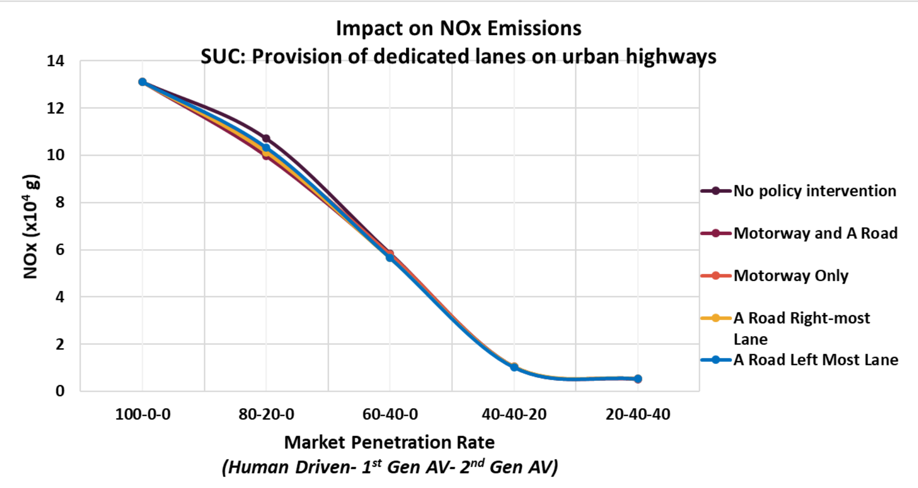
4.4 Emissions

The environmental impacts were directly obtained from the AIMSUN Next microscopic simulation for dedicated lanes on urban highways, parking space regulations, parking price policies, automated ridesharing, and GLOSA system implementation. AIMSUN Next simulation provides four emission models, out of which Panis et al. (2006) emission model has been chosen for LEVITATE project. The Panis et al. (2006) emission model computes instantaneous pollution emissions caused by acceleration or deceleration and speed for all the vehicles in the simulation (AIMSUN, 2021). More specifically, this model considers three emission indicators named Carbon Dioxide (CO_2), Nitrogen Dioxide (NOx) and Particulate Matter (PM). It should be noted that all AVs will be electric vehicles (EVs).

4.4.1 Provision of Dedicated Lanes on Urban Highways

Overall, a decreasing trend in emissions results on CO_2, NOx, and PM, emissions can be observed in the following graphs (Figure 4.32); however, the decrease with increasing MPR is mainly due to the electrification of vehicles which was assumed for CAVs.





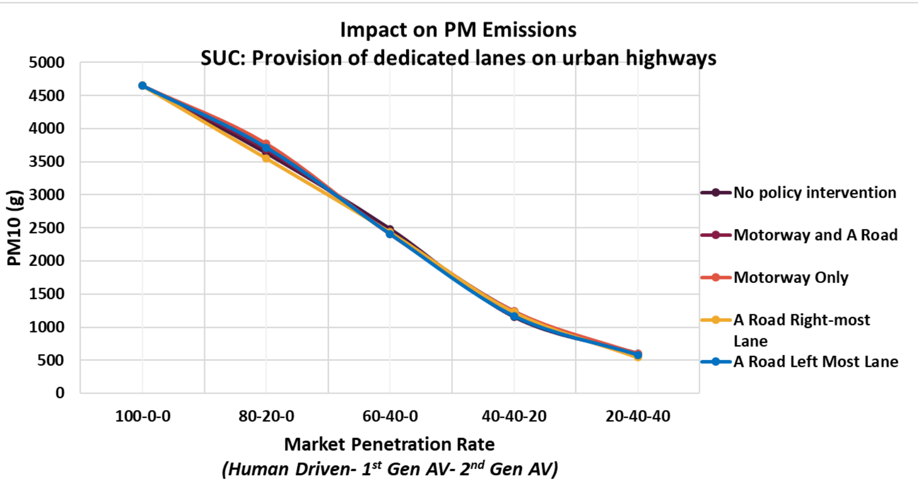


Figure 4.32: Impact on CO2, PM, and NOx emissions due to MPR of CAVs and provision of dedicated lane

In order to determine the impact of emissions coming from the dedicated lanes intervention, the percentage change was calculated from the respective baseline scenario and presented in Tables 4.13 to 4.15 below. Percentage reduction in emissions due to dedicated lane under different MPR scenarios varied as follows.:

- CO_2: 0.2% (min) to 4.3% (max)
- NOx: 0.8% (min) to 6.9% (max)
- PM:0.5% (min) to 9.3% (max)

In general, the upper limit of PM reduction was more than that of CO2 and NOx emissions; however, no consistent pattern was observed in terms of maximum reduction under a particular scenario as shown in the tables below. For example, in cases where travel time is lesser, vehicles under such cases/scenarios may be able to move faster due to lesser traffic densities, consequently increasing emissions. For example, a maximum decrease in travel time was observed (Haouari et al., 2021) under the 60-40-0 scenario at A Road leftmost lane case, which may not necessarily give maximum benefits with regard to emissions as can be observed through the values in the following tables.

Table 4.13: Percentage change in CO2 Emissions with respect to the intervention baseline for dedicated lanes SUC

MPR	Motorway and A Road	Motorway Only	A Road Right-most Lane	A Road Left Most Lane
80-20-0	-3,2%	-0,7%	-4,3%	-0,2%
60-40-0	-3,2%	-2,0%	-3,2%	0,7%
40-40-20	0,0%	0,3%	-1,1%	-2,8%
20-40-40	-3,2%	-1,8%	-4,0%	0,3%

Table 4.14: Percentage change in NOx Emissions with respect to the intervention baseline for dedicated lanes SUC

MPR	Motorway and A Road	Motorway Only	A Road Right-most Lane	A Road Left Most Lane
80-20-0	-6,9%	-4,5%	-5,4%	-3,6%
60-40-0	-2,6%	-0,8%	-3,5%	-3,4%
40-40-20	-2,1%	-1,1%	-1,4%	-3,8%
20-40-40	-3,5%	-1,5%	-3,0%	-3,0%

Table 4.15: Percentage change in PM Emissions with respect to the intervention baseline for dedicated lanes SUC

MPR	Motorway and A Road	Motorway Only	A Road Right-most Lane	A Road Left Most Lane
80-20-0	1,4%	3,9%	-2,2%	2,4%
60-40-0	-1,9%	-3,1%	-1,9%	-1,2%
40-40-20	7,8%	7,6%	6,5%	-6,0%
20-40-40	-6,0%	-0,5%	-9,3%	3,2%

4.4.2 Parking Price Policies

The following plots (Figure 4.33) show the effects of CAV penetration rates on emissions in different parking strategies. It can be observed that as the penetration of CAVs increases the emissions reduce drastically. This was consistent in all the different scenarios tested in the study. The major reason for this is the electrification of CAVs considered in the simulation model. Hence, as the proportions of CAVs was increasing the emissions were reduced.

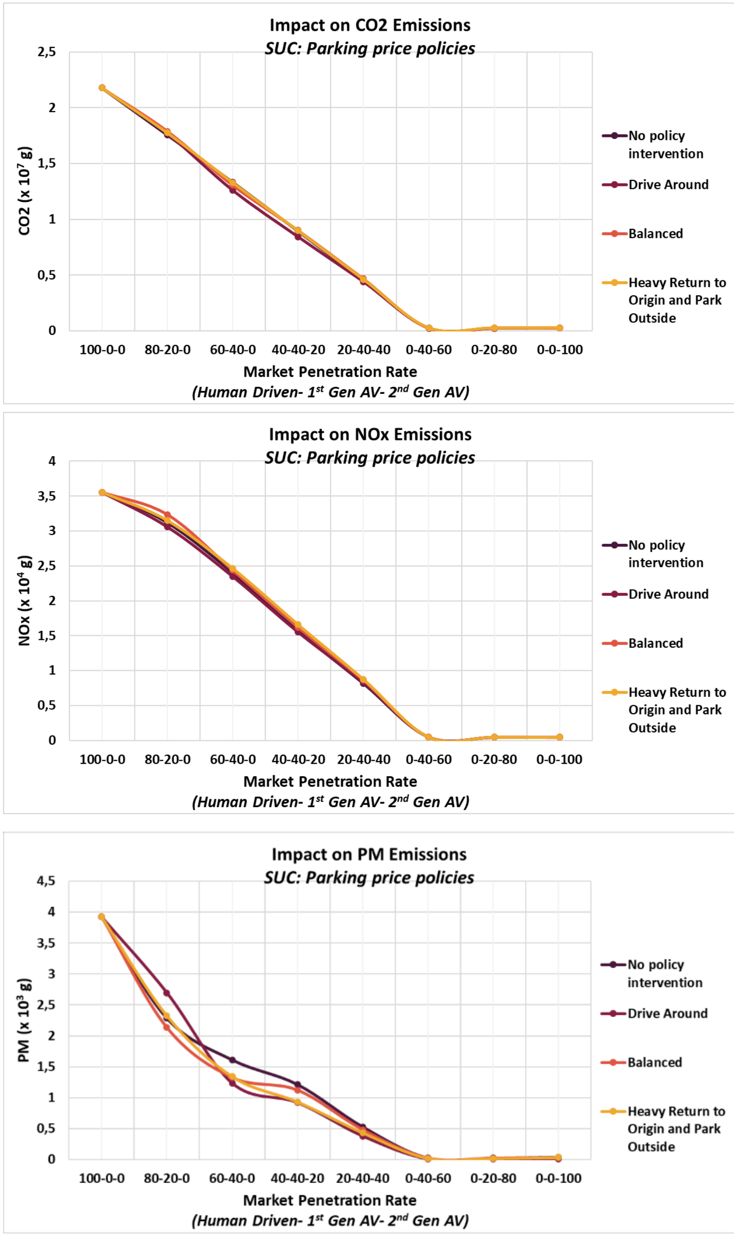


Figure 4.33: Impact on CO2, PM, and NOx emissions due to MPR of CAVs and parking price policies interventions

Further, it can be observed from tables below (Tables 4.16 to 4.18) that the emissions can reduce significantly in drive around scenarios compared to the baseline. However, it is important to understand that this cannot be considered as the advantages because the traffic flow is negatively impacted in driver around case as compared to baseline and other scenarios (Figure 4.34), making network congested. The major reduction of emissions in drive around case is attributable to the reduced traffic flow and lesser number of vehicles in the network within analysis (simulation) duration. Emissions calculated in the full CAVs scenarios (from 0-40-60 to 0-0-100 MPR), are due to background public transport vehicles, which were not considered electric vehicles.

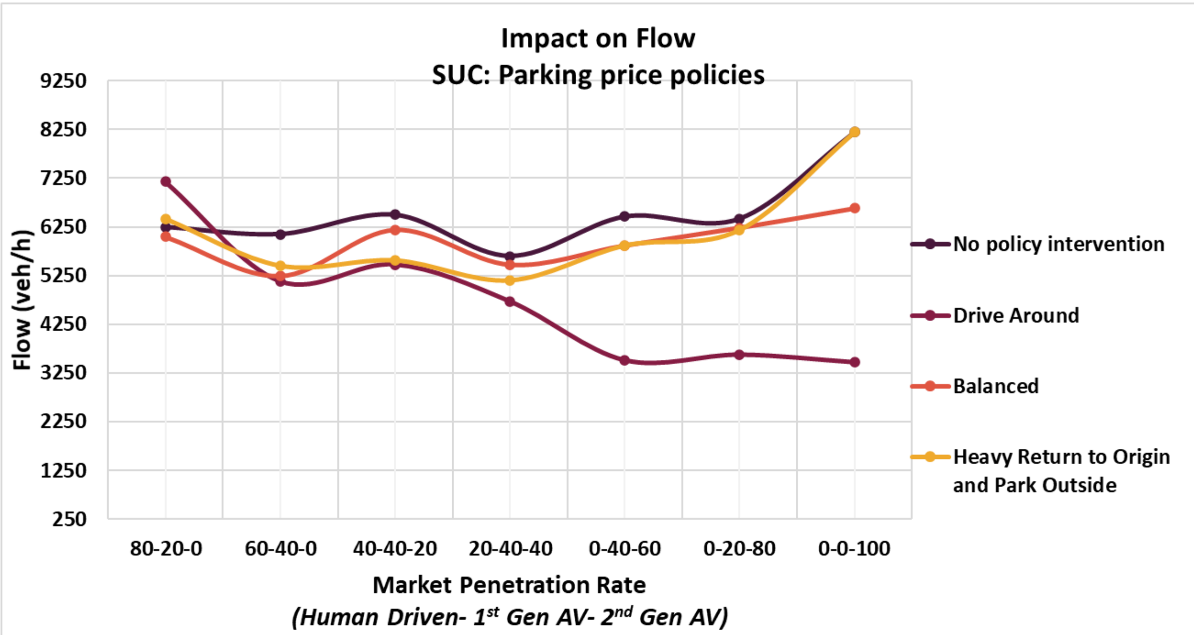


Figure 4.34: Traffic flow with increased MPR of CAVs and parking price policies interventions

Table 4.16: Change in CO_2 emissions with respect to the intervention baseline for parking price policies SUC

MPR	Drive Around	Balanced	Heavy Return to Origin and Park Outside
80-20-0	1%	2%	1%
60-40-0	-5%	-2%	0%
40-40-20	-6%	1%	0%
20-40-40	-3%	3%	2%
0-40-60	-14%	-3%	0%
0-20-80	-16%	8%	5%
0-0-100	-9%	4%	9%

Table 4.17 Change in NOx emissions with respect to the intervention baseline for parking price policies SUC

MPR	Drive Around	Balanced	Heavy Return to Origin and Park Outside
80-20-0	-2%	4%	1%
60-40-0	-2%	2%	3%
40-40-20	-1%	3%	6%
20-40-40	2%	6%	7%
0-40-60	4%	7%	6%
0-20-80	-2%	8%	7%
0-0-100	2%	6%	4%

Table 4.18 Change in PM emissions with respect to the intervention baseline for parking price policies SUC

MPR	Drive Around	Balanced	Heavy Return to Origin and Park Outside
80-20-0	18%	-7%	2%
60-40-0	-23%	-18%	-17%
40-40-20	-24%	-8%	-23%
20-40-40	-29%	-9%	-18%
0-40-60	-73%	-21%	-19%
0-20-80	-62%	-15%	-15%
0-0-100	-79%	-34%	-13%

4.4.3 Parking space regulations

Figure 4.35 provides an overview of the emission results for baseline and all interventions based on fleet market penetration rate. It is clearly seen that the emission for all three indicators (CO_2, NOx, and PM) reduce dramatically as the CAV fleet penetration level increases. This is to be expected as all CAVs were considered as electric CAVs within LEVITATE projects. In addition, CAVs are expected to travel at a consistent speed that leads to fewer stop-and-go situations in the traffic stream, which would reduce traffic emissions (Stogios, 2018). It is worth noting that in full penetration rate scenarios (0-40-60 to 0-0-100), there is still a small number of emissions for all three indicators. They are due to the background public transport (bus) vehicles in the network, which were not modelled as having electric vehicles.

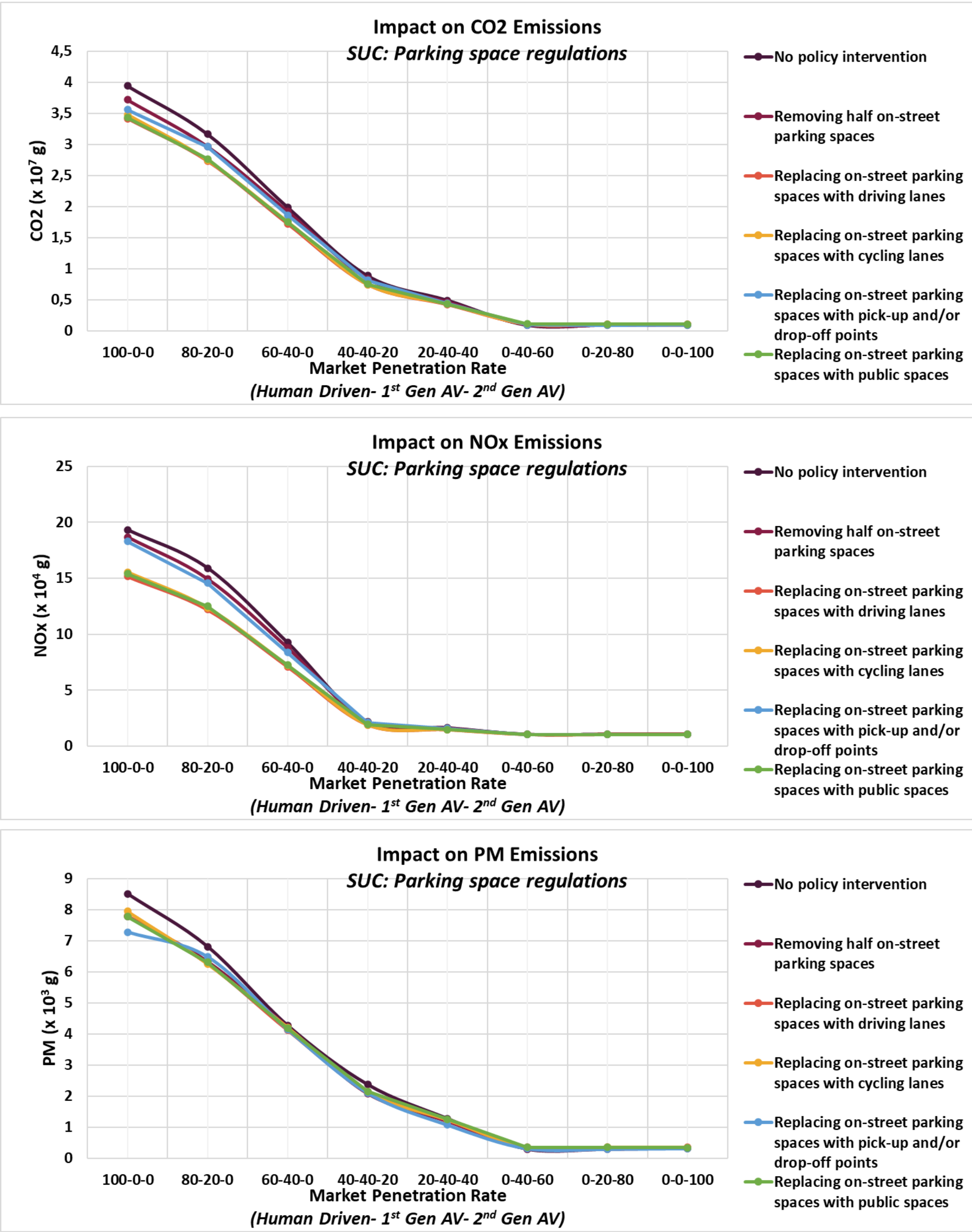


Figure 4.35: Impact on CO2, NOx, and PM10 emissions due to MPR of CAVs and interventions for parking space regulations SUC

Even though the major share in emissions reduction is due to electric considered for CAVs, some change in emissions can be observed between no policy intervention and various on-street parking replacement measures, especially under scenarios where human driven vehicles are present. In order to determine the impact of various interventions exclusively, percentage change in the emission of CO_2, NOx, and PM were calculated by comparing the values between with and without policy intervention in the corresponding baseline MPR scenario (presented in Tables 4.19 - 4.21). It can be observed that the interventions of replacing on-street parking with driving lane, cycle lane and public spaces have shown better performance in reducing CO_2, NO_x, and PM emissions compared to removing half of the on-street parking spaces and replacing them with pick-up/drop-off spaces. As indicated by the findings presented in D6.2 and D6.3, pick-up/drop-off parking spaces can negatively impact traffic flow due to increased stop and go operation and causing intermittent queues in the network, which are the main reasons for increased emissions under this case as also showed by various previous studies (Chai et al., 2020; Winter, Cats, Martens, & Arem, 2021; ITF, 2018).

It is interesting to note in the percentage change in emissions presented in Tables 4.19 - 4.21 that at higher MPRs, there is an increase in emissions especially CO_2 compared to the corresponding baseline scenario. For example, at the full penetration rate, the CO_2 emission increased 14%, 13% and 11%, respectively for interventions of replacing with driving lane, cycle lane and public spaces. However, this increase can be attributed to increased flow (increased number of vehicles during simulation period) at higher MPRs in the network due to these policy interventions, as shown through the results presented in D6.2. Improved network performance, with less interruptions in flow making vehicles to travel at higher speeds can also contribute an increase in emissions due to the engine needs to deliver more power to travel at high speeds (Boulter & Webster, 1997; Lutfie, Samang, Adisasmita, & Ramli, 2018).

Table 4.19: Percentage change in CO2 Emissions with respect to intervention baseline for parking space regulations

MPR	Removing half on-street parking spaces	Replacing on-street parking spaces with driving lanes	Replacing on-street parking spaces with cycling lanes	Replacing on-street parking spaces with pick-up and/or drop-off points	Replacing on-street parking spaces with public spaces
100-0-0	-6%	-13%	-12%	-10%	-13%
80-20-0	-6%	-14%	-13%	-6%	-13%
60-40-0	-3%	-13%	-12%	-6%	-12%
40-40-20	-5%	-16%	-16%	-8%	-15%
20-40-40	-6%	-14%	-13%	-10%	-12%
0-40-60	3%	19%	16%	5%	19%
0-20-80	-9%	9%	9%	-7%	9%
0-0-100	6%	14%	13%	2%	11%

Table 4.20: Percentage change in NOx Emissions with respect to intervention baseline for parking space regulations

MPR	Removing half on-street parking spaces	Replacing on-street parking spaces with driving lanes	Replacing on-street parking spaces with cycling lanes	Replacing on-street parking spaces with pick-up and/or drop-off points	Replacing on-street parking spaces with public spaces
100-0-0	-3%	-21%	-20%	-5%	-20%
80-20-0	-6%	-23%	-22%	-8%	-21%
60-40-0	-5%	-23%	-22%	-10%	-21%
40-40-20	-1%	-12%	-12%	-3%	-12%
20-40-40	-3%	-11%	-10%	-4%	-9%
0-40-60	0%	0%	0%	-1%	1%
0-20-80	-2%	-3%	-2%	-1%	-2%
0-0-100	1%	0%	0%	-1%	-1%

Table 4.21: Percentage change in PM Emissions with respect to intervention baseline for parking space regulations

MPR	Removing half on-street parking spaces	Replacing on-street parking spaces with driving lanes	Replacing on-street parking spaces with cycling lanes	Replacing on-street parking spaces with pick-up and/or drop-off points	Replacing on-street parking spaces with public spaces
100-0-0	-9%	-28%	-27%	-19%	-30%
80-20-0	-12%	-33%	-34%	-12%	-32%
60-40-0	-11%	-31%	-30%	-14%	-31%
40-40-20	-16%	-29%	-33%	-18%	-32%
20-40-40	-12%	-25%	-28%	-24%	-26%
0-40-60	-3%	-9%	-13%	-3%	-8%
0-20-80	-11%	-18%	-21%	-16%	-19%
0-0-100	1%	-16%	-18%	-2%	-14%

4.4.4 Automated ride sharing

The emission results for the different automated ridesharing interventions described in section 3.1.2, along with the baseline results, are shown in Figures 4.36- 4.38. The amount of CO_2, NOx, PM10 in the results with increasing AVs show a consistent decreasing trend, which is expected since the AVs used in this study are assumed to be electric vehicles. However, the change in emissions under mixed fleet scenarios comparing results with and without inclusion of SAVs indicate that the introduction of automated ridesharing service can potentially increase all three indicators of emissions (CO_2, NOx, and PM10) compared to the baseline scenario, regardless of the percentage of the demand served by the introduced service. Tables 4.22- 4.24 display the percentage change of CO_2, NOx, and PM10, respectively, with respect to the corresponding baseline scenario. The results show that the impact of automated ridesharing interventions varied with the level of willingness to share.

From the results in Tables 4.22- 4.24, it can be seen that with 5% and 10% SAV demand, the negative impact of automated ridesharing on CO_2, NO_x and PM emissions decreases while moving from low to high willingness to share rate. For 20% SAV demand, some negative values can be seen with 20% and 50% willingness, especially under low MPR (80-20-0, 60-40-0), but this does not indicate better performance. These results are related to having fewer vehicles in the network due to the congestion resulting from the way the shared vehicles circulate the network and the interactions between mixed vehicle fleets.

Overall, the findings indicate that the rate of shared trips is a key factor in determining the impact of automated ridesharing services on emissions. With low willingness to share, the occupancy of the vehicle reduces, which will result in an increase in VKT due to the empty pickup trips. The present findings seem to be consistent with those of Lu et al. (2018) who suggest that the introduction of an autonomous taxi (aTaxi) system increases the GHG and SO_2 emissions by 16% and 25%, respectively, in scenarios where internal combustion engine aTaxis were used, and replacing these vehicles with electric aTaxis did not improve the environmental impact of this system.

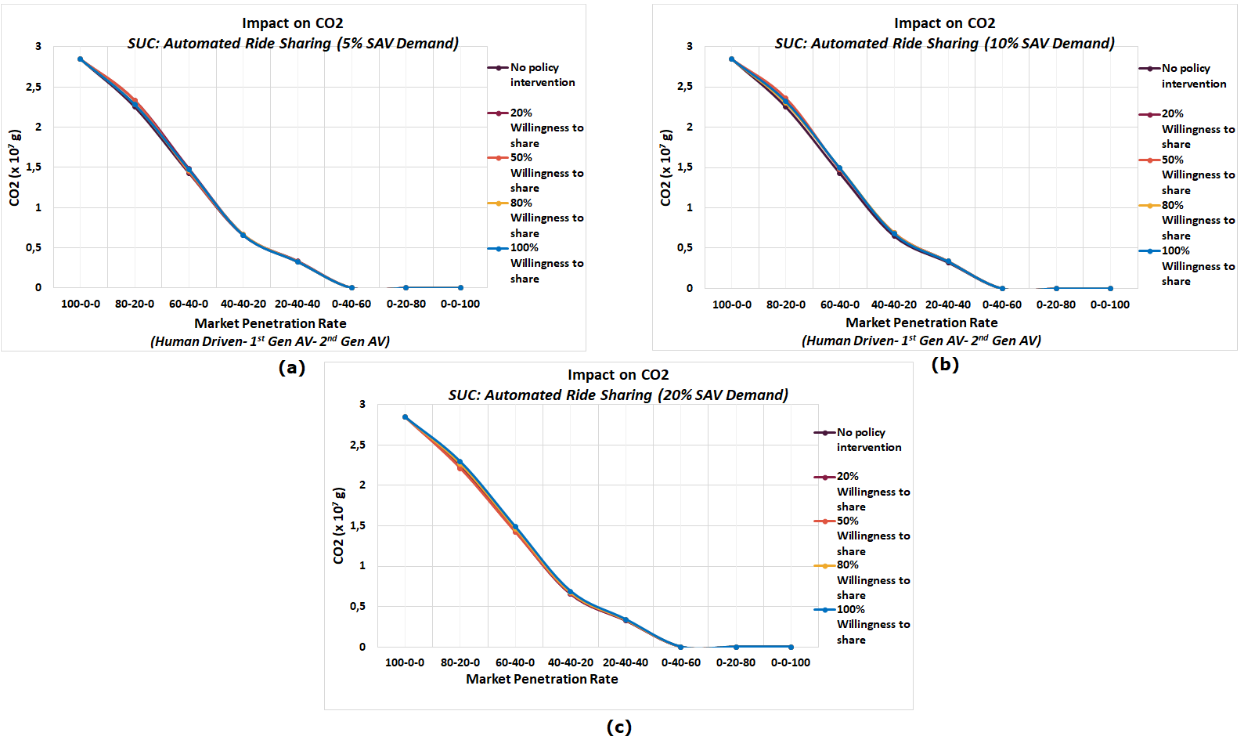
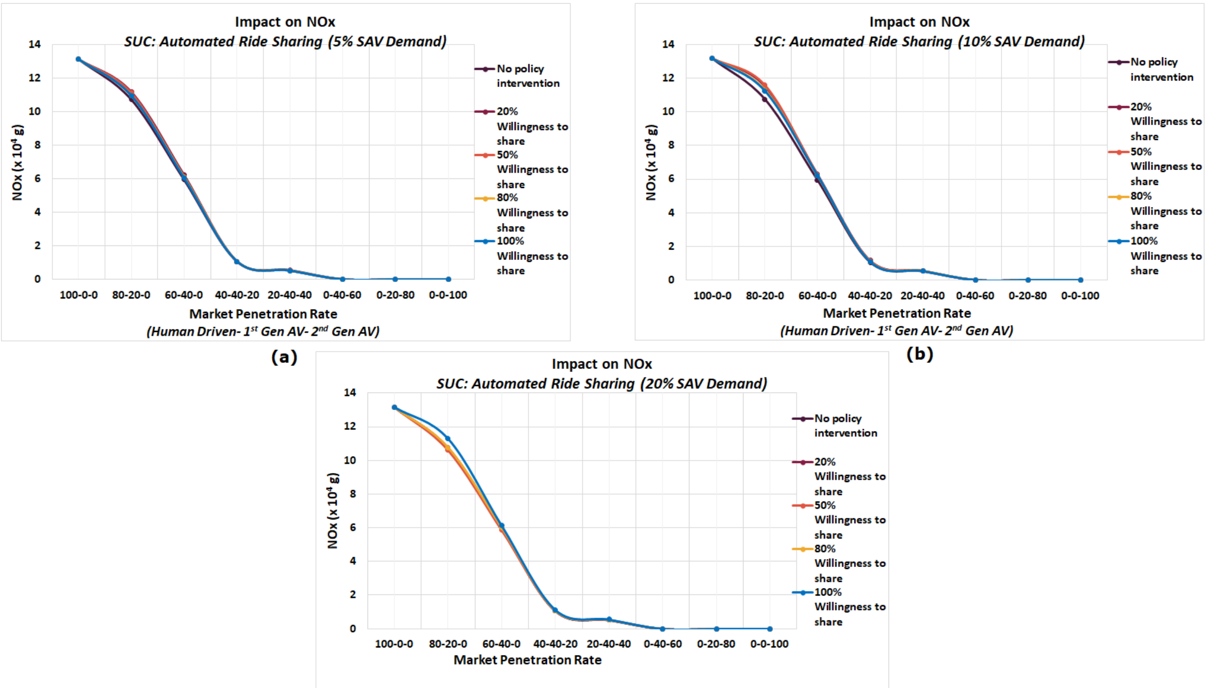
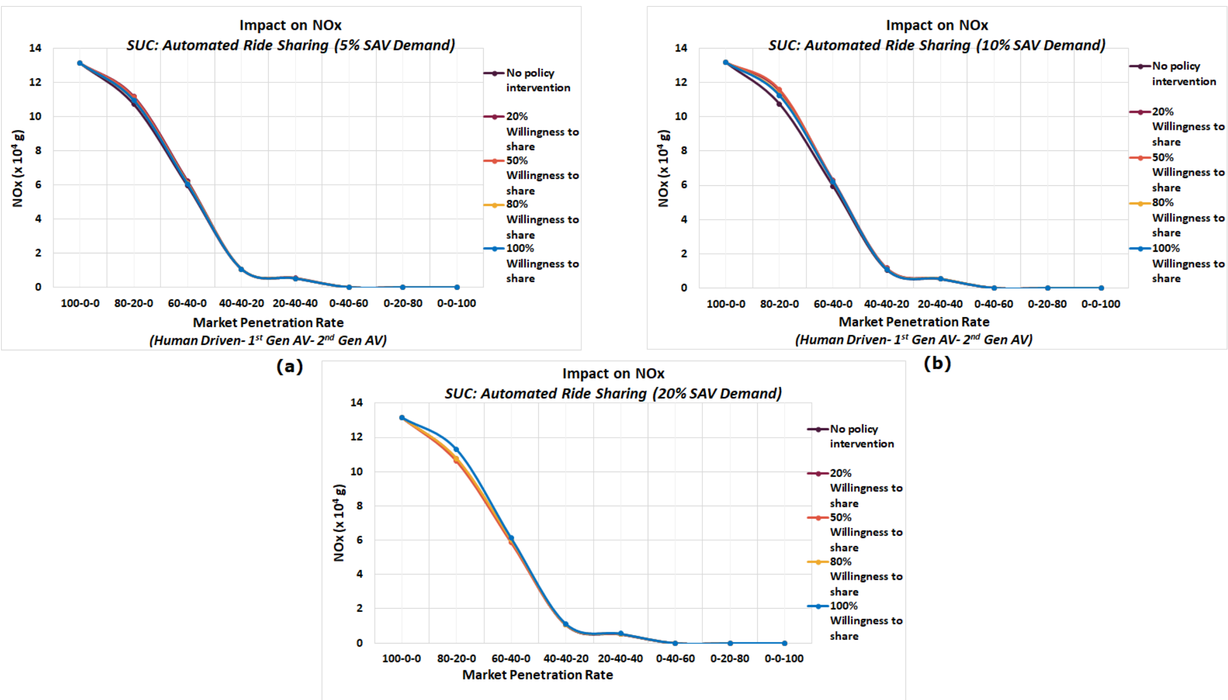


Figure 4.36: Impact on CO2 emissions due to of CAV and Automated Ride Sharing service



(c)

Figure 4.37: Impact on PM10 emissions due to MPR of CAVs and Automated Ride Sharing service



(c)

Figure 4.38: Impact on NOx emissions due to MPR of CAVs and Automated Ride Sharing service

Table 4.22: Percentage change in CO_2 Emissions with respect to intervention baseline for automated ride sharing service

MPR	5% SAV demand				10% SAV demand				20% SAV demand			
	20%*	50%*	80%*	100%*	20%*	50%*	80%*	100%*	20%*	50%*	80%*	100%*
80-20-0	3,7%	3,7%	1,5%	1,4%	3,2%	4,9%	2,1%	3,1%	-1,5%	-1,8%	0,6%	1,9%
60-40-0	3,8%	0,8%	2,3%	2,9%	3,9%	3,5%	4,5%	4,4%	-0,3%	-0,6%	2,4%	4,0%
40-40-20	1,5%	1,3%	1,5%	0,4%	5,5%	6,0%	5,4%	3,8%	-0,3%	1,4%	2,6%	5,3%
20-40-40	3,0%	1,1%	0,8%	0,3%	4,3%	3,6%	3,5%	3,1%	-0,2%	2,0%	2,3%	4,8%
(*)=willingness to share												

Table 4.23: Percentage change in NOx Emission with respect to intervention baseline for automated ride sharing service

MPR	5% SAV demand				10% SAV demand				20% SAV demand			
	20%*	50%*	80%*	100%*	20%*	50%*	80%*	100%*	20%*	50%*	80%*	100%*
80-20-0	4,3%	3,7%	2,2%	2,2%	7,1%	7,8%	5,1%	4,6%	-0,4%	-1,3%	0,3%	5,1%
60-40-0	4,7%	2,9%	2,8%	1,9%	5,5%	5,0%	4,2%	4,5%	-0,3%	-1,5%	1,2%	3,0%
40-40-20	2,1%	0,3%	1,4%	0,8%	8,8%	6,7%	3,7%	2,6%	0,5%	1,8%	2,3%	5,7%
20-40-40	5,1%	0,9%	2,4%	0,6%	4,4%	4,7%	4,4%	1,9%	1,9%	4,3%	3,4%	5,1%
(*)=willingness to share												

Table 4.24: Percentage change in PM10 Emissions with respect to intervention baseline for automated ride sharing service

MPR	5% SAV demand				10% SAV demand				20% SAV demand			
	20%*	50%*	80%*	100%*	20%*	50%*	80%*	100%*	20%*	50%*	80%*	100%*
80-20-0	3,3%	4,1%	0,4%	1,0%	-1,1%	2,4%	-1,9%	1,4%	-2,9%	-2,6%	0,1%	-0,5%
60-40-0	4,7%	-0,8%	2,7%	6,0%	1,6%	0,8%	5,0%	3,8%	1,1%	0,1%	3,6%	6,4%
40-40-20	-2,9%	0,1%	1,3%	-2,4%	-0,8%	1,5%	6,6%	5,9%	-5,5%	2,8%	2,2%	4,1%
20-40-40	-5,5%	-3,4%	-3,9%	-5,7%	-0,8%	-1,1%	0,7%	3,4%	-9,6%	-5,4%	-0,6%	4,2%
(*)=willingness to share												

4.4.5 Green light optimal speed advisory (GLOSA)

The impact of GLOSA system with increasing automation on emissions is presented through the following plots (Figure 4.39).

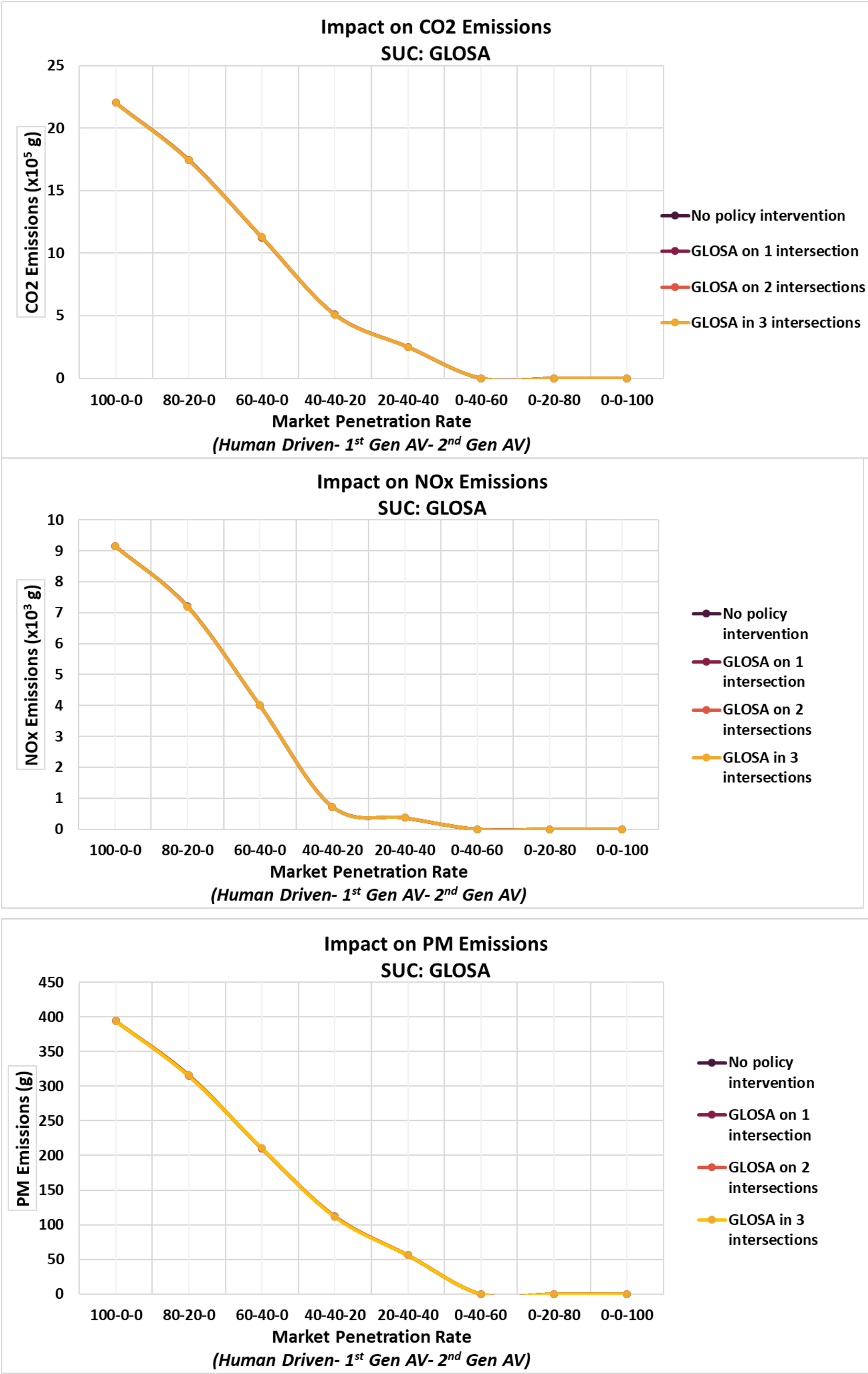


Figure 4.39: Impact on CO2, NOx, and PM10 emissions due to MPR of CAVs and GLOSA system

As only CAVs were considered as GLOSA equipped, the decrease in emissions is predominantly due to electrification considered for CAVs. Nonetheless, the changes in speeds and overall traffic flow could also potentially have an impact on the emission results under mixed fleet scenarios with human-driven vehicles. In order to determine this impact, the percentage change was calculated comparing the results of with and without GLOSA scenario, presented in Tables 4.25 to 4.27, which shows marginal reduction in emissions due to only having CAVs to be GLOSA equipped in the network.

Table 4.25: Percentage change in CO_2 emissions with regards to baseline intervention for GLOSA SUC

MPR	GLOSA on 1 intersection	GLOSA on 2 intersections	GLOSA in 3 intersections
80-20-0	0.01%	-0.23%	-0.16%
60-40-0	-0.07%	0.07%	0.10%
40-40-20	0.19%	0.01%	-0.20%
20-40-40	0.00%	0.21%	-0.06%

Table 4.26: Percentage change in NOx emissions with regards to Baseline intervention for GLOSA SUC

MPR	GLOSA on 1 intersection	GLOSA on 2 intersections	GLOSA in 3 intersections
80-20-0	0.03%	-0.13%	-0.09%
60-40-0	-0.04%	0.03%	0.05%
40-40-20	-0.02%	-0.21%	-0.38%
20-40-40	0.00%	0.00%	-0.11%

Table 4.27: Percentage change in PM10 emissions with regards to Baseline intervention for GLOSA SUC

MPR	GLOSA on 1 intersection	GLOSA on 2 intersections	GLOSA in 3 intersections
80-20-0	-0.02%	-0.35%	-0.25%
60-40-0	0.01%	0.10%	0.21%
40-40-20	0.33%	-0.09%	-0.39%
20-40-40	0.25%	0.55%	-0.04%

4.5 Public health

Public health (subjective rating of public health state, related to transport) is also an impact estimated using the Delphi method.

4.5.1 Road use pricing (RUP)

The general experts' opinion in the 1st round was that the baseline scenario will lead to an improvement (13,3%) of public health, which is compatible with the microsimulation results on emissions. Regarding the city toll scenarios, all curves present some oscillations depending on AVs market penetration rates. In the long term for 100% AVs market penetration rate, all scenarios will improve public health, which is also explained by their impact on energy efficiency (section 4.3.1) according to experts answers in 1st round. The introduction of static city tolls and empty km pricing will lead to the same impact in the long-term reaching an improvement of 10% on public health. Dynamic city toll will increase public health by 12,6% in the short term and 8% in the long term.

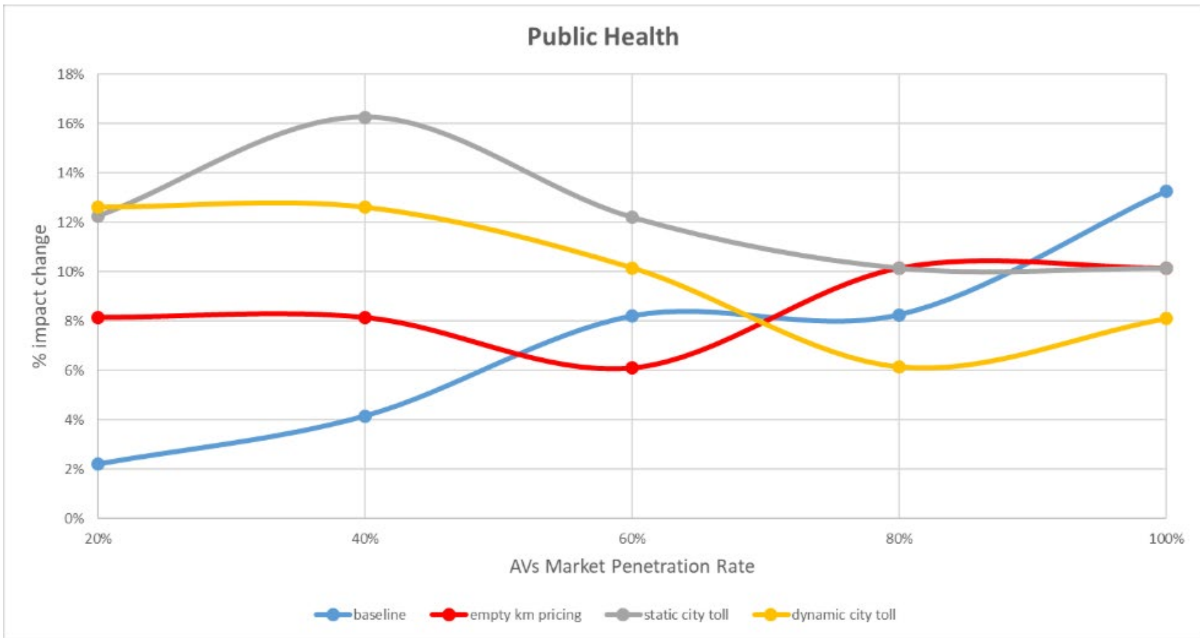


Figure 4.40: 1st round Delphi public health results for the city toll scenarios

In the 2nd Delphi round questionnaires, the majority of experts stated that they definitely (14%-28%) or moderately (43%-72%) agree with the resulted curves. Some experts slightly (14%) or not at all agreed (14%-29%) with the proposed trends and suggested that none of the studied scenarios will affect public health.

Figure 4.41: 2nd round Delphi public health results for baseline and empty km pricing

Table 4.28: Final PST coefficients for public health for the city toll scenarios

	Baseline		**Empty km pricing**		**Static toll**		**Dynamic toll**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	2,1%	1,021	7,7%	1,077	10,8%	1,108	11,1%	1,111
40%	3,8%	1,038	7,7%	1,077	14,3%	1,143	11,1%	1,111
60%	7,4%	1,074	5,7%	1,057	10,8%	1,108	9,0%	1,090
80%	7,4%	1,074	9,6%	1,096	9,0%	1,090	5,4%	1,054
100%	11,8%	1,118	9,6%	1,096	9,0%	1,090	7,1%	1,071

4.5.2 Provision of dedicated lanes on urban highways

The general experts' opinion in the 1st round was that the baseline scenario will lead to a deterioration (-11,2%) of public health, which is compatible with the scenario's effect on modal split using active travel according to experts. Regarding the AV dedicated lane scenarios, all curves present some oscillations depending on AVs market penetration rates. In the long term for 100% AVs market penetration rate, all scenarios will improve public health, which is also explained by their impact on energy efficiency (section 4.3.2) according to experts. The introduction of AV dedicated lane on the outermost motorway lane will mostly improve (10,7%) public health.

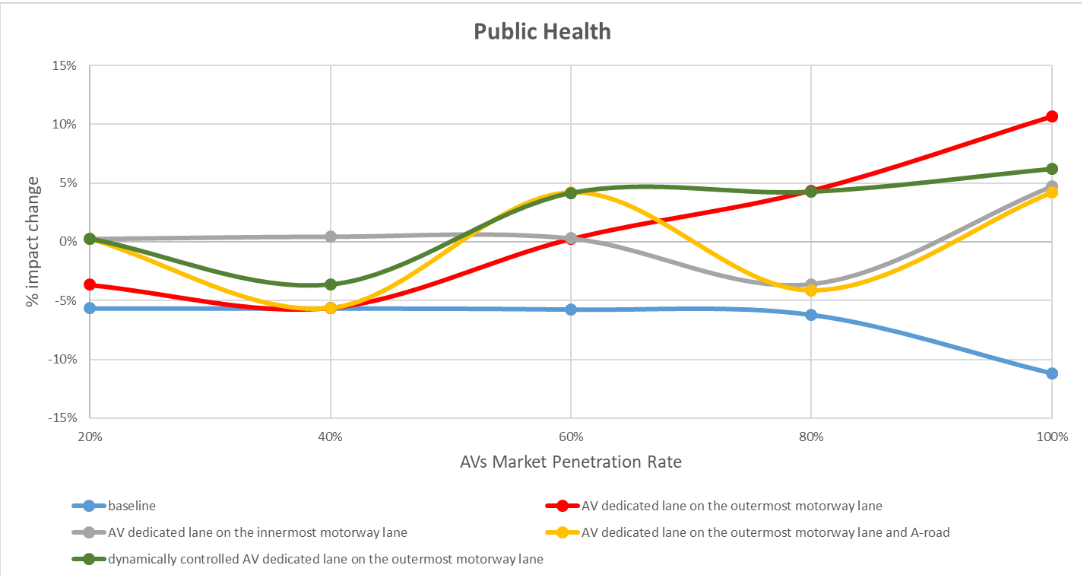


Figure 4.42: 1st round Delphi public health results for the AV dedicated lanes scenarios

In the 2nd Delphi round questionnaires, all experts stated that they definitely (33%) or moderately (67%) agree with the resulted curves for baseline scenario. Regarding the AV dedicated lanes scenarios, the majority (67%) of experts moderately agreed with the 1st round trends. Two experts (33%) do not at all agree with the proposed curves and suggested that all AV dedicated lane scenarios should present curves closer to the baseline scenario and negatively affect public health at an average percentage of -5%.

Figure 4.43: 2nd round Delphi public health results for baseline and dynamically controlled AV dedicated lane

Table 4.29 Final PST coefficients for public health for the AV dedicated lanes scenarios

	Baseline		**Outermost motorway lane**		**Innermost motorway lane**		**Outermost motorway lane and A-road**		**Dynamically controlled AV dedicated lane**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	-5,7%	0,944	-3,8%	0,962	-0,4%	0,996	-0,4%	0,996	-0,4%	0,996
40%	-5,7%	0,944	-5,5%	0,945	-0,2%	0,998	-5,6%	0,944	-3,8%	0,962
60%	-5,8%	0,943	-0,4%	0,996	-0,4%	0,996	3,1%	1,031	3,0%	1,030
80%	-6,2%	0,938	3,2%	1,032	-3,8%	0,962	-4,3%	0,957	3,1%	1,031
100%	-11,2%	0,888	8,7%	1,087	3,5%	1,035	3,1%	1,031	4,8%	1,048

4.5.3 Parking price policies

The general experts' opinion in the 1st round was that the baseline scenario will lead to a small improvement of public health, which is compatible with the reduced emissions resulted in microsimulations. More precisely, the improvement of public health due to the baseline scenario will reach a maximum of 8,9%, same as the improvement after the introduction of CAVs parking inside and parking outside for 100% AVs market penetration rate. CAVs returning to origin will not significantly affect the studied impact. On the other hand, CAVs driving around will reduce by 25% the quality of public health which is also explained by the scenario's effect on energy efficiency according to experts.

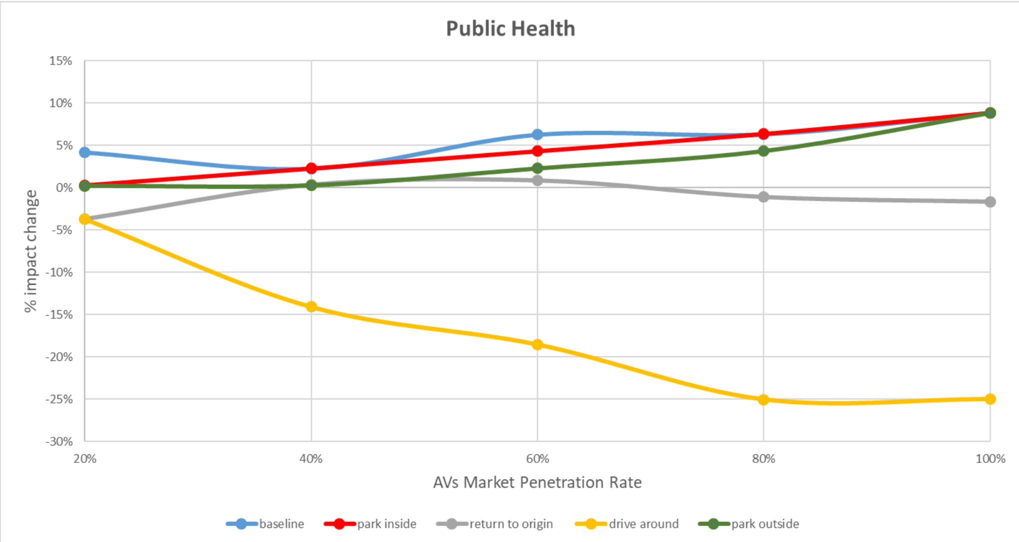


Figure 4.44: 1st round Delphi public health results for the CAV parking behaviour scenarios

In the 2nd round the majority of experts agreed definitely (50%) or moderately (33%) with the 1st round results. One expert suggested that all studied scenarios will negatively affect public health at a percentage of -5%.

Figure 4.45: 2nd round Delphi public health results for baseline and park inside scenarios

Table 4.30: Final PST coefficients for public health for the CAV parking behaviour scenarios

	Baseline		**Park inside**		**Return to origin**		**Drive around**		**Park outside**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	3,6%	1,036	-0,1%	0,999	-3,8%	0,962	-3,8%	0,962	-0,1%	0,999
40%	1,8%	1,018	1,8%	1,018	0,0%	1,000	-13,5%	0,865	-0,1%	0,999
60%	5,5%	1,055	3,7%	1,037	0,5%	1,005	-17,7%	0,823	1,8%	1,018
80%	5,6%	1,056	5,6%	1,056	-1,3%	0,987	-23,8%	0,762	3,7%	1,037
100%	8,0%	1,080	8,0%	1,080	-1,9%	0,981	-23,8%	0,763	7,9%	1,079

4.5.4 Parking space regulations

The general experts' opinion in the 1st round was that the baseline scenario will lead to a small improvement of public health, which is compatible with the reduced emissions resulted in microsimulations. More precisely, the baseline scenario will improve public health the least reaching a maximum of 10,3%. Replacing on-street parking space with space for public use will improve public health the most, according to 1st round answers, reaching 44,5% for 100% AVs market penetration rate, which is also explained by the increase of modal split using active travel (walking, cycling) presented in (section 4.4 in D6.3). Replacing on-street parking space with pick-up/drop-off parking space will lead to an increase of 12,9% in the long term. On the other hand, replacing on-street parking space with driving lanes will deteriorate public health leading to a decrease of 32,1% when AVs market penetration rate reaches 100%.

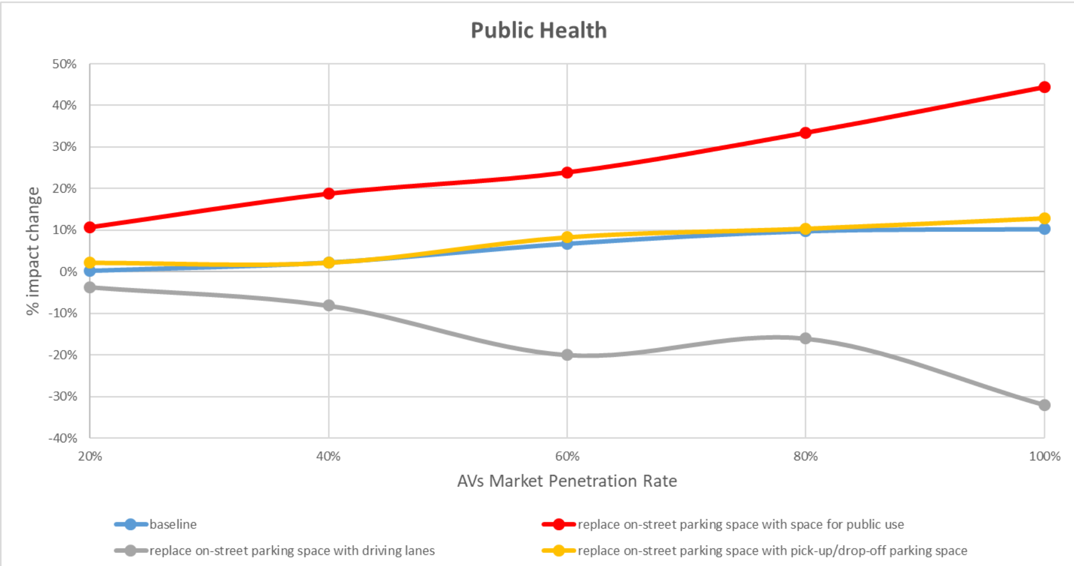


Figure 4.46: 1st round Delphi public health results for parking space regulation scenarios

In the 2nd round all the experts agreed definitely (60%-100%) or moderately (0%-40%) with the 1st round results.

Figure 4.47: 2nd round Delphi public health results for baseline and replacing on-street parking spaces with driving lanes

Table 4.31: Final PST coefficients for public health for parking space regulation scenarios

	Baseline		**Space for public use**		**Driving lanes**		**Pick-up/drop-off**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	0,3%	1,003	10,7%	1,107	-3,7%	0,963	2,2%	1,022
40%	2,3%	1,023	18,8%	1,188	-8,2%	0,919	2,2%	1,022
60%	6,8%	1,068	23,9%	1,239	-20,1%	0,800	8,3%	1,083
80%	9,8%	1,098	33,5%	1,335	-16,1%	0,839	10,4%	1,104
100%	10,3%	1,103	44,5%	1,445	-32,1%	0,679	12,9%	1,129

4.5.5 Automated Ride Sharing

The general experts' opinion in the 1st round was that the baseline scenario and automated ride sharing will lead to an improvement of public health reaching 9,7% and 11,7% respectively, which is compatible with the microsimulation results on emissions.

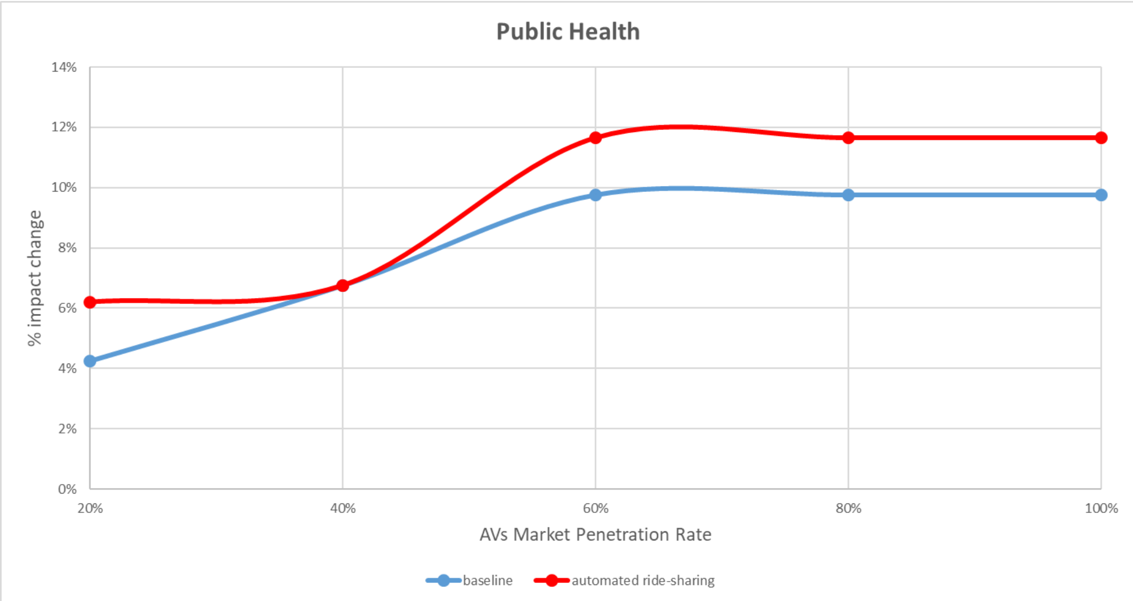


Figure 4.48: 1st round Delphi public health results for the automated ridesharing scenarios

In the 2nd Delphi round questionnaires, half of experts stated that they definitely or moderately agree with the resulted curves and half of them slightly or not at all agreed with the 1st round results, suggesting that the baseline scenario and automated ridesharing will in fact reduce public health by 15%.

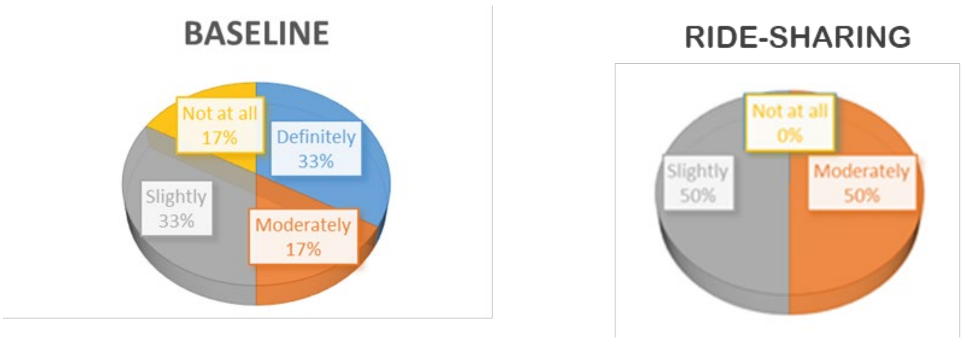


Figure 4.49: 2nd round Delphi for public health results for Baseline scenario

Table 4.32: Final PST coefficients for public health for the automated ridesharing scenarios

	Baseline		**Automated ridesharing**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	2,5%	1,025	4,4%	1,044
40%	4,5%	1,045	4,9%	1,049
60%	7,0%	1,070	8,8%	1,088
80%	7,0%	1,070	8,8%	1,088
100%	7,0%	1,070	8,8%	1,088

4.5.6 Green Light Optimal Speed Advisory (GLOSA)

The general experts' opinion in the 1st round was that the baseline scenario will lead to an improvement of public health reaching 9,7%, which is compatible with the microsimulation results on emissions. Regarding the GLOSA scenario, experts suggested that this scenario will not at all affect public health.

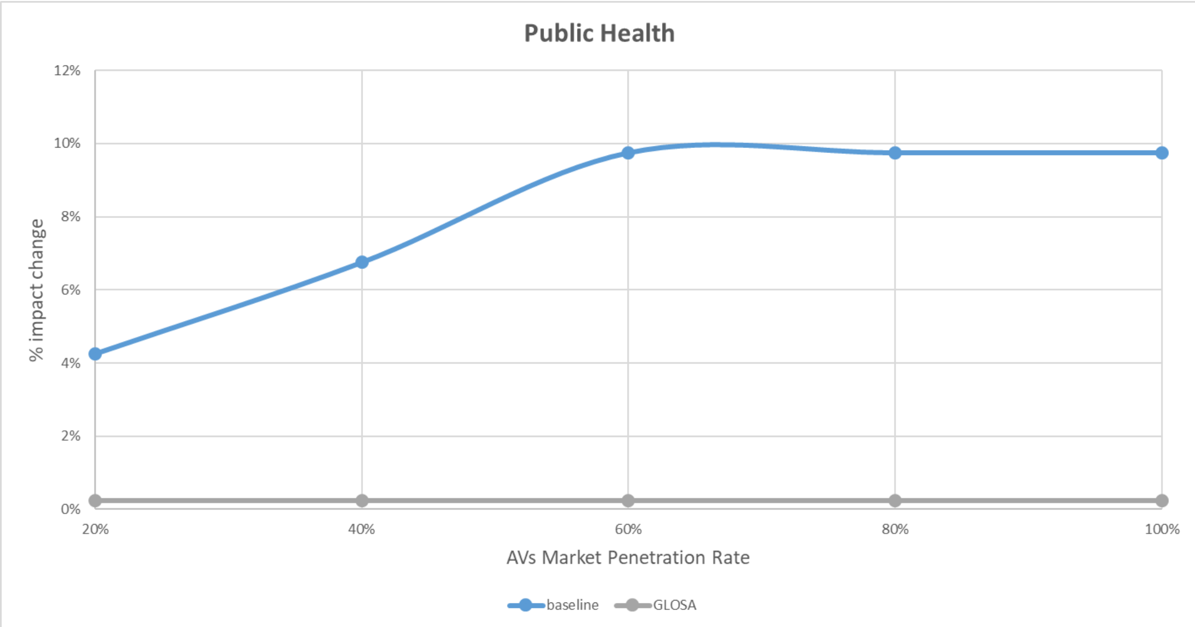


Figure 4.50: 1st round Delphi public health results for GLOSA scenarios

In the 2nd Delphi round questionnaires, half of experts stated that they definitely or moderately agree with the resulted curves and half of them slightly or not at all agreed with the 1st round results, suggesting that the baseline scenario will in fact reduce public health by 15%.

Figure 4.51: 2nd round Delphi public health results for baseline and GLOSA scenarios

Table 4.33: Final PST coefficients for public health for GLOSA scenarios

	Baseline		GLOSA	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	2,5%	1,025	0,2%	1,002
40%	4,5%	1,045	0,2%	1,002
60%	7,0%	1,070	0,2%	1,002
80%	7,0%	1,070	0,2%	1,002
100%	7,0%	1,070	0,2%	1,002

4.6 Accessibility in transport

The accessibility in transport is the degree to which transport services are used by socially disadvantaged and vulnerable groups including people with disabilities measured using a10 point Likert scale. This impact due to the automated passenger cars baseline scenario and various associated policy interventions (sub-use cases) was estimated by the Delphi method.

4.6.1 Road use pricing (RUP)

In the 1st round results, experts suggested that the baseline scenario, the introduction of AVs with no other intervention will improve accessibility in transport by 18,4% for 100% AVs market penetration rate. Regarding the city toll scenarios, will all negatively affect accessibility in transport. Static city toll presents the biggest variation leading in the short term to the maximal deterioration (-11,5%) of accessibility in transport among the other city toll scenarios, and in the long term in is the only city toll that reaches a 2% improvement on accessibility in transport. Empty km pricing and dynamic city toll both negatively affect accessibility in transport by -4% and 8% respectively.

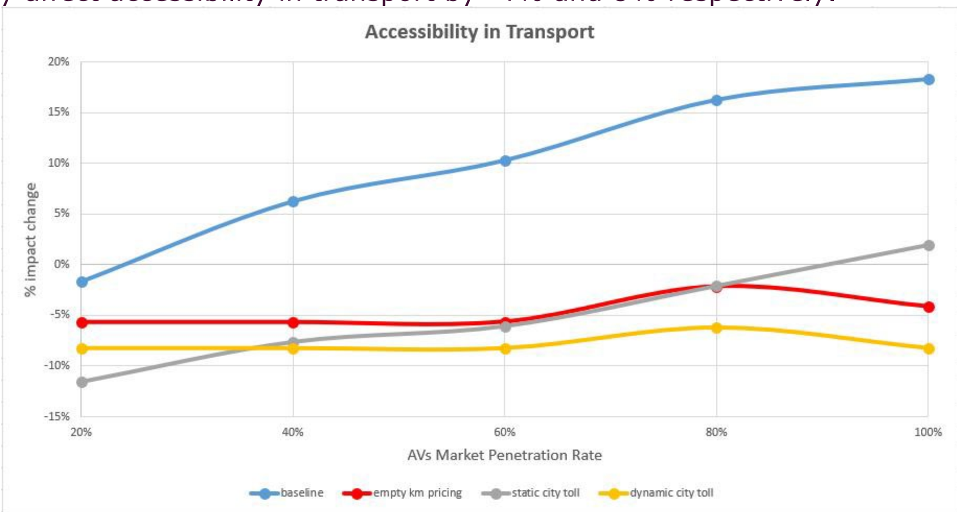


Figure 4.52: 1st round Delphi accessibility in transport results for the city toll scenarios

In the 2nd Delphi round questionnaires, the majority of experts (57%) slightly agreed with the resulted curves for all scenarios and suggested that all scenarios will increase accessibility in transport by 5%.

Figure 4.53: 2nd round Delphi accessibility in transport results baseline and empty km pricing

Table 4.34: Final PST coefficients for accessibility in transport for the city toll scenarios

	Baseline		**Empty km pricing**		**Static toll**		**Dynamic toll**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	-0,7%	0,993	-3,8%	0,962	-8,2%	0,918	-5,7%	0,943
40%	5,4%	1,054	-3,8%	0,962	-5,2%	0,948	-5,7%	0,943
60%	8,5%	1,085	-3,7%	0,963	-4,0%	0,960	-5,7%	0,943
80%	13,1%	1,131	-1,1%	0,989	-1,0%	0,990	-4,2%	0,958
100%	14,6%	1,146	-2,6%	0,974	2,0%	1,020	-5,7%	0,943

4.6.2 Provision of dedicated lanes on urban highways

In the 1st round results, experts suggested that the baseline scenario, the introduction of AVs with no other intervention will improve accessibility in transport by 6% for 100% AVs market penetration rate. Regarding the AV dedicated lane scenarios, their curves present some fluctuations depending on AVs market penetration rates. The scenario of AV dedicated lane on the outermost motorway lane will negatively affect accessibility in transport reaching a maximum reduction of 9,9% for 80% AVs market penetration rate. The dynamically controlled AV dedicated lane, and the AV dedicated lane on the outermost motorway lane and A-road will generally improve accessibility in transport reaching a maximum of 6,2% and 10,1% respectively for 60% AVs market penetration rate.

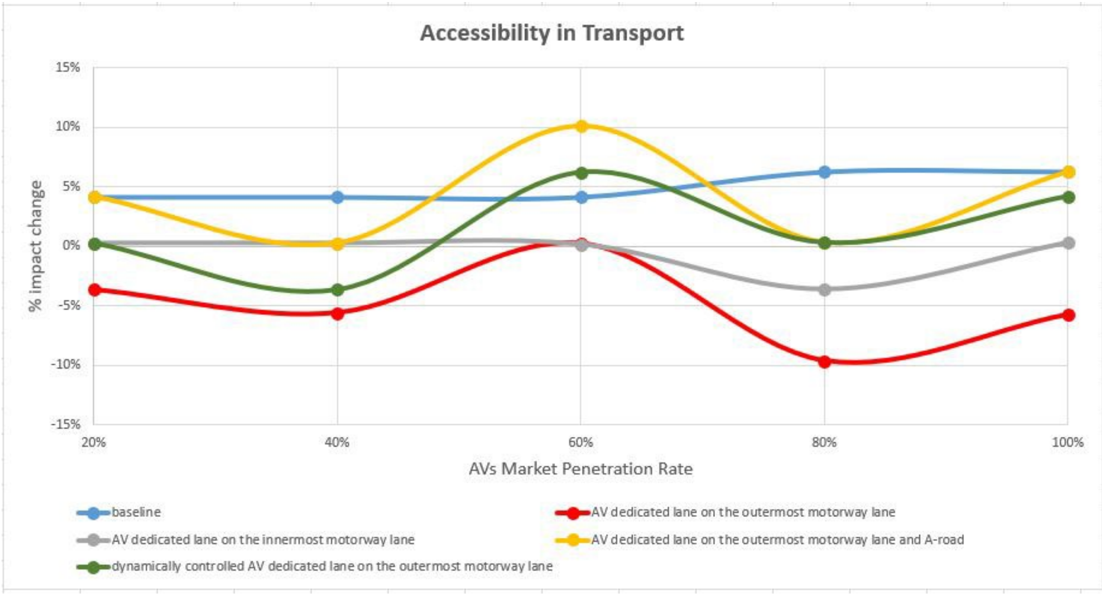


Figure 4.54: 1st round Delphi accessibility in transport results for the AV dedicated lanes scenarios

In the 2nd Delphi round questionnaires, all experts stated that they definitely (33%) or moderately (67%) agree with the resulted curves for baseline scenario. Regarding the AV dedicated lanes scenarios, the majority of experts moderately (67%) agreed with the 1st round trends. Two experts (33%) do not at all agree with the proposed curves and suggested that all AV dedicated lane scenarios should present curves closer to the baseline scenario with no fluctuations.

Figure 4.55: 2nd round Delphi accessibility in transport results baseline and AV dedicated lane on the outermost motorway lane

Table 4.35: Final PST coefficients for accessibility in transport for the AV dedicated lanes scenarios

	Baseline		**Outermost motorway lane**		**Innermost motorway lane**		**Outermost motorway lane and A-road**		**Dynamically controlled AV dedicated lane**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	4,2%	1,042	-3,2%	0,968	0,2%	1,002	3,6%	1,036	0,2%	1,002
40%	4,2%	1,042	-4,9%	0,951	0,2%	1,002	0,2%	1,002	-3,2%	0,968
60%	4,2%	1,042	0,2%	1,002	0,1%	1,001	8,8%	1,088	5,4%	1,054
80%	6,3%	1,063	-8,4%	0,916	-3,2%	0,969	0,3%	1,003	0,3%	1,003
100%	6,3%	1,063	-5,0%	0,950	0,3%	1,003	5,5%	1,055	3,7%	1,037

4.6.3 Parking price policies

In the 1st round results, experts suggested that the baseline scenario, the introduction of AVs with no other intervention will improve accessibility in transport by 26,5% for 100% AVs market penetration rate. The only CAVs parking behaviour that will significantly improve accessibility in transport, according to experts is returning to origin. On the other hand, CAVs driving around will negatively affect accessibility in transport, leading to an increase of 8,6% in the long term. CAVs parking outside will negatively affect accessibility in transport in the short term, but in the long term there is no significant impact. Similarly, CAVs parking inside will improve accessibility in transport in the short term but this impact is reduced with the increasing of AVs market penetration rate.

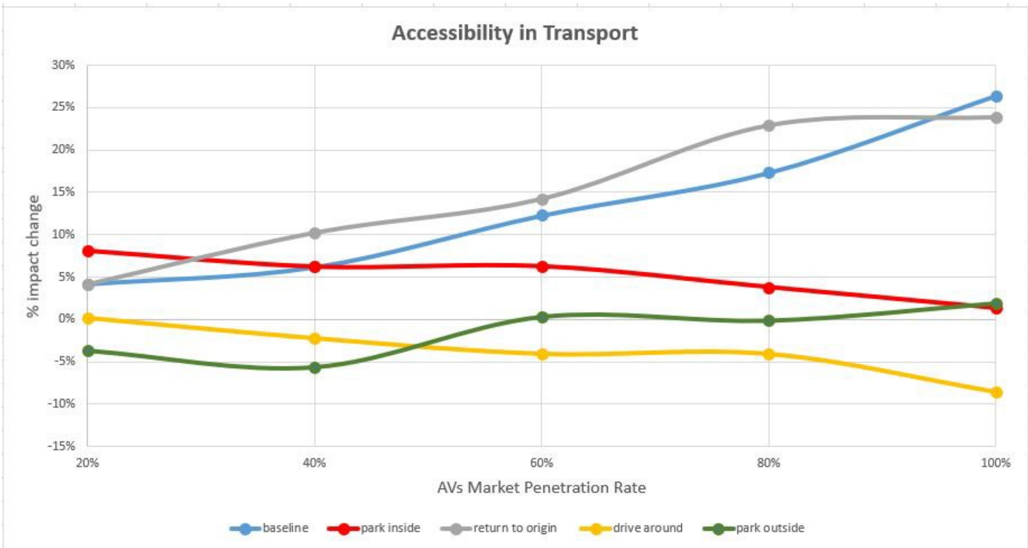


Figure 4.56: 1st round Delphi accessibility in transport results for the CAV parking price policies scenarios

In the 2nd round the majority of experts agreed definitely (50%) or moderately (33%) with the 1st round results. One expert suggested that none of the studied scenarios will affect accessibility in transport regardless of AVs market penetration rate.

Figure 4.57: 2nd round Delphi accessibility in transport results CAV parking inside and driving around scenarios

Table 4.36: Final PST coefficients for accessibility in transport for the CAV parking price policies scenarios

	Baseline		**Park inside**		**Return to origin**		**Drive around**		**Park outside**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	3,9%	1,039	7,6%	1,076	3,8%	1,038	0,2%	1,002	-3,5%	0,965
40%	5,8%	1,058	5,9%	1,059	9,6%	1,096	-2,1%	0,979	-5,3%	0,947
60%	11,5%	1,115	5,9%	1,059	13,3%	1,133	-3,8%	0,962	0,3%	1,003
80%	16,3%	1,163	3,6%	1,036	21,5%	1,215	-3,8%	0,962	-0,1%	0,999
100%	24,8%	1,248	1,2%	1,012	22,4%	1,224	-8,0%	0,920	1,8%	1,018

4.6.4 Parking space regulations

In the 1st round results experts suggested that replacing on-street parking space with driving lanes or with pick-up/drop-off parking space will both affect positively accessibility in transport reaching 20,9% and 9,8% respectively. The only parking regulation that will reduce accessibility in transport is replacing on-street parking space with space for public use reaching -13,1% for AVs market penetration rate of 100%. On the other hand, according to experts, the baseline scenario, the introduction of AVs with no other intervention will improve accessibility in transport by 12,4% for 100% AVs market penetration rate.

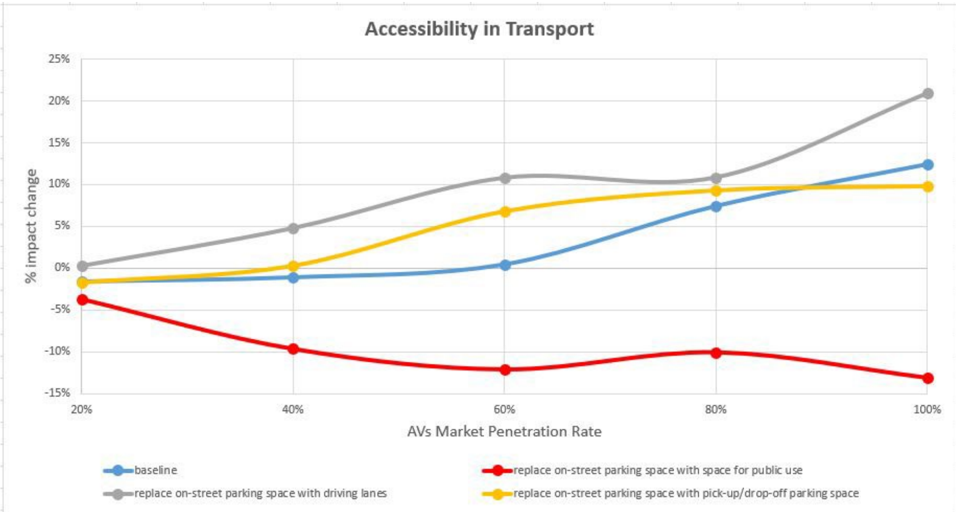


Figure 4.58: 1st round Delphi accessibility in transport results for parking space regulation scenarios

In the 2nd round all the experts agreed definitely (0%-60%) or moderately (40%-100%) with the 1st round results and made no further suggestions.

Figure 4.59 : 2nd round Delphi accessibility in transport results baseline and replacing on-street parking with spaces for public use

Table 4.37: Final PST coefficients for accessibility in transport for parking space regulation scenarios

	Baseline		**Space for public use**		**Driving lanes**		**Pick-up/drop-off**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	-1,3%	0,987	-3,7%	0,963	0,3%	1,003	-1,7%	0,983
40%	-0,8%	0,992	-9,7%	0,904	4,8%	1,048	0,3%	1,003
60%	0,7%	1,007	-12,1%	0,879	10,8%	1,108	6,8%	1,068
80%	7,7%	1,077	-10,1%	0,900	10,9%	1,109	9,3%	1,093
100%	12,7%	1,127	-13,1%	0,869	20,9%	1,209	9,8%	1,098

4.6.5 Automated ride sharing

The general experts' opinion was that the introduction of AVs in the urban environment will progressively improve (19,8%) accessibility in transport. The introduction of automated ridesharing will also improve the studied impact by 10% to 21,8% depending on AVs market penetration rate.

Figure 4.60: 1st round Delphi accessibility in transport results for the automated ridesharing

In the 2nd Delphi round questionnaires, half of experts stated that they moderately agree with the resulted curves and half of them slightly or not at all agreed with the 1st round results, suggesting that the baseline scenario and automated ridesharing impact on accessibility in transport was overestimated and proposed an average improvement of 5%-10%.

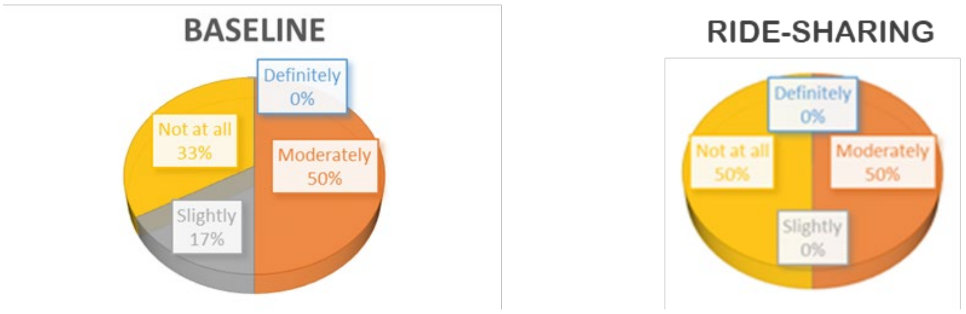


Figure 4.61: 2nd round Delphi accessibility in transport results baseline scenario (automated ridesharing)

Table 4.38: Final PST coefficients for accessibility in transport for the automated ridesharing

	Baseline		Automated ridesharing	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	9,1%	1,091	9,1%	1,091
40%	9,1%	1,091	13,7%	1,137
60%	12,9%	1,129	18,6%	1,186
80%	18,7%	1,187	17,1%	1,171
100%	17,1%	1,171	13,8%	1,138

4.6.6 Green light optimal speed advisory (GLOSA)

The general experts' opinion was that the introduction of AVs in the urban environment will progressively improve (19,8%) accessibility in transport. Regarding the GLOSA scenario, experts proposed a general increase (6,1%) of the studied impact regardless of the AVs market penetration rate.

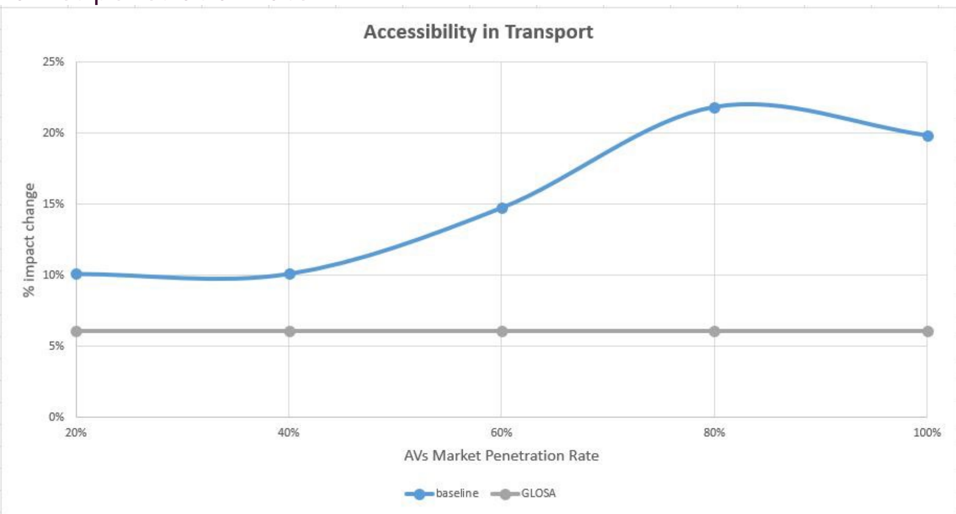


Figure 4.62: 1st round Delphi inequality in transport results for GLOSA scenarios

In the 2nd Delphi round questionnaires, half of experts stated that they moderately agree with the resulted curves and half of them slightly or not at all agreed with the 1st round results, suggesting that the baseline scenario impact on accessibility in transport was overestimated and proposed an average improvement of 5%-10%. Regarding GLOSA experts stated that this intervention will not at all affect the studied impact.

Figure 4.63: 2nd round Delphi accessibility in transport results for the baseline and GLOSA scenarios

Table 4.39: Final PST coefficients for accessibility in transport for the automated ridesharing and GLOSA scenarios

	Baseline		**GLOSA**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	9,1%	1,091	5,0%	1,050
40%	9,1%	1,091	5,0%	1,050
60%	12,9%	1,129	5,0%	1,050
80%	18,7%	1,187	5,0%	1,050
100%	17,1%	1,171	5,0%	1,050

4.7 Commuting distances

The impact of different policy interventions included in this deliverable on commuting distances was determined through system dynamics model explained under section 3.2. The results are presented in the following Figure 4.64. Since the average commuting distance is influenced by many parameters which are not part of the SD model, the figure shows the relative commuting distance - the fraction relative to "no-automation" scenario. (A value of 1.01 indicates an increase of 1% compared to the “no-automation” case.)

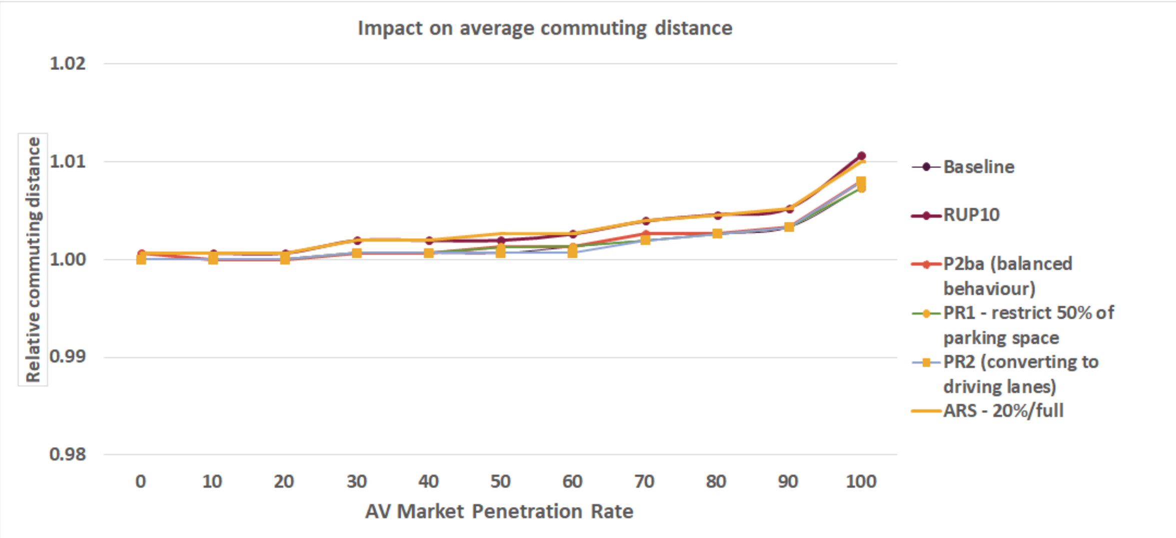


Figure 4.64: Impact of various policy interventions on average commuting distance (RUP=road use pricing, P2ba=Parking behaviours under balanced scenario, PR1=remove 50% on-street parking spaces, PR2=replacing on-street parking with driving lane, ARS-20% full= Automated ride sharing with 20% demand and 100% willingness to share)

Overall, there is a slight increase in commuting distance with increasing automation under baseline and with the implementation of each policy intervention, reaching maximum value at full penetration of CAVs.

The model results also show larger commuting distances with the implementation of road use pricing. Even if this might seem surprising, it can be explained in the model due to the fact that also inner-city residents would be subject to road use pricing and might therefore decide to relocate to outer zones (which might not happen in reality if they are exempted). And while road use pricing would not help to reduce the commuting distances, it would definitely support a switch to other (non-car) modes as shown in D6.3 (Sha et al., 2021).

Under automated ride sharing services, considering 20% demand and 100% willingness to share, the results indicate maximum increase in commuting distances as compared to the baseline and due to other interventions. This is explainable as such service would provide access and serve customers anywhere to anywhere. In addition, the option to share a ride with others would add to the total distance travelled.

Replacing on-street parking with driving lanes would encourage a greater number of vehicles and potentially increase distance travelled, however, results do not indicate much change in commuting distances due to this policy measure. A similar trend was found under removing 50% of the on-street parking scenario. With regard to parking behaviours or parking pricing policy, balanced scenario, which was found to be the most suitable strategy (see D 6.2) with respect to its impacts on traffic performance, was analysed in SD. There was marginal difference in commuting distances with comparison to the baseline, as reflected through Figure 4.64.

5 Discussion

The long-term or wider impacts due to CCAM were analysed through different methods including microsimulation, system dynamics, and Delphi method. The wider impacts included demand for parking spaces, road safety, energy efficiency, emissions, public health, inequality in transport, and commuting distances. In microsimulation, CAVs were modelled through defining their behaviours based on existing knowledge available in literature on early level automated vehicles. The impacts analysed through microsimulation included emissions and safety. System dynamics modelling approach was used to forecast demand for public parking spaces and commuting distances. Impacts on energy efficiency, public health, and transport inequality were envisaged through Delphi study.

The impacts were analysed under baseline/no policy intervention scenario (with increasing MPR of CAVs only) and with implementation of several key policy interventions, which were identified by previous literature and through discussions with various city and industry officials. The findings on the impacts are summarised as follows.

Demand for parking

System dynamic model results indicated an increase in demand for parking with increasing MPR in the baseline scenario, reaching more than 40% at full fleet penetration, due to the increased share of private cars. However, with some disagreements, majority of experts' opinion in this regard (through the Delphi study) indicated the reduction in parking demand in urban environment with increasing MPR of AVs, which might be explained by implicit consideration of effects like empty AVs driving around or increased shared mobility.

Implementation of parking space regulations involving 50% on-street parking removal would likely have negative impact on automobile travel and lower the demand for parking as compared to the baseline condition. On the other hand, the policy intervention of conversion to driving lanes would likely lead to an increased travel demand (as compared to 50% parking space removal) due to encouraging additional vehicles on road. In comparison with baseline, the increase in parking demand will potentially occur with increased automation (at least 50% or above). General experts' opinion in this regard indicated that the introduction of parking regulations will progressively reduce parking spaces required.

Under parking pricing, policies causing balanced parking behaviours were analysed as it was found to be most suitable strategy through microsimulation analysis presented in D 6.2. As expected, this policy intervention is estimated to significantly reduce demand for parking as compared to the baseline with the relative demand for parking space staying constantly slightly above 20% with increasing MPR. Majority of experts' opinion in this regard also suggested that the CAVs parking behaviour would reduce the requirement of parking spaces. CAVs parking inside the city centre would decrease the parking demand up to 40%. The requirement of parking spaces for CAVs returning to origin, driving around and parking outside scenarios will be reduced by 19.7%, 36.2% and 12.2% respectively for 100% AVs market penetration rate.

The road use pricing policy implementation was estimated to significantly reduce the demand for parking space. Delphi study results also indicated the same effect with road use pricing strategies while empty km pricing was predicted to cause the maximum reduction in the long-term reaching up to 11%.

Majority of the experts predicted reduction in parking demand with inclusion of services like automated ridesharing, almost by 25% as found through the Delphi study. However, system dynamics modelling results indicated almost no change in parking demand as compared to the baseline, considering 20% share of total demand and 100% willingness to share. Intuitively, more demand served by SAVs would reduce the number of personal vehicles cars on the road. However, due to pick-ups, drop-offs, and waiting for passengers, the requirement for parking spaces may not significantly reduce.

Energy efficiency

The impact on energy efficiency within LEVITATE project refers to energy consumption of vehicles during operation only, and not related to their manufacturing and disposal. The impact on energy efficiency due to increasing CAVs in the transport systems as well as with various policy measures was estimated through Delphi panel study.

Overall experts predict improvement in energy efficiency with the increment in market penetration of CAVs (baseline).

All road using pricing schemes were predicted to improve the energy efficiency. More specifically, it was indicated through the Delphi results that the increase in energy efficiency could be maximum with dynamic city toll up to 15%, while static city toll can potentially increase energy efficiency by almost 11% in the short term and 7% in the long term. The increase with empty km pricing was predicted to be up to 10%.

The Delphi study findings on the impact of AV dedicated lanes on energy efficiency indicated no impact to slight reduction in the short term (under different placement scenarios) but an increase can be expected in the long term only for AVs market penetration rate higher than 60%, leading to a maximal increase of 6%. Under various configurations, the innermost motorway lane was indicated to improve energy efficiency the most leading to an increase by almost 11%.

Under the given on-street parking replacement options, most of the experts indicated that replacing on-street parking space with space for public will improve energy efficiency the most i.e., by almost 13%. However, replacement of on-street parking space with driving lanes or with pick-up/drop-off spaces will both negatively affect energy efficiency.

With regard to parking price policies, majority of the responses gathered through the Delphi study indicated improvement in energy efficiency with various tested parking price policies except the drive around strategy. The expectation on the improvement was indicated to be 29% for 'park inside' (the city centre), 16% for 'return to origin', and 14% for 'park outside' scenario at 100% MPR of CAVs. On the other hand, CAVs driving around will potentially have a negative impact on the energy efficiency, reducing it by almost 14%.

Automated ride sharing services are also expected to strongly impact energy efficiency potentially improving it by almost 22%.

Most of the experts predicted largest impact on energy efficiency due to implementation of GLOSA, with an expected increase of almost by 31%.

Emissions

Microsimulation results showed significant reduction in emissions with CAVs MPR primarily due to electrification considered in the models for CAVs. However, the impact of various interventions tested was also analysed by determining the percentage difference with intervention vs. no intervention (baseline) case under mixed fleet scenarios with human driven vehicles.

The dedicated CAV lane configurations tested on A-level road and motorway within the Manchester network exhibited reductions in emissions on average; however, the percentage reduction exhibited fluctuations (no consistent pattern) across different placement strategies and MPR scenarios. Percentage reduction in PM emissions was found to be more than CO_2 and NOx emissions.

Under parking price policies, it was found that parking strategies can strongly influence the vehicular emissions especially PM proportions. Surprisingly, the microsimulation results showed maximum reduction in overall emissions under ''Drive around'' parking behaviour as compared to ''return to origin and park outside'' and ''balanced'' parking behaviours scenarios. However, the major reduction of emissions in drive around case is attributable to the reduced traffic flow and lesser number of vehicles in the network within analysis (simulation) duration. The balanced option in this regard was found to be the optimal one as compared to others.

Parking space regulations results from microsimulation showed that the emission for all three indicators CO_2, NOx and PM reduce dramatically as the CAV fleet penetration level increases. This is mainly because of electric powertrain considered for all CAVs within the project. However, if CAVs were considered non-electric, their characteristics leading to more uniform speed and less stop and go situations could potentially contribute in reducing emissions. The interventions of replacing on-street parking with driving lane, cycle lane and public spaces have shown a better performance in reducing the CO_2, NOx, and PM emissions compared to those interventions of removing half of the on-street parking spaces and replacing them with pick-up/drop-off spaces. This is potentially due to the reason that pick-up/drop-off manoeuvres may generate queue build-up on the road, while vehicles pick up or drop off passengers leading to increased stop and go situations and emissions. The introduction of automated ride sharing services in the study network showed increase in emissions under mixed fleet scenarios. Rate of shared trips was found to be crucial factor in this regard as empty VKT could increase due to empty pick-up trips resulting from low willingness to share.

Literature has indicated promising benefits of GLOSA application on environment. Within LEVITATE, since electrification of CAVs was considered, mainly the reduction in emissions with increasing MPR is attributable to this assumption. Additionally, under GLOSA sub-use case, due to only considering CAVs to be GLOSA equipped, impact of the system on emissions cannot be directly determined. in terms of seeing how GLOSA equipped vehicles caused the changes in network flow which in-turn can have an effect on emissions, marginal reduction was found in the results.

Road Safety

Safety is affected in various ways by increasing MPR levels of CAVs and the specific sub-use cases that are investigated in this WP. The impacts on car-car/truck crashes are estimated using micro-simulation in combination with the Surrogate Safety Assessment Model (SSAM). For all sub-use cases, the baseline scenario, i.e., increasing MPR of CAVs without an additional policy intervention being implemented, results in a decrease in car-car crashes. The magnitude of the decrease, however, differs between sub-use cases. Fatalities among vulnerable road users in crashes with cars are expected to decrease by more than 90% in case of a MPR of CAVs of 100%.

Dedicated lanes are expected to increase the number of crashes per km travelled compared to the baseline scenario (no dedicated lane) at low and high MPR levels. This can be explained by high traffic volumes in respectively lanes for non-automated vehicles and lanes for automated vehicles. When the vehicle fleets are more equally split, a small benefit can be seen of dedicated lanes when implemented on A-level roads.

The sub-use case focusing on parking price and parking behaviour shows that crash rates might increase at lower MPRs, with 20-40% of the vehicle fleet being automated. This is primarily due to interactions between human-driven vehicles and automated vehicles, which are expected to have different driving styles and capabilities. This increased risk due to mixed traffic is particularly visible in the "drive-around" scenario, where the automated vehicles cause additional congestion on the road—and therefore, additional opportunities for conflicts.

According to the results of the microsimulation, removing or replacing on street parking by other facilities does not seem to have an additional impact on the crash rate of car-car crashes compared to the baseline scenario in which parking spaces are not removed. The replacement of on-street parking with cycling lanes or public space can be expected to have an impact on VRU accident numbers. The replacement of pick-up and drop-off points could affect pedestrian safety, via unexpected interactions between pedestrians and cyclists or cars.

Automated ride sharing is expected to slightly increase crash rates of car-car crashes compared to the baseline scenario, although the differences are small and appear to show some random variation. Neither the percentage of demand served nor the willingness of passengers to share trips show a clear relationship with the crash rate.

The surrogate safety assessment of GLOSA system showed improvement in safety (lower crash rate) with the GLOSA implementation at multiple intersections in the test network, particularly at low CAV MPR scenarios, as compared to baseline scenario (without GLOSA) and single intersection implementation.

Public health

Public health was associated with the changes in active travel, and impact on environment through energy consumption and emissions indicators, Majority of experts opinion showed positive expectation on public health due to increasing AVs in baseline scenario. However, some responses indicated a potential deterioration (almost by 11%) of public health, which is compatible with the scenario's effect on modal split using active travel according to experts.

Regarding the AV dedicated lane scenarios, all prediction curves presented some oscillations depending on AVs market penetration rates. In the long term for 100% AVs market penetration rate, all scenarios will improve public health, which is also explained by their impact on energy efficiency according to experts.

Regarding parking space regulations, as expected, the Delphi results indicated that replacing on-street parking space with public spaces will improve public health the most. On the other hand, replacing on-street parking space with driving lanes will deteriorate public health.

A significant decline in public health was foreseen by majority of the experts under 'drive around' scenario due to parking price, reaching up to 25% in long term which can be explained by its impact on energy efficiency. Whereas 'park inside' and 'park outside' scenarios were predicted by most of the experts to improve public health in long-term reaching up to 9%. 'Return to origin' scenario was indicated to have no effect on public health.

Automated ride sharing services are expected to improve public health by almost 12% at full fleet penetration of AVs. This can be expected with increasing willingness to share the ride, leading to reduction in number of personal vehicles on road, which in turn will decrease emissions. It is important to note that such services could negatively impact active travel, as indicated by the SD results in D 6.3 (Sha et al., 2021).

Regarding the impacts of GLOSA system, overall, majority of the experts indicated no effect at all on public health.

Accessibility in transport

This impact refers to equality in access to transport and was assessed through determining the degree to which transport services are used by socially disadvantaged and vulnerable groups including people with disabilities (10 points Likert scale). In order to foresee the potential impacts of CCAM on equality in access to transport, opinion was collected from various experts who participated in the Delphi study.

Majority of the responses from experts in the Delphi study suggested that the baseline scenario, the introduction of AVs with no other intervention will improve accessibility in transport. However, the expectation on degree of improvement varied from 6 to 20%.

All city tolling schemes can be expected to negatively impact accessibility in transport while majority of the experts predicted maximum impact with static city toll strategy.

Regarding the AV dedicated lane scenarios, the results present some fluctuations depending on AVs market penetration rates. The scenario of AV dedicated lane on the outermost motorway lane will negatively affect accessibility in transport reaching a maximum reduction of almost 10% for 80% AVs market penetration rate. It was estimated that under the schemes of dynamically controlled AV dedicated lane, and the AV dedicated lane on the outermost motorway lane and A-road, the accessibility to transport will generally improve by almost 6% and 10% respectively, at 60% AVs market penetration rate. In the second round, majority of the experts moderately agreed with these results.

Experts indicated that replacing on-street parking space with driving lanes or with pick-up/drop-off spaces will both positively affect accessibility in transport. Replacing on-street parking space with public spaces will reduce accessibility in transport.

Under parking price policies, experts predicted improvement in accessibility in transport under 'return to origin' parking scenario. However, in all other scenarios a negative impact of parking price policies was observed. The worst impact was foreseen in 'drive around' scenario, with a decrease of around 10%.

In this regard, the experts' opinion on automated ride sharing services was that it will improve the equality in access to transport almost from 10 to 22%.

Due to implementation of GLOSA system, some experts indicated a general increase in accessibility while half of the participants in the second round showed disagreement and indicated no effect at all due to GLOSA application.

Commuting distances

Overall, only a small increase in commuting distance was estimated, through the SD model, with increasing automation under baseline scenario and with implementation of each policy intervention studies in this deliverable, reaching maximum value at full penetration of CAVs.

Maximum impact on commuting distances was estimated to be with the inclusion of automated ride sharing services with higher demand and willingness to share (20% demand and 100% willingness to share), as compared to the baseline scenario. This can be expected as such service would provide access and serve customers anywhere to anywhere. In addition, the option to share a ride with others would add to the total distance travelled.

The results indicated that replacing on-street parking with driving lanes would encourage a greater number of vehicles on roads and potentially increase distance travelled, however, results do not indicate much change in commuting distances due to this policy measure. A similar trend was found under removing 50% of the on-street parking spaces. With parking price policies creating balanced parking behaviours, there was marginal difference in commuting distances with comparison to the baseline.

SD model estimates on road use pricing implementation indicated increase in commuting distances due to the fact that inner city residents would be subject to road use pricing and might therefore decide to relocate to outer zones.

6 Conclusions and future work

At present, there is no real-world data available on fully automated vehicles performance, and we need better knowledge of their behaviours. There are also challenges involved in testing fully automated vehicles under real-world traffic conditions. However, existing available knowledge can be used for enhanced understanding on the large-scale and wider level implications of CCAM technologies.

In this regard, within LEVITATE, an extensive literature review was performed based on theoretical, simulation based, and experimental studies on early level automated vehicles while also have made several necessary assumptions in the models. Results should be examined and evaluated also according to the assumptions used.

6.1 Conclusions

Based on the analysis and discussions provided under section 4 and 5, respectively, some conclusions can be formulated as follows.

- Overall, under baseline scenario (increasing MPR of CAVs only), the results from different methods including microsimulation, Delphi and system dynamics, identify several positive and negative impacts in the long-term i.e., at 100% CAVs market penetration. The positive impacts are identified on safety, emissions, energy efficiency, and accessibility in transport. In contrast, demand for parking and public health can be negatively impacted with increasing parking demand and deterioration of health due to reduced active travel.
- No significant change was found on commuting distances with increasing automation and with the policies analysed in this deliverable.
- Parking space regulation and parking pricing related policies/strategies can have some adverse impacts on demand for parking. Replacing on-street parking with driving lanes would encourage more vehicles on road adding to parking demand while potentially reduce active travel and impact public health. Parking price policies involving a balance of different parking strategies can significantly reduce demand for parking as compared to the baseline condition. Implementation of road use pricing can also significantly reduce demand for parking.
- Since all CAVs were considered as electric vehicles while human driven vehicles had combustion engines there was significant reduction in emission results. However, within the mixed fleet scenarios, variations were also observed across different parking strategies. Emissions can also be strongly impacted due to the parking space regulations and price policies. Replacing on-street parking with driving lane, cycle lane and public spaces have shown a better performance in reducing the CO2, NOx, and PM emissions compared to removing half of the on-street parking spaces and replacing them with pick-up/drop-off spaces.

- Road safety is affected in various ways by increasing MPR levels of CAVs and the specific sub-use cases (SUCs) that are investigated in this WP. Microsimulation in combination with the Surrogate Safety Assessment Model (SSAM) shows that crash rates of car-car crashes decrease with increasing MPR of CAVs. However, it should be noted that for some SUCs crash rates slightly increase at lower MPRs (20%-40%). This could be due to the network characteristics and complexity in of interactions between human-driven vehicles and automated vehicles. Moreover, fatalities among vulnerable road users in crashes with cars are expected to decrease by more than 90% in case of a MPR of CAVs of 100%.

- The additional impacts of the SUCs that are investigated in this WP are in general small compared to the impact of increasing MPRs. Dedicated lanes are expected to increase the number of crashes per km travelled compared to the baseline scenario (no dedicated lane) at low and high MPR levels. When the vehicle fleets are more equally split, a small benefit can be seen of dedicated lanes when implemented on A-level roads. For the parking price SUC, the 'drive-around' scenario shows the strongest increased risk due to mixed traffic. According to the results of the microsimulation, removing or replacing on street parking by other facilities does not seem to have an additional impact on the crash rate of car-car crashes compared to the baseline scenario, yet some scenarios can be expected to have a positive impact on VRU safety. Automated ride sharing is expected to slightly increase crash rates of car-car crashes compared to the baseline scenario, although the differences are small and appear to show some random variation. Implementation of GLOSA system at corridor level showed improvement in safety, especially at low MPR of CAVs, as compared to the baseline scenario or individual intersection implementation.

- Introduction of CAVs and increment in the MPR is considered to improve energy efficiency. Additionally, various policy measures can further significantly impact the energy efficiency particularly implementation of GLOSA system as well as the introduction of automated ride sharing services with higher willingness to share the ride.

- The accessibility in transport is expected to improve with several policy measures including replacement of on-street parking with driving lanes or pick-up/drop-off spaces, and with the introduction of automated ride-sharing services. Road use pricing is expected to negatively impact accessibility in transport.

- Public health was indicated to improve if on-street parking spaces are replaced with public spaces. Automated rid sharing services with increased willingness to share can decrease the number of private cars on road and consequently reduce emissions indicating positive impacts on public health. However, active travel could be affected with such services.

Within LEVITATE, several methods have been used to estimate the societal level impacts of future CCAM. Due to the applied multi-method approach, some of the results, in particular for the baseline scenario where no interventions are applied, seem to be conflicting. Different methods and different sub-use cases have used different data sets and assumptions which makes part of the results difficult to compare. Nevertheless, the focus of results that are delivered to the PST is on the *relative* changes compared to the baseline of each model / method – and these relative values were found to be consistent across methods where a comparison was possible.

Findings from different methods can be combined together to find the most optimal policy interventions tested under various SUCs in the project. Through the findings there are opportunities for cities to develop strategies for mitigating the potentially adverse impacts.

6.2 Future work

Future work involves analysing the impacts of various policy interventions (within WP 6) on different networks to help identifying the suitable deployment strategy and analyse the applicability under different study areas. Additionally, combined effect of various policy interventions will also be examined. Broader tasks within LEVITATE concern the inclusion of the presented results within the LEVITATE PST for forecasting, backcasting and Cost-Benefit Analysis, as well as subsequent quality control of the outputs.

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