D5.4 The long-term impacts of cooperative, connected, and automated mobility on urban transport

Deliverable D5.4 – WP5 –PU

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

D5.4 The long-term impacts of cooperative, connected, and automated mobility on urban transport

Work package 5, Deliverable D5.4

Please refer to this report as follows:
Roussou, J., Oikonomou, M., Mourtakos, V., Vlahogianni, E., Ziakopoulos, A., Gebhard, S., Mons, C, Zwart, R.d., Weijermars, W., Zach, M., Chaudhry, A., Hu, B., Yannis, G., (2021). *Long-term impacts of cooperative, connected, and automated mobility on urban transport, Deliverable D5.4 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
Coordinator:	Andrew Morris, Prof. of Human Factors in Transport Safety Loughborough University Ashby Road, LE11 3TU Loughborough, United Kingdom
	This project has received funding from the European Union's Horizon 2020 researc and innovation programme under grant agreement No 824361.

Deliverable details:	
Version: **Dissemination level:** **Due date:** **Submission date:**	Final PU 31/10/2021 03/11/2021

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

Lead contractor for this deliverable:
NTUA

Report Authors:	Roussou, J., Oikonomou, M., Mourtakos, V., Ziakopoulos, A., Vlahogianni, E., Yannis G. (NTUA), Greece Chaudhry, A. (LOUGH), United Kingdom Gebhard, S., Mons, C, Zwart, R.d., Weijermars, W. (SWOV), The Netherlands Zach, M., Hu, B. (AIT), Austria

Revision history

Date	Version	Reviewer	Description
13/10/2021	Preliminary draft 1	Knut Veisten (TOI)	Review round 1 – Accepted with reservations
28/10/2021	Preliminary draft 2	Maria José Rojo (POLIS)	Review round 2 – Accepted
29/10/2021	Final draft	George Yannis (NTUA), Vanessa Millar (LOUGH)	
31/10/2021	Final report	Camellia Hayes (LOUGH)	
03/11/2021	Final deliverable	Andrew Morris – Loughborough University ➔ EC	

List of abbreviations

ADAS	Advanced Driver Assistance Systems
AUSS	Automated Urban Shuttle Service
AEB	Autonomous Emergency Braking
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CAFE	Corporate Average Fuel Economy
CAV	Connected and Automated Vehicle
CCAM	Cooperative, Connected and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
CV	Connected Vehicle
DisA	Distraction Alert
DrowA	Drowsiness Alert
ERTRAC	European Road Transport Research Advisory Council
EU	European Union
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FORS	Fleet Operation Recognition Scheme
GDPR	General Data Protection Regulation
IMA	Intersection Movement Assist
ISA	Intelligent Speed Assist
IVS	In-vehicle Signage
LCA	Lane Change Assist
LDW	Lane Departure Warning
LKA	Lane Keeping Assist
MATSim	Multi-Agent Transport Simulation
MPR	Market Penetration Rate
mUoM	marginal Utility of Money
NHTSA	National Highway Traffic Safety Administration
NRC	National Research Council
PST	Policy Support Tool
SAE	Society of Automotive Engineers
SD	System Dynamics
SRG	Stakeholder Reference Group
SSAM	Surrogate Safety Assessment Model
SUC	Sub-Use Case
TA	Turn Assist
TTC	Time to Collision
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to everything
VKT	Vehicle Kilometers Travelled

Table of contents

Table of figures

Table of tables

Executive summary

The aim of the LEVITATE project is to prepare a new impact assessment framework to enable policymakers to manage the introduction of cooperative, connected and automated mobility, maximize the benefits and utilize 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), that includes impacts on safety, environment, economy and society.

This report focuses on urban transport, more precisely on automated urban shuttle services (AUSS). The report provides an analysis for the long-term impacts of different urban transport sub-use cases. The impacts to be studied have been defined in Deliverable 3.1 (Elvik et al., 2019), which provided a preliminary taxonomy of the potential impacts of CCAM. The long-term impacts of CCAM developed in the present report are those described as wider impacts; namely changes occurring both inside and outside the scientifically examined transport system. More precisely, road safety, emissions, energy efficiency, parking space, public health, accessibility in transport and commuting distances are considered. After an extensive literature review and a Stakeholder Reference Group (SRG) workshop, a preliminary list of the urban transport sub-use cases was developed, presented in Deliverable 5.1 (Roussou et al., 2019). The proposed automated urban transport sub-use cases have been prioritized for their consideration in further investigation. During prioritizing, factors such as widespread studies being followed on those sub-use cases and the feasibility of impact assessment have been considered. The resulting sub-use cases that are presented in this report, are the point-to-point automated urban shuttle service, and the on-demand automated urban shuttle service that includes the anywhere to anywhere, last-mile and e-hailing services.

The next step of the impact assessment was to identify the appropriate methods to be used for each impact. The short-term impacts are presented in Deliverable 5.2 (Roussou et al., 2021) and the medium-term impacts of CCAM on urban transport are presented in Deliverable 5.3 (Roussou et al., 2021); the impacts are covered in a manner similar to the present report. The long-term impacts presented in this report were quantified using microscopic simulation, system dynamics, road safety impact assessment method and the Delphi method. Microscopic simulation is used to quantify the impacts of the adoption of CCAM on traffic, including traffic volume and traffic emissions to the environment under several traffic simulation scenarios and to evaluate the influence of difference traffic volume levels the presence of automation features both on a microscopic and a macroscopic level. The expected road safety impacts related to CCAM are quantified to the extend that is possible by combining different methods. Impacts on crashes between motorized vehicles are estimated by means of microsimulation. Impacts on crashes between vulnerable road users and motorized vehicles are estimated by a statistical approach and certain rebound effects are estimated by combining information on crash rates and changes in distance travelled by various traffic modes. System dynamics is a modelling technique where the whole system is modelled at an abstract level by modelling the sub-systems at component level and aggregating the combined output. This method was used to quantify the changes on parking space required and on commuting distances. The Delphi method is a process used to arrive at a collective, aggregate group opinion or decision by surveying a panel of experts. Within LEVITATE, the Delphi method was used to determine all impacts that cannot be defined by the other quantitative methods. Regarding the long-term CCAM impacts, this method was used to identify the changes on parking space required, energy efficiency, public health and accessibility in transport.

The overall results of the impact assessment demonstrated that the introduction of the studied automated urban shuttle services in the urban transport will positively affect road safety and accessibility in transport. The use of CCAM in urban transport will reduce emissions and increase energy efficiency, and thus improve public health. The results on parking space required by the different impact assessment methods used were controversial and depend on the methods' assumptions. Commuting distances will be slightly increased by the introduction of AVs and by the last-mile AUSS. The results regarding the long-term/wider impacts of CCAM will be included in the final LEVITATE product which is the LEVITATE Policy Support Tool (PST).

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 cooperative, connected and automated mobility (CCAM), maximise the benefits and utilise the technologies to achieve societal objectives.

Specifically LEVITATE has four key objectives:

- 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
- 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.
- 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.
- To incorporate the 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 tool box 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 5 and Deliverable 5.4 within LEVITATE

Work package 5 (WP5) focuses on the impacts that the deployment of cooperative, connected and automated vehicles (CAV) are expected to have on urban transport operations, through advanced city shuttles and other micro-transit vehicles. Forecasting of impacts will consider three main components: (i) Mode of transport: public transport, motorised individual transport, active mobility and automated urban shuttle services (AUSS) (ii) Actors: drivers / operators, passengers, transit companies / authorities, cities authorities; (iii) The automation levels of the Society of Automotive Engineers (SAE): urban shuttle modes are directly considered at SAE Level 4. Forecasting will be based on the methodology developed in WP3 (Elvik et al., 2019) and the scenarios developed in WP4 to identify and test specific scenarios regarding the impacts of CCAM on urban transport. More specifically, the objectives of WP5 are:

- To identify how each area of impact (safety, mobility, environment, economy, and society) will be affected by Cooperative, Connected and Automated Mobility (CCAM) in

urban transport operations, 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 CCAM for urban transport.
- To test interactions of the examined impacts in urban transport scenarios and
- To prioritise considerations for a public policy support tool to help authority decisions.

The purpose of Deliverable 5.4 is to present the long-term impacts of a range of mobility policies and interventions against the background of increasing CAV deployment in the vehicle fleet. The impacts to be studied have been defined in the Deliverable 3.1 (Elvik et al., 2019), which provided a preliminary taxonomy of the potential impacts of CCAM. The long-term impacts of CCAM developed in the present report are those described as wider impacts; are changes occurring inside and outside the transport system and more precisely road safety, emissions, energy efficiency, parking space, public health, accessibility in transport and commuting distances. The main methodological approaches to forecast the long-term impacts are microscopic simulation, road safety impact assessment, system dynamics and the delphi method. In the following table all the impacts studied within the LEVITATE project are presented with the method used to quantify them.

Table 1.1: Overview of the impacts in WP5. 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/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		
Amount of travel	*Person kilometres of travel per year in an area*	*Mesoscopic simulation/Microscopic simulation*
Congestion	*Average delays to traffic (seconds per vehicle-kilometer) as a result of high traffic volume*	*Microscopic simulation*
Modal split using public transport	*% of trip distance made using public transportation*	*Mesoscopic simulation/Delphi*
Modal split using active travel	*% of trip distance made using active transportation (walking, cycling)*	*Mesoscopic simulation/Delphi*
Shared mobility rate	*% of trips made sharing a vehicle with others*	*Mesoscopic simulation/Delphi*
Vehicle utilisation rate	*% of time a vehicle is in motion (not parked)*	*Mesoscopic simulation/Delphi*
Vehicle occupancy	*average % of seats in use*	*Mesoscopic simulation/Delphi*
Long term impacts / wider impacts		
Road safety	*Number of traffic crashes per vehicle-kilometer 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*
NO_x due to vehicles	*Concentration of NO_x pollutants as grams per vehicle-kilometer (due to road transport only)*	*Microscopic simulation*
CO_2 due to vehicles	*Concentration of CO_2 pollutantsas grams per vehicle-kilometer (due to road transport only)*	*Microscopic simulation*

PM_{10} due to vehicles	*Concentration of PM_{10} pollutantsas grams per vehicle-kilometer (due to road transport only)*	*Microscopic simulation*
Public health	*Subjective rating of public health state, related to transport (10 points Likert scale)*	*Delphi*
Accessibility of 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) in km*	*System dynamics*

2 Sub-use cases

Sub-use case in this deliverable refers to subcategory (interventions) under automated urban shuttle services (AUSS) use-cases developed to study the quantifiable impacts of CCAM within urban transport. A stakeholder reference group workshop (presented in detail in D5.1 - Roussou et al, 2019) was conducted to gather views on future of CCAM and possible use cases of urban transport, termed sub-use cases, from city administrators and industry. A list of sub-use cases of interest for urban transport from the perspective of CCAM has been developed. Within LEVITATE, this list has been prioritized and refined within subsequent tasks in the project to inform the interventions and scenarios related to urban transport. In turn, these sub-use cases 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 (described in detail in Deliverable 5.1 – Roussou et al., 2021):

- Scientific literature/studies: They indicate 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: They indicate the relevance of sub-use cases from the industrial/ political point of view, independent of available scientific methodologies.
- SRG Workshop: They contain first hand feedback for the sub-use cases, but might only reflect the opinions of organisations and people who participated.

The automated urban transport related sub-use cases that were formulated after this procedure are the following:

- **Point-to-point automated urban shuttle service** (AUSS): Automated urban shuttles travelling between fixed stations, complementing existing urban transport.
    - **Point to point AUSS connecting two modes of transport**
    - **Point to point AUSS in a large-scale network**
- **On-demand urban shuttle service**, including:
    - **Anywhere-to-anywhere AUSS**: Automated urban shuttles travelling between not fixed locations.
    - **Last-mile AUSS**: Automated urban shuttles providing convenient first/last mile solutions, complementing public transport.
    - **E-hailing**: on-demand last-mile AV shuttles.

2.1 Point to point automated urban shuttle service

The point-to-point AUSS, operate on fixed stations in a defined area in the city. The minibuses use dedicated lanes on the network which connect the AUSS stops. The importance of this service was highlighted by the stakeholders during the SRG workshop, as this will be the first CCAM service to be introduced in the cities, in a smaller or larger scale depending on the cities goals. This SUC was divided in two separate SUCs for the impact assessment using microscopic simulation. These SUCs are the point-to-point AUSS connecting two modes of transport and the point-to-point AUSS in a large-scale network. The point-to-point AUSS connecting two modes of transport, concerns a service that connected the metro station "Eleonas" (Ελαιώνας) with the Athens intercity bus hub. This small-scale service was studied in order to design the system and verify the selected parameters before assessing the impacts of the introduction of this SUC at the city level. The point-to-point AUSS in a large-scale network, was designed as an automated shuttle service, consisting of shuttle buses with a capacity of 10 passengers, operating in parallel with the existing transit service, connecting various destinations and areas with low transit coverage. Since the microsimulation provides a high number of precise impacts, it was decided to retain this division for all methods.

Concerning the road sector, automation will not only refer to private passenger cars, but also to public transportation. One of the modes that will be influenced by the automation technology and the various functions are the shuttle buses where driverless minibuses will transfer passengers from one point to another. Shuttle services widely exist worldwide serving transfer and connection purposes for medium and short distances. Autonomous shuttles and more specifically those that are electrically powered, are expected to reduce operational costs while increasing ridership (Popham, 2018), as well as costs related to fuel consumption and driver employment (Zhang et al., 2019).

There are many projects concerning the use of autonomous shuttles for transit purposes, such as Park Shuttle I and II for transferring people from a car park to the airport of Amsterdam and within Rivium Business Park in Rotterdam respectively (Prokos, 1998; Pruis, 2000; Bootsma & Koolen; 2001, Ritter, 2017). Both projects revealed the efficiency of autonomous shuttles as well as their attractiveness as a large number of people are using them on daily basis. The same results were achieved by the use of small autonomous vehicles for connecting Heathrow Airport in London with the business car park within the CityMobil European Project (City Mobil European Project – Alessandrini, 2018). Autonomous shuttles exist also in Las Vegas, USA (Parent & Bleijs, 2001).

Real-time experiments and simulation tests or surveys have been conducted worldwide in order to reveal and assess the impacts of autonomous shuttle bus on traffic conditions, safety and environment in order to make them more attractive to passengers. The issue of scheduling autonomous shuttle buses was investigated by (Cao & Ceder, 2019) who applied the deficit function for skip-stop and departure time optimization based on real-time passenger demand, showing a reduction in total passenger travel time and in the number of vehicles. Low speed autonomous vehicle and shuttles have been analyzed in terms of their behavior in crowded areas and their interaction with vulnerable road users by applying the collision avoidance algorithm (Emirler et al., 2016; Wang et al. 2018, Ararat & Aksun-Guvenc, 2018;), based on real world conditions or simulation studies.

2.2 On-demand automated urban shuttle service

In contrast to the point-to-point AUSS, on-demand AUSS is designed more flexibly. The points for pick up and drop off passengers are not predefined, but can take place at any location in the operation area. There are also no dedicated lanes reserved for AUSS but the vehicles are instead using the common network structure for cars. The vehicles of the on-demand AUSS are automated shuttle buses of 8 and 15 people capacities.

Public transportation was estimated to potentially benefit from the deployment of AV technology as it can be more cost effective and customizable than human-operated bus service to fill service gaps, reduce road congestion and improve road safety (Nesheli et al., 2021). A relevant problem that arises for transport planners is the first/last mile problem. The first/last mile problem refers to the beginning/end segment of an individual's transit trip and the challenge comes from the fact that public transport is typically unable to take people directly from their homes to their destinations. It is well established that this gap in the public transport network is a major reason why many people prefer the convenience of private cars over taking public transport (Bunting, 2004). The automation of street transit can also potentially reduce operating costs by eliminating the need for human drivers while simultaneously improving the experience of passengers by providing flexible and demand responsive services that connect users to high frequency transit services.

Automation can also facilitate a transition to Mobility as a Service (MaaS) that could limit the negative effects of road transport, such as congestion, air and noise pollution, fuel overconsumption and safety risks (European Commission, 2017), as long as it promotes car sharing, ride sharing or sourcing and not private mobility solutions. According to Firnkorn and Müller, (2015), automation could attract more people to car sharing for the first or last mile of their trip instead of walking, cycling or using a private car. Autonomous taxis or car sharing could be considered as part of the public transport as with suitable business models they can promote sustainability, reducing the number of private cars and accordingly, the congestion. Fewer vehicles that operate more efficiently would reduce car traffic and advance public transport (Pakusch & Bossauer, 2017).

The experiences with early pilot projects have greatly impacted the advancement of on-demand automated urban shuttle service. Small, automated cars for people or good transfer were designed within the framework of CyberCars (www.2getthere.eu) and CyberCars2 (http://www.cvisproject.org/en/links/cybercars-2.htm) projects offering door-to door and on demand services. The development and on-road testing of co-operative Cybernetic Transport Systems, within these projects, demonstrated that CAVs will improve road safety, traffic efficiency and fuel consumption (CyberCars2, 2009). Within the framework of the Railcab project, an autonomous shuttle system was developed based on on-demand scheduling providing transfer of both passengers and goods. The project results also suggested that safety is ensured in all operating modes (Diethelm et al., 2005; Giese & Klein, 2005; Khendek & Zhang, 2005). The autonomous on-demand services in public transportation have also been investigated by Vernier et al. (2016), Chong et al., (2013) and Salazar et al. (2018). In addition, Gelbal (Gelbal et al., 2017) proposed an architecture for automated driving using passenger cars and an autonomous electric shuttle.

In Europe there already exist particular solutions involving high automation with low velocity vehicles and specific infrastructure. A study by OECD (2016) study has further explored the potential of all car trips replacement with shared or on-demand vehicles. According to the ERTRAC Connected Automated Driving Roadmap (2019), there are two development paths that relate to high levels of automation in the urban environment: The first is the Personal Rapid Transit (PRT) including urban shuttles and the second are city-buses and coaches. PRT involves smaller vehicles mostly utilised for the transportation of people, e.g. for first and last mile use or even longer distances. They can operate both in a collective or individual mode on restricted, specific or open roads. Automated PRT or shuttles that will operate on dedicated infrastructure and on designated lanes could be enriched by other automated functions to improve traffic flow and safety, possibly regulating other vehicles as well. These services could be incorporated into public transport.

Within the LEVITATE project on-demand AUSS includes three different services: (i) the anywhere-to-anywhere AUSS, (ii) last-mile AUSS and (iii) e-hailing. These three SUCs where prioritized by the stakeholders during the SRG workshop as the most important after the point-to-point AUSS. The actual implementation of the services is very similar while the usage may vary since each scenario covers a specific application of AUSS and will all compliment the existing urban transport system. More precisely, last-mile AUSS enables transit users' access to and from stations/stops in the networks of urban rail transit and buses or other slower modes of transit. This service is expected to contribute to improvements in transit accessibility, particularly in suburban areas or lower-density areas (Ohnemus & Perl, 2016). The anywhere-to-anywhere AUSS refers to a service allowing users to travel between various not fixed locations around the city, not necessarily close to each other. Finally, e-hailing is a considerably researched service that provides passengers the possibility to book an automated shuttle bus (usually using a smartphone app), in order to travel between convenient points, and thus e-hailing will be used as a demand-responsive feeder for existing public transit services. For the needs of microscopic simulation these SUCs will be modelled as one on-demand AUSS SUC; this is the form with which the results will be presented in the PST as well.

3 Methods

A taxonomy of potential impacts of connected and automated vehicles at different levels of implementation (Elvik et al., 2019) have been estimated and forecasted using appropriate assessment methods, such as a mesoscopic traffic simulation, a microscopic traffic microsimulation, a system dynamics approach and the Delphi panel method. For the long-term impacts described in this deliverable, we refer to results from the microscopic traffic simulation, system dynamics, road safety impact assessment as well as the Delphi method. Traffic simulation provides 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 transferability 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 users. Table 3.1 provides an overview over the different methods and their use in the different sub-use case and scenarios.

Table 3.1: Overview of methods applied to the sub-use cases and their scenarios. The methods used to show the long-term impacts in this Deliverable are highlighted in green.

Subuse Case	Scenario	Method				
		Microscopic simulation	Mesoscopic simulation	Delphi	System Dynamics	Road safety impact assessment
Point to point AUSS	Point to point with two modes	x		x		x
	Point to point large scale network	x		x		x
On-demand AUSS	Anywhere-to-anywhere	x	x	x		x
	Last mile	x	x	x	x	x
	E-hailing	x		x		x

3.1 System Dynamics

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), the demand for public parking space and the (average) commuting distance. While the modal split is already covered in WP5 by mesoscopic simulations in Deliverable 5.3 (Roussou et al., 2021), the demand for public

parking and the commuting distance rely on system dynamic results. In particular, for the commuting distance, no other method is in a position to provide results currently.
A full introduction of system dynamics as a method to assess certain impacts of connected and automated vehicles is given in Deliverable D6.3 (Sha et al., 2021) – where it is used for a wider range of SUC. In the following sections, 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 AUSS sub-use case in the system dynamics model is described.

3.1.1 Description of the base System Dynamics 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 3.1:

- 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*, i.e. modal split using active travel (e.g., walking, cycling), modal split using public transport and private cars 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 CAV 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 CAV 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, result 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.

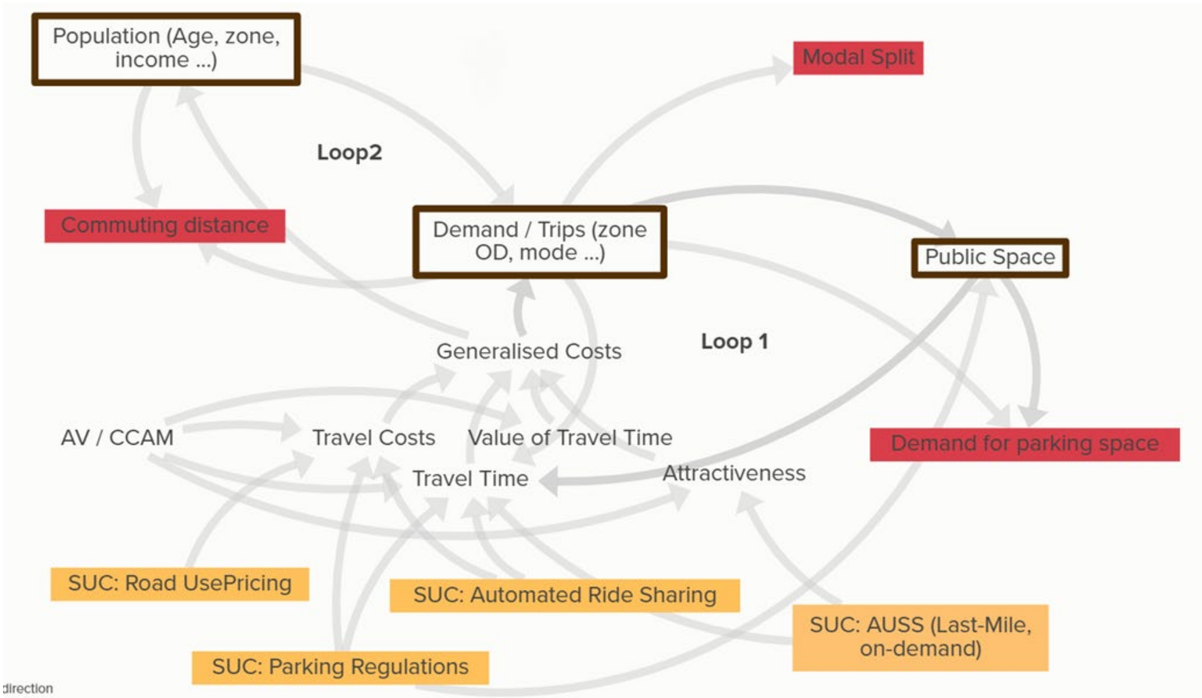

Figure 3.1: High level overview of the Levitate System Dynamics Model, showing main sub-modules (boxes), calculated impact variables (red) and implemented sub-use cases (yellow)

3.1.2 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 et al., 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 3.2, 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.

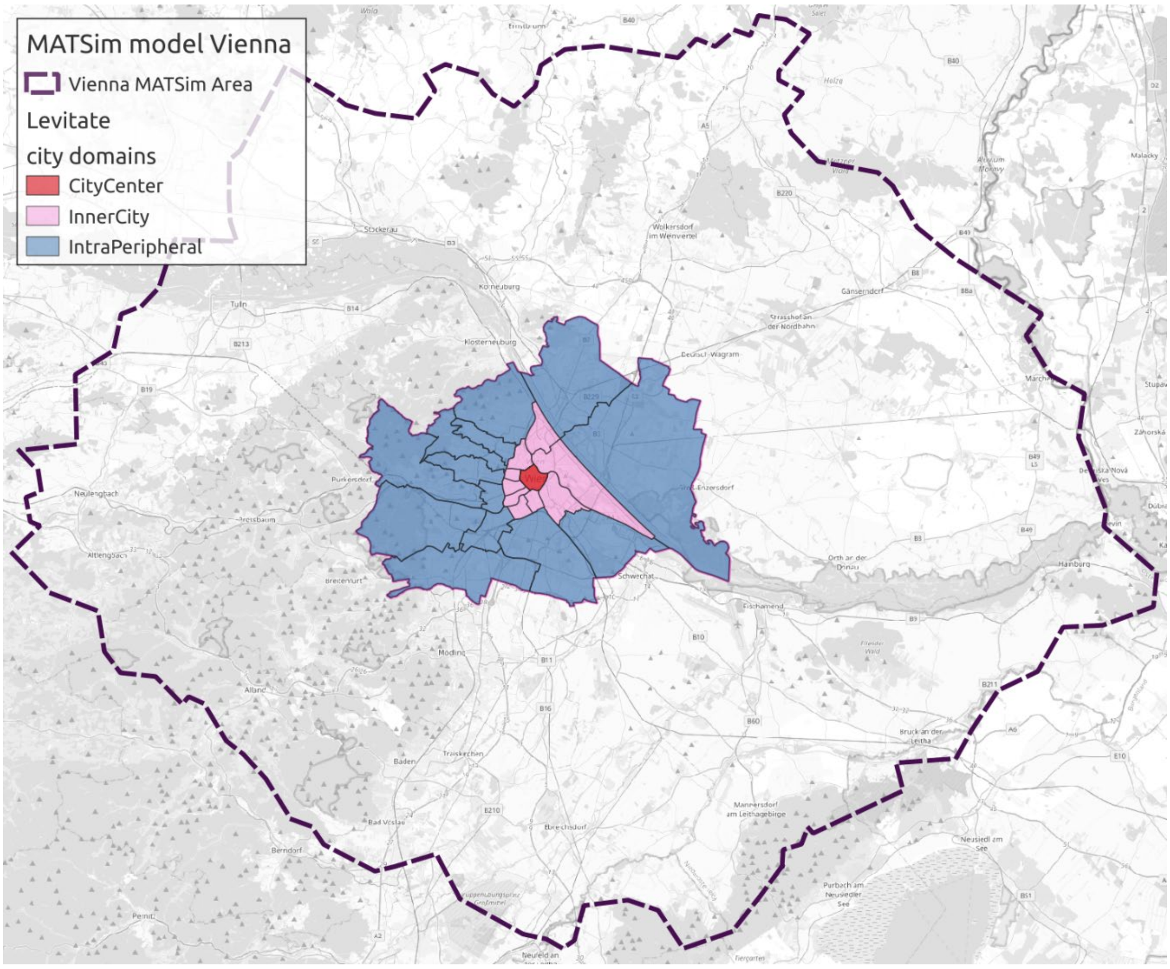

Figure 3.2: SD model total area overview (taken over from MATSim model). The color-shaded domains within the model area cover the actual extent of the city of Vienna. The dashed line marks the wider model region surrounding the city.

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 center (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 modelled 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.

3.1.3 Implementation of the AUSS sub-use case

Due to the highly aggregated level of the SD model, compared to other simulation methods, only the SUC "On-demand automated urban shuttle service" is considered, focusing on the last-mile shuttle service. This is implemented in the following way.

The introduction of an AUSS in a certain part of the model region impacts two variables of the SD model as shown in Figure 3.3:

1. The *travel time* for the Public Transport mode is reduced, because the access time to public transport gets significantly smaller. More precisely, the access time in an area where the last-mile shuttle is in operation (this is assumed to be in zone 3 only, i.e. in the outer districts of Vienna), is multiplied with a factor (1 – 0.5 * Coverage), where the Coverage parameter specifies which fraction of the actual demand can be served by the the last-mile shuttle service. This is assumed to be 50%, resulting in multiplying the original access time with 0.75 - i.e. a reduction of average acces time to publc transport by 25% in zone 3. Note that this effect of travel time reduction due to lower access time cannot be derived from the travel time results that have been documented in D5.2, because those results include trips with a switch from car to AUSS.
2. The *attractiveness* (which is contributing to the generalized costs in negative way and can therefore be expressed in EUR, as perceived added value independent of travel time) is increased by 1 EUR * Coverage, i.e. for trips by public transport starting or terminating in zone 3, it is increased by 0.50 EUR in average.

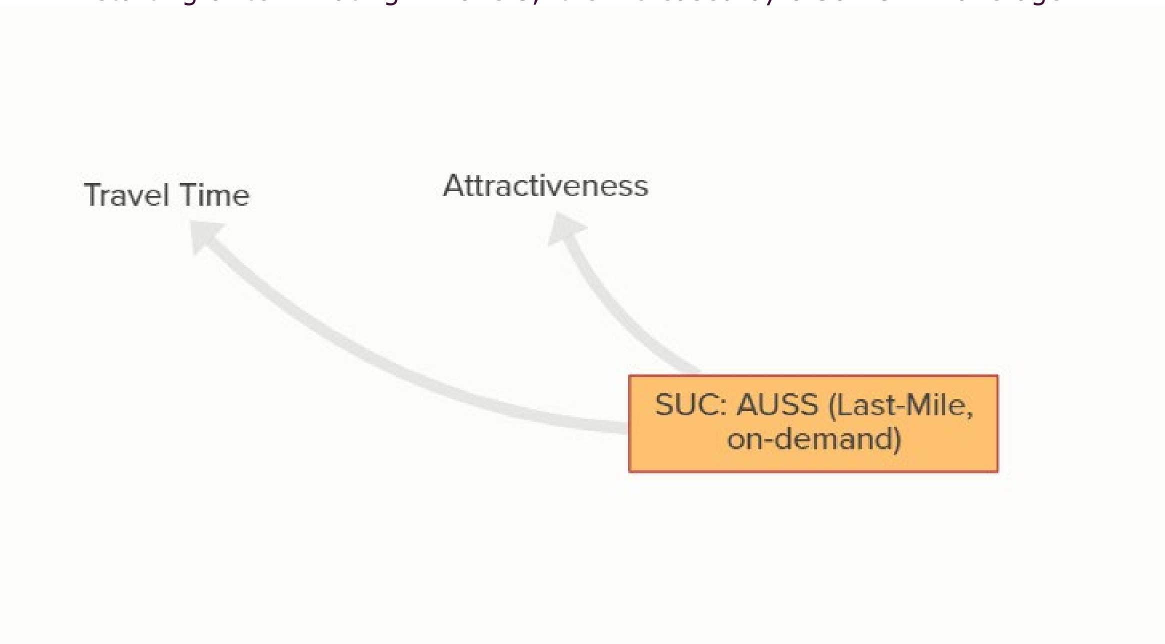

Figure 3.3: Impact of the introduction of AUSS on the variables of the SD Model

Below, the SUC specific parameters and assumptions are summarized.

- Last Mile Shuttle Service is represented by a Coverage parameter (fraction of demand / public transport trips that can be served) per zone
    - This parameter is set to 0.5 (50%) in zone 3 (Intra peripheral area) and set to 0 for other zones.
- If a last-mile shuttle is used, the access time to public transport is reduced by 50% in average.

- If a last-mile shuttle is used, the increased attractiveness (perceived added value) for the public transport trip is assumed as 1 EUR.
- Last Mile Shuttle Service is provided free of additional cost for users of the Public Transport system.
- The value of travel time is not changed by the use of the Last Mile Shuttle Service.

3.2 Microscopic simulation

Traffic microscopic simulation (microsimulation) is one of the main assessment methods used in LEVITATE. The purpose of traffic simulation is: (i) to identify the impacts of the adoption of CCAM on traffic, including travel time, traffic volume, and traffic emissions to the environment under several traffic simulation scenarios and (ii) to evaluate the influence of different traffic volume levels, that the presence of automation features both on a microscopic and a macroscopic level. Traffic microsimulation provides information related to single vehicles, whereas a more macroscopic model refers to entire flow streams. There are also certain hybrid models, such as the model of AIMSUN, which allow for all levels of analysis, namely macroscopic, mesoscopic and microscopic analysis. The simulation inputs include data from various sources such as the road geometry and design, traffic volume, modal split, O-D matrices etc. This analysis will examine impacts mainly on traffic, environment and energy efficiency and will provide insights into the impacts of microscopic flow characteristics of CCAVs. The tools used for this analysis mainly include microscopic modelling tools for autonomous transport.

Microscopic simulation in urban transport studied three sub-use cases: i) The point-to-point automated urban shuttle service connecting two modes of transport; ii) the point-to-point AUSS in a large-scale network; and iii)on-demand AUSS.

The microscopic simulation and the setup for the sub-use cases are described in detail in Deliverable 5.3 (Roussou et al., 2021, section 3.1).

3.3 Estimation of road safety impacts

Road safety impacts are estimated following a two-step approach. First, on the basis of expert knowledge and literature, the ways in which road safety is impacted by the specific sub-use case are identified. Second, different types of road safety impacts are quantified to the extend that is possible by combining three approaches:

1. Impacts on crash rates of vehicle-vehicle crashes are estimated by postprocessing microsimulation output using the software tool SSAM
2. Impacts on crash rates between vulnerable road users and vehicles are estimated by using crash data and assumptions concerning types of crashes that can be prevented by the specific SUC.
3. The estimated impacts on crash rates are combined with estimated impacts on distance travelled that are determined via other methods within LEVITATE to estimate the overall impact on the number of crashes.

Section 4.2 discusses road safety impacts of specific SUCs compared to a baseline scenario of the network without the SUC. Increasing penetration levels of CAVs as such also substantially affect road safety and these impacts are discussed in Weijermars et al (2021).

3.4 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. Within LEVITATE, the Delphi method is used to determine all impacts that cannot be defined by the other aforementioned quantitative methods (traffic microsimulation, system dynamics, etc.). The Delphi method consisted of two rounds of e-mails. During the first round, experts received a questionnaire (30-45 min 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. They were asked to evaluate the potential influence of the proposed interventions on different impact areas. Their answers were then analyzed in order to create anonymized summaries for the different CCAM related interventions, which were sent during the second round of the Delphi, giving the experts the opportunity to change their answer or retain the original. The complete method and the results analysis are described in detail in Deliverable 5.2 (Roussou et al., 2021, section 3.2).

4 Impacts

In order to provide a structure to assist in understanding how CCAM impacts will emerge in the short, medium and long-term, a preliminary taxonomy of the potential impacts of CCAM was developed by Elvik et al. (2019). This process involved identifying an extensive range of potential impacts which may occur from the future expansion of CCAM. A range of impacts were classified into three categories, direct impacts, systemic impacts and wider impacts. The short-term impacts of CCAM are those described as direct impacts; travel time, vehicle operating cost and access to travel. These impacts refer to changes noticed by each road user on each trip and can be measured directly after the introduction of intervention or technology. Systemic impacts are impacts wide enough to be observed across the entirety of the transport system. These are measured indirectly from direct impacts and are considered medium-term. Wider impacts are even broader changes occurring outside the transport system, such as parking space required, road safety, accessibility in transport, public health. These are inferred impacts measured at a larger scale and are the result of direct and system wide impacts. Wider impacts are considered to be long-term impacts and are described in the following sub-sections.

4.1 Parking space

4.1.1 Delphi results

Parking space is considered as the required parking space in the city centre per person (m2/person). The estimate of the impact of automation on parking space was obtained by the Delphi method. The general experts' opinion was that the introduction of automation in urban transport will reduce parking space required. More precisely, the introduction of AVs in the baseline scenario will lead to a reduction of 22. 1% on parking space for 100% AVs market penetration rate. Regarding the automated urban transport interventions, point to point AUSS will reduce the most parking space required reaching -23.1% for 100% AVs market penetration rate. Anywhere to anywhere AUSS, last-mile AUSS and e-hailing will reduce parking space by 19.7%, 16,4% and 13.2% respectively when AVs market penetration rate reaches 100%.

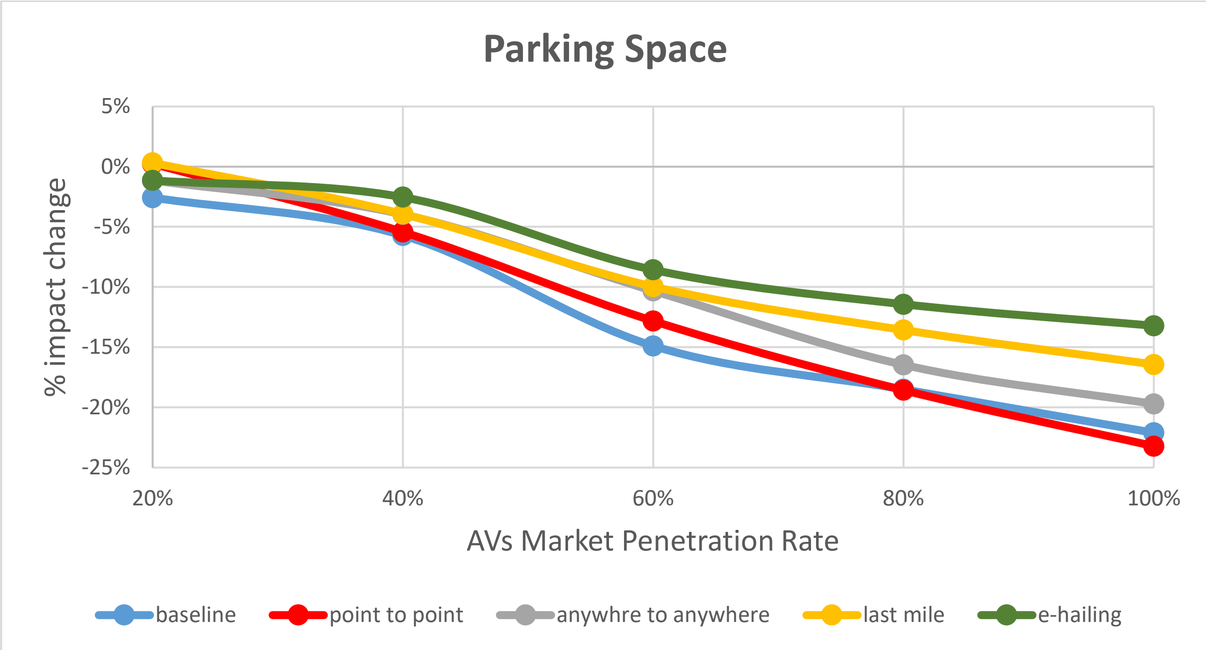

Figure 4.1: 1st round Delphi parking space results

The majority of the experts participating in the 2nd round stated that they agree definitely (45%-56%) or moderately (44%) with the resulted trends. There were also some suggestions that the baseline scenario, point-to-point AUSS and anywhere-to-anywhere AUSS would not affect parking space requirements. On the other hand, 11% of the experts stated that they slightly agree with the 1st round results for last-mile AUSS and e-hailing and suggested that these SUCs will reduce parking space by 20% and 25% respectively.

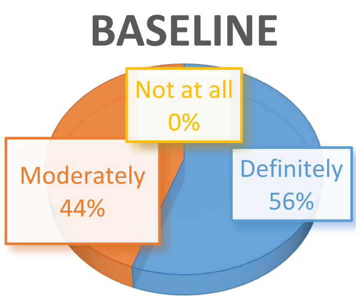

Figure 4.2: 2nd round Delphi results Baseline scenario

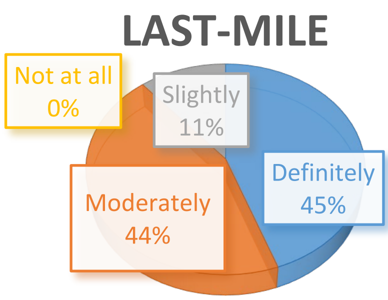

Figure 4.3: 2nd round Delphi results last-mile AUSS scenario

These suggestions have been taken into consideration in order to form the final coefficients to be introduced in the PST, only for the SUCs that system dynamics do not quantify.

Table 4.1: Final PST coefficients for parking space

	Baseline		**Point to point AUSS**		**Anywhere to anywhere AUSS**		**Last-mile AUSS**		**E-hailing**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	-2,5%	0,975	0,2%	1,002	-1,1%	0,989	-0,6%	0,994	-2,2%	0,978
40%	-5,5%	0,945	-5,2%	0,948	-3,8%	0,962	-4,6%	0,954	-3,5%	0,965
60%	-14,2%	0,858	-12,3%	0,877	-9,9%	0,901	-10,4%	0,896	-9,3%	0,907
80%	-17,7%	0,823	-17,8%	0,822	-15,7%	0,843	-13,9%	0,861	-12,0%	0,880
100%	-21,1%	0,789	-22,2%	0,778	-18,9%	0,811	-16,6%	0,834	-13,7%	0,863

4.1.2 System dynamics results

As an alternative method, the demand for parking space was also calculated by the SD model. The preconditions in this approach are slightly different compared to the Delphi method, because the baseline here only considers the increasing market penetration rate of (privately owned) CAVs and no expected side effects like automated ride sharing or policy interventions to restrict individual traffic, since these are covered in corresponding SUCs. This leads to a higher modal share of private cars for increasing CAV penetration rate in the SD model – and consequently one might also expect an increasing demand for parking space in the absence of further regulations.

In Figure 4.4 the baseline result is compared against the Last-Mile Shuttle Service case in order to evaluate any possible influence of this single SUC on the demand for parking space. The impact is shown based on the relative demand for public parking space (% of the available public space) for zone 2 (inner city). As expected within this model, the baseline shows increasing demand with increasing CAV penetration rate. Compared to the baseline, the value for implementation of a Last Mile Shuttle Service in zone 3 (LMSZ3) is slightly below, i.e. this SUC supports the reduction of demanded parking space. Compared to other investigated SUC, however, which are part of WP6 (in particular road use pricing and parking pricing), this influence should be considered as minimal.

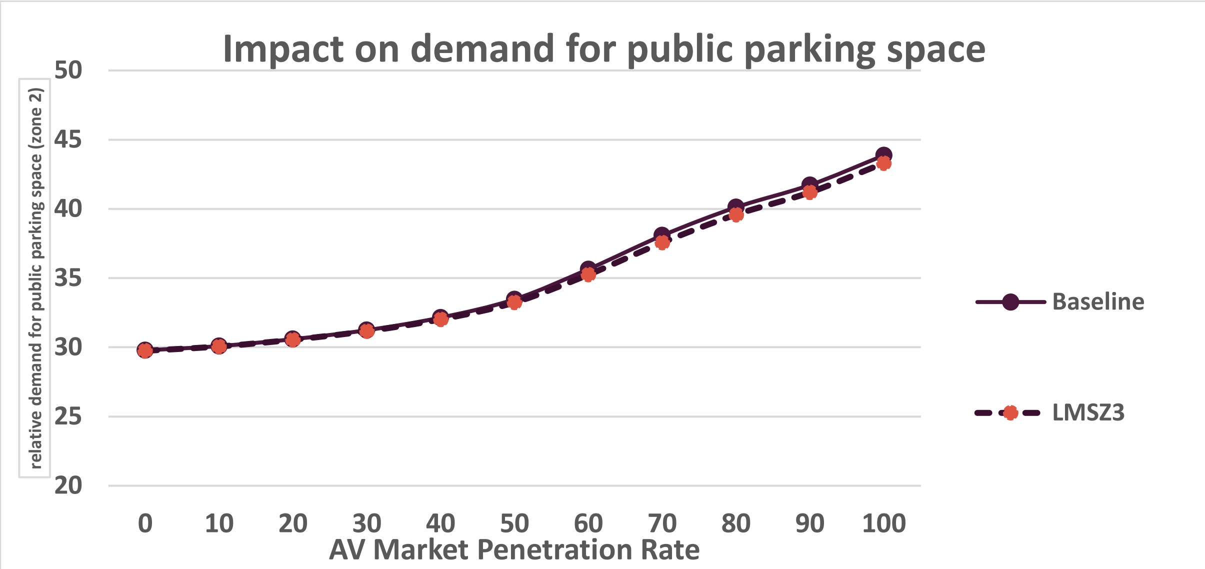

Figure 4.4: SD Results for demand for public parking space (baseline and last-mile shuttle in zone 3)

4.2 Road safety

Within LEVITATE, road safety impacts of both a general-traffic 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. Firstly, input from the literature is used to establish 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. Secondly, the effects are quantified using microsimulation in AIMSUN combined with the SSAM tool which identifies potentially dangerous traffic interactions (also known as traffic conflicts). A prediction for the resulting changes in the number of car crashes is made for both a general baseline scenario (increasing penetration of CAVs without AUSS) as well as the AUSS scenarios discussed in this Work Package. Third, the effects of a potential shift in modal split resulting from increasing automation and AUSS have been quantified using mesoscopic modelling techniques. The crash predictions and road safety impacts of a modal shift are described for the three microsimulation sub-use cases in Section 4.2.2.

4.2.1 Expected road safety impacts impacts

Road safety is expected to be impacted by both a general increase in CAV penetration levels (baseline scenario) as well as an automated urban shuttle system. These safety impacts are summarized in Figure 4.5.

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, certain 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 traveled, 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).

Regarding the more specific case of automated urban shuttle systems (AUSS), both direct effects on traffic interactions as well as indirect effects on travel behaviour and infrastructure are expected. Firstly, automated shuttles may drive comparatively slowly relative to other traffic. When no dedicated lane is implemented, this can result in dangerous interactions with human-driven vehicles, due to both speed differences and irritation of human drivers. Previous studies have linked speed differences between vehicles to increased crash rates (Aarts & Van Schagen, 2006), and a study regarding the implementation of intelligent speed assistant (ISA) systems found that drivers exhibited aggressive driving behaviours in response to the 'slow' driving vehicles (Rijkswaterstaat Adviesdienst Verkeer en Vervoer, 2001).

To reduce these risks of mixed traffic, an existing traffic or bus lane may be converted to a dedicated automated shuttle lane. Dedicated lanes are expected to be primarily relevant in the case of point-to-point shuttles due to these vehicles having predetermined routes. However, dedicated lanes also induce the risk that traffic intensity will subsequently increase on non-dedicated lanes, potentially resulting in more conflicts or crashes in these lanes. On-demand shuttles, on the other hand, by design do not need to follow predetermined routes with designated boarding/alighting zones in the infrastructure. Combined with the short trip distance and the number of passengers, it is likely that the frequency at which a shuttle is parked alongside the road will increase. Due to the size of the shuttle, visibility will be poor for other road users which increases the difficulty and time of the manoeuvre required to drive around the shuttle and thus the potential for risky interactions.

The effects of speed differences (excluding aggressive reactionary behaviour), dedicated lanes (for point-to-point shuttles), and more frequent stops (for on-demand shuttles) on traffic safety are considered in the microsimulation analysis described in the following section.

Furthermore, depending on the convenience and reliability that the shuttles provide we might see changes in modal split. If an AUSS attracts users of private, human-driven vehicles, this is expected to positively impact road safety as the risk of an automated vehicle is expected to be lower than the risk or a human driven vehicle. Changes in modal split are quantified using mesoscopic simulation, and are then incorporated within the road safety effects as a change in exposure in Section 4.2.2.

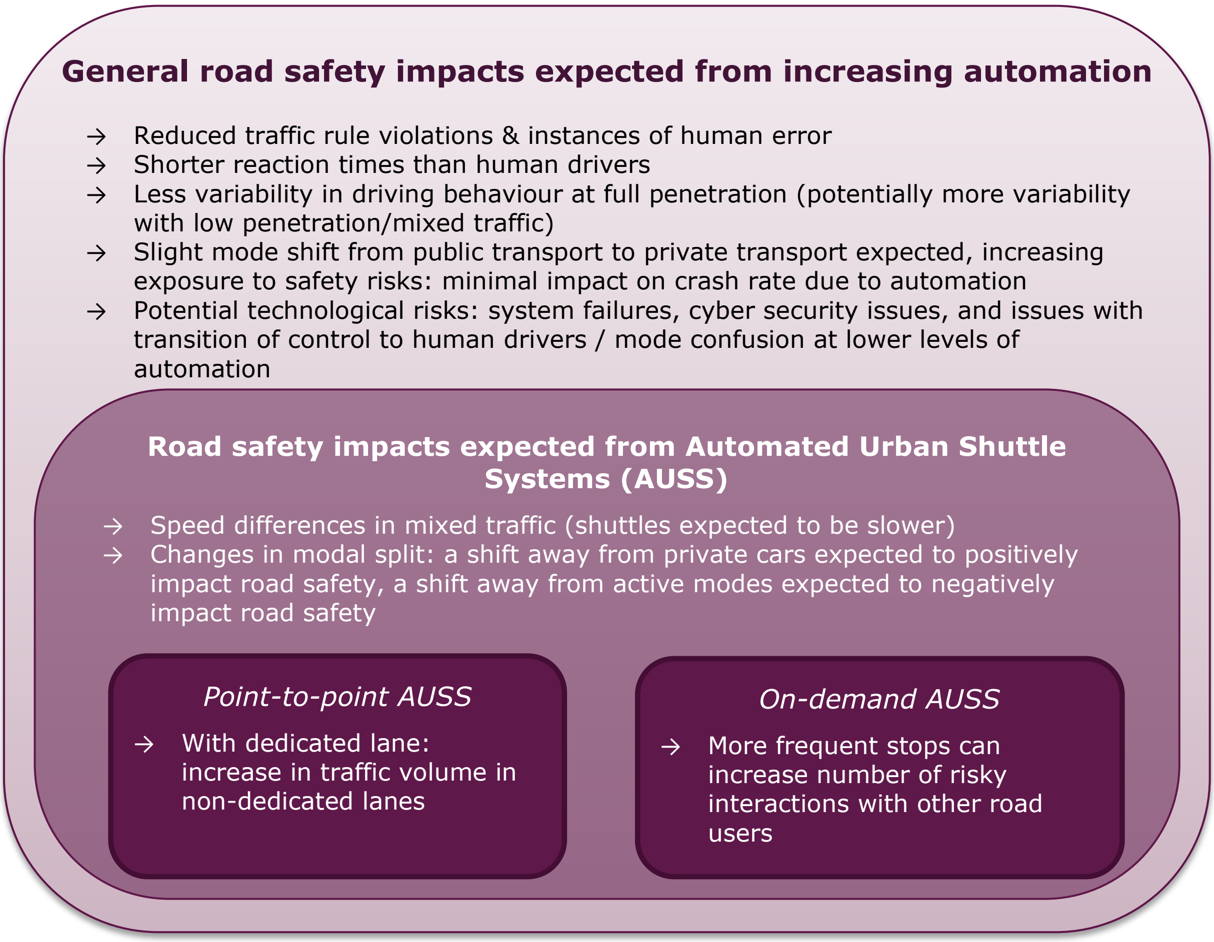

Figure 4.5: Road safety impacts of increasing CAV penetration

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) which identifies potentially dangerous traffic interactions (traffic conflicts). SSAM, developed by the U.S. Federal Highway Administration (FHWA), uses trajectory files from microscopic simulation to identify instances where vehicles in the network overstep threshold values of Time to Collision (TTC) and Post Encroachment Time (PET)[1], 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 general baseline scenario (increasing penetration of automated vehicles without AUSS) as well as the AUSS microsimulation scenarios

1. 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).

discussed in this Work Package: point-to-point connecting two modes of transport, point-to-point in a large-scale network, and on-demand AUSS.

Multiplying the change in risk rate of a certain mode of transport by its change in share of the modal split gives an estimate of the change in the expected number of crashes. When this is done for all modes of transport, a new total impact on the number of crashes can be determined. We distinguish five different modes of transport within this approach: Human driven cars, first and second generation CAVs, VRUs, and other vehicles which describe buses and public transport. The changes in transport volume for the different transport modes are estimated using system dynamics and mesoscopic simulation as mentioned earlier. The risks for the different modes are a result of the microsimulation and vulnerable road user methods described earlier in Chapters 3.2 and 3.3. Based on the expected changes in risk and changes in exposure of the different transport modes, the expected change in the number of crashes (% decrease or increase) can be calculated.

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. The sub-use cases on automated urban shuttles are not expected to have a large additional effect specifically on vulnerable road users compared to the base scenario, and where larger potential impacts are expected (e.g. on-demand shuttles stopping for boarding/alighting) it is not possible to quantify the impacts with the available data and simulation methods. Therefore, impacts on VRUs are not quantified for these sub-use cases.

4.2.2.1 Point to point AUSS connecting two modes of transport

In Figure 4.6, the predicted **crash rates** (crashes per vehicle kilometer travelled) during several peak-hour and off-peak scenarios are visualized. In the almost all scenarios, including the baseline, the crash rates present many oscillations. This can in part be explained due to the smaller size of the network used in this point-to-point scenario (see microsimulation methodology in Deliverable 5.3), making small variations in crash rates more visible.

Generally, automation among the entire vehicle fleet (baseline scenario) as well as the addition of point-to-point shuttles are expected to reduce the crash rates at high penetration rates. At the highest penetration scenarios (0-20-80 and 0-0-100), all five of the AUSS scenarios result in lower crash rates (77-95% reduction) than the baseline scenario (66% reduction). However, the results at intermediate stages when human drivers are still on the road are mixed. As is seen in several of the sub-use cases within LEVITATE, a smaller effect and sometimes even an increase in crash rates can be seen at lower penetration rates of automated vehicles. This is primarily due to interactions between human-driven vehicles and automated vehicles, which are expected to have different driving styles (eg. automated vehicles adopting shorter headways) and different capabilities (eg. human drivers' longer reaction times) which may lead to an initial increase in risks when many human drivers are still on the road. Another contributing factor might be the unfamiliarity of human drivers with overall CAV behavior on the road. The increase predicted at the 60% penetration scenario (40-40-20) when 2nd generation Automated Vehicles first enter the simulation is expected to have the same cause due to their more aggressive, even shorter headways. These risks are partially accounted for in the dedicated lane scenarios, the difference of which is particularly evident in off-peak conditions.

In the scenario in which an incident occurs, vehicles are forced to change lanes more often in order to overtake the incident, resulting in a mostly higher crash rate than the other peak-hour scenarios.

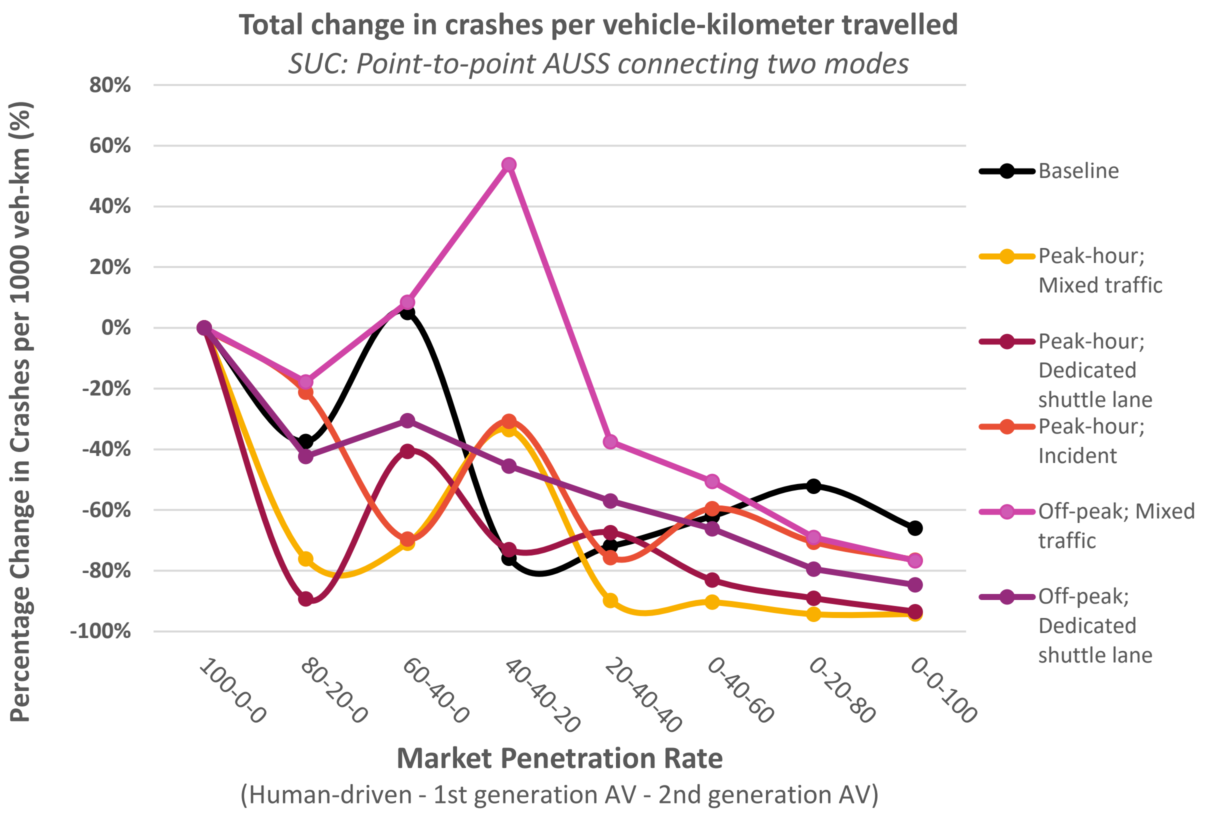

Figure 4.6: Predicted change in crashes per 1000 vehicle km for the simulation scenarios, measured in terms of percentage change from the respective starting scenario at a 0% penetration rate of automated vehicles

Indirect impacts
The expected modal split changes caused by the implementation of an automated urban shuttle service (see deliverable 5.3) will, through the change in exposure, impact road safety. By combining the microsimulation results with the results on modal split we are able to estimated the combined effect on road safety. The differences between predicted crashes with and without modal split change are presented in Table 4.2 below.

Table 4.2: Difference in road safety between results without modal split and results including modal split changes. Rounded to nearest whole number.

Penetration Rate	Baseline	Peak hour - Mixed traffic	Peak hour - Dedicated lane	Peak hour - Incident	Off Peak hour - Mixed traffic	Off Peak hour - Dedicated lane
100-0-0	0%	0%	0%	0%	0%	0%
80-20-0	-4%	-1%	-1%	-5%	-5%	-3%
60-40-0	-4%	-1%	-2%	-1%	-5%	-3%
40-40-20	-1%	-2%	-1%	-2%	-5%	-2%
20-40-40	0%	0%	0%	0%	-1%	0%
0-40-60	0%	0%	0%	0%	0%	0%
0-20-80	1%	0%	0%	0%	0%	0%
0-0-100	1%	0%	0%	0%	0%	0%

A negative number indicates a prediction of further reduction in crash rates per 1000 vehicle kilometers. At lower penetration rates the inclusion of modal split changes results in slightly lower crash rate predictions. This effect might be due to the interactions between human driven vehicles and automated vehicles as also discussed earlier in this document. The differences become less pronounced as the penetration rates increase. Due to the small scale of this sub-use case the overall effects of modal split change are limited, almost completely disappearing at higher penetration rates.

4.2.2.2 Point to point AUSS in a large-scale network

In Figure 4.7, the predicted **crash rates** (crashes per vehicle kilometer travelled) during three peak-hour and off-peak scenarios are visualized for point-to-point shuttles at a city-wide scale in Athens. In all scenarios, including the baseline (increasingly automated vehicle fleet without shuttles), a large reduction in crash rate is expected due to automation. As discussed in Section 4.2.2.1, the reduction is initially minimal at low penetration rates due to potentially risky interactions between human drivers and automated vehicles. However, at this larger city-wide scale, none of the scenarios predict an increase in crash rates even at low penetrations.

Compared to the baseline scenario, both peak-hour scenarios exhibit roughly the same trend in crash rates. Only at the 60-40-0 scenario does the addition of shuttles in peak-hour traffic lead to a slightly higher crash rate, possibly due to the additional traffic volume increasing congestion and therefore conflicts at a point with high levels of both human-driven and automated vehicles. In the off-peak scenario, which has fewer total kilometers traveled due to the lower traffic intensity, the crash rate is higher at all penetration rates. This suggests that the predicted crashes in this scenario are not exactly proportional to the total traffic intensity, but may be related to more specific types of interactions; however, the differences between all scenarios remain minimal.

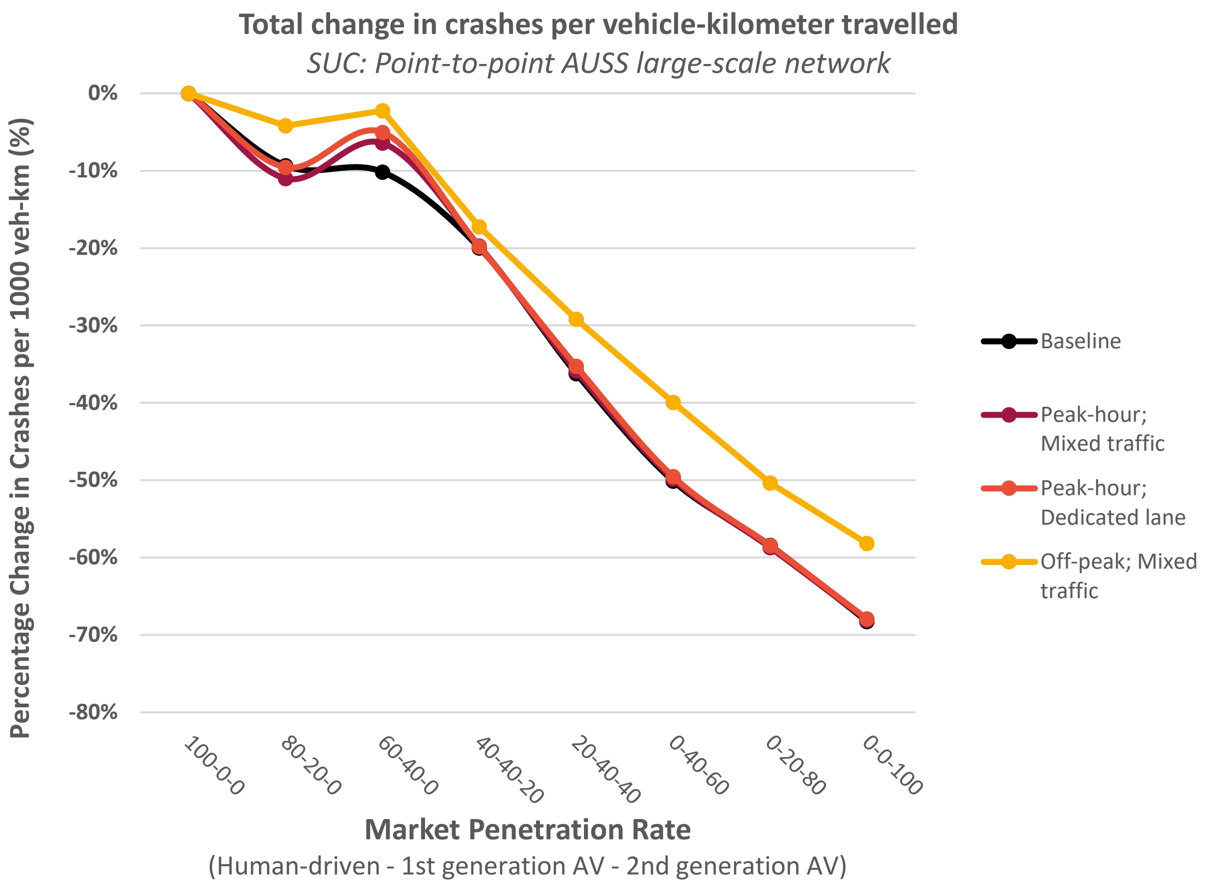

Figure 4.7: Predicted change in crashes per 1000 vehicle km for the simulation scenarios, measured in terms of percentage change from the respective starting scenario at a 0% penetration rate of automated vehicles

Indirect impacts

The expected modal split changes caused by the implementation of an automated urban shuttle service (see deliverable 5.3 – Roussou et al., 2021) will, through the change in exposure, impact road safety. By combining the microsimulation results with the results on modal split we are able to estimated the combined effect on road safety. This total effect is presented in Table 4.3 below. It is important to note that for this analysis we assume that there are no significant changes in population size.

Table 4.3: Comparison of predicted change in crashes per 1000 vehicle km with and without modal split change.

	Baseline		**Peak-hour; Mixed traffic**		**Peak-hour; Dedicated lane**		**Off-peak; Mixed traffic**	
Penetration Rate	Without	With	Without	With	Without	With	Without	With
100-0-0	0%	0%	0%	0%	0%	0%	0%	0%
80-20-0	-9%	-15%	-11%	-16%	-10%	-15%	-4%	-10%
60-40-0	-10%	-14%	-6%	-10%	-5%	-9%	-2%	-6%
40-40-20	-20%	-22%	-20%	-22%	-20%	-22%	-17%	-19%

20-40-40	-36%	-37%	-36%	-37%	-35%	-37%	-29%	-29%
0-40-60	-50%	-51%	-50%	-50%	-50%	-50%	-40%	-39%
0-20-80	-58%	-58%	-59%	-58%	-58%	-58%	-50%	-50%
0-0-100	-68%	-68%	-68%	-67%	-68%	-67%	-58%	-57%

At lower penetration rates the difference due to modal split is most apparent. This effect might be due to the interactions between human driven vehicles and automated vehicles as also discussed earlier in this document. The differences become less pronounced as the penetration rates increase. Overall, there is a small effect on road safety indicators due to the changes in modal split of travel with no difference between the scenarios.

4.2.2.3 On-demand AUSS

In Figure 4.8, the predicted **crash rates** (crashes per vehicle kilometer travelled) during three peak-hour and off-peak scenarios are visualized for on-demand shuttles at a city-wide scale in Athens. While in all scenarios a large reduction (63-67%) in crash rates is predicted at full automation of the vehicle fleet, addition of the on-demand shuttles to the network does result in higher predicted crash rates than the Baseline scenario during the transition phases. This is especially true at lower penetration rates when there are still many human-driven vehicles on the road, and when there are more shuttles on the road (10% demand served) or more-frequently stopping shuttles (15-person capacity). As discussed for the previous two SUCs, interactions between human-driven and automated vehicles can pose a risk which initially mitigates some of the safety benefits expected from automated vehicles. This is expected to be due to having different driving styles (eg. automated vehicles adopting shorter headways) and different capabilities (eg. human drivers' longer reaction times) which may lead to an initial increase in risks when many human drivers are still on the road. As was seen in Section 4.2.2.2 for the large-scale point-to-point shuttles, the addition of shuttles to the network appears to put additional pressure on these interactions in mixed traffic; most likely due to an increase in congestion and/or lane-changing manoeuvres to overtake a stopping shuttle.

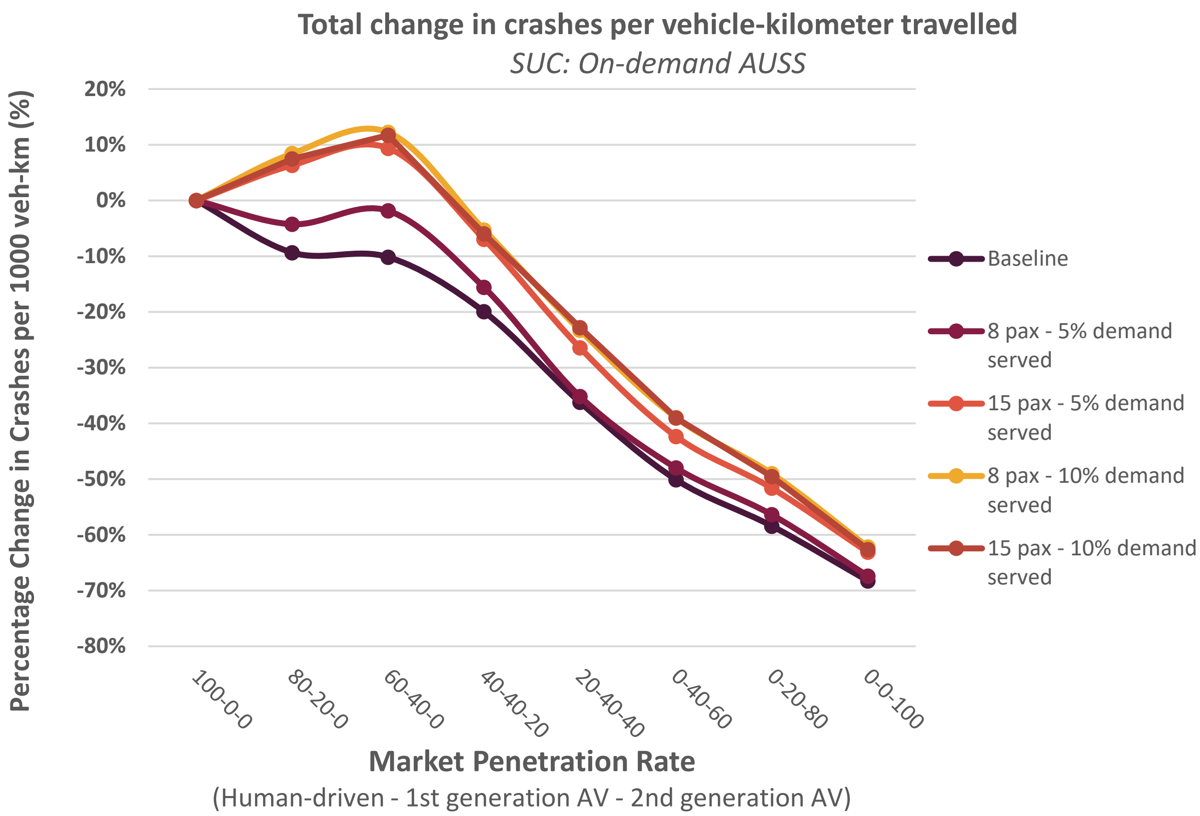

Figure 4.8: Predicted change in crashes per 1000 vehicle km for the simulation scenarios, measured in terms of percentage change from the respective starting scenario at a 0% penetration rate of automated vehicles.

Indirect impacts

The expected modal split changes caused by the implementation of an automated urban shuttle service (deliverable 5.3 – Roussou et al., 2021) will, through the change in exposure, impact road safety. By combining the microsimulation results with the results on modal split we are able to estimated the combined effect on road safety. The differences between predicted crashes with and without modal split change are presented in Table 4.4 below.

Table 4.4: Difference in road safety between results without modal split and results including modal split changes. Rounded to nearest whole number.

Penetration Rate	Baseline	8 pax - 5% demand served	15 pax - 5% demand served	8 pax - 10% demand served	15 pax - 10% demand served
100-0-0	0%	0%	0%	0%	0%
80-20-0	5%	5%	6%	6%	6%
60-40-0	3%	3%	4%	4%	4%
40-40-20	2%	2%	2%	3%	2%
20-40-40	1%	1%	1%	1%	1%
0-40-60	-1%	-1%	-1%	-1%	-1%

0-20-80	-1%	-1%	-1%	-1%	-1%
0-0-100	-1%	-1%	-1%	-1%	-1%

A negative number indicates a prediction of further reduction in crash rates per 1000 vehicle kilometers. At lower penetration rates the inclusion of modal split changes results in slightly higher crash rate predictions. With only 20% penetration of CAVs, the crash prediction including modal split changes ends 5% higher compared to the predictions made without modal split change. This effect might be due to the interactions between human driven vehicles and automated vehicles as also discussed earlier in this document. The differences become less pronounced as the penetration rates increase, ending in a slight reduction in predicted crash rates when including modal split change compared to the results without modal split.

4.3 Energy efficiency

Energy efficiency is defined as the average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%). 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 14.7% when AVs market penetration rate reaches 100%. Based on the 1st round answers, anywhere-to-anywhere AUSS and point to point AUSS will improve energy efficiency the most reaching an increase of 23.5% and 22.1% respectively for 100% AVs market penetration rate. Last-mile AUSS will increase energy efficiency by 12% and e-hailing by 17.9% for AVs market penetration rate of 100%.

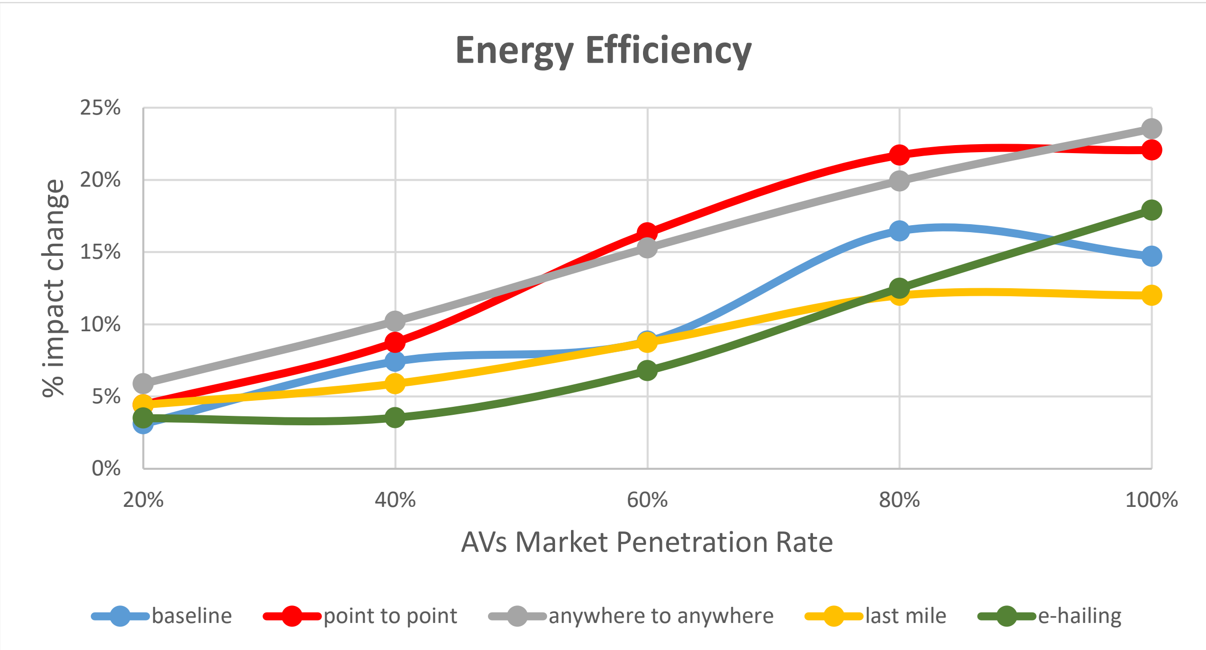

Figure 4.9: 1st round Delphi energy efficiency results

In the 2nd round all the experts agreed definitely (22%-44%) or moderately (56%-78%) with the 1st round results, but there were suggestions that anywhere-to-anywhere AUSS and e-hailing will in fact reduce energy efficiency by 10% and 15% respectively, given the fact that these vehicles will use the roads throughout the entire day.

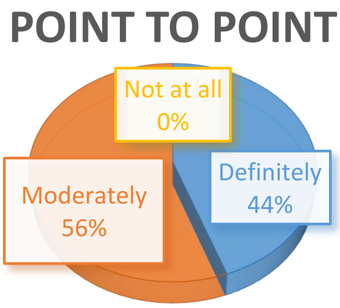

Figure 4.10: 2nd round Delphi results point to point AUSS scenario

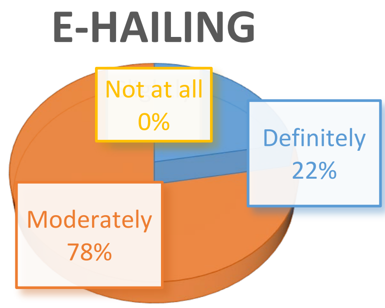

Figure 4.11: 2nd round Delphi results e-hailing scenario

Table 4.5: Final PST coefficients for energy efficiency

	Baseline		**Point to point AUSS**		**Anywhere to anywhere AUSS**		**Last-mile AUSS**		**E-hailing**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	3,0%	1,030	4,2%	1,042	5,2%	1,052	4,2%	1,042	2,7%	1,027
40%	7,1%	1,071	8,4%	1,084	9,3%	1,093	5,6%	1,056	2,7%	1,027
60%	8,4%	1,084	15,6%	1,156	14,2%	1,142	8,4%	1,084	5,8%	1,058
80%	15,7%	1,157	20,8%	1,208	18,6%	1,186	11,5%	1,115	11,3%	1,113
100%	14,1%	1,141	21,1%	1,211	22,1%	1,221	11,5%	1,115	16,5%	1,165

4.4 Emissions

The environmental impacts were obtained by the microscopic simulation using the Aimsun software for the three sub-use cases. More specifically, they were calculated applying the formula developed by Panis et al. (2006). This model computes carbon dioxide (CO_2), nitrogen oxides (NO_X) and particulate matter (PM_{10}) emissions from instantaneous speed and acceleration. The model's parameters for each vehicle type and pollutant were configured for instantaneous emissions calculation and the corresponding emissions were computed for each vehicle trip.

4.4.1 Point to point AUSS connecting two modes of transport

Concerning emissions according to Figure 4.12, CO_2, NOx and PM_{10} levels are significantly lower when the number of autonomous vehicles is increased. More specifically, CO_2, NOx and PM_{10} emissions were reduced for the shuttle service scenarios due to the appearance of autonomous vehicles, compared to the baseline scenario. In the rest of the market penetration rate scenarios when more autonomous vehicles existing the network, the different implementation types of the automated shuttle bus service did not seem to have any significant differences for both peak and off-peak scenarios.

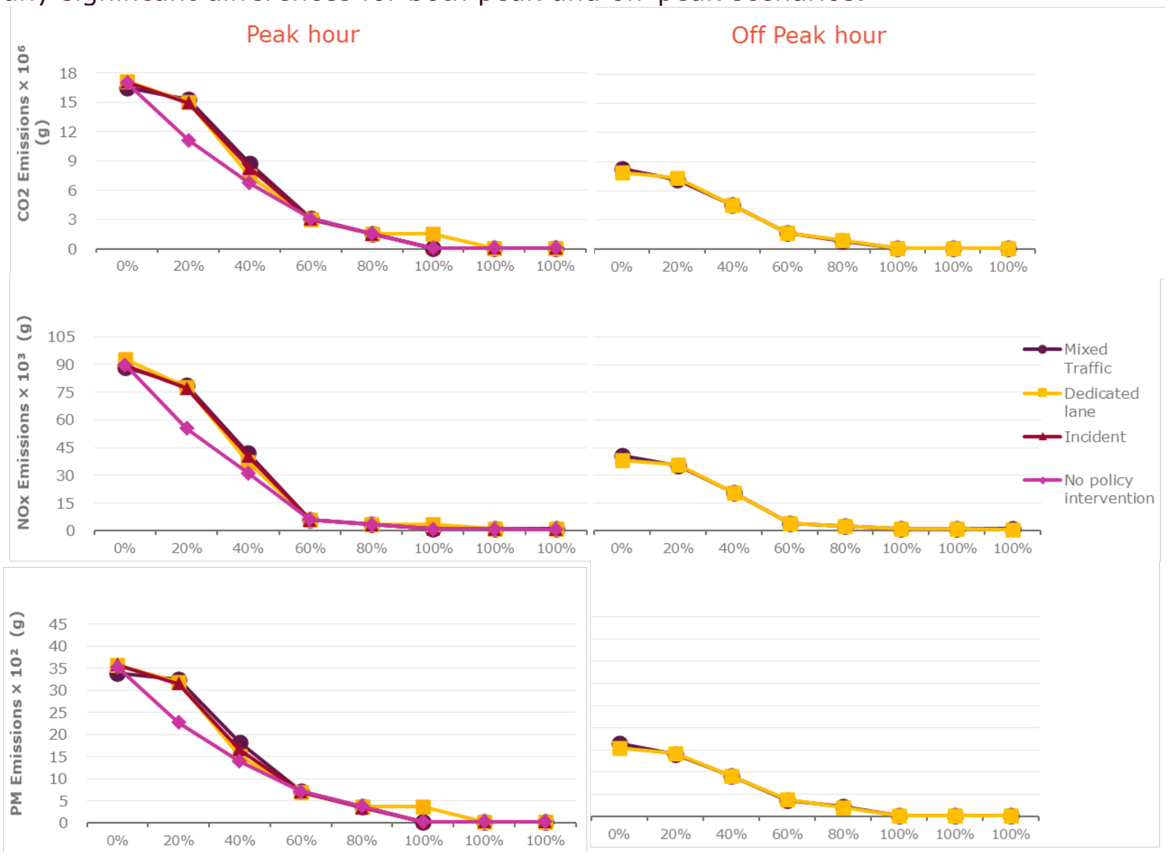

Figure 4.12: Environmental Measurements for point-to-point AUSS conncecting two modes of transport

4.4.2 Point to point AUSS in a large-scale network

Concerning emissions according to Figure 4.13, the CO_2, NOx and PM_{10} levels are significant lower when the number of autonomous vehicles is increased. In addition, the different implementation types of the automated shuttle bus service do not seem to incur any significant differences.

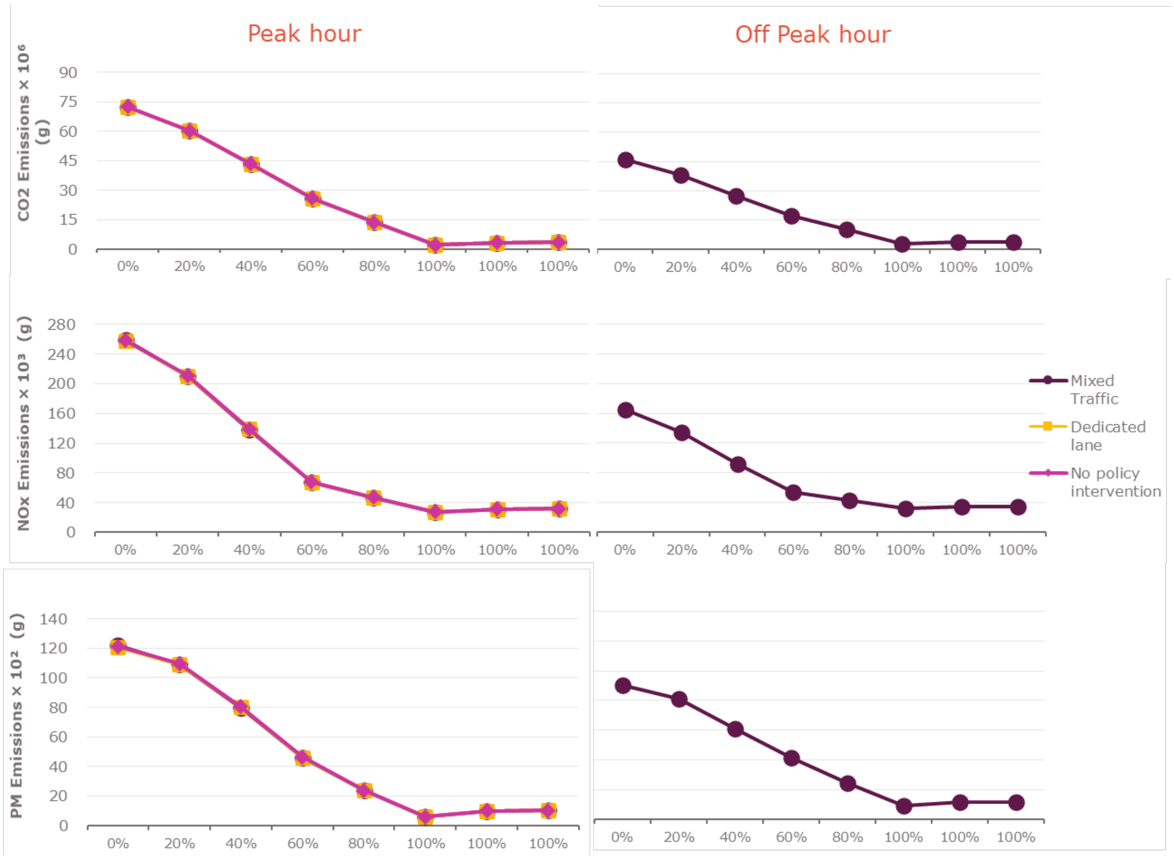

Figure 4.13: Environmental Measurements for point-to-point AUSS in a large-scale network

4.4.3 On-demand AUSS

Concerning emissions according to Figure 4.14, the CO_2, NOx and PM_{10} levels are significant lower when the number of autonomous vehicles was increased. In addition, the different implementation types of the automated on-demand service do not seem to incur any significant differences.

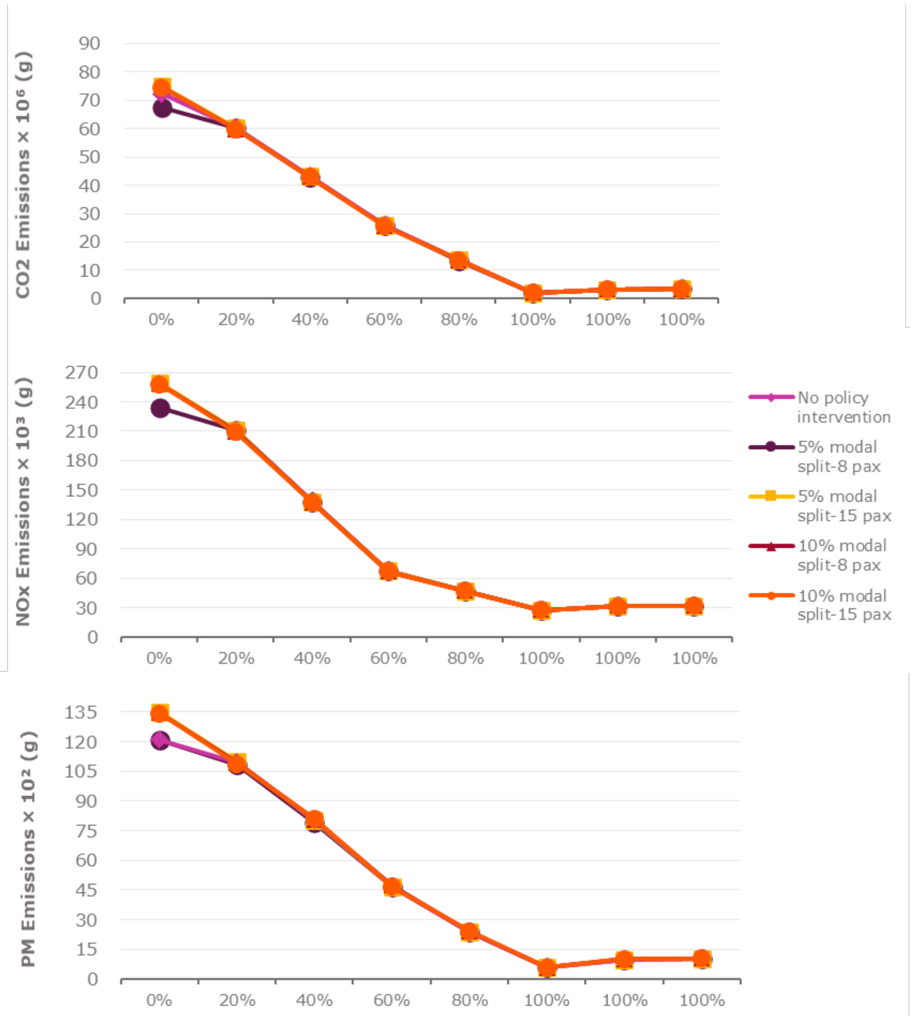

Figure 4.14: Environmental Measurements for on-demand AUSS

4.5 Public health

Public health (subjective users' rating of public health state, related to transport, such as air quality, noise pollution) is also an impact estimated using the Delphi method. The general experts' opinion in the 1st round was that all automated transport sub-use cases including the baseline scenario will lead to a small improvement of public health, which is compatible with the reduced emissions resulted in microsimulations. More precisely, it is estimated that the baseline scenario will improve public health the least reaching a maximum of 5%. Anywhere to anywhere AUSS will lead to a 6% of increase for 100% AVs market penetration rate and last-mile AUSS will have the biggest impact on public health for 40% AVs market penetration rate reaching an improvement of 7.4%. Point to point AUSS will improve public health the most, according to 1st round answers, reaching 13.5% for 100% AVs market penetration rate. Finally, e-hailing will improve public health by 9.3% when AVs market penetration rate reaches 100%.

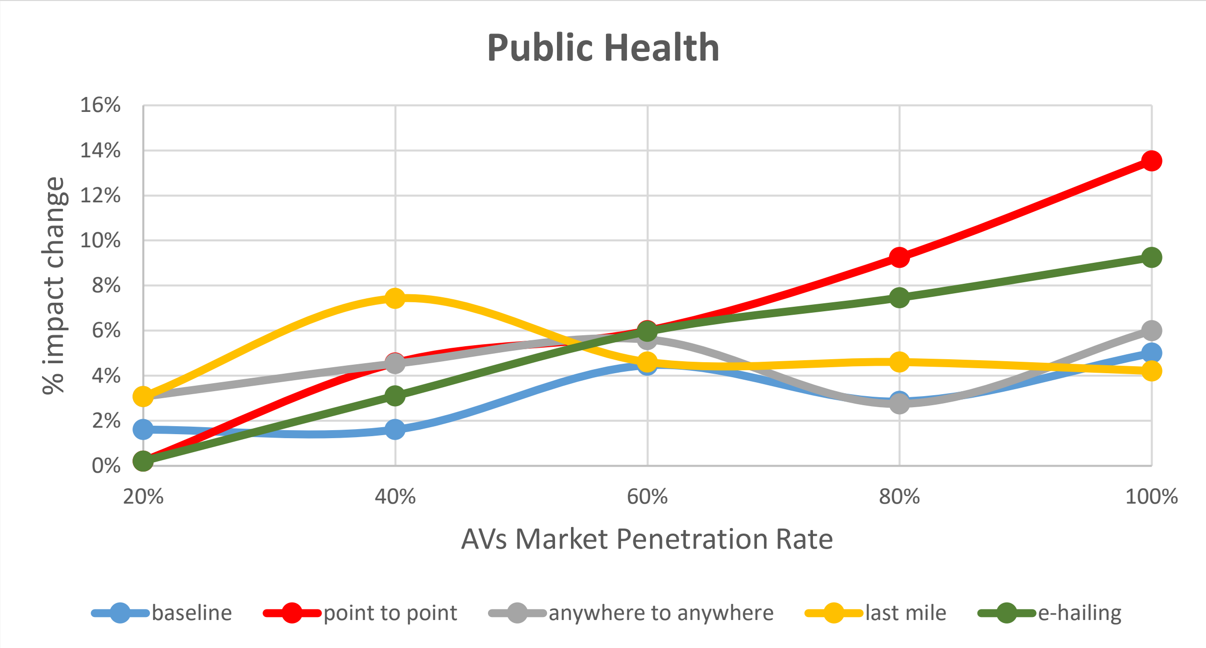

Figure 4.15: 1st round Delphi public health results

In the 2nd round the majority of experts commented that they agree definitely (22%-45%) or moderately (44%-78%) with the resulted trends. 11% of the experts stated that they do not at all agree with the 1st round outcome, and proposed that given the negative impact on modal split using active travel (walking, cycling) automation will not improve public health but instead reduce it by 10%.

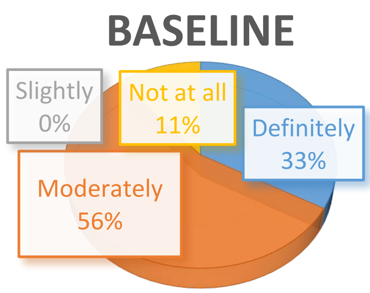

Figure 4.16: 2nd round Delphi results Baseline scenario

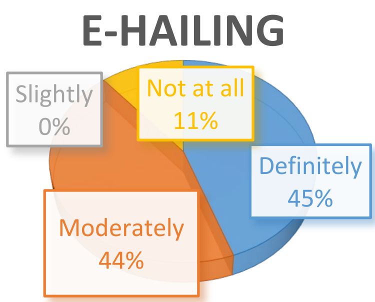

Figure 4.17: 2nd round Delphi results e-hailing scenario

Table 4.6: Final PST coefficients for public health

	Baseline		Point to point AUSS		Anywhere to anywhere AUSS		Last-mile AUSS		E-hailing	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	1,0%	1,010	-0,2%	0,998	2,8%	1,028	3,0%	1,030	-0,2%	0,998
40%	1,0%	1,010	3,7%	1,037	4,1%	1,041	7,0%	1,070	2,4%	1,024
60%	3,6%	1,036	5,0%	1,050	5,1%	1,051	4,4%	1,044	5,0%	1,050
80%	2,2%	1,022	8,0%	1,080	2,5%	1,025	4,4%	1,044	6,4%	1,064
100%	4,1%	1,041	11,9%	1,119	5,5%	1,055	4,1%	1,041	8,0%	1,080

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 (10 points Likert scale). The impact of the automated urban transport sub-use cases including the baseline scenario (when no policy intervention is applied, apart from the introduction of AVs) was estimated by the Delphi method. Based on the 1st round results experts suggested that point to point AUSS, last-mile AUSS and e-hailing will not affect accessibility in transport more than +/- 5%. The only automated urban transport intervention that will improve accessibility in transport is anywhere to anywhere AUSS reaching 9% increase 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 24.4% for 100% AVs market penetration rate.

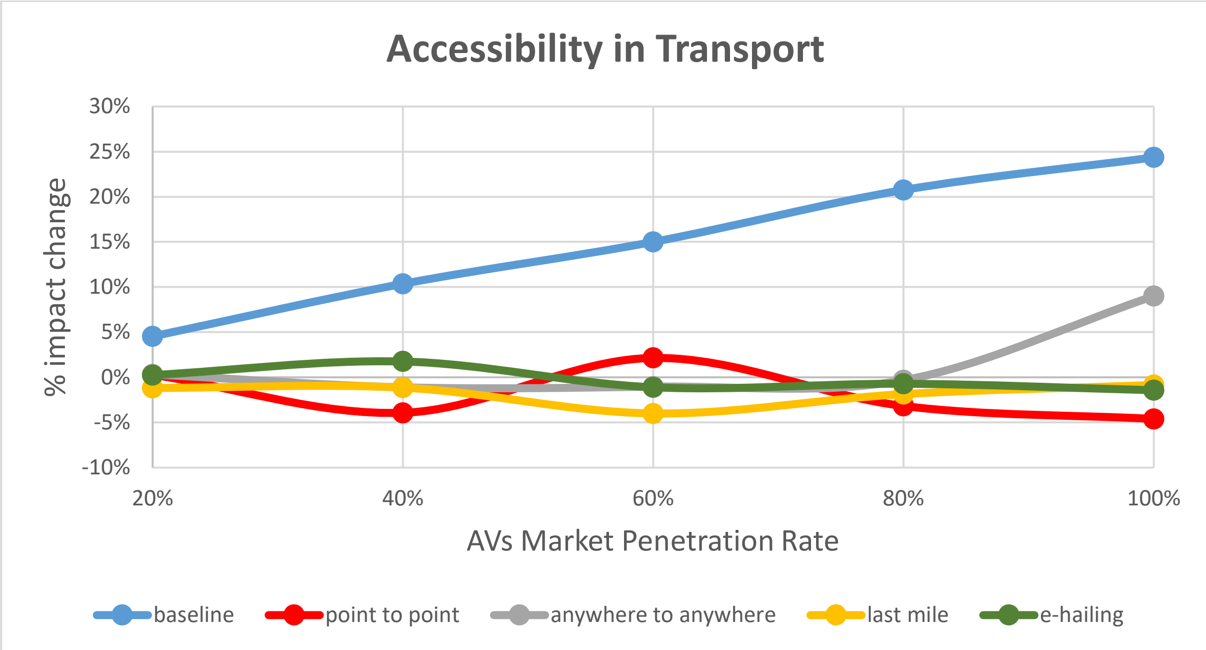

Figure 4.18: 1st round Delphi accessibility in transport results

In the 2nd round all the experts suggested that the resulted curves are definitely (33%) or moderately (67%) compatible with their view of the future. Some suggested that none of these scenarios will affect accessibility in transport.

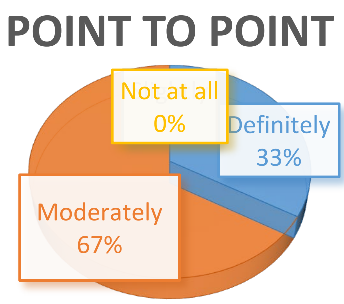

Figure 4.19: 2nd round Delphi results point to point AUSS scenario

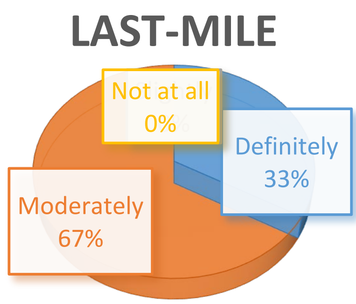

Figure 4.20: 2nd round Delphi results last-mile AUSS scenario

Table 4.7: Final PST coefficients for accessibility in transport

	Baseline		**Point to point AUSS**		**Anywhere to anywhere AUSS**		**Last-mile AUSS**		**E-hailing**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients

20%	4,4%	1,044	0,3%	1,003	0,3%	1,003	-1,1%	0,989	0,2%	1,002
40%	9,7%	1,097	-3,8%	0,962	-1,1%	0,989	-1,1%	0,989	1,7%	1,017
60%	13,9%	1,139	2,0%	1,020	-1,0%	0,990	-3,8%	0,962	-1,1%	0,989
80%	19,2%	1,192	-3,0%	0,970	-0,3%	0,997	-1,8%	0,982	-0,7%	0,993
100%	22,5%	1,225	-4,4%	0,956	8,6%	1,086	-0,8%	0,992	-1,4%	0,986

4.7 Commuting distances

This impact was only covered through the system dynamics model in a simplified way. Based on the average distances of trips between the four zones and the geographical distribution of work locations, a (rough) average commuting distance can be calculated in the model. Assuming that this geographical distribution of work locations stays constant over time, the average commuting distance will change only due to migration to or from the defined zones. While this migration depends on a variety of influencing factors that are by far out of scope of the model (and is considered as exogeneous), the additional impact on migration from AVs and CCAM related SUCs can be made endogenous.

Similar to the dynamics of travel demand and the shifting between modes of transport, the generalized costs for travelling, contributing to the total costs for living, are also assumed to drive relocating decisions of people between zones: Taking into account, for example, the reduced value of travel time saved due to AVs, the total cost of living might get lower in zone 4 than in zone 2/3, while continuing to work in zone 1 – which would increase the average commuting distance as a long-term effect.

Figure 4.21 shows the relative changes (compared to the case of no automation) of the commuting distance for the baseline (no intervention, just showing the effect of increasing AV penetration rate) and the implementation of last-mile shuttle service in zone 3. It can be observed that the baseline shows the expected long-term increase of commuting distance, even if this increase is quite small (~1% for 100% AV rate). Introduction of the last-mile shuttle in zone 3, on the other hand, clearly overcompensates this effect, leading to a slight decrease in average commuting distance compared to the 'No Automation' scenario. Looking into the detailed dynamics of the modelled system, this result is quite plausible since zone 3 – with high population number - is made more attractive and relocation into zone 4 is prevented.

As a final note, it has to be clearly stated here that the calculation of this impact has to be considered with reservation. As the commuting distances in future will depend from a variety of unknown factors and the relative changes calculated in this SD model are rather small (in the order of 1%), they should mainly be considered as qualitative indicators if a certain SUC / policy intervention may contribute towards reduction of commuting distances or not.

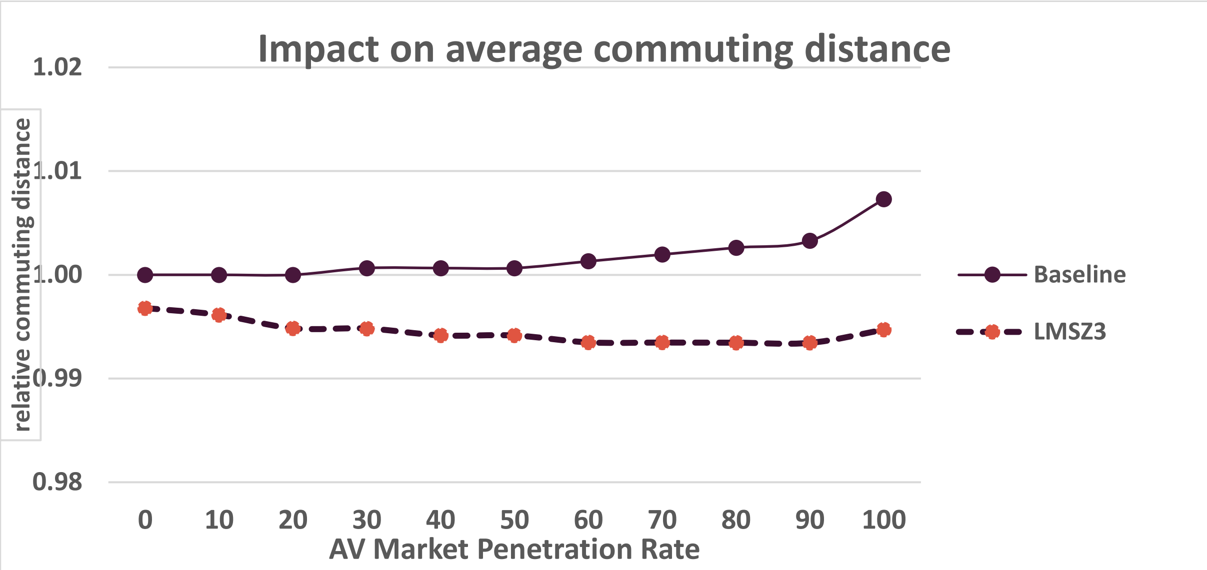

Figure 4.21: SD Results for average commuting distance changes (baseline and last-mile shuttle in zone 3 – LMSZ3)

5 Discussion

Overall, the analyses regarding the long-term impacts of CCAM in urban transport reveal several interesting findings. The introduction of the studied automated urban shuttle services (AUSS) in the urban transport landscape will positively affect road safety and accessibility in transport. The use of CCAM in urban transport will reduce emissions and increase energy efficiency, and thus improve public health. The results on parking space required by the different impact assessment methods used were controversial, and depend on the methods' assumptions. Commuting distances will be slightly affected by the introduction of AVs and by the last-mile AUSS. Regarding the different assessed automated urban transport SUCs, point-to-point AUSS, seems to present higher positive impacts on parking space, public health and energy efficiency. On the other hand, accessibility is more affected by the on-demand service. Road safety and emissions present similar trends with the increase of CAVs MPR.

According to the literature, the large-scale introduction of CCAM in urban environments will affect fundamentally urban transport and space (Fraedrich et al., 2019). The wide adoption of automated passenger vehicles is expected to have a profound and prolonged impact on land use (Bagloee, Tavana, Asadi, & Oliver, 2016). More specifically, research suggests that there are two leading theories for potential impacts (Cavoli et al., 2017), either the implementation of CCAM will contribute to a more dispersed and low-density land-use, due to the improved geographic accessibility and the reduced travel time. Alternatively, researchers predict a drastic reduction in land used for parking stimulating urban growth in central districts, particularly under a scenario where the use of automated public transport services is high. This would manifest as vehicles would serve many customers, and would not need to park for a large amount of the day (Frisoni et al., 2016; Fagnant et al., 2015; Anderson et al., 2014). The aforementioned reduction of parking space required agrees with the Delphi method results about the impact of the studied SUCs on parking space.

The results of the road safety impact assessment are also supported by the literature since the benefits from fully automated public transport could include reduced crash rate, increased punctuality, shorter headways and greater availability (Pakusch & Bossauer, 2017). The elimination of the human factor could lead to a substantial reduction of road crashes with the widespread deployment of stage 4 or 5 AVs (International Transport Forum, 2015). Alessnadrini et al. (2014) in the CityMobil2 project estimated that a reduction of 40% of crashes is realistic after the introduction of AVs in the urban environment. According to Logan et al. (2017), the US Federal Highway Administration predicted that 50-80% of highway crashes could be eliminated with the adoption of Automated Highway Systems. A more general assessment is provided by Fagnant and Kockelman (2015) who suggested based on the fact that more than 40% of fatal crashes in the US are due to alcohol, distraction, medication and/or fatigue, CCAM not affected by these factors could have the potential to contribute at a reduction of at least 40% in fatalities.

One of the most important impacts of the introduction of CCAM in urban transport according to the literature is the potential to improve energy efficiency and decrease pollution generated by conventional road transport. This positive environmental impact of the studied automated urban shuttle services is also supported by the outcomes of microscopic simulation and the Delphi method. Autonomous public transport and new mobility services will provide increased freedom of choice of the most suitable mobility mode for each individual trip. By providing a wider palette of mobility solutions, users can lower their dependency on private cars and start using a wider spectrum of services. This can improve the resource efficiency and have a strong self-reinforcing effect on the popularity of the active travel modes, such as walking and biking (Ainsalu et al., 2018). Furthermore, automated urban shuttle services could have a positive impact on the environment by reducing traffic in the cities, and shuttles could provide such services 24/7 by exploiting algorithms that could optimise the process of identifying the closest vehicle and the number of passengers for a similar route. Changes in vehicle design could include using lighter, less energy demanding materials for building the vehicles, since vehicles are less likely to crash; this would allow energy saving gains (KPMG & Center for Automotive Research, 2012). However, research also notes that this change would only occur under high AV penetration scenarios, once all manually driven vehicles have been phased out of the urban environment (Begg, 2014).

The potential effect of AVs on physical activity, and by extension public health, is not widely addressed in the literature. On the one hand the aforementioned reduction of the pollution could also improve public health, on the other hand the studied AUSS could cause people to spend more time in the shuttles and consequently less time being physically active. In the D5.3 experts in the Delphi method suggested that the introduction of AUSS will reduce modal split using active travel. This decreased level of physical activity increases the risk of adverse health impacts (Thomopoulos & Givoni, 2015). Additionally, AVs in the urban environment might lead to an increase in vehicle-miles travelled, which might in turn lead to lack of physical activity and increased obesity rates (Fagnant et al., 2015).

Similarly, to public health, accessibility in transport has not been widely addressed in literature. Experts in the Delphi method suggested that the implementation of automated urban shuttle services will improve accessibility in transport. A number of authors have stressed the potential AVs have to improve accessibility for a range of people. Many authors report that the use of AVs could enable elder persons, disabled and non-drivers, such as underage children, to become more mobile (Fagnant et al., 2015; Ticoll, 2015). Furthermore, Alessandrini et al. (2015), argue that shared AV shuttles have the potential to improve accessibility for people living in areas that are not well connected to collective transport.

The slight increase of commuting distances after the introduction of AVs in the urban environment, indicated in the system dynamics results, is also supported by the literature. Olsen & Sweet in their study used data from a 2016 survey of residents in Southern Ontario, Canada, to estimate the characteristics and motivations of individuals indicating the most interest in commuting further using AVs. Some of the expected benefits of AVs, such as safety improvements, better reliability, improved parking, reduced congestion will also motivate longer commutes (Kim et al., 2020).

Naturally, the present approach adopted within LEVITATE has some limitations. First of all, a certain degree of uncertainty is underlying in every method, while this quantity is inherently different for each method. More precisely, each quantitative method has different parameters and is applied in a different city model, partly due to the resources in which the LEVITATE partners had access to, for example the mesoscopic simulation (presented in D5.2 – Roussou et al., 2021) is using the MATSim model for Vienna, the microscopic simulation (presented in D5.3 - Roussou et al., 2021) considers the AIMSUN model for Athens, and on the other hand the Delphi method is a qualitative method, based on the experts' opinions and not on a specific city model. Regarding the Delphi method, limitations are posed by the number of experts, the specificity of the scenarios and the accuracy of their estimations. Thus, the Delphi results will be used to fill in the PST when no other method can. Approaches such as Delphi can be updated when CCAM reach increased maturity and revisited for future efforts either in projects such as LEVITATE or in broader research. Ultimately, the PST user will be informed regarding transferability of results and will be able to receive an educated estimate of how to use these results for CCAM-related predictions or design. Furthermore, all methods are bound to specific MPR scenarios, with the aim to create a functional PST, and thus the results lack degrees of freedom they might otherwise have. Finally, another limitation of the LEVITATE project is that there was enough capacity to examine only two CAV profiles, even though it is probable that much more granular CAV profiles will function in the future network.

6 Conclusions and future work

6.1 Conclusions

The advent of automation is expected to considerably transform the transport market. For transport researchers, practitioners and stakeholders alike, it is prudent to anticipate and plan for the impacts that the introduction of automation will introduce. For the purposes of this project, short-, medium- and long-term impacts would be those defined by deliverable 3.1 (Elvik et al., 2019) as direct, systemic and wider impacts, respectively. Based on that taxonomy, seven impacts were considered as long-term/wider and presented in this report; namely parking space required, road safety, emissions, energy efficiency, public health, accessibility in transport and commuting distances. Four methods were used in order to quantify these impacts; microscopic simulation, system dynamics, road safety impact assessment and the Delphi method.

The findings of the methods used have demonstrated the benefits of automation in urban transport as it has been also suggested by the relevant literature. More precisely, microscopic simulation and the Delphi method indicated the reduction of emissions and the improvement in energy efficiency respectively. Road safety impact assessment has provided an extensive quantification of the impacts of the studied automated urban shuttle services on road safety, indicating a reduction in crashes. System dynamics results demonstrated an increase in parking space requirements in contrary to the Delphi method where experts suggested a reduction in parking space required for all the studied SUCs. This result is explained by the different assumptions in the two methods. System dynamics also demonstrated a slight increase in commuting distances for higher AVs MPRs which is also supported by the literature. Finally, public health and accessibility are the long-term impacts with the least literature references, since they depend on various parameters. Experts participating in the Delphi method stated that the studied SUCs will positively affect both these impacts.

6.2 Future work

Further work to be carried out in WP5 includes the following tasks:

1. Formulation of policy recommendations (Task 5.5).
2. Provision of input to WP8 for the development of the PST regarding urban transport.

The impact assessment outcomes from the Deliverables 5.2, 5.3 and 5.4 that present the impacts of the introduction of urban transport related policy interventions in the short-, medium- and long-term respectively, will be synthetized in Task 5.5 in order to provide a comprehensive overview of the impacts of CCAM in urban transport and produce guidelines and policy recommendations. All the obtained results will inform the PST development and will be integrated into WP8 for the creation of the online dynamic tool.

References

Aarts, L., & Van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. Accident Analysis & Prevention, 38(2), 215-224.

Ainsalu, J., Arffman, V., Bellone, M., Ellner, M., Haapamäki, T., Haavisto, N., ... & Åman, M. (2018). State of the art of automated buses. Sustainability, 10(9), 3118.

Alessandrini, A.; Alfonsi, R.; Delle Site, P. & Stam, D. (2014) Users' preferences towards automated road public transport: Results from european surveys. Transportation Research Procedia. 3, pp. 139-144. Available at: http://ac.els-cdn.com/S2352146514002622/1-s2.0-S2352146514002622-main.pdf?_tid=ee8d6576-a0d3-11e6-b4aa00000aab0f26&acdnat=1478074458_f28c73f9772cd395f5184295fc96501d

Alessandrini, A.; Campagna, A.; Site, P. D.; Filippi, F. & Persia, L. (2015) Automated vehicles and the rethinking of mobility and cities. In: Transportation Research Procedia. 5, pp.145-160.

Alessandrini, A. (2018) Chapter 6 - CityMobil2 Impacts Seen from Outside, Implementing Automated Road Transport Systems in Urban Settings, Elsevier, 2018, Pages 295-310, ISBN 9780128129937, https://doi.org/10.1016/B978-0-12-812993-7.00006-1.

Anderson, J. M.; Kalra, N.; Stanley, K. D.; Sorensen, P.; Samaras, C. & Oluwatola, O. A. (2014) Autonomous Vehicle Technology. A Guide for Policymakers. RAND Corporation. Available at http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-2/RAND_RR443-2.pdf

Ararat, O. and Aksun-Guvenc, B. "Development of a collision avoidance algorithm using elastic band theory." Proceedings of the seventeenth IFAC world congress, 2008, p. 8520–5.

Bagloee, S. A., Tavana, M., Asadi, M., & Oliver, T. (2016). Autonomous vehicles: challenges, opportunities, and future implications for transportation policies. Journal of modern transportation, 24(4), 284-303.

Begg, D. (2014). A 2050 vision for London: What are the implications of driverless transport. Retrieved from https://www.transporttimes.co.uk/Admin/uploads/64165-transport-times_a-2050-vision-for-london_aw-web-ready.pdf

Bunting, P. M. Making public transport work. McGill-Queen's Press-MQUP, 2004.

Cao, Z. and Ceder, A. "Autonomous shuttle bus service timetabling and vehicle scheduling using skip-stop tactic", Transportation Research Part C: Emerging Technologies, Volume 102, 2019, Pages 370-395.

Cavoli, C., Phillips, B., Cohen, T., & Jones, P. (2017). Social and behavioural questions associated with Automated Vehicles A Literature Review. UCL Transport Institute January.

Chong, Z. J., Qin, B., Bandyopadhyay, T., Wongpiromsarn, T., Rebsamen, B., Dai, P., Rankin, E. S. and Ang, M. H. "Autonomy for mobility on demand. In Intelligent Autonomous Systems", 12: Volume 1 Proceedings of the 12th International Conference IAS-12, pages 671–682. Springer Berlin Heidelberg, Berlin, Heidelberg, 2013.

Cybercars project. url: www.2getthere.eu.

Cybercars2 project..

CyberCars2, 2009. Final report. Close Communications for Co-operation Between CyberCars

Diethelm, I., Geiger, L. and Zündorf, A. "Applying Story Driven Modeling to the Paderborn Shuttle System Case Study." In: Leue S., Systä T.J. (eds) Scenarios: Models, Transformations and Tools. Lecture Notes in Computer Science, 2005, vol 3466. Springer, Berlin, Heidelberg

Elvik, R. Quddus, M. Papadoulis, A. Cleij, D. Weijermars, W. A. M. Millonig, A. Vorwagner, A. Hu, and P. B & Nitsche. "LEVITATE Societal Level Impacts of Connected and Automated Vehicles. Deliverable D3. 1 of the H2020 project LEVITATE: A taxonomy of potential impacts of connected and automated vehicles at different levels of implementation." (2019).

Emirler, M.T., Wang, H. and Aksun-Guvenc, B. "Socially acceptable collision avoidance system for vulnerable road users Istanbul Turkey", IFAC control in transportation systems, May 18-20, 2016.

ERTRAC. (2019). Connected Automated Driving Roadmap, ERTRAC. Retrieved from https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf

European Commission, (2017). Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package, SWD (2017) 223 final.

Fagnant, D. J. & Kockelman, K. (2015) Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transportation Research Part A: Policy and Practice. 77, pp. 167-181

Firnkorn, J. and Müller, M., (2015). 'Free-Floating Electric Carsharing-Fleets in Smart Cities: The Dawning of a Post-Private Car Era in Urban Environments?', Environmental Science & Policy, Vol. 45, pp. 30-40.

Fraedrich, E., Heinrichs, D., Bahamonde-Birke, F. J., & Cyganski, R. (2019). Autonomous driving, the built environment and policy implications. Transportation research part A: policy and practice, 122, 162-172.

Frisoni, R.; Dall'Oglio, A.; Nelson, C.; Long, J.; Vollath, C.; Ranghetti, D. & McMinimy, S. (2016) Self-Piloted Cars: the future of road transport? Steer Davies Gleave & European Parliament, Committee on Transport and Tourism. Available at: http://www.europarl.europa.eu/RegData/etudes/STUD/2016/573434/IPOL_STU(2016)573434_EN.pdf

Gelbal, S., Chandramouli, N., Wang, H., Aksun-Guvenc, B. and Guvenc, L. "A unified architecture for scalable and replicable autonomous shuttles in a smart city.", 2017, 3391-3396.

Giese, H. and Klein, F. "Autonomous Shuttle System Case Study. In: Leue S., Systä T.J. (eds) Scenarios: Models, Transformations and Tools. Lecture Notes in Computer Science, 2005, vol 3466. Springer, Berlin, Heidelberg

Haouari, R., Chaudhry, A., Hua, S., Richter, G., Singh, M., Boghani, H.C., Roussou, J. Papazikou, E., Papadoulis, A., Hu, B., Quddus, M., Thomas, P., Morris, A. (2021). Short-term Impacts of CATS on Passenger Transport, Deliverable D6.2 of the H2020 project LEVITATE.

International Transport Forum. (2015) Automated and Autonomous Driving. Regulationunder uncertainty. OECD. Available at: http://www.itfoecd.org/sites/default/files/docs/15cpb_autonomousdriving.pdf

Khendek, F. and Zhang, X.J. "From MSC to SDL: Overview and an Application to the Autonomous Shuttle Transport System.", In: Leue S., Systä T.J. (eds) Scenarios: Models, Transformations and Tools. Lecture Notes in Computer Science, 2005, vol 3466. Springer, Berlin, Heidelberg

Kim, S. H., Mokhtarian, P. L., & Circella, G. (2020). Will autonomous vehicles change residential location and vehicle ownership? Glimpses from Georgia. Transportation Research Part D: Transport and Environment, 82, 102291.

Kpmg, C., Silberg, G., Wallace, R., Matuszak, G., Plessers, J., Brower, C., & Subramanian, D. (2012). Self-driving cars: The next revolution. Kpmg: Seattle, WA, USA.

Nesheli, M., Li, L., Palm, M., Shalaby, A. (2021). Driverless shuttle pilots: Lessons for automated transit technology deployment, Case Studies on Transport Policy, Volume 9, Issue 2, Pages 723-742, ISSN 2213-624X, https://doi.org/10.1016/j.cstp.2021.03.010.

OECD/ITF (2016). Shared mobility: innovation for liveable cities. ITF Corporate Partnership Board Report, Paris.

Ohnemus, M., & Perl, A. (2016). Shared autonomous vehicles: Catalyst of new mobility for the last mile?. Built Environment, 42(4), 589-602.

Pakusch, C., & Bossauer, P. (2017). User Acceptance of Fully Autonomous Public Transport Mittelstand 4.0-Kompetenzzentrum Usability View project Einfach Teilen (Easy P2P Carsharing) View project User Acceptance of Fully Autonomous Public Transport. 2(Icete), 52–60. https://doi.org/10.5220/0006472900520060

Panis, I. L., Broekx, S., & Liu, R. (2006). Modelling instantaneous traffic emission and the influence of traffic speed limits. Science of the Total Environment, 371(1–3), 270–285. https://doi.org/10.1016/j.scitotenv.2006.08.017

Parent M. and Bleijs, C. "The cycab : an electric vehicle specifically designed for car-free cities.", In EVS 15 Symposium, 2001.

Polak, P. H. (2001). De aantallen in ziekenhuizen opgenomen verkeersgewonden, 1985-1997: koppeling van gegevens van de verkeersongevallenregistratie en de registratie van de ziekenhuizen. In opdracht van het Directoraat-Generaal Rijkswaterstaat, Adviesdienst Verkeer en Vervoer AVV.

Popham, K. Transportation Electrification. Smart Cities, 2018

Prokos, A. "Rapport marktonderzoek parking hopper (market research report for the parking hopper)", Technical report, Amsterdam Airport Schiphol, Amsterdam, 1998.

Pruis, J.O. "Evaluatie proefproject parkshuttle: Eindrapport exploitative" (vertrouwelijk) (evaluation of the pilot project parkshuttle: Final report operation), Technical report, ANT, Rotterdam, 2000

Ritter, K. "Driverless electric shuttle being tested in downtown Vegas". [Online], 2017, Available: https://phys.org/news/2017-01- driverless-shuttle-thrill-downtown-las.html.

Roussou, J., Papazikou, E., Zwart,R.d., Hu, B., Boghani, H.C., Yannis, G., (2019). Defining the future of urban transport, Deliverable D5.1 of the H2020 project LEVITATE.

Roussou, J., Oikonomou, M., Müller, J., Ziakopoulos, A., Yannis, G., (2021). Short-term impacts of CCAM on urban transport, Deliverable D5.2 of the H2020 project LEVITATE.

Roussou, J., Oikonomou, M., Mourtakos, V., Müller, J., Vlahogianni, E., Ziakopoulos, A., Hu, B., Chaudhry, A., Yannis, G., (2021). Medium-term impacts of CCAM on urban transport, Deliverable D5.3 of the H2020 project LEVITATE.

Salazar, M., Rossi, F., Schiffer, M., Onder, C. and Pavone, M. (2018) "On the Interaction between Autonomous Mobility-on-Demand and Public Transportation Systems".

Sha, H., Chaudhry, A., Haouari R., Zach, M., Richter, G., Singh, M., Boghani, H.C., Roussou, J., Hu, B., Thomas, P., Quddus, M., Morris, A. (2021). The medium-term impacts of CCAM on passenger transport, Deliverable D6.3 of the H2020 project LEVITATE.

Tarko, A. P. (2018). Estimating the expected number of crashes with traffic conflicts and the Lomax Distribution – A theoretical and numerical exploration. Accident Analysis and Prevention, 113(November 2017), 63–73. https://doi.org/10.1016/j.aap.2018.01.008.

Thomopoulos, N., & Givoni, M. (2015). The autonomous car—a blessing or a curse for the future of low carbon mobility? An exploration of likely vs. desirable outcomes. European Journal of Futures Research, 3(1), 1-14.

Ticoll, D. (2015) Driving Changes: Automated Vehicles in Toronto. Discussion Paper.University of Toronto Transportation Research Institute. Available at:http://uttri.utoronto.ca/files/2016/04/Driving-Changes-Automated-Vehicles-in-Toronto.pdf

Vernier, M., Redmill, K., Ozguner, U., Kurt, A. and Guvenc, B. A., "Osu smooth in a smart city," in Science of Smart City Operations and Platforms Engineering (SCOPE) in partnership with Global City Teams Challenge, 2016 1st International Workshop on. IEEE, 2016, pp. 1–6.

Wang, H., Tota, A., Aksun-Guvenc, B. and Guvenc, L. "Real time implementation of socially acceptable collision avoidance of a low speed autonomous shuttle using the elastic band method", Mechatronics, Volume 50, 2018, Pages 341-355.

Weijermars, W. et al. (2021). Road safety related impacts within the Levitate project. Working paper of the road safety working group of the H2020 project LEVITATE.

Zhang, W., Jenelius, E. and Badia, H.. "Efficiency of Semi-Autonomous and Fully Autonomous Bus Services in Trunk-and-Branches Networks", Journal of Advanced Transportation. 2019. 1-17.