D5.2 Short-term impacts of cooperative, connected, and automated mobility on urban transport

Deliverable D5.2 – WP5 – PU

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D5.2 Short-term impacts of CCAM on urban transport

Work Package 5, Deliverable D5.2

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Coordinator:	Andrew Morris, Prof – Prof. of Human Factors in Transport Safety Loughborough University Ashby Road, LE11 3TU Loughborough, United Kingdom
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Lead contractor for this deliverable:
NTUA

Report Author(s):	Roussou, J., Oikonomou, M., Ziakopoulos, A., Yannis, G. (NTUA), Greece Müller, J. (AIT), Austria

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Legal Disclaimer

List of abbreviations

AUSS	Automated Urban Shuttle Service
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CAFE	Corporate Average Fuel Economy
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
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
SRG	Stakeholder Reference Group
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

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Executive summary

The aim of the LEVITATE project is to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, 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). These systems include impacts on safety, environment, economy and society.

This report specifically focuses on urban transport, specifically providing an analysis for the short-term impacts of different urban transport sub-use cases. The impacts to be studied have been defined in the Deliverable 3.1, which provided a preliminary taxonomy of the potential impacts of CCAM. The short-term impacts of CCAM developed in the present report are those described as direct impacts; changes that are noticed by each road user on each trip and more precisely travel time, vehicle operating cost and access to travel. 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 the 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 resulted 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 presented in this report were quantified using the mesoscopic simulation and the Delphi method. The mesoscopic simulation framework MATSim, is an agent-based modelling (ABM) framework, allowing the simulation of mobile agents that strive to fulfil their daily plans of activities (the "activity chain") and the trips in between their locations. This method was used to quantify the impact on travel time and other medium-term impacts of CCAM (Deliverable 5.3 – Roussou et al.,2021). 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 short-term CCAM impact, this method was used to identify the changes on travel time, vehicle operating cost and access to travel.

The results demonstrated that the introduction of CCAM in the urban transport will reduce travel time, especially for high CAV market penetration rates since more people will use the urban transport services thus reducing traffic. Vehicle operating cost will also present a reduction for high AVs MPR, given the fact that the human factor will be progressively removed and vehicles will perform more efficiently. The access to travel will significantly improve after the implementation of the on demand AUSS since more people will be able to travel using urban transport even if they do not possess a private vehicle. These results regarding the short-term/systemic 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 5.2 within LEVITATE

This WP focuses on the impacts that the deployment of cooperative, connected and autonomous vehicles are expected to have on urban transport operations, through advanced city shuttles and other micro-transit vehicles. Forecasting of impacts will consider four 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 SAE automation levels: urban shuttle modes are directly considered at SAE 4. Forecasting will be based on the methodology developed in WP3 (Deliverable 3.1: Elvik et al., 2019) and the scenarios developed in WP4 to identify and test specific scenarios regarding the impacts of CCAM on urban transport. Specifically, the objectives of Work Package 5 (WP5) are:

- To identify how each area of impact (safety, mobility, environment, economy, and society) will be affected by Connected and automated transport systems (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 5.2 is to present the short-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 short-term impacts of CCAM developed in the present report are those described as direct impacts; changes that are noticed by each road user on each trip and more precisely travel time, vehicle operating cost and access to travel. The main methodological approaches to forecast the short-term impacts are mesoscopic simulation 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 short-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/Delphi*
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 conflicts 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*

2 Sub-use cases

The term '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:

- 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 non-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 AUSS

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 city's goals. This SUC was divided in two separate SUCs for the impact assessment using microscopic simulation (descriped in detail in D5.3 – Roussou et al.,2021). 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" 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 in a city level. The point-to-point AUSS in a large-scale network was designed as an automated shuttle service 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 buses 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 (Pruis, 2000; Prokos, 1998; 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). 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 (Wang et al. 2018, Ararat and Aksun-Guvenc, 2018, Emirler et al., 2016), 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 capacity.

Public transportation can 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). 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 unable to take people directly from their homes to their destinations. This gap in the public transport network is a major reason why many people prefer the convenience private cars over taking public transport. 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. Automated 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 (ttp://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 automated shuttle system was developed based on on-demand scheduling providing both passenger and goods transfer, and suggested that safety is ensured in all operating modes (Diethelm et al., 2005; Giese and Klein, 2005; Khendek and Zhang, 2005). The automated on-demand services in public transportation has also been investigated by Vernier et al. (2016), Chong et al., (2013) and Salazar et al. (2018). In addition, Gelbal et al. (2017) proposed an architecture for automated driving using passenger cars and an automated 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 and 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 much studied 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

The types of impacts that are presented in Deliverable 3.1: A taxonomy of potential impacts of connected and automated vehicles at different levels of implementation (Elvik et al., 2019) have been estimated and forecasted using appropriate assessment methods, such as traffic microsimulation, system dynamics and Delphi panel method. For the short-term impacts described in theis deliverable, we refer to results from the mesoscopic traffic simulation as well as the Delphi method since they provide direct results. Traffic simulation provides input to assess medium-term impacts by processing those results appropriately to infer such impacts (Deliverable 5.3 – Roussou et al.,2021). System level analysis (such as by tools found within system dynamics) can provide measure of long-term impacts (Deliverable 5.4 – Roussou et al.,2021). 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 subuse cases and their scenarios. The methods used to show the medium-term impacts in this Deliverable are highlighted in green.

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

3.1 Mesoscopic simulation

The mesoscopic simulation is used as a method to estimate the impacts of AUSS on the travel time (4.1) and other medium-term impacts described in Deliverable 5.3 (Roussou et al.,2021).

3.1.1 Model description

The mesoscopic MATSim simulation model for Vienna is described in detail in (Müller et al., 2021). In short, the simulation area covers about 4,100 square kilometers with a population of about 2.3 million including the 1.7 million inhabitants of Vienna (Eurostat, 2019). We used a 12.5% sample of the mobile population which corresponds to around 200,000 agents in the whole simulation area. By simulating traffic in the vicinity of at minimum 30 kilometers from the city center, large parts of the Vienna metropolitan area are covered. The road network for the simulations comprises of 156,000 links, and various facilities like workplaces, schools, shopping areas, and leisure areas.

MATSim requires an initial set of travel diaries of the agent plans that have fixed activity locations and a fixed sequence of activities. Since these parameters do not change over simulation iterations and in the scenario simulations. To simulate traffic on the road network, two main data inputs are needed. The first is travel diaries with detailed origin-destination matrices, mode choice, and various socioeconomic indicators. This information comes from the representative survey Österreich Unterwegs 2013-2014 which is representative at the municipality level within the city of Vienna (Tomschy et al., 2016). The second input dataset are the locations of facilities or points of interest extracted from OpenStreetMap. They are necessary to indicate locations when disaggregating the origin-destination relations for the districts to specific activity locations (facilities) categorized by housing, work, education, shopping, recreation, and errands. These data are supplemented with population density maps derived from (Eurostat, 2019) to spatially map the facilities along with the potential places of residence and work for the simulated agents.

Thus, disaggregating the activity location survey information means selecting appropriate points of interest from the specified community area code. This selection is done by applying an optimization algorithm based on the travel times and travel distances specified in the travel survey data. As a result, we obtain optimal matching locations for each agent's activity sequence within the set of possible locations for each activity type.

After the synthetic population is generated, the plans are fed into an inter-modal routing algorithm to generate the paths a trip will take. This is done using Austrian Institute of Technology's (AIT) proprietary inter-modal routing algorithm *Ariadne* (Prandtstetter, Straub & Puchinger, 2013)

MATSim works with a scoring function to evaluate the success of an agent's travel diary at the end of the day. The basic logic behind this utility function is to consider times spent at an activity positively and penalize all travel times according to the mode. The scoring parameters for each mode are estimated from a stated and revealed preference survey (Hössinger, et al., 2020; Jokubauskaite, et al., 2019). The model is calibrated by the modal split for each trip according to the travel diaries given in the Österreich Unterwegs 2013/2014 survey. After adjusting the constant of the mode utility functions, we achieved a deviation from the observed data of less than 1% for each mode.

3.1.2 Implementation of AUSS

In the MATSim framework, the on-demand AUSS is implemented with the module for the dynamic routing vehicle problem (dvrp) (Maciejewski and Nagel, 2011). This module performs the matching between agents with AUSS vehicles allowing AUSS to be treated as automated taxis or carsharing vehicles. In contrast to private cars, these vehicles can be shared, and they do not need to be taken back to the agent's home. Different operational schemes can be implemented. Next to the general door-to-door service and the stop-based service, the vehicles can be used in a defined area as door-to-door service. The restriction holds for picking up and dropping off people while driving outside this area is still allowed.

The AUSS fleet consists of vehicles with a capacity of up to 4 people. A higher capacity of vehicles would technically be possible to implement but it is assumed that the flexible pick up and drop off of people will lead to longer detours of trips resulting in fewer acceptance of the service. The AUSS vehicles are at the beginning of each iteration located at their initial spots which have been randomly generated. These initial links function as depots comparable to taxi stands. Idle vehicles will return to these depots. Every three hours, the demand will be generated, and the vehicles will be relocated accordingly. The raster used for the demand generation consists of cells with an edge length of 500m.

The different car fleet partitioning of CAV of the 1st generation (cautious CAV) and CAV of the 2nd generation (aggressive CAV) will be reflected by assigning different utility functions for private cars to shares of the population. Using a CAV1 will be treated as 80% of the value of travel time savings (VTTS) of a private car, and a CAV2 as 75% the car's VTTS. The private cars will remain the same in regards of their driving behavior on the road. As the throughput of roads will increase with a higher automation rate due to more densely packed moving vehicles, the simulation model parameter "flow capacity factor" of the road network was adapted, to account for this effect. This was done in accordance with earlier project results obtained by microscopic simulations (PCU-Aimsun) and is also shown in (Table 3.2). The flow capacity factor is generally set to the percentage of population that is simulated (in our case 12.5%) as it represents the relative number of vehicles that can pass a link (Llorca and Moeckel, 2019).

The VTTS for riding an AUSS shuttle is set to 75% of a private car's VTTS following studies from literature (Fosgerau, 2019; Ho et al., 2015). Agents will be charged a time-based fare of 0.30 EUR/min.

The rationale behind setting the parameters for CAV1, CAV2 and AUSS is based on studies on the estimation of the VTTS for automated vehicles and shuttles. Whereas Lu et al. (2018) found no differences in the VTTS between drivers and passengers of a car, Fosgerau (2019) and Ho et al. (2015) come to the conclusion that the VTTS for a passenger can be regarded as about 75 % of the rate for car drivers. We follow in our model these latter findings and slightly increase the VTTS for CAV1 as the driving experience is assumed to be not as convenient as with an CAV2.

3.1.3 Scenarios

Within the mesoscopic simulation, we will consider two scenarios of the sub-use case of on-demand AUSS. In terms of implementation, point-to-point AUSS without dedicated lanes would work similarly to on-demand AUSS with the minor difference that users would only be able to board and alight from the shuttle vehicles at the defined points. An assignment of lanes for AUSS is technically possible but would require several assumptions which are difficult to define in a mesoscopic model.

For the subuse case of on-demand AUSS, the anywhere-to-anywhere AUSS as well as the last-mile AUSS will be simulated.

3.1.3.1. Anywhere-to-anywhere AUSS

The AUSS shuttle service in this sub-use case is implemented to operate in the city center and inner city areas as shown in Figure 3.1

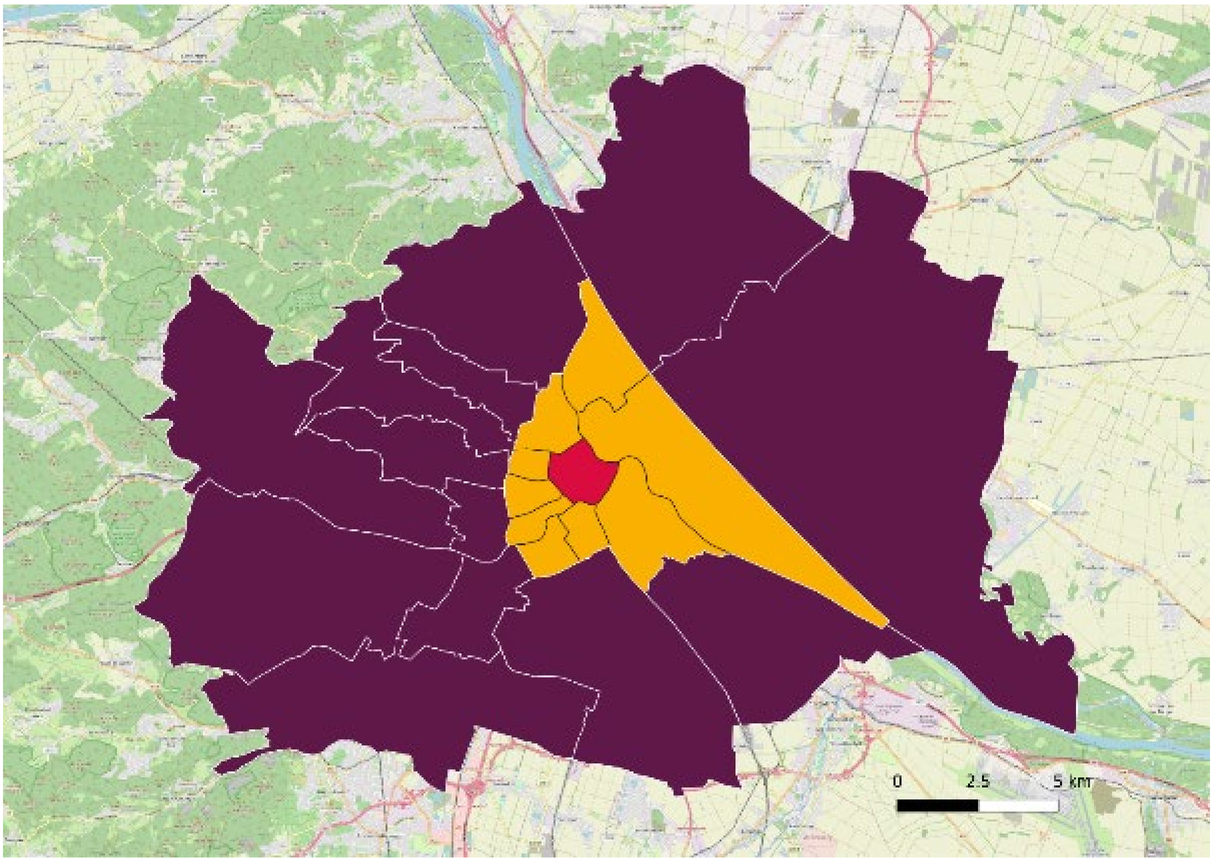


Figure 3.1: City center (red), inner city (orange) and inner peripheral areas (purple) of Vienna.

The shuttles are initially randomly distributed in the city center and inner city. Two different fleet sizes 250 and 500 vehicles are simulated. Since the mesoscopic simulation for Vienna is based on a 12.5% sample of the total population, the fleet sizes will correspond to 2000 and 4000 vehicles and thus be comparable to the taxi fleet in Vienna (there are around 7500 taxis registered in the entire city). In addition, three different scenarios of the economic situation of agents are simulated. The marginal utility of money was either left to the baseline settings (no economic change) or set to an increase/decrease of 5% of the ratio of disposable income and inflation rate. The common eight different market penetration rates (MPR) of privately owned CAV1 and CAV2 were simulated in addition for every constellation of fleet size and marginal utility of money as indicated in Table 3.2.

Table 3.2: The CAV market penetration rate scenarios

Type of Vehicle	A	B	C	D	E	F	G	H
Human-Driven Car	100%	80%	60%	40%	20%	0%	0%	0%
1st Generation (Cautious) CAV	0%	20%	40%	40%	40%	40%	20%	0%
2nd Generation (Aggressive) CAV	0%	0%	0%	20%	40%	60%	80%	100%
Flow capacity factor	0.1150	0.1205	0.1262	0.1317	0.1368	0.1413	0.1413	0.1413

3.1.3.2. Last-mile AUSS

The AUSS shuttle service is implemented to operate in 16 zones which are located in the periphery of the city as shown in Figure 3.2. For each of the zones, one AUSS fleet is defined as a new transport mode. This implementation is necessary to prevent interzonal trips with the vehicles. Starting locations for the AUSS were randomly selected inside these 16 zones. The routing becomes by the implementation of 16 additional modes very complex and it would require a lot of iterations until an agent would get the correct AUSS mode chosen for his/her plan. Therefore, the choice of transportation modes is restricted in the way that only the AUSS mode could be used, which operates in the zone of destination or origin of an agent's trip.

The zones are chosen in the way that at least one train or subway station with good connections to the inner city was within one zone. Zones also include larger areas when continuous settlement is evident in the periphery.

Figure 3.2: The purple zones mark the zones where the AUSS is operation. The shaded area indicates the intra-peripheral areas of the city.

The scenarios for the last-mile scenarios are similarly designed as the on-demand AUSS. Two different fleet sizes of 1118 and 2338 vehicles will be simulated, in addition to three different scenarios for the economic situation and the eight settings of market penetration rates (Table 3.2). The AUSS fleet sizes have been created in dependence of the number of facilities (locations where agents can perform an activity) in the zones. The marginal utility of money was either left to the baseline settings (no economic change) or set to an increase/decrease of 5% of the ratio of disposable income and inflation rate.

3.2 Delphi

3.2.1 Background of the Delphi method

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

3.2.2 The Delphi method within LEVITATE

Within LEVITATE, the Delphi method was used to determine all impacts that cannot be defined by the other quantitative methods (traffic microsimulation, system dynamics, operations research, etc.). Initially, a long list of experts was identified for each use case (i.e. urban transport, passenger cars and freight transport), and contacted via an introductory e-mail asking them to express a willingness to participate. Those who responded positively participated in the main Delphi process, amounting to 70 experts in total (5 experts accepted to answer to 2 questionnaires). Experts come from various organisations such as research institutes, companies and universities (presented in Figure 3.3), where they have different job positions, such as directors, professors and managers (presented in Figure 3.4) and they come from different countries (presented in Figure 3.5)

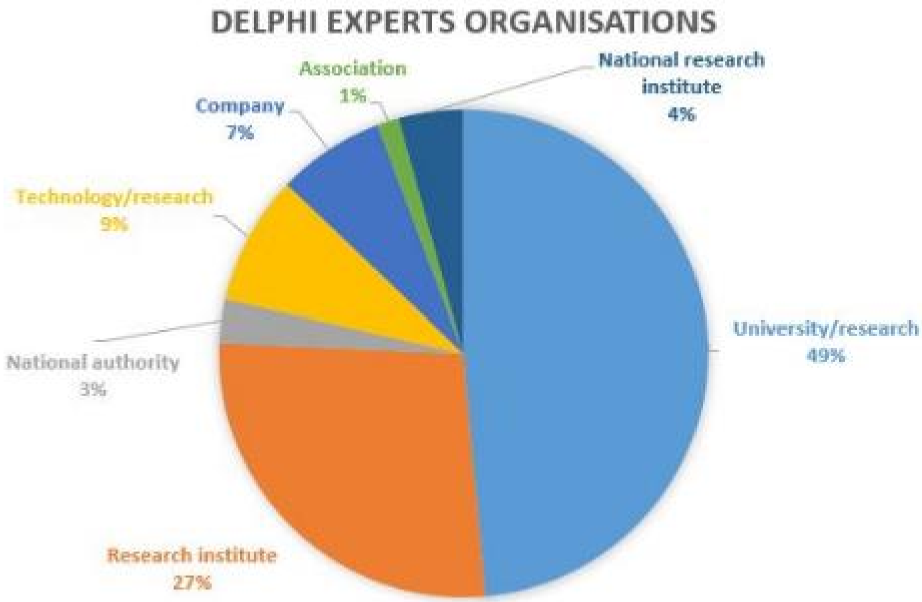


Figure 3.3: Delphi experts' organisations

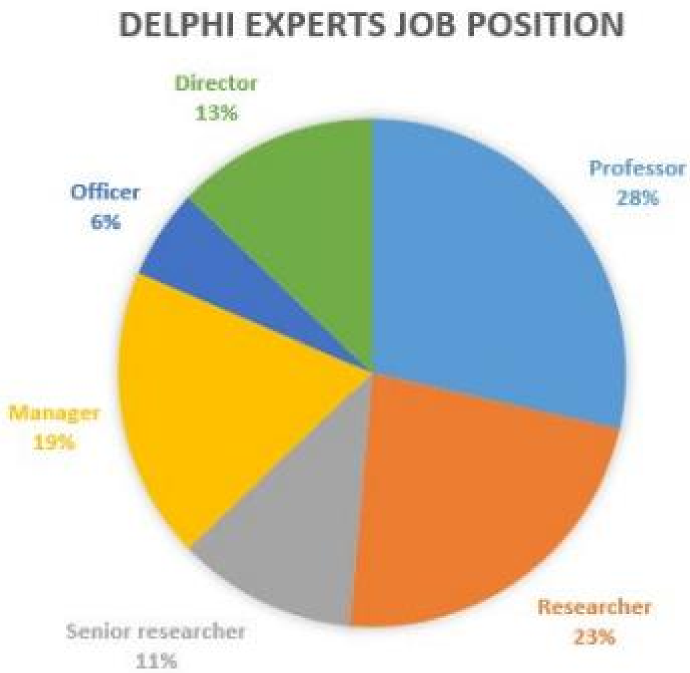


Figure 3.4: Delphi experts' job positions

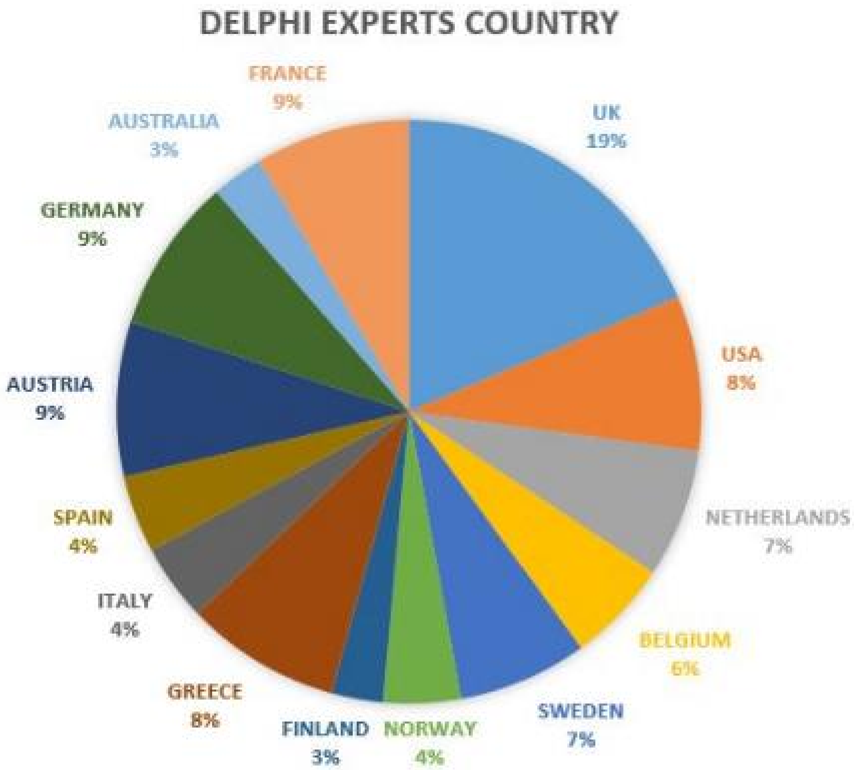
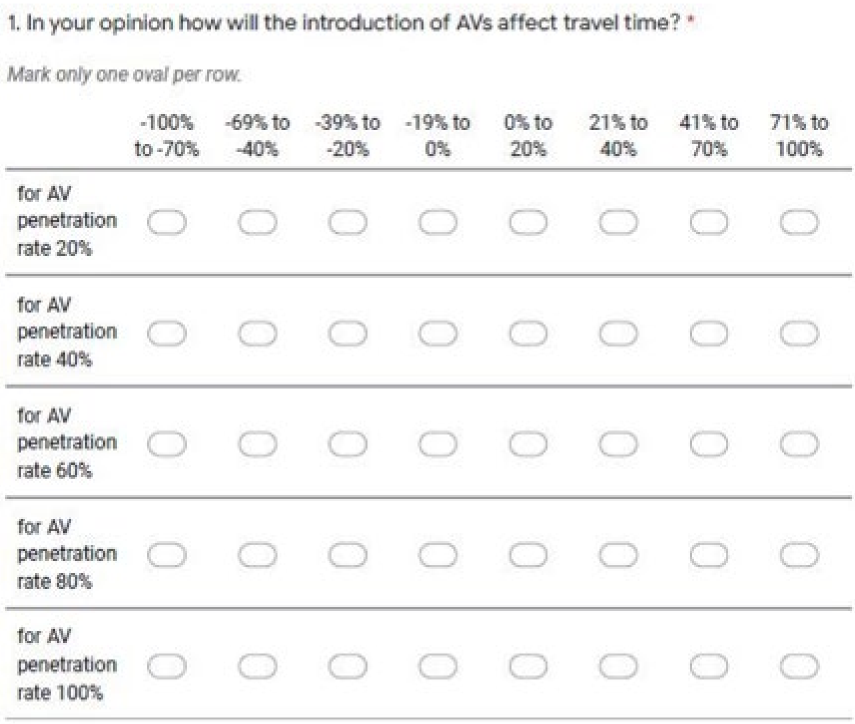


Figure 3.5: Delphi experts' countries

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

In each first round questionnaire, experts were asked about the influence of automation related interventions on the proposed impacts for different connected & automated vehicle (CAV) market penetration rates. The CAV market penetration rates used are 0% (the baseline scenario), 20%, 40%, 60%, 80% and 100%, as defined by micro-simulation scenarios; all impact assessment methods used in the LEVITATE have been using the same CAV market penetration rate scenarios to achieve uniformity of the different results. For each impact and each automation related scenario the participants were asked to indicate the percentage of change that the intervention would have for the mentioned CAV market penetration rates (Figure 3.6). The percentages varied from -100% to +100% where the negative (minus sign) was either an improvement or a deterioration depending on the type of impact. For example, a negative effect on travel time would mean a reduction and thus an improvement, while on the other hand a negative percentage of change on public health would mean a deterioration. The entire automated urban transport questionnaire can be found in the appendix.


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

Mark only one oval per row.

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

Figure 3.6: Example Delphi question

Participants were divided in seven groups. Each group had a different questionnaire related to a specific type of interventions based on their expertise. Each questionnaire concerned 2-4 automation related interventions, including the baseline scenario where no policy intervention is applied except the introduction of CAVs in the urban environment. The urban transport questionnaire included 5 scenarios: baseline scenario, point-to-point AUSS, anywhere to anywhere AUSS, last-mile AUSS and e-hailing. For LEVITATE WP5, 14 experts participated in the first Delphi round for the urban transport sub-use cases. The questionnaire was also separated with size limitations in mind, as passenger cars would constitute an immense single questionnaire if their sub-use cases were considered all at once. The Baseline scenario concerns the introduction of AVs in various MPRs from 20% to 100% (with a 20% increments) with no other policy intervention being applied. The point-to-point AUSS proposes the introduction of automated shuttles travelling between fixed stations, complementing existing urban transport. The anywhere-to-anywhere AUSS refers to the introduction of automated urban shuttles travelling between not fixed locations around the city. Last-mile AUSS refers to a service of automated urban shuttles providing convenient first/last mile solutions, complementing public transport. Finally, e-hailing is a service of booking automated shuttles in order to travel between convenient points around the city.

After the reception of the answers of the 1st Delphi round questionnaires, subsequent aggregation coding and analysis followed. For each intervention and each impact, a table was created: its rows represented the CAVs market penetration rates and the columns the different percentages of change (Table 3.3). All experts' answers were introduced in the table and then for each row (each CAVs market penetration rate) the percentage equal with the average of all answers was extracted.

Table 3.3: Example 1st round Delphi answers analysis

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

This percentage is the coefficient that will be used in the PST (Table 3.4). The conversion to percentage fluctuations ensures that the PST operates with different starting values provided either by default or by the user, to increase the flexibility and applicability of the tool.

Table 3.4: Example table PST coefficients

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

Additionally, for each impact, a graph was created representing the values of the percentages for the different CAV market penetration rates. The resulting graphs for all interventions and impacts were presented to the experts for the 2nd round of the Delphi, who were then asked whether they agreed with the 1st round results. In total, 9 out of the 14 participants of the 1st round participated in round 2. They were given the opportunity to propose different percentages in case they disagreed (Figure 3.7). These suggestions were then incorporated in the final coefficients introduced in the LEVITATE PST through a weighted average scheme to make sure that each expert contributes equally.

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

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

Figure 3.7: Example round 2 question

4 Obtained 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 developed in the present report 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. The short-term impacts for different sub-use cases are described in the following sub-sections. Systemic impacts are system-wide impacts within the transport system. These are measured indirectly from direct impacts and are considered medium-term. Wider impacts are changes occurring outside the transport system, such as changes in land use and employment. These are inferred impacts measured at a larger scale and are the result of direct and system wide impacts. They are considered to be long-term impacts.

4.1 Travel time

4.1.1 Mesoscopic simulation

The travel time refers to the time passengers spend for a 5km trip in the city centre. Figure 4.1 shows the average travel time of agents in the baseline scenario for all simulated MPRs of the mesoscopic simulation. Trips of 5km take around 60min and will reach an equilibrium once a 100% MPR is reached. The travel time is slightly longer for a marginal utility of money (mUoM). A higher value of this parameter indicates that agents react more sensitive to higher prices and therefore do not mind spending more time on slower means of transport. A lower mUoM in contrast represents a better economic situation of agents who are likely to spend more money on faster transportation. Details can be found in Axhausen et al. (2016).

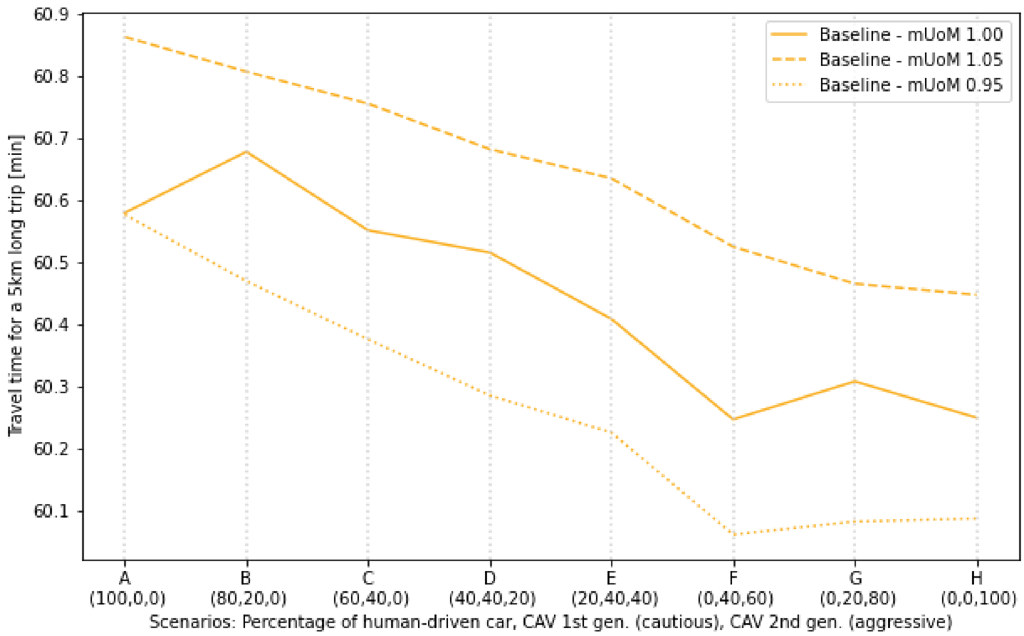


Figure 4.1: Average travel time (min) for 5km trips in the city centre of the baseline scenarios (no AUSS) for all MPR. Dashed lines indicate a higher marginal utility of money, dotted line a lower one.

Introducing anywhere-to-anywhere AUSS (Figure 4.2) leads to a dip of travel times in relation to the baselines with different MPR. While a smaller fleet size reduces travel times by up to 5%, larger fleet size of AUSS decrease them by up to 11%. A higher MPR has hereby a positive effect on the travel time reduction. When the economic situation of agents indicated by a lower mUoM gets better, the travel time savings are slightly lower and vice versa

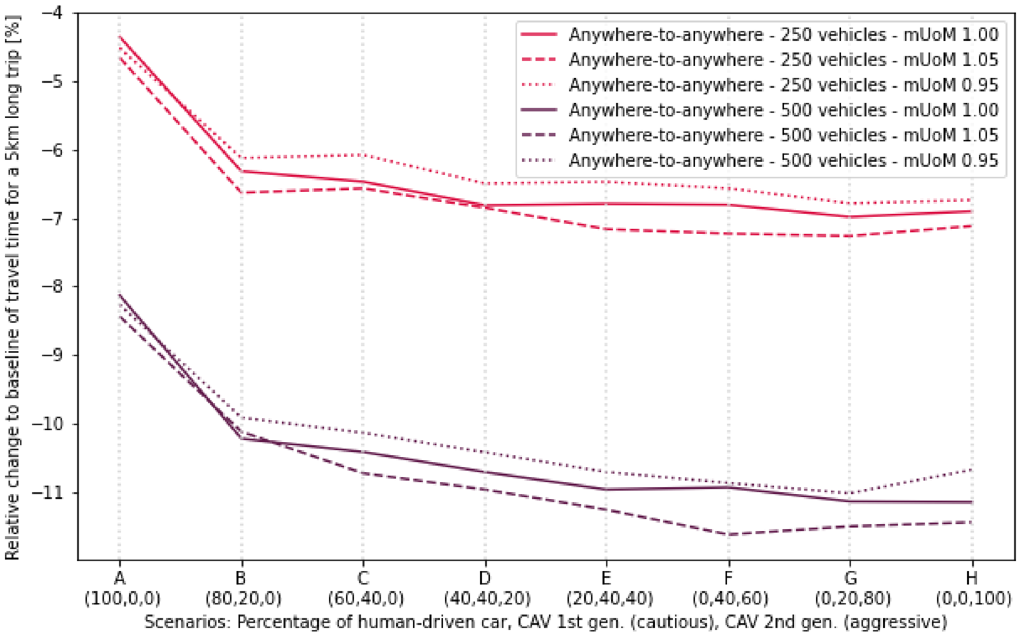


Figure 4.2: Average travel time (min) for 5km trips in the city of anywhere-to-anywhere AUSS for a smaller (red) and a larger (purple) AUSS fleet size. Dashed lines indicate a higher marginal utility of money, dotted line a lower one.

In the last-mile scenario (Figure 4.3), the travel time increases generally. This effect is explainable by the shorter duration of trips in this scenario in comparison to the anywhere-to-anywhere scenario. Agents still choose the new transport mode and take also longer travel times into account. The positive effects of AUSS on travel time predominate if higher MPR are reached and the mUoM increases.

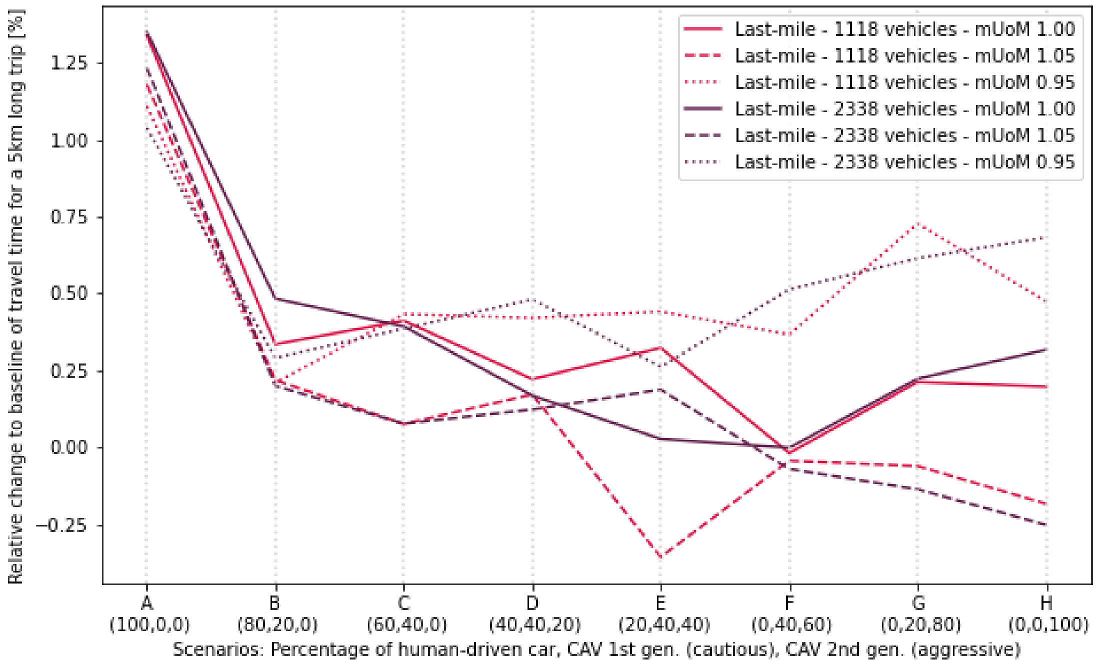


Figure 4.3: Average travel time (min) for 5km trips in the city of last-mile AUSS for a smaller (red) and a larger (purple) AUSS fleet size. Dashed lines indicate a higher marginal utility of money, dotted line a lower one.

In both scenarios, the travel times reduce significantly when the first private CAVs are introduced in the market. It is assumed that the first private CAVs lead to relative high attraction of AUSS, since they also benefit from the better traffic flow. This positive effect is relatively seen not that strong for higher MPR anymore.

4.1.2 Delphi method

The impact of the studied AUSS on travel time was also assessed in the Delphi method. According to the experts' answers in the first round of the Delphi (Figure 4.5), the introduction of AVs in the baseline scenario (no intervention) will increase travel time at a percentage of 25% for AV market penetration rates up to 60%. Then for AV market penetration rates from 60% to 100% the impact on travel time is reduced. This outcome is also supported by the literature, as it has been shown that mixed traffic (the use of urban roads by both conventional and automated vehicles) will have a small negative effect on traffic flow and road capacities, and that any improvement in traffic flow and thus travel time will only be seen at penetration rates above 70% (Calvert, et al., 2017). Regarding the urban transport sub-use cases experts suggested that there will be no significant impact on travel time by the introduction of point-to-point AUSS, last-mile AUSS and e-hailing. As it was also supported by mesoscopic simulation when these services are implemented in mixed traffic conditions (sharing the roads with conventional vehicles) travel time is higher than when only CAVs use the roads. Finally, the introduction of anywhere-to-anywhere AUSS will lead to a reduction of 20,5% on travel time for AV market penetration rate of 100%. The tendency to increase travel time for mixed traffic conditions and then reduce it when the majority of vehicles moving around the city are CAVs is common for all studied SUCs.

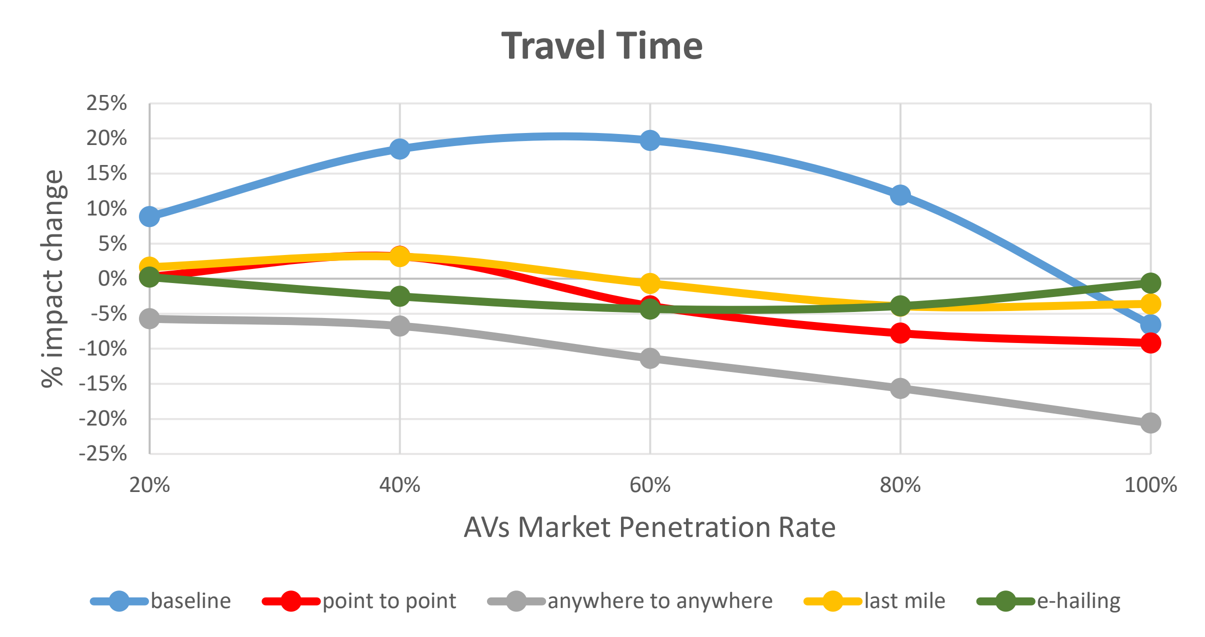


Figure 4.4: 1st round Delphi travel time results

All of the 2nd round participants stated that they agree definitely (33%-44%) or moderately (56%-67%) with the resulted 1st round curves (as seen in Figure 4.6 and Figure 4.7).

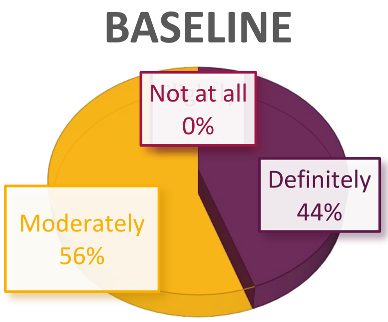


Figure 4.5: 2nd round Delphi results baseline scenario

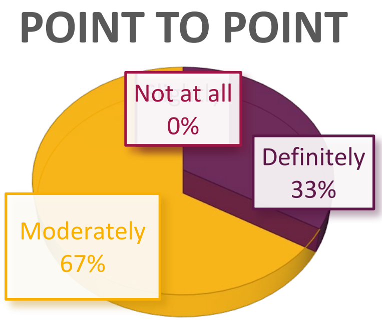


Figure 4.6: 2nd round Delphi results point-to-point AUSS

One expert suggested that the average percentage of impact of the different urban transport SUCs on travel time should be 5% for the baseline scenario, for the point-to-point AUSS and for anywhere-to-anywhere AUSS, 10% for the last-mile AUSS and 8% for e-hailing. These suggestions were taken into consideration in the final coefficients (Table 4.1) that will then be introduced in the PST, for the SUCs that the mesoscopic simulation has not quantified.

Table 4.1: Final coefficients for travel time

	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%	8,7%	1,087	0,5%	1,005	-5,2%	0,948	2,0%	1,020	0,6%	1,006
40%	17,9%	1,179	3,3%	1,033	-6,2%	0,938	3,4%	1,034	-2,1%	0,979
60%	19,1%	1,191	-3,5%	0,965	-10,6%	0,894	-0,2%	0,998	-3,8%	0,962
80%	11,6%	1,116	-7,2%	0,928	-14,7%	0,853	-3,3%	0,967	-3,4%	0,966
100%	-6,1%	0,939	-8,6%	0,914	-19,5%	0,805	-3,0%	0,970	-0,3%	0,997

4.2 Vehicle operating cost

Vehicle operating cost is considered as the direct outlays for operating a vehicle per kilometer of travel (€/km). The impact on vehicle operating cost of the introduction of automation in urban transport is estimated by the Delphi method. According to experts, the baseline scenario (no intervention) will lead to a slight increase for MPR up to 40% and then a small reduction of vehicle operating cost for AV market penetration rates up to 100%. This fluctuation is explained by the fact that during the early transition period, it will be more expensive to own an AV than a conventional vehicle. On the other hand, when fully automated AVs conquer the roads, the improved traffic flow will lead to less fuel consumption, and fewer collisions as a result of more law-abiding vehicles will lower demand for auto repair, and insurance (Clements & Kockelman, 2017). The introduction of last-mile AUSS and e-hailing will not affect more than 5% the studied impact regardless of the different AV market penetration rates. On the other hand, point-to-point AUSS and anywhere to anywhere AUSS will both reduce vehicle operating cost reaching a reduction of 16,5% and 21,8% respectively for AV market penetration rate of 100% and are suggested to be the most efficient services. This is explained by the fact that they merge the positives of automation and of ridesharing in public transport. These automated services could provide a higher level of service at lower cost than the current transit system since personnel costs will be reduced due to the removal of human factor and traffic flow will be improved leading to a more afficient service (Merlin, L.A., 2017).

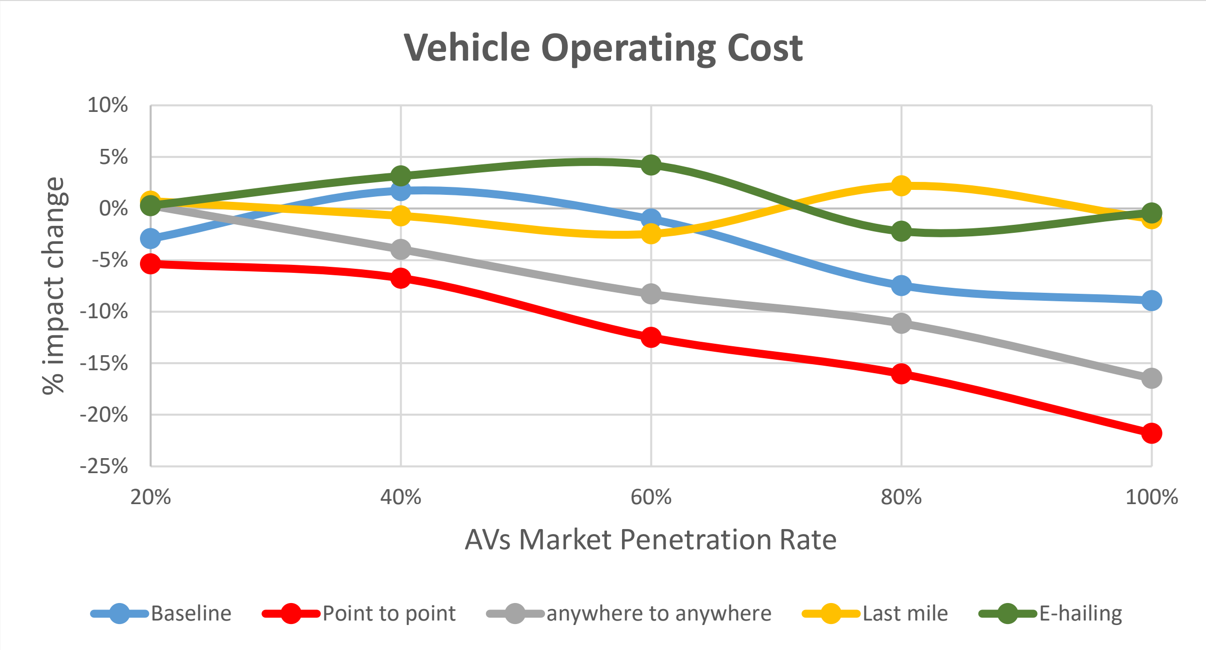


Figure 4.7: 1st round Delphi vehicle operating cost results

The majority of the 2nd round participants stated that they agree definitely (22%-33%) or moderately (45%-78%). Some experts (22%) slightly agreed with the resulted trends and proposed higher reduction of vehicle operation cost for Av market penetration rate of 100% reaching -50% for all scenarios.

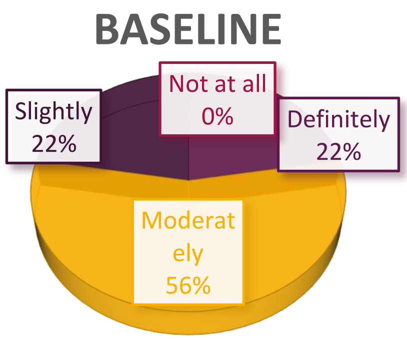


Figure 4.8: 2nd round Delphi results baseline scenario

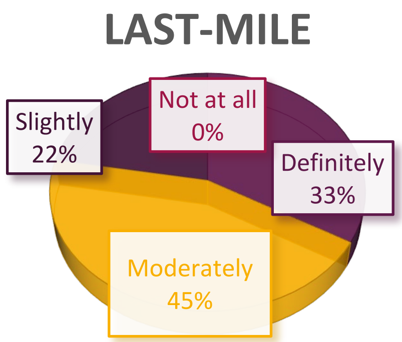


Figure 4.9: 2nd round Delphi results last-mile scenario

The 2nd round results and experts' suggestions were used to define the final PST coefficients.

Table 4.2: Final PST coefficients for vehicle operating cost

	Baseline	Point-to-point AUSS	Anywhere-to-	Last-mile AUSS	E-hailing

					anywhere AUSS					
AV penet ration rates	Aggr egate chan ge	PST coeffi cients	Aggr egate chan ge	PST coeffi cients	Aggr egate chan ge	PST coeffi cients	Aggr egate chan ge	PST coeffi cients	Aggr egate chan ge	PST coeffi cients
20%	-2,7%	0,973	-4,5%	0,955	0,3%	1,003	0,7%	1,007	0,3%	1,003
40%	1,1%	1,011	-6,2%	0,938	-4,1%	0,959	-1,1%	0,989	2,4%	1,024
60%	-1,8%	0,982	-11,8%	0,882	-8,4%	0,916	-3,1%	0,969	3,0%	1,030
80%	-8,3%	0,917	-15,7%	0,843	-11,7%	0,883	0,5%	1,005	-3,5%	0,965
100%	-10,3%	0,897	-21,6%	0,784	-17,2%	0,828	-3,1%	0,969	-2,6%	0,974

4.3 Access to travel

Access to travel is defined as the opportunity of taking a trip whenever and wherever wanted (10 points Likert scale which is a qualitative scale used to assess the level of agreement or disagreement with various statements). The estimate of the impact of automation on access to travel was made by using the Delphi method. The general experts' opinion was that the introduction of automation in urban transport will increase access to travel. More precisely, the introduction of AVs will not influence access to travel for AVs penetration rate up to 40%, then with the increase of AVs market penetration rate access to travel increases.This can be explained by the fact that in the early transition period, from conventional to automated vehicles, people will not trust AVs, as it was also suggested by several user acceptance studies, that showed a general reluctance to the overall adoption of AVs (Kyriakidis, Happee, & de Winter, 2015). Similarly, neutral or negative public opinion regarding AVs was proved by other studies (Clark, Parkhurst, & Ricci, 2016; Haboucha, Ishaq, & Shiftan, 2017). Additionally, AVs will be more expensive than a conventional vehicle and thus economically unapproachable, as willingness to pay is is a factor that influences adoption of CCAM. According to the survey conducted by the global market research company Power and Associates (2012), 37% of the participants (17400 vehicle owners), would purchase an automated driving mode. However, this percentage dropped to 20% when they were informed that the estimated market price would be 3000$. Regarding, the urban transport sub-use cases, they will all lead to a rise of access to travel for all AVs market penetration rates. Point-to-point AUSS will increase access to travel by 44% for 100% AVs market penetration rates, anywhere to anywhere AUSS will increase access to travel by 45,8%, last-mile AUSS will lead to a 30% rise in access to travel and finally e-hailing will increase the studied impact by 32,5%. These services being public will not require the purchase of an AV in order to travel, and thus the only factor that affects access to travel is user acceptance and the quality of services. Several studies were optimistic overall about the user acceptance of these systems (World Economic Forum, 2015; Bansal & Kockelman, 2017; Kyriakidis et al., 2015) and according to a study conducted by Pakusch and Bossauer (2017), willingness to use AVs is high (77,6%) and affected by previous experience with autonomous transport. The quality of the proposed services, will be improved with the rise of AVs MPR, as the improved traffic conditions will lead to a reduction on waiting times, benefiting public transport users (Tirachini & Antoniou, 2020). The services density will also improve and people from more city locations will have access to travel using the studied AUSS.

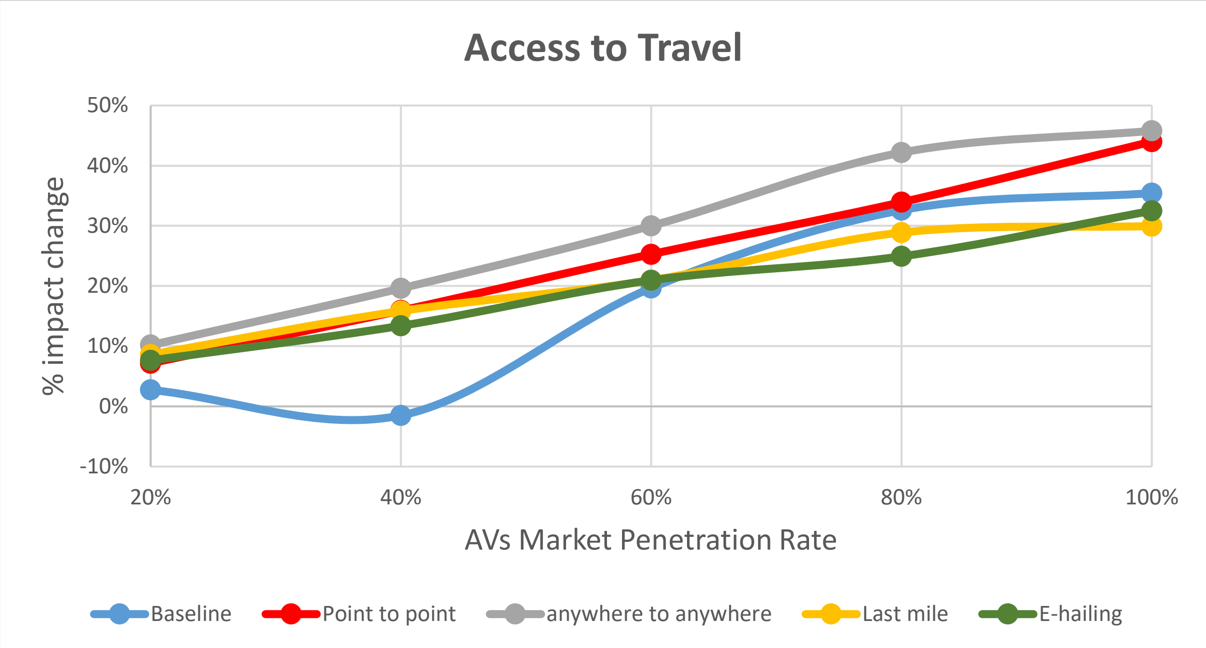


Figure 4.10: 1st round Delphi access to travel results

In the second Delphi round experts stated that they definitely (44%) and moderately (56%) agree with the curves of the 1st round. One expert suggested that none of the studied scenarios will affect negatively or positively the access to travel.

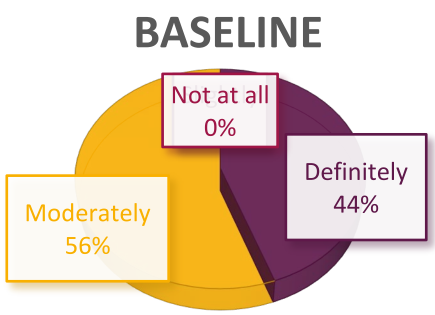


Figure 4.11: 2nd round Delphi results Baseline scenario

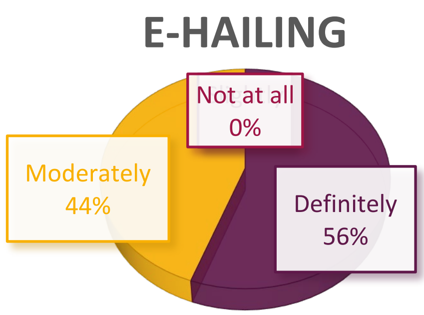


Figure 4.12: 2nd round Delphi results e-hailing scenario

The experts' opinion regarding the 2nd round results was used to calculate the final coefficients that will be added in the PST.

Table 4.3: Final PST coefficients for access to travel

	Baseline	**Point-to-point AUSS**	**Anywhere-to-**	**Last-mile AUSS**	**E-hailing**

					anywhere AUSS					
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	2,6%	1,026	6,9%	1,069	9,7%	1,097	8,2%	1,082	7,3%	1,073
40%	-1,4%	0,986	15,2%	1,152	18,8%	1,188	15,2%	1,152	12,8%	1,128
60%	18,8%	1,188	24,2%	1,242	28,7%	1,287	20,1%	1,201	20,1%	1,201
80%	31,2%	1,312	32,5%	1,325	40,3%	1,403	27,6%	1,276	23,8%	1,238
100%	33,9%	1,339	42,1%	1,421	43,8%	1,438	28,7%	1,287	31,1%	1,311

5 Discussion

Overall, the analyses regarding the short-term impacts of CCAM in urban transport reveal several interesting findings. Regarding the studied automated urban transport SUCs both methods, mesoscopic simulation and the Delphi method, suggested that travel time will reduce for higher AVs MPRs, as the proposed services will contribute to the amelioration of traffic conditions and the reduction of delay times. Vehicle operating cost and access to travel will be also positively influenced by the introduction of automated urban shuttle services, as it was suggested by the experts within the Delphi method.

The mesoscopic simulation results showed that travel time will be reduced for high CAV MPR after the introduction of CAVs in the urban environment, an outcome that is also suggested by the Delphi method experts as well as by the literature. More precisely, during the transition period when vehicles of various automation levels will share the roads along with conventional vehicles, travel time may increase because of the negative effect of mixed traffic on traffic flow and road capacities (Calvert, et al., 2017). In contrast, when the CAV MPR reaches higher levels, the connected systems will self-balance and optimize traffic flow and reduce congestion (Folsom, 2012). This is also the case for the studied AUSS, as their impact on travel time seems to be higher for higher AVs MPRs. The International Transport Forum (2015), simulated different scenarios of automated transport systems, penetration rates and availability of high-capacity public transport. This report stated that automated shuttles could replace conventional vehicles, offering equal levels of mobility with up to 89.6% (65% during rush hour) fewer vehicles on the roads, reducing congestion and travel time.

The findings of the Delphi method indicate that vehicle operating costs were projected to mostly decrease as CAV MPR increases. E-hailing and last-mile scenarios are estimated to produce an oscillating but ultimately not large change in vehicle operating costs. This outcome is explained by the fact that the human factor will be progressively removed from the driving procedure, and thus the CAVs will perform more efficiently. Additionally, according to Elvik (2020), the first commercially available autonomous cars will not be affordable to the majority of the customers. Nevertheless, over the time automated vehicles are considered to become inexpensive to most of the customers. However, these limitations should not be considered as prohibitive in public transport planning, especially if other costs are suppressed (such as reductions in personnel costs or delays).

As per the aggregated estimate of the Delphi panel, the impact of access to travel is expected to increase in all automated urban transport SUCs as MPR increases with the only exception being the baseline case which displays an initial dip towards 40% MPR. Most studies report that CCAM could increase travel demand by 3% to 27% due to changes in destination choices (for example, longer journeys), changes in transport mode (shift from public transport), and the introduction of new users. The key advantage of automated urban shuttle services is suggested to be the potential for offering a higher frequency of service in the off-peaks, provided the operating costs are lower than a conventional bus. Also, there is a potential for higher flexibility in adapting the supply to demand because of the lack of drivers' scheduling constraints (Alessandrini et al., 2014). According to the outcomes of hypothetical and realistic simulations in the city of Zurich, one shared automated vehicle could replace approximately 10 to 14 conventional vehicles (Boesch, Ciari, & Axhausen, 2016; Zhang, Guhathakurta, Fang, & Zhang, 2015).

Of course, 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, for example the mesoscopic simulation is using the MATSim model for Vienna 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 the 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, three impacts were considered as direct and presented in this report; namely travel time, vehicle operating cost and access to travel. Two methods were used in order to quantify these impacts; mesoscopic simulation and the Delphi method.

The results indicated that the introduction of CAVs in urban transport will reduce travel time, and vehicle operating cost and increase access to travel for high CAVs MPRs. The automated urban transport services studied within LEVITATE WP5 will positively affect the urban transport as they provide various destination choices, promoting the shift to public transport and the introduction of new users. At the same time, traffic conditions will be improved by the use of connected systems of CAVs and by the reduction of private vehicles in the urban roads, especially after the introduction of point-to-point AUSS. The majority of Delphi method participants agreed definitely or moderately with the resulted trends for all the impacts and all the studied SUCs, verifying that the obtained results are reasonable, as it was also supported by the literature.

6.2 Future work

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

1. Analysis of medium-term impacts using appropriate methodologies (Task 5.3).
2. Analysis of long-term impacts using appropriate methodologies (Task 5.4).
3. Formulation of policy recommendations (Task 5.5).
4. Provision of input to WP8 for the development of the PST regarding urban transport.

Tasks 5.3 and 5.4 will respectively assess medium- and long-term impacts, as they are presented in deliverable 3.1 of LEVITATE (Elvik et al., 2019). Each type of impact will be forecasted using the appropriate assessment methods. These methods are microscopic and mesoscopic simulations used to identify the medium-term impacts, system dynamics that is a system level analysis providing long-term impacts analysis, and the Delphi method for the impacts that the aforementioned methods cannot quantify. The impact assessment outcomes 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 feed into WP8 for the creation of the online dynamic tool.

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7 Appendix

LEVITATE: Delphi questionnaire for the introduction of AVs in urban transport

The aim of the LEVITATE project (https://levitate-project.eu/) is to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives. As part of this work the LEVITATE project seeks to forecast societal level impacts of connected and automated transport systems (CATS). These include impacts on safety, environment, economy and society.

Within the activities of LEVITATE, the Delphi method will receive expert opinions on the fluctuations of various network-related impacts based on the onset of automation in general and on specific interventions in particular. To that end, your expertise on this subject would be of great value to this project, as it will help us quantify the impacts of CATS in urban areas.

The Delphi method will consist of two rounds of e-mails. During the first round you will fill in this questionnaire (30min duration) regarding the baseline scenario and 4 automation interventions related to automated urban transport. You will then be asked to evaluate their potential influence on different impact areas. Your answers will be then analyzed and we will create anonymized summaries for the different CATS related interventions which will be sent during the second round of the Delphi, giving you the opportunity to change your answer or retain the original.

For more information you can find the participant information sheet in the following link. https://www.dropbox.com/s/bmzfdv8yy8946j1/LEVITATE-Delphi%20method-Participant%20Information%20Sheet%20and%20Consent%20Form%202.pdf?dl=0

*Required

Informed Consent Form

Please read carefully the following statements:

Taking Part

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethics Approvals (Human Participants) Sub-Committee.
I have read and understood the information sheet and this consent form.
I have had an opportunity to ask questions about my participation.
I understand that taking part in the project will involve providing personal information.
I understand that the personal information collected will be email address.
I understand that I am under no obligation to take part in the study, have the right to withdraw from this study at any stage for any reason, and will not be required to explain my reasons for withdrawing.

Use of Information

I understand that all the personal information I provide will be processed in accordance with data protection legislation on the public task basis and will be treated in strict confidence unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others or for audit by regulatory authorities.
I understand that information I provide will be used for the LEVITATE PST, publications and reports.

1. I voluntarily agree to take part in this study. *

Mark only one oval.

- Yes, i agree and i accept the conditions that are described in the Informed Consent Form *Skip to question 2*
- No, i do not agree and i do not accept the conditions that are described in the Informed Consent Form *Skip to section 3 (Thank you for your time)*

Skip to question 2

Thank you for your time

2. Please fill-in your email address *

____

Baseline scenario	Impacts estimation after the introduction of Automated Vehicles in the urban environment. The questions regarding the impacts are multiple choice. You are asked to choose between different groups of percentages that range from -100% to 100% and represent a percentage of improvement or worsening of the respective impact. Please keep in mind that while negative percentage signs constitute a deterioration for some impacts (such as public health), they constitute an improvement for other impacts (such as travel time).

Terminology 1/2

Impacts		Description/ Measurement
1.	Travel time	Average duration of a 5km trip inside the city centre
2.	Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel (€/km)
3.	Amount of travel	Person kilometres of travel per year in an area
4.	Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)
5.	Modal split of travel using public transport	% of trip distance made using public transportation
6.	Modal split of travel using active travel	% of trip distance made using active transportation (walking, cycling)

Terminology 2/2

Impacts		Description/ Measurement
7.	Shared mobility rate	% of trips made sharing a vehicle with others
8.	Vehicle utilisation rate	% of time a vehicle is in motion (not parked)
9.	Vehicle occupancy	average % of seats in use
10.	Parking space	Required parking space in the city centre per person (m2/person)
11.	Energy efficiency	Average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%)
12.	Public health	Subjective rating of public health state, related to transport (10 points Likert scale)
13.	Inequality in transport	To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)

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

Mark only one oval per row.

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

4. 2. In your opinion how will the introduction of AVs affect vehicle operating cost? *

Mark only one oval per row.

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

5. 3. In your opinion what will be the impact of the introduction of AVs on the access to travel? *

Mark only one oval per row.

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

6. 4. At what percentage do you consider that the introduction of AVs will affect the amount of travel? *

Mark only one oval per row.

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

7. 5. In your opinion what will be the impact on modal split of travel using public transport after the introduction of AVs? *

Mark only one oval per row.

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

8. 6. In your opinion what will be the impact on modal split of travel using active travel after the introduction of AVs? *

Mark only one oval per row.

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

9. 7. In your opinion what will be the impact on shared mobility rate after the introduction of AVs? *

Mark only one oval per row.

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

10. 8. In your opinion what will be the impact on vehicle utilization rate after the introduction of AVs? *

Mark only one oval per row.

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

11. 9. What will be the impact on vehicle occupancy after the introduction of AVs? *

Mark only one oval per row.

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

12. 10. In your opinion how will the introduction of AVs affect parking space? *

Mark only one oval per row.

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

13. 11. At what percentage do you consider that the introduction of AVs will affect energy efficiency? *

Mark only one oval per row.

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

14. 12. In your opinion what will be the impact of the introduction of AVs on public health? *

Mark only one oval per row.

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

15. 13. In your opinion what will be the impact of the introduction of AVs on inequality in transport? *

Mark only one oval per row.

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

Point to point automated urban shuttle service

Introduction of point to point urban AV shuttles: Automated urban shuttles travelling between fixed stations, complementing existing urban transport.

The questions regarding the impacts are multiple choice. You are asked to choose between different groups of percentages that range from -100% to 100% and represent a percentage of improvement or worsening of the respective impact. Please keep in mind that while negative percentage signs constitute a deterioration for some impacts (such as public health), they constitute an improvement for other impacts (such as travel time).

Terminology 1/2

Impacts	Description/ Measurement
1. Travel time	Average duration of a 5km trip inside the city centre
2. Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel (€/km)
3. Amount of travel	Person kilometres of travel per year in an area
4. Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)
5. Modal split of travel using public transport	% of trip distance made using public transportation
6. Modal split of travel using active travel	% of trip distance made using active transportation (walking, cycling)

Terminology 2/2

Impacts	Description/ Measurement
7. Shared mobility rate	% of trips made sharing a vehicle with others
8. Vehicle utilisation rate	% of time a vehicle is in motion (not parked)
9. Vehicle occupancy	average % of seats in use
10. Parking space	Required parking space in the city centre per person (m2/person)
11. Energy efficiency	Average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%)
12. Public health	Subjective rating of public health state, related to transport (10 points Likert scale)
13. Inequality in transport	To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)

16. 1. In your opinion how will the introduction of point to point automated urban shuttle service affect travel time? *

Mark only one oval per row.

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

17. 2. In your opinion how will the introduction of point to point automated urban shuttle service affect vehicle operating cost? *

Mark only one oval per row.

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

18. 3. In your opinion what will be the impact of the introduction of point to point automated urban shuttle service on the access to travel? *

Mark only one oval per row.

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

19. 4. At what percentage do you consider that the introduction of point to point automated urban shuttle service will affect the amount of travel? *

Mark only one oval per row.

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

20. 5. In your opinion what will be the impact on modal split of travel using public transport after the introduction of point to point automated urban shuttle service? *

Mark only one oval per row.

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

21. 6. In your opinion what will be the impact on modal split of travel using active travel after the introduction of point to point automated urban shuttle service ? *

Mark only one oval per row.

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

22. 7. In your opinion what will be the impact on shared mobility rate after the introduction of point to point automated urban shuttle service ? *

Mark only one oval per row.

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

23. 8. In your opinion what will be the impact on vehicle utilization rate after the introduction of point to point automated urban shuttle service ? *

Mark only one oval per row.

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

24. 9. What will be the impact on vehicle occupancy after the introduction of point to point automated urban shuttle service ? *

Mark only one oval per row.

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

25. 10. In your opinion how will the introduction of point to point automated urban shuttle service affect parking space? *

Mark only one oval per row.

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

26. 11. At what percentage do you consider that the introduction of point to point automated urban shuttle service will affect energy efficiency? *

Mark only one oval per row.

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

27. 12. In your opinion what will be the impact of the introduction of point to point automated urban shuttle service on public health? *

Mark only one oval per row.

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

28. 13. In your opinion what will be the impact of the introduction of point to point automated urban shuttle service on the inequality in transport? *

Mark only one oval per row.

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

Anywhere to anywhere automated urban shuttle service

The following questions concern the introduction of an 'anywhere-to-anywhere' automated urban shuttle service: Automated urban shuttles travelling between not fixed locations.

The questions regarding the impacts are multiple choice. You are asked to choose between different groups of percentages that range from -100% to 100% and represent a percentage of improvement or worsening of the respective impact. Please keep in mind that while negative percentage signs constitute a deterioration for some impacts (such as public health), they constitute an improvement for other impacts (such as travel time).

Terminology 1/2

Impacts	Description/ Measurement
1. Travel time	Average duration of a 5km trip inside the city centre
2. Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel (€/km)
3. Amount of travel	Person kilometres of travel per year in an area
4. Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)
5. Modal split of travel using public transport	% of trip distance made using public transportation
6. Modal split of travel using active travel	% of trip distance made using active transportation (walking, cycling)

Terminology 2/2

Impacts	Description/ Measurement
7. Shared mobility rate	% of trips made sharing a vehicle with others
8. Vehicle utilisation rate	% of time a vehicle is in motion (not parked)
9. Vehicle occupancy	average % of seats in use
10. Parking space	Required parking space in the city centre per person (m2/person)
11. Energy efficiency	Average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%)
12. Public health	Subjective rating of public health state, related to transport (10 points Likert scale)
13. Inequality in transport	To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)

29. 1. In your opinion how will the introduction of anywhere to anywhere automated urban shuttle service affect travel time? *

Mark only one oval per row.

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

31. 2. In your opinion how will the introduction of anywhere to anywhere automated urban shuttle service affect vehicle operating cost? *

Mark only one oval per row.

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

32. 3. In your opinion what will be the impact of the introduction of anywhere to anywhere automated urban shuttle service on the access to travel? *

Mark only one oval per row.

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

33. 4. At what percentage do you consider that the introduction of anywhere to anywhere automated urban shuttle service will affect the amount of travel? *

Mark only one oval per row.

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

34. 5. In your opinion what will be the impact on modal split of travel using public transport after the introduction of anywhere to anywhere automated urban shuttle service? *

Mark only one oval per row.

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

35. 6. In your opinion what will be the impact on modal split of travel using active travel after the introduction of anywhere to anywhere automated urban shuttle service ? *

Mark only one oval per row.

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

36. 7. In your opinion what will be the impact on shared mobility rate after the introduction of anywhere to anywhere automated urban shuttle service ? *

Mark only one oval per row.

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

37. 8. In your opinion what will be the impact on vehicle utilization rate after the introduction of anywhere to anywhere automated urban shuttle service ? *

Mark only one oval per row.

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

38. 9. What will be the impact on vehicle occupancy after the introduction of anywhere to anywhere automated urban shuttle service ? *

Mark only one oval per row.

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

39. 10. In your opinion how will the introduction of anywhere to anywhere automated urban shuttle service affect parking space? *

Mark only one oval per row.

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

40. 11. At what percentage do you consider that the introduction of anywhere to anywhere automated urban shuttle service will affect energy efficiency? *

Mark only one oval per row.

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

41. 12. In your opinion what will be the impact of the introduction of anywhere to anywhere automated urban shuttle service on public health? *

Mark only one oval per row.

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

42. 13. In your opinion what will be the impact of the introduction of anywhere to anywhere automated urban shuttle service on the inequality in transport? *

Mark only one oval per row.

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

Last-mile automated urban shuttle service	The following questions concern the introduction of a 'last-mile' automated urban shuttle service: Automated urban shuttles providing convenient first/last mile solutions, complementing public transport. The questions regarding the impacts are multiple choice. You are asked to choose between different groups of percentages that range from -100% to 100% and represent a percentage of improvement or worsening of the respective impact. Please keep in mind that while negative percentage signs constitute a deterioration for some impacts (such as public health), they constitute an improvement for other impacts (such as travel time).

Terminology 1/2

Impacts	Description/ Measurement
1. Travel time	Average duration of a 5km trip inside the city centre
2. Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel (€/km)
3. Amount of travel	Person kilometres of travel per year in an area
4. Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)
5. Modal split of travel using public transport	% of trip distance made using public transportation
6. Modal split of travel using active travel	% of trip distance made using active transportation (walking, cycling)

Terminology 2/2

Impacts	Description/ Measurement
7. Shared mobility rate	% of trips made sharing a vehicle with others
8. Vehicle utilisation rate	% of time a vehicle is in motion (not parked)
9. Vehicle occupancy	average % of seats in use
10. Parking space	Required parking space in the city centre per person (m2/person)
11. Energy efficiency	Average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%)
12. Public health	Subjective rating of public health state, related to transport (10 points Likert scale)
13. Inequality in transport	To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)

43. 1. In your opinion how will the introduction of last-mile automated urban shuttle service affect travel time? *

Mark only one oval per row.

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

44. 2. In your opinion how will the introduction of last-mile automated urban shuttle service affect vehicle operating cost? *

Mark only one oval per row.

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

45. 3. In your opinion what will be the impact of the introduction of last-mile automated urban shuttle service on the access to travel? *

Mark only one oval per row.

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

46. 4. At what percentage do you consider that the introduction of last-mile automated urban shuttle service will affect the amount of travel? *

Mark only one oval per row.

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

47. 5. In your opinion what will be the impact on modal split of travel using public transport after the introduction of last-mile automated urban shuttle service? *

Mark only one oval per row.

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

48. 6. In your opinion what will be the impact on modal split of travel using active travel after the introduction of last-mile automated urban shuttle service? *

Mark only one oval per row.

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

49. 7. In your opinion what will be the impact on shared mobility rate after the introduction of last-mile automated urban shuttle service? *

Mark only one oval per row.

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

50. 8. In your opinion what will be the impact on vehicle utilization rate after the introduction of last-mile automated urban shuttle service? *

Mark only one oval per row.

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

51. 9. What will be the impact on vehicle occupancy after the introduction of last-mile automated urban shuttle service? *

Mark only one oval per row.

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

52. 10. In your opinion how will the introduction of last-mile automated urban shuttle service affect parking space? *

Mark only one oval per row.

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

53. 11. At what percentage do you consider that the introduction of last-mile automated urban shuttle service will affect energy efficiency? *

Mark only one oval per row.

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

54. 12. In your opinion what will be the impact of the introduction of last-mile automated urban shuttle service on public health? *

Mark only one oval per row.

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

55. 13. In your opinion what will be the impact of the introduction of last-mile automated urban shuttle service on the inequality in transport? *

Mark only one oval per row.

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

E-hailing

The following questions concern the introduction of 'e-hailing': on-demand last-mile AV shuttles.

The questions regarding the impacts are multiple choice. You are asked to choose between different groups of percentages that range from -100% to 100% and represent a percentage of improvement or worsening of the respective impact. Please keep in mind that while negative percentage signs constitute a deterioration for some impacts (such as public health), they constitute an improvement for other impacts (such as travel time).

Terminology 1/2

Impacts	Description/ Measurement
1. Travel time	Average duration of a 5km trip inside the city centre
2. Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel (€/km)
3. Amount of travel	Person kilometres of travel per year in an area
4. Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)
5. Modal split of travel using public transport	% of trip distance made using public transportation
6. Modal split of travel using active travel	% of trip distance made using active transportation (walking, cycling)

Terminology 2/2

Impacts	Description/ Measurement
7. Shared mobility rate	% of trips made sharing a vehicle with others
8. Vehicle utilisation rate	% of time a vehicle is in motion (not parked)
9. Vehicle occupancy	average % of seats in use
10. Parking space	Required parking space in the city centre per person (m2/person)
11. Energy efficiency	Average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%)
12. Public health	Subjective rating of public health state, related to transport (10 points Likert scale)
13. Inequality in transport	To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)

56. 1. In your opinion how will the introduction of e-hailing affect travel time? *

Mark only one oval per row.

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

57. 2. In your opinion how will the introduction of e-hailing affect vehicle operating cost?
*

Mark only one oval per row.

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

58. 3. In your opinion what will be the impact of the introduction of e-hailing on the access to travel? *

Mark only one oval per row.

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

59. 4. At what percentage do you consider that the introduction of e-hailing will affect the amount of travel? *

Mark only one oval per row.

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

60. 5. In your opinion what will be the impact on modal split of travel using public transport after the introduction of e-hailing? *

Mark only one oval per row.

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

61. 6. In your opinion what will be the impact on modal split of travel using active travel after the introduction of e-hailing? *

Mark only one oval per row.

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

62. 7. In your opinion what will be the impact on shared mobility rate after the introduction of e-hailing? *

Mark only one oval per row.

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

63. 8. In your opinion what will be the impact on vehicle utilization rate after the introduction of e-hailing? *

Mark only one oval per row.

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

64. 9. What will be the impact on vehicle occupancy after the introduction of e-hailing? *

Mark only one oval per row.

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

65. 10. In your opinion how will the introduction of e-hailing affect parking space? *

Mark only one oval per row.

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

66. 11. At what percentage do you consider that the introduction of e-hailing will affect energy efficiency? *

Mark only one oval per row.

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

67. 12. In your opinion what will be the impact of the introduction of e-hailing on public health? *

Mark only one oval per row.

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

68. 13. In your opinion what will be the impact of the introduction of e-hailing on the inequality in transport? *

Mark only one oval per row.

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

Thank you very much !!

69. Your input will be invaluable in determining and forecasting societal level impacts of connected and automated transport systems (CATS). We would like to acknowledge the experts that have helped us, please tick the box if you would like to be added to the experts list that will be published with the project results.

Tick all that apply.

☐ Yes, i would like to be included in the experts list