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Guidelines and recommendations for future policy of automated urban transport

Deliverable D5.5 – WP5 – PU

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Guidelines and recommendations for future policy of automated urban transport

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Table of contents

List of abbreviations i
Technical definitions ii
About LEVITATE iv
Executive summary 1
1 Introduction 5
  1.1 General LEVITATE approach 5
  1.2 Work Package 5 7
  1.3 Purpose and structure of report 9
2 Background 11
  2.1 Urban mobility and transport goals 11
  2.2 Expected impacts automation 13
  2.3 Expected impacts of automated urban transport 15
  2.4 Sub-use cases 18
  2.5 Approach to synthesizing results 20
3 Main findings: quantified impacts 23
  3.1 Impacts on the environment 23
  3.2 Impacts on mobility 25
  3.3 Impacts on society, safety & economy 30
4 Discussion 35
  4.1 Main findings 35
    4.1.1 Impacts on Environment 35
    4.1.2 Impacts on Mobility 36
    4.1.3 Impacts on Society, safety & economy 38
  4.2 Strengths and Limitations 39
  4.3 Policy issues concerning implementation 41
    4.3.1 Governance of automated mobility in urban environments 41
    4.3.2 Experiences with urban shuttle services 44
5 Conclusions and Recommendations 50
  5.1 Conclusions 50
  5.2 Policy recommendations 53
References 55
Appendix A Methods and operationalisation 63
Appendix B CAV parameters in microsimulation 67

Appendix C Full results 1

List of abbreviations

AUSS	Automated Urban Shuttle Service
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AV	Automated Vehicle
A2A	Anywhere-to-anywhere shuttle service
CACC	Cooperative Adaptive Cruise Control
CCAM	Cooperative, connected and automated mobility
CATS	Connected and Automated Transport Systems
CAV	Connected and Automated Vehicle
CCAM	Cooperative, Connected and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
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
GLOSA	Green light optimal speed advisory
ISA	Intelligent Speed Assist
LCA	Lane Change Assist
LDW	Lane Departure Warning
LKA	Lane Keeping Assist
MPR	Market Penetration Rate
NHTSA	National Highway Traffic Safety Administration
NRC	National Research Council
PST	Policy Support Tool
SAE	Society of Automotive Engineers
SAV	Shared Autonomous Vehicle
SAEV	Shared Autonomous Electric Vehicles
SRG	Stakeholder Reference Group
SUC	Sub-Use Case
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to everything
VKT	Vehicle Kilometres Travelled

Technical definitions

Indicator	Definition or operationalisation (and relevance)
Amount of travel	The amount of travel is defined as the number of person (or vehicle) kilometres travelled in a year in a particular study area, region or country. This is generally a measure of mobility and reflects the total displacement of people, goods and vehicles in a given time period and region. This can be disaggregated to reflect for example specific modes or commodities. In LEVITATE we generally refer to person-km travelled. The amount of travel has an obvious relevance for transport policy and is a primary indicator of mobility. Changes in mobility needs impact on traffic safety, environment, accessibility, infrastructure provision and other policy domains.
Emissions	In LEVITATE the emissions are defined as the (total) amount of vehicle exhaust emissions and expressed by the amount of carbon dioxide (CO_2), nitrogen oxides (NOX) and particulate matter (PM10) emissions in kilogrammes/km or kilotons. In LEVITATE WP5 the focus is on carbon dioxide emissions although particulates and NOX are also briefly discussed.
Energy efficiency	Energy efficiency was defined as the average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%).
Equal accessibility of transport	The equal accessibility of transport was defined as the degree to which transport services are used by socially disadvantaged and vulnerable groups including people with disabilities.
First generation automated vehicles	Vehicles having limited sensing and cognitive ability, long gaps, early anticipation of lane changes than human driven vehicles and longer time in give way situations. The performance of these vehicles has been compared with a cautious driving style.
Modal split	Modal split (or modal share) describes the relationship between the means of transport (the modes) and the volume (number) of persons or commodities transported by each mode within a region. So, in effect it is the proportion of travellers using a specific type of transport. By modal split we typically refer to the percentages of people travelling on foot (walking); cycling; by bus, train or other public transport, in private cars etc. In freight transport we may distinguish on the basis of the mass (or volume) of specific (categories) commodities being transported by specific vehicle types. Modal split is one of the most essential inputs for transportation planning and modelling and is equally important for transport policies. For example, an increasing demand for travel by private cars in favour of public transport is generally enough incentive for decision makers to take steps to improve public transport or to discourage private transport through pricing or other disincentives.
Parking space	Parking space is defined as the required parking space in the city centre per person (m2/person).

Indicator	Definition or operationalisation (and relevance)
Public health	Public health was operationalised as a subjective rating of public health state, related to transport.
Road safety	Within LEVITATE, road safety impacts were estimated from a combination of the AIMSUM microsimulation using the Surrogate Safety Assessment Model (SSAM), estimates of crashes involving vehicles and vulnerable road users and other secondary impacts. In the microsimulation estimates crashes involve only motorised vehicles (cars, buses and trucks) whereas crashes involving vulnerable road users (cyclists and pedestrians) were estimated from accident statistics, based on data from Austria and Vienna. In the estimation of road safety impacts crashes for motorised traffic (from SSAM) were expressed as crash rates (crashes per 1000 veh.km) and for crashes involving vulnerable road users as absolute numbers. For both these the effect on CAV introduction was expressed as a percentage change.
Second generation automated vehicles	Vehicles having advanced sensing and cognitive ability, data fusion usage, confident in taking decisions, small gaps, early anticipation of lane changes than human driven vehicles and less time in give way situations. The performance of these vehicles has been compared with an 'aggressive' driving style.
Shared mobility rate	The shared mobility rate in LEVITATE is defined as the proportion of trips that are made by persons sharing a particular mode of transport with others and is a proxy to vehicle occupancy. This aspect is also relevant for transport policy particularly where large numbers of private cars are used to transport relatively low numbers of people. Influencing vehicle occupancy may hold significant benefits for reducing the demand for road space by reducing the number of vehicles. This has significant benefits for all policy domains.
Vehicle utilization rate	Within LEVITATE the vehicle utilisation rate is considered as the percentage of time a vehicle is in motion (not parked). Vehicle utilisation is particularly relevant for freight and public transport vehicle operators where vehicles need to be optimally utilised to minimise operating costs. For road authorities this is an indicator for, for e.g., the demand for parking versus the demand for road capacity.

About LEVITATE

Societal Level Impacts of Connected and Automated Vehicles (LEVITATE) is a European Commission supported Horizon 2020 project with the objective to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, to maximise the benefits and to utilise these technologies to achieve societal objectives.

Connected and automated transport systems (CATS), or recently the more accepted term Cooperative, Connected and Automated Mobility (CCAM), are expected to be introduced in increasing numbers over the next decade. Automated vehicles have attracted the public imagination and there are high expectations in terms of traffic safety, mobility, environment and economic growth. With such systems not yet in widespread use, there is a lack of data and knowledge about impacts.

The potentially disruptive nature of highly automated vehicles makes it very difficult to determine future impacts from historic patterns. Estimates of future impacts of automated and connected mobility systems may be based on forecasting approaches, yet there is no agreement over the methodologies nor the baselines to be used. The need to measure the impact of existing systems as well as forecasting the impact of future systems represents a major challenge. The dimensions for assessment are themselves quite broad ranging from impacts on traffic safety to the environment and potentially including sub-divisions within the domains which adds to the complexity of future mobility forecasts.

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 back casting** 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 toolbox allowing the impact of measures to be assessed individually. A Decision Support System will enable users to apply back casting methods to identify the sequences of CCAM measures that will result in their desired policy objectives.

Executive summary

Goals and impacts

Mobility of people and goods is the lifeline of the modern city. In planning for future urban mobility, European cities like Manchester and Vienna have set goals in which future mobility should contribute to a cleaner city environment, to easier, more comfortable, more cost-effective travel within the city, and to a better, more inclusive society with equal travel opportunities for all social groups. 'Smart mobility' - where various types of vehicles in the city, such as passenger cars, urban transport vehicles, freight vehicles, are connected to information systems that help them to navigate more efficiently and safely through city traffic – is seen as one of the prime movers of the transition towards smart cities. Within LEVITATE, important goals for future mobility have been identified for the environment, mobility, and for society & economy. A literature study has identified the direct, systemic and wider impacts that smart mobility may have on the city traffic network, and how these impacts are mutually connected.

In LEVITATE, several methods—including a literature study, microsimulation, meso-simulation, system dynamics model, and a Delphi survey—have been used to study the expected impacts of the increasing presence of first- and second-generation automated vehicles in city traffic on the domains of environment, mobility, and society and economy (see Appendix A). The major studied impacts in these domains include for example congestion, emissions, energy efficiency, access to travel, modal split, total kilometres travelled, parking space, road safety, public health, vehicle operating costs.

Within LEVITATE, first-generation automated vehicles have been defined as vehicles with limited sensing and cognitive ability, long following gaps, earlier anticipation of lane changes than human driven vehicles and longer time in give way situations, whereas second generation automated vehicles have been defined as having advanced sensing and cognitive ability, data fusion usage, confident in taking decisions, small following gaps, earlier anticipation of lane changes than human driven vehicles and less time in give way situations (Roussou et al., 2021b). The technical definition of vehicle parameters describing these two generations are given in Appendix B.

LEVITATE has also estimated the additional impacts of specific policy interventions (termed 'sub-use cases') such as automated urban shuttle services, or hub-to-hub freight transport, on these domains. These estimated effects are presented as effects over and above the effect resulting from the increasing presence of automated vehicles anticipated as part of Cooperative, connected and automated mobility (CCAM).

Approach to summarizing LEVITATE results

The goal of this Deliverable is to summarize the more detailed results presented in D5.2-D5.4 in order to provide an overview of the main expected trends for each impact. To quantify the impacts expected from an increasing penetration rate of connected and automated vehicles in the total vehicle fleet as well as the implementation of an automated urban shuttle system (AUSS), four methods (Appendix A) were used:

microsimulation, mesosimulation, system dynamics and Delphi. Within each method, AUSS sub-use cases were defined and quantified for a number of sub-use case scenarios. To summarize these results, for each sub-use case an average (where applicable) is taken of its scenarios in order to derive an average percentage change for the respective sub-use case. For some impacts both the Delphi method and either micro- or meso-simulation have been used; for these impacts, only the simulation results are reported in this synthesis due to these being considered the more rigorous methods within LEVITATE.

In this synthesis the impacts are presented in overview tables that distinguish between a (natural) baseline development, i.e. the expected development of impacts as the share of automated vehicles as proportion of all traffic increases to 100%, and an intervention-based development, i.e. the expected development of the same impact when both the intervention (or sub-use case concerning automated urban transport) and increasing automated vehicles in total traffic are at work. Thus the percentage changes are reported across increasing market penetration rates of CAV throughout the entire vehicle fleet in the urban network, as used throughout LEVITATE.

Illustration of overview tables

		Increasing penetration rates of automated vehicle in traffic							
		100% human-driven vehicles							100% automated vehicles
		1	2	3	4	5	6	7	8
Impact (e.g., emissions, road safety, congestion)	Baseline – no intervention	0% (reference)	% change	% change	% change	% change	% change	% change	% change
	Intervention	% change	% change	% change	% change	% change	% change	% change	% change

In the illustration above it can be seen that the impacts are expressed as a percentage change from the first stage of the baseline scenario which starts out at 0% penetration of automated vehicles and a starting value taken as the neutral reference point (zero percentage change). Thus, the development of impacts (expressed as percentages that indicate decrease or increase from the initial impact) under the baseline indicates the sole expected effect of increasing CAV penetration in total traffic. The development of impacts under the intervention-based condition indicates the expected effect of the combination of the intervention (introduction automated urban transport) and the growing automation.

Since the automated urban transport – or automated urban shuttle services - studied in this report only make up a small part of the total traffic network, the combined impacts of the intervention and the growing automation on the total network can be expected to make a relatively small difference compared to the baseline development of increasing automation. Thus, in the studied SUCs it is the background changes in total traffic that tend to be the dominant influence and the intervention has a relatively small impact.

Findings

With the reservation in mind that the estimated (percentage) impacts are very much dependent upon specific models, assumptions and studied city networks and have limited generalisability, the following summary of main findings for WP5 can be presented:

- Increasing penetration levels of connected and automated vehicles in the urban city area are estimated to have positive impacts on the environment (less emissions, higher energy efficiency), on society and economy (improved road safety, public health, and lower vehicle operating costs) and on mobility (more access to travel and less congestion).
- For the road safety, emissions, and congestion impacts substantial positive effects have been estimated at relatively low levels of CAV penetration (emissions - 17-40% reduction; road safety - 9% to 10% improvement - and congestion - 11 to 12% reduction at 20% to 40% CAV). These initial positive impacts increase significantly (double or even triple) at higher CAV penetration levels where 60 to 100% vehicles are automated.
- For a number of other impacts, such as access to travel, equal accessibility of transport and public health, positive effects have been estimated at higher levels of automation (60% of vehicles automated) and these impacts remain stable at higher stages of automation (60 to 100% of all vehicles automated); at penetration levels of 60% automated vehicle, access to travel substantially improves (19%), equal accessibility of urban transport improves (14%), and general public health in the city improves (4%).
- The effects on parking space and the kilometres travelled present us with more complexity and uncertainty.
- For parking different methods have estimated different trends for the demand for parking space under growing vehicle automation. Regarding demand on parking space the Delphi method predicts less demand with increasing levels of CAV and no AUSS. The additional impact of on demand AUSS is small, even suggesting that it offsets some of the positive CAV effects. System dynamics on the other hand predicts a growing demand for parking space with increased levels of CAV penetration. On demand AUSS is estimated to slightly reduce this demand.
- For mobility effects (expressed as kilometres travelled) the apparent increase of kilometres travelled under various market penetration rates could be assumed to be a favourable impact since it signifies both an increase of completed trips and decreased delay time in the city network. However, at the same time a possible downside may be that more kilometres travelled use up more energy, may shift trips from public transport to private vehicles, may cause more exposure to traffic safety risks, and may use up more public space.
- As the penetration levels of first- and second-generation CAVs increase, the point-to-point automated urban shuttle service (AUSS) is estimated to generate further benefits for the city in terms of an additional increase in energy efficiency (5 to 6% improvement on the baseline), better access to travel (5 to14 % improvement on the baseline), further improvement of the public health (2 to 8 % improvement on the baseline), and a further lowering of vehicle operating costs (5 to 11 % improvement on the baseline).
- The point-to-point and on-demand automated urban shuttle service (AUSS) have no apparent additional effect on the amount of travel and the kilometres travelled in network. The primary effects are the result of increased penetration levels of first and second generation CAVs.
- Compared with baseline, the on-demand sub use case of automated urban transport is associated with shorter travel time, better access to travel and less congestion. The

experts' expectations for additional benefits of on-demand AUSS in terms of access to travel, parking space, public health, shared mobility, and vehicle operating costs, are below the expectations for point to point AUSS.
- The AUSS scenarios regarding dedicated shuttle lanes and varying on-demand fleet capacities had little additional impact on the quantified results

Strengths and limitations of LEVITATE

The following observations pertain to strengths and limitations of research within WP5 LEVITATE. A potential *strength* of the LEVITATE project is that both smart city transport policy interventions and the associated impacts have been selected by a diverse group of stakeholders. A wide variety of impacts were studied at the same time and the project tried to capture interdependencies. The best available methods - microsimulation, mesosimulation, Delphi, and other complementary methods such as system dynamics and operations research - were used to study and quantify the expected impacts of mobility interventions intended to support CAV deployment and sustainable city goals. Within LEVITATE project these impacts provide essential input for developing a practical Policy Support Tool for city policy makers. Finally, a strong point of LEVITATE is that a consistent framework for assessing impacts across the project was used so that impacts may be more comparable across all use cases.

Concerning *limitations* of the present LEVITATE studies it should be pointed out that there are general scientific difficulties in predicting impacts of connected and automated mobility due to uncertainties about propulsion energy, future capacity of power grids, employment, development of costs, and about the behaviour and acceptance with regard automated vehicles. The results of the models in LEVITATE are dependent upon specific assumptions which limit the generalisability of these results. Currently, there are no large fleets of CAVs in use in traffic, so it was not possible to actually measure the specific vehicle characteristics for the modelling purposes. The simulation models used examined only two CAV profiles (first generation versus second generation); future work may extend the number of driving profiles. The safety results of the microsimulation did not include crashes where vulnerable road users are involved.

Policy recommendations

Based on the findings of WP5 and recent literature on automated urban transport and mobility, the report provides a number of policy recommendations. The recommendations are focused on the new role of public authorities in managing future urban transport and mobility, the importance of strategic plans and agendas, the prevention of unwanted side-effects, decision criteria for future projects, integration of shuttle services with public transportation, clear communication, further developing existing guidelines and lists impacts for future urban transportation development plans.

1 Introduction

Vehicle automation technology is expected to impact many areas of society. Highly automated vehicle technologies, complying to SAE levels 4 and higher, are expected to stimulate new innovations and policy interventions across the transport sector. These could include, for example, new vehicle types, new transport services and changes to infrastructure. The LEVITATE project is directed at studying—and where possible, quantifying—the expected impacts of vehicle automation on society and in particular on mobility, safety, the environment, and the economy. This report provides a synthesis of the results achieved in Work Package 5 which studied the impacts of a number of sub-use cases within the broader domain of automated urban transport. This specific chapter introduces the general scientific approach and methodology adopted by LEVITATE. Furthermore, it describes the aims of and Work Package 5 and provides an overview of the structure of the report.

1.1 General LEVITATE approach

Within LEVITATE, a range of cooperative, connected and automated mobility (CCAM) applications and interventions are studied under three use cases: **automated urban transport**, **automated passenger cars** and **automated freight transport**. These correspond to Work Packages 5, 6 and 7 respectively.

In each WP, a stakeholder reference group workshop was organised among city administrators, industry representatives and transport specialists to gather views on the future and impacts of CCAM on these three primary use cases. Part of the workshop aimed at identifying specific developments, applications or policy interventions within each sector (or use case). These were termed sub-use cases. Within LEVITATE, these lists were subsequently prioritized and refined in order to inform the interventions and scenarios related to urban transport, passenger cars or freight transport. The prioritisation of the sub-use cases mainly took three input directions into account: the scientific literature, roadmaps detailing the deployment of CCAM (ERTRAC, 2019) and the workshop among stakeholders. This resulted in the 13 sub-use cases listed in *Table 1.1*.

Table 1.1: Sub-use cases (SUCs) investigated in LEVITATE.

Urban transport (WP5)	Passenger vehicles (WP6)	Freight transport (WP7)
Point to point automated urban shuttle service connecting two modes of transport (small-scale)	Provision of dedicated lanes for AVs	Automated urban freight delivery
Point to point automated urban shuttle service in a large-scale network	Replace on street parking with other facilities	Automated freight consolidation
On-demand automated urban shuttle service	Road use pricing	Hub to hub automated delivery
Last mile automated urban shuttle service	Parking price regulation	
	Green light optimal speed advisory (GLOSA)	
	Automated ride sharing	

Within LEVITATE, the impacts of the cooperative, connected and automated mobility (CCAM) sub-use cases are evaluated at three impact levels: direct, systemic and wider.

Direct impacts are changes that are noticed by each road user on each trip (Elvik et al., 2020). These impacts are considered as short-term and can be measured directly after the introduction of an intervention or technology, such as changes in travel time or costs. Systemic impacts are system-wide impacts within the transport system which are typically secondary effects resulting from direct impacts. These include measures such as congestion or modal split. These are considered as mid-term impacts. Wider impacts are those aspects on which transport systems rely to make mobility possible and also those which are in essence a by-product of mobility. Examples of wider impacts are changes in land use and employment, energy demand and public health. These are inferred impacts measured at a larger scale and are the result of direct and system wide impacts. They are considered as long-term impacts (Elvik et al., 2020). *Table 1.2* presents the impacts considered within LEVITATE, their impact level and the policy area(s) to which they are most related.

Table 1.2: Overview of (estimated) impacts in relationship to policy, scale, term and method (WP5).

Quantified impacts see D5.2-5.4 (Roussou et al., 2021a-c)	**Impact level** see D3.1 (Elvik et al., 2020)	**Relevant policy areas**
Travel time	Direct	Mobility
Vehicle operating cost		Society, economy
Access to travel		Mobility, society
Amount of travel per person	Systemic	Mobility, society
Total kilometres travelled		Mobility, society
Congestion		Mobility, society
Modal split		Mobility, society
Vehicle utilization rate		Mobility, society
Vehicle occupancy		Mobility, society
Parking space required	Wider	Mobility, society
Road safety		Safety
Energy efficiency		Environment, economy
Emissions		Environment
Public health		Society
Equal accessibility of transport		Society

In Section 2.4 we further describe how the impacts in *Table 1.2* have been operationalised and studied in various methods.

Scenarios: baseline-only and policy intervention-scenarios
LEVITATE considers the impacts of two simultaneous developments: an expected growth in the popularity of connected and automated vehicles (CAVs) over time, as well as the policy intervention scenarios defined in the sub-use cases. These are defined in terms of scenarios, for which the impacts in *Table 1.2* are estimated:

- **Baseline scenario:** growing penetration of connected and automated vehicles (CAVs) within the entire vehicle fleet in the network WITHOUT a policy intervention
- **Sub-use case scenarios:** growing penetration of connected and automated vehicles (CAVs) within the entire vehicle fleet in the network WITH a policy intervention implemented in the network (see *Table* 1.1)

For all scenarios it is assumed that the percentage of CAVs in the vehicle fleet will increase over time and that CAVs will be SAE level 5. As the exact time scale of highly automated vehicle (SAE level 5) development and adoption is still undefined, this growth is quantified in so-called “deployment scenarios” at varying market penetration rates of

CAVs (see *Table 1.3*). These penetration rates reflect the transition from a driver-dependant vehicle fleet (100% human-driven vehicles) to a driverless vehicle fleet (0% human-driven vehicles).

In addition, two types of CAVs are distinguished in the deployment scenarios to represent an expected evolution in technology (*Table 1.3*). The first generation CAVS have been defined as vehicles with limited sensing and cognitive ability, long gaps, early anticipation of lane changes than human driven vehicles and longer time in give way situations, whereas second generation vehicles have been defined as having advanced sensing and cognitive ability, data fusion usage, confident in taking decisions, small gaps, early anticipation of lane changes than human driven vehicles and less time in give way situations (Roussou et al., 2021b). The technical definition of vehicle parameters describing these two generations are given in *Appendix B*.

Table 1.3: CAV Baseline deployment scenarios used within LEVITATE

Type of vehicle	**Deployment scenarios**							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Human-Driven Vehicle	100%	80%	60%	40%	20%	0%	0%	0%
1st generation CAV	0%	20%	40%	40%	40%	40%	20%	0%
2nd generation CAV	0%	0%	0%	20%	40%	60%	80%	100%
Human-driven freight vehicle	100%	80%	40%	0%	0%	0%	0%	0%
Freight CAV	0%	20%	60%	100%	100%	100%	100%	100%

1.2 Work Package 5

WP5 focuses on the impacts that the deployment of cooperative, connected and automated mobility may have on urban transport operations, through advanced city shuttles and other micro-transit vehicles. Forecasting of impacts will consider four main components:

i. Type of transport: road vs. rail, motorised vs. non-motorised, personal vs. shared.
ii. Modes of transport: passenger cars, micro-transit shuttles, public transport (buses), pedestrians, cyclists.
iii. Actors: drivers / operators, passengers, transit companies / authorities, cities authorities.
iv. The SAE levels: urban shuttle modes are directly considered at SAE 4. It will be based on the methodology developed in WP3 and the scenarios developed in WP4 to identify and test specific scenarios regarding the impacts of CCAM on urban transport.

Combining the input from these directions, five major automated urban transport related sub-use cases were formulated:

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

The expected impacts of these five automated urban transport sub-use cases on the environment, economy, mobility, safety and society are described in detail in four deliverables (D5.1 to D5.4). In preparation for the quantitative analysis, the expected impacts were first evaluated with a literature review and stakeholder workshop and described in Deliverable 5.1. Subsequently, the projected impacts of CAVs and, more specifically, the automated urban transport SUCs were estimated in a series of quantitative analyses and reported in Deliverables 5.2 (direct impacts, Roussou et al., 2021a), 5.3 (systemic impacts, Roussou et al., 2021b), and 5.4 (wider impacts, Roussou et al., 2021c). The purpose of this report, Deliverable D5.5, is to summarise the main impacts of the studied sub-use cases and to provide more general recommendations for policymakers. Based on these results described in D5.1 to 5.4 and on literature on the transition to smart mobility in smart cities and other general guidelines, recommend-dations are developed to potentially inform future policy on CAVs and automated urban transport.

Table 1.4 presents an overview of the various methods used in WP5 and the Deliverables in WP5 that describe the results of these methods. Further explanation of the method is given in *Appendix A* of this report.

Table 1.4: Methods used to evaluate and quantify the expected impacts of automation within the urban transport sector

Goal	Method	Explanation	Deliverable
Exploration	Literature review	Existing literature on CCAM/CAVs/ADAS	5.1
	Stakeholder workshop	A group of key stakeholders – international/ twinning partners, international organisations, road user groups, actors from industry, insurances and health sector support the project and participated in workshops.	5.1
Quantifi-cation	Delphi study	The Delphi method was used to determine those impacts that cannot be defined by the other quantitative methods	5.2, 5.3, 5.4
	Traffic micro-simulation	AIMSUN microsimulation of traffic at the city-district level (based on modelling individual vehicles)	5.3, 5.4
	Traffic meso-simulation	MATsim modelling of behaviours and choices of individuals (based on groups or streams of vehicles) at the city level	5.2, 5.3, 5.4
	System dynamics (SD)	The LEVITATE System Dynamics model consists of 3 interacting sub-models: 1. A Transport Model modelling travel demand and trips ; 2. A population model used to calculate demand (which also calculates the average commuting distance); 3. A Public Space model based on modelling public space at a zone level, distinguishing between parking space, driving lanes and other uses. The relative demand for parking space is calculated in this model (See Sha et al., 2021b)	5.4
Synthesis & discussion	Synthesis	Major impacts summarized for the policy areas Environment, Mobility and Society/ Economy/ Safety	5.5
	Policy considerations	Recommendations & considerations for policymakers based on the wider literature	5.5

1.3 Purpose and structure of report

The purpose of this synthesis report is to present the expected impacts of a range of mobility policies in the urban transport domain against the background of increasing CAV deployment in the urban vehicle fleet on the environment, mobility, society, safety and economy.

This report is structured as follows. After this general introduction to the LEVITATE project (Chapter 1), *Chapter 2* provides a more detailed theoretical and empirical background to the expected impacts of automated urban transport and it describes the approach that was used to summarise the various impact results from earlier LEVITATE Deliverables D5.2, D5.3 and D5.4.

Chapter 3 presents the main summarised findings of the quantitative analyses which were reported in deliverables D5.2 to D5.4.

In Chapter 4, strengths and limitations of the LEVITATE approach are discussed and broader policy considerations regarding the potential impacts of CCAM further discussed.

In Chapter 5, final conclusions are drawn, and some limitations of the present approach are discussed.

2 Background

The transition towards cooperative, connected and automated mobility (CCAM is expected to contribute to the goals of smart and sustainable cities. In LEVITATE, the impacts of CCAM including automated urban transport on these goals have been studied by adopting various methods on different sub-use cases. This Chapter describes the major policy goals towards which automated urban mobility may contribute (Section 2.1) and how the various distinct impacts on transport system are interrelated and related to the policy goals (Section 2.2). In Section 2.3, the expected impacts of automated urban transport are described. The two main studied sub-use cases of automated urban transport – automated point to point shuttle service (AUSS) and on demand shuttle service – are further described in Section 2.4. The approach taken in this report to summarise the impact results is explained in section 2.5.

2.1 Urban mobility and transport goals

There is not yet a standard European approach for defining goals and indicators for the further development of smart cities. Within the LEVITATE project (WP4), two existing city transport strategies from Greater Manchester in the UK, and Vienna in Austria have been looked at in more detail, specifically in terms of high-level goals on transport developments (Papazikou et al., 2020; D4.4). WP4 covers the effects of autonomous vehicle share on the goals set out by policymakers of these cities (Papazikou et al., 2020).

The Greater Manchester Transport Strategy 2040 follows the vision “World class connections that support long-term, sustainable economic growth, and access to opportunity for all”. The strategy has seven core principles to be applied across their transport network (City of Manchester, 2017):

1. Integrated – allow individuals to move easily between modes and services
2. Inclusive – provide accessible and affordable transport
3. Healthy – promote walking and cycling for local trips
4. Environmentally responsible – deliver lower emissions, better quality vehicles
5. Reliable – confidence in arrival, departure and journey times
6. Safe and secure – reduce road accidents especially injuries and deaths
7. Well maintained and resilient – able to withstand unexpected events and weather conditions

Table 2.1 summarizes the Greater Manchester Transport Strategy 2040 vision goals and a method to measure the impacts. For example, under the policy field, the goal is to improve road safety, this will be measured by number of injury or fatalities, as well as the perception of personal security by transport mode.

Table 2.1: Overview of goals of the City of Manchester for a viable transport system of the future and corresponding impact targets (City of Manchester, 2017).

Policy field	Policy goal	Measured impact
Environment	Reduced greenhouse gas emissions	CO_2 and NO_2 emissions
	Best use of existing infrastructure in order to reduce environmental impacts	Percentage of new homes having > level 4 accessibility to the public transport network
Mobility	More reliable journey times	departure/arrival time reliability by mode of transport
	Reduced congestion	Journey duration by mode
	Increase use of sustainable transport (reduce negative impact car use)	Modal split of sustainable transport
		Share of non-sustainable transport modes
Safety	Improved safety and personal security	Number of killed and seriously injured
		Perception of personal security by transport mode
Society	Greater health	Number of walking and cycling trips
	Better access to services	Sustainable transport catchment population for key locations – town centres/hospitals

The second strategy is The Viennese Urban Mobility Plan, under the "STEP 2025 Urban Development Plan". It includes the following goals (City of Vienna, 2015):

1. Fair – street space is allocated fairly to a variety of users and sustainable mobility must remain affordable for all.
2. Healthy – the share of active mobility in every-day life increases; accident-related personal injuries decline.
3. Compact – distances covered between work, home, errands and leisure activities are as short as possible.
4. Eco-Friendly – mobility causes as little pollution as possible, the share of eco-mobility in the trips made in Vienna and its environs is rising. The relative change in the modal shift will be largest in bicycle traffic. In absolute figures, the largest increase in the number of trips will be attributable to public transport.
5. Robust – mobility is as reliable and crisis-proof as possible. Mobility should be possible without necessarily owning a means of transport.
6. Efficient – resources are used in a more efficient way, helped by innovative technologies and processes.

The goals for Vienna span four policy domains and were subdivided into specific policy goals for each domain each with its own impact measure (see *Table 2.2*).

Table 2.2: Overview of goals of the City of Vienna for a viable transport system of the future and corresponding impact targets (WP4).

Policy field	Policy goal	Measured impact
Environment	Mobility causes as little pollution as possible	Modal split changes
Mobility	Resources are used in a more efficient way	Absolute final energy consumption of the Vienna transport system
	Distances covered between work, home, errands and leisure activities are as short as possible	The share of trips done on foot or by bike to shop for supplies or accompany someone as well as distances covered for leisure time activities
	Mobility is reliable and crisis-proof	Bicycle availability
Safety	Safe road travel	The number of traffic casualties and persons injured in traffic accidents
Society	Better health: The share of active mobility in every-day life increases	The share of people in the Viennese population who are actively in motion for 30 minutes daily as they run their daily errands
	Fairness: Street space is allocated fairly to a variety of users and sustainable mobility must remain affordable for all	The total sum of spaces for cycling, walking and public transport in all conversion and urban renewal projects

These two city transport strategies reveal that CCAM could contribute toward achieving these policy goals although specific policy will need to be adopted to make that achievable. For each of the Policy domains described above, one or more key impact indicators have been defined/operationalized for the Policy Support Tool that is intended to help policy makers' decision-making concerning interventions that may support automated driving.

2.2 Expected impacts automation

It is expected that CCAM will have substantial impacts on road transport. Deliverable 3.1 (Elvik et al., 2019) presents a taxonomy of potential impacts of CCAM/CATS which makes a distinction between direct, systemic and wider impacts. **Direct impacts** are changes that are experienced by each road user on each trip. **Systemic impacts** are system-wide impacts within the transport system and **wider impacts** are changes that occur outside the transport system, such as changes in land use and employment. Moreover, a distinction is made between **primary impacts** and **secondary impacts**. Primary impacts are intended impacts that directly result from the automation technology, whereas secondary impacts (rebound impacts) are generated by a primary impact.

Figure 2.1 presents the various impacts of the taxonomy and their expected interrelations (based on scientific literature and expert consultation). In the figure, impacts are ordered from those that are direct, shown at the top, to those that are more indirect or wider, shown further down in the diagram. The diagram is inspired by the detailed model of Hibberd et al. (2018).

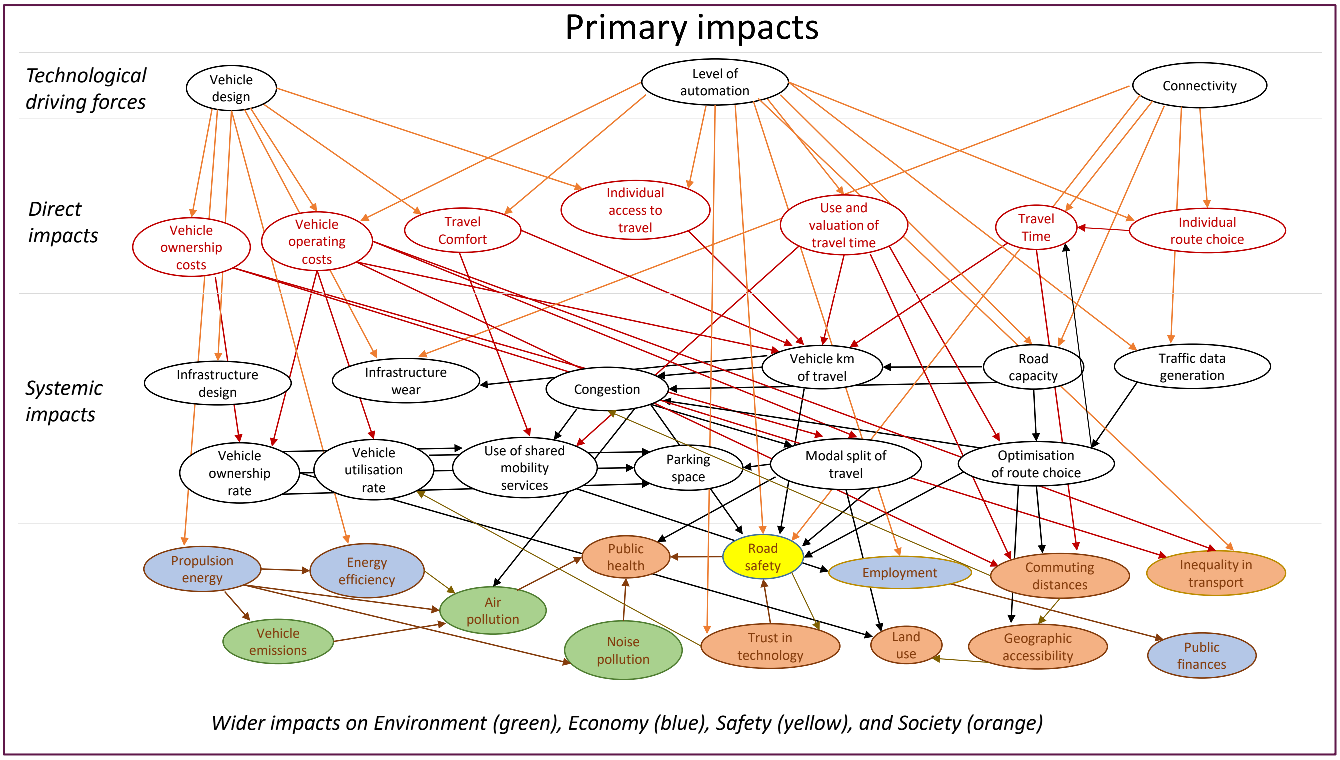

Figure 2-1: Taxonomy of impacts generated by transition to connected and automated vehicles

Figure 2.1 shows the different paths by which impacts are generated by automation technology. Three aspects of it are identified in *Figure 2.1*: vehicle design, level of automation (SAE 1 to 5), and connectivity (Elvik et al., 2019). These characteristics of technology can give rise to different impacts. For example, vehicle design - which includes aspects such as vehicle size, setup of electronic control units, powertrain (fossil fuel or electric) and ease of getting in or out the vehicle – will, through the technology built into connected and automated vehicles, influence both vehicle ownership cost and vehicle operating cost (Elvik et al., 2019). The choice of powertrain will influence propulsion energy and energy efficiency of the engine. Vehicle design may also influence infrastructure design and infrastructure wear, depending on, for example, the mass of the vehicle and its facilities for vehicle to infrastructure communication (Elvik et al., 2019). Finally, vehicle design may influence travel comfort and individual access to transport. As an example, vehicles with high ground clearance and no ramps will be difficult to access for wheelchair users.

Another example of pathways in *Figure 2.1* concerns the primary impacts of CCAM on road safety. Road safety is influenced by level of automation, as human operator errors will be eliminated at the highest level of automation (there may still be software errors in computer programmes operating the vehicle, but there will be no driver who can make mistakes) (Elvik et al., 2019). The level of automation may also influence road safety indirectly, by way of trust in technology, in particular before the highest level of automation is attained. However, even fully automated vehicles will have to interact with users of non-automated vehicles, who may place excessive trust in the capabilities of the technology to detect them, brake or make evasive manoeuvres. Connectivity will influence safety by reducing or eliminating speed variation between vehicles travelling in the same direction and by shortening reaction times in case of braking (Elvik et al.2019). Finally, road safety and in the end public health will be influenced by potential changes in the amount of congestion, vehicle kilometres of travel, changes in the modal split of travel and optimisation of route choice (Elvik et al., 2019).

2.3 Expected impacts of automated urban transport

Roussou et al. (2019, 2021a, b, c) have examined the expected impacts of automated urban transport by means of a literature study and a workshop among a reference stakeholder group.

Public transport findings
Literature findings on automated urban transport systems have been earlier reported in Roussou et al. (2019, 2021a, b, c). Below we repeat main findings.

Public transport constitutes a significant element of urban mobility (Pakusch & Bossauer, 2017) as it can alleviate congestion issues in cities and promote sustainability. The large-scale introduction of CCAM in urban environments will fundamentally affect urban transport and space (Freadrich et al., 2019). The expected benefits from fully automated public transport include reduced crash rates, increased punctuality, shorter headways and greater availability (Pakusch & Bossauer, 2017). Under these circumstances, a greater proportion of people are expected to use public transport.

However, the role of automated vehicles for public transport can be controversial. According to VDV (2015), there are two extreme scenarios describing the uptake of CCAM as far as urban transport is concerned. According to the pessimistic scenario, public transport will suffer due to the focus on autonomous private cars, whereas, according to the optimistic one, shared autonomous cars will be fully integrated into public transport and provide great coverage for all regions of the city, thus rendering private cars superfluous.

Specific types of mobility service may bring unwanted consequences. For example, using automated vehicles to provide first and last mile transport services can potentially boost the use of other transport systems by providing efficient door to door transport, creating opportunities for commuters to have more time to relax, work or read while travelling, but at the same time an improved attractiveness of public transport by door-to-door services may negatively impact modal split. These changes in modal split can lead to congestion unless changes in the road network are also implemented (Boesch & Ciari, 2015).
A study by Owczarzak and Żak (2015) compared several public transport solutions in relation to automated vehicles and regular urban transport. Their main conclusion was that the combination of automated vehicles with the urban bus system is likely to increase travel comfort by reducing crowdedness and enhancing privacy, reduced travel costs and increased availability, timeliness and reliability of transportation service. These authors also stated that the operation of automated vehicles in public transport systems could be beneficial towards their efficiency and effectiveness of the latter.

Automation can also facilitate a transition to Mobility as a Service (MaaS) that may limit the negative effects of road transport (European Commission, 2017), provided that it promotes car sharing, ride sharing or sourcing rather than private mobility solutions.

According to Firnkorn and Müller (2015), automation will attract more people to car sharing for the first or last mile of their trip instead of walking, cycling or using a private car. Autonomous taxis or car sharing can be considered as new valuable part of the public transport system; with suitable business models these new transport options can promote sustainability, reducing the number of private cars and accordingly, the congestion. A fewer number of vehicles that operate more efficiently will reduce car traffic and advance public transport (Pakusch & Bossauer, 2017).

Autonomous public transport and new mobility services can provide a wider palette of mobility solutions, so that users may become less dependent on private cars and may use wider spectrum of services. This can improve the resource efficiency and have a strong self-reinforcing effect on the popularity of the active travel modes, such as walking and biking (Ainsalu et al., 2018). Furthermore, automated urban shuttle services could have a positive impact on the environment by reducing traffic in the cities, and shuttles could provide such services 24/7 by exploiting algorithms that could optimise the process of identifying the closest vehicle and the number of passengers for a similar route. Changes in vehicle design could include using lighter, less energy demanding materials for building the vehicles, since vehicles are less likely to crash; this would allow energy saving gains (KPMG & Centre for Automotive Research, 2012). However, Begg notes that this change would only occur under high AV penetration scenarios, once all manually driven vehicles have been phased out of the urban environment (Begg, 2014).

The International Transport Forum - ITF (2015) simulated different scenarios of automated transport systems, penetration rates and availability of high-capacity public transport. It was concluded 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. According to the realistic simulations in the city of Zurich, one shared automated vehicle could replace approximately 10 to 14 conventional vehicles contributing to the amelioration of traffic conditions (Boesch et al., 2016; Zhang et al., 2015).

Shuttle services findings
Findings on shuttle services have been earlier reported in Roussou et al. (2021b). Below we repeat main findings. 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 a 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 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 analysed in terms of their behaviour in crowded areas and their interaction with vulnerable road users by applying the collision avoidance algorithm based on real world conditions or simulation studies (Wang et al., 2018, Ararat & Aksun-Guvenc, 2018; Emirler et al., 2016).

Workshop findings
Further findings on automated urban transport were obtained by a workshop among stakeholders; approximately half of the workshop participants (53%) were from local and national authority organisations whereas the rest represented specialist groups (associations related to car, cycles, pedestrian; research organisations and, R&D departments within commercial organisations) (Roussou et al, 2019).

In future cities connected and automated transport systems can contribute to sustainable solutions. More specifically, connected and automated urban transport systems can potentially offer inclusive solutions to customers with improved pricing and mobility services. The local economy can grow with new modes for short journeys and shared solutions that improve door to door public transport services by integrating the first and last mile of the journey into the public transport routes. Urban transport is already more controlled with rules and planned routes; hence it can be quicker and easier to automate that experience. The concept of MaaS will be a key feature in that development (Roussou et al., 2019).

When asked about planning for the future of connected and automated urban transport vehicles participants in the "Automated urban transport" workshop made the following observations (Roussou et al., 2019):

- The concept of Mobility as a Service, C-ITS services, digital infrastructure and data sync are key enablers to plan for the future of automated urban transport systems.
- It is important to implement connected and automated urban transport systems due to their expected positive environmental and societal impacts.
- Public acceptance and trust are considered fundamental for the implementation of connected and automated urban transport systems. For this reason, authorities must use social media to promote automated urban transport.
- While planning for the future, there remains a dependence on political decisions.
- Automated urban transport should not compete with public transport but should complement it.
- There is serious concern that implementation of connected and automated urban transport systems may negatively affect active and healthy modes of transport, such as walking and cycling.

The majority of participants claimed that they are planning based on a twenty-five-year timeframe. According to stakeholders, the most important short-term issues were user acceptance and trust of the systems and the promotion of automated urban transport by authorities via social media (Roussou et al., 2019). In terms of mid-term developments, infrastructure and technology were the most important subjects under consideration. In terms of long-term developments, the issues of mixed traffic and behaviour change were considered to be of prime importance (Roussou et al., 2019). The technological and traffic management related issues are seen as immediate issues but there is also rising need for improved governance. Amended financial regulations and controls will be required to accommodate the new and more complex models for providing public transport.

2.4 Sub-use cases

Sub-use case in this synthesis refers to subcategory (interventions) under automated urban shuttle services (AUSS) use-cases developed to study the quantifiable impacts of CCAM within urban transport (Roussou et al., 2021c). In LEVITATE, a stakeholder reference group workshop was conducted to gather views from city administrators and industry on the future of CCAM and possible use cases of urban transport, termed sub-use cases (Roussou et al., 2019). A number of sub-use cases of interest for urban transport were identified and prioritized and refined for further LEVITATE scenario studies on urban transport. The sub-use cases are also included in the LEVITATE Policy Support Tool (PST) (Roussou et al. 2021c). This section provides further description of the two main studied sub-use cases of automated urban transport: **point-to-point AUSS** and **on demand** services. This description is based on earlier Deliverables (Roussou et al., 2021c; D5.4).

The **point-to-point AUSS** operates on fixed stations in a defined area in the city. The minibuses are implemented with and without the use of dedicated lanes in the network which connect the AUSS stops. The importance of this service was highlighted by the stakeholders during the SRG workshop, as this will be the first CCAM service to be introduced in the cities, in a smaller or larger scale depending on the cities' goals. This SUC was divided in two separate SUCs for the impact assessment using microscopic simulation (see Table 2.3). These SUCs are the point-to-point AUSS connecting two modes of transport (small-scale network) 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.

For these two point-to-point SUCs (small and large scale networks) *microsimulation* was used to estimate the effects under several scenarios (see *Table 2.3)*. These scenarios varied the traffic volume (peak hour vs. off-peak hour conditions), as well as whether or not the shuttle system operates on its own dedicated lane or in mixed traffic. The effects of a dedicated lane were considered as particularly relevant during peak-hour conditions, as with the "incident" scenario in which an incident on the shuttle bus route causes a part of a road segment to be blocked off such that traffic must change lanes to overtake.

Point-to-point shuttles were also studied using the *Delphi* method within LEVITATE. In this method, point-to-point was studied as one SUC having the characteristics of the point-to-point AUSS in a large-scale network. No point-to-point scenarios have been considered with the Delphi method.

Table 2.3: Point-to-point SUCs and scenarios considered in Work Package 5

Method	Sub-use case	Scenarios
Microsimulation (Athens network)	Point-to-point AUSS connecting two modes (small-scale network)	• Peak hour[1] - Mixed traffic • Peak hour[1] - Dedicated lane • Peak hour[1] - Incident • Off Peak hour[2] - Mixed traffic • Off Peak hour[2] - Dedicated lane
	Point-to-point AUSS (large-scale network)	• Peak hour[1] - Mixed traffic • Peak hour[1] - Dedicated lane • Off Peak hour[2] - Mixed traffic
Delphi study (expert survey)	Point-to-point AUSS	No sub-scenarios

[1]Peak hour traffic simulation includes 100% of the network's travel demand
[2]Off peak hour traffic simulation includes 60% of the network's travel demand

Within the LEVITATE project, **on-demand AUSS** includes three different types of services: the anywhere-to-anywhere AUSS, last-mile AUSS and e-hailing. These three SUCs were prioritized by the stakeholders during the SRG workshop as the most important after the point-to-point AUSS. 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. The last-mile AUSS enables transit users' access to and from stations/stops in the networks of urban rail transit and buses or other slower modes of transit. This service is expected to contribute to improvements in transit accessibility, particularly in suburban areas or lower-density areas (Ohnemus & Perl, 2016). 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.

On-demand AUSS was evaluated using four methods: microsimulation, mesosimulation, system dynamics and a Delphi study (*Table 2.4*). For *microsimulation*, one on-demand SUC was estimated based on an anywhere-to-anywhere shuttle system, where the shuttle fleet can serve customers anywhere within the city centre of Athens, Greece without fixed stops or routes. The microsimulation scenarios estimated vary two factors: the percentage of the total travel demand which uses the shuttles (% modal split), as well as the capacity of the shuttles (8 or 15). In the *mesosimulation* conducted for Vienna, two SUCs have been estimated based on an anywhere-to-anywhere shuttle system in the city centre or last-mile shuttles connecting travellers to public transport stops in the city's peripheral districts. For each of these two SUCs, two fleet size scenarios were calculated. In the *system dynamics* model, a last-mile shuttle service is tested to serve connections to existing public transport stops in the peripheral Zone 3 of Vienna, Austria. Within Zone 3, travel time to public transport stops (referred to as "access time") is assumed to be cut in half due for 50% of the travel demand serviced by the shuttles, resulting in an average 25% reduction in access time to public transport within Zone 3. Lastly, in the *Delphi* method all three types of on-demand AUSS described above have been evaluated separately in the survey.

Table 2.4: On-demand SUCs and scenarios considered in Work Package 5

Method	Sub-use case (SUC)	Scenarios
Microsimulation (Athens network)	On-demand	• 5% modal split - 8 pax • 5% modal split - 15 pax • 10% modal split - 8 pax • 10% modal split - 15 pax
Mesosimulation (Vienna network)	On-demand: Anywhere-to-anywhere	• 250 shuttles • 500 shuttles
	On-demand: Last-mile	• 1118 vehicles • 2338 vehicles
System dynamics (Vienna network)	On-demand: Last-mile	• Vienna periphery; 25% reduction in the access time to PT
Delphi study (expert survey)	On-demand	• Anywhere-to-anywhere • Last-mile • E-hailing

2.5 Approach to synthesizing results

The goal of this Deliverable is to summarize the more detailed results presented in D5.2-D5.4 (Roussou et al., 2021a, b, c). As has been explained in Section 1.2, the impacts expected from an increasing penetration rate of CAVs in the total vehicle fleet as well as the implementation of an automated urban shuttle system (AUSS) were studied using three primary methods: microsimulation, mesosimulation and Delphi consultation. Within each methodology, a Baseline and AUSS scenarios were defined and quantified (see *Section 2.4*).

For the purposes of this synthesis, the many results estimated within Work Package 5 of LEVITATE have been condensed in order to provide an overall overview (*Table 2.5).* The full results, broken down per scenario, can be found in Appendix C. In Chapter 3, the quantified results of Work Package 5 are summarized using averages per SUC in order to arrive at general expected trends (% change) per impact (see Table 2.5 Table 2.5; rightmost column). The following approach was used in order to summarize and structure the quantified results for WP5:

- Impacts are presented as a **percentage change** from the *Baseline 100-0-0 scenario*, where neither AUSS nor CAVs have been implemented in the network and all vehicles are human-driven. These percentage changes are reported across increasing market penetration rates of CAVs throughout the entire vehicle fleet in the network, as used throughout LEVITATE.
- The *Baseline* refers to a "no intervention" scenario which is essentially the expected autonomous development of CAVs from human dependence to human independence (see Section 1.1). In the Baseline scenarios there is no automated urban shuttle system (AUSS) added to the network.
- The **impacts of CAVs alone** on network performance can be established by comparing the *Baseline* scenarios with each other, starting at the *Baseline 100-0-0 scenario* (100% human-driven vehicles) and ending at the *Baseline 0-0-100 scenario* (0% human-driven vehicles).

Table 2.5: Synthesized AUSS sub-use case scenarios from Deliverables 5.2-5.4

Method	Sub-use case	Scenarios included	Synthesized results and measured effect
Microsimulation (Athens network)	Baseline (no AUSS)	• Large-scale network (peak hour)	Baseline (no AUSS): % change
	Point-to-point	Large-scale network: • Mixed traffic • Dedicated lane	Point-to-point: Average % change of scenarios
	On-demand	• 5% modal split 8 pax • 5% modal split 15 pax • 10% modal split 8 pax • 10% modal split 15 pax	On-demand: Average % change of scenarios
Mesosimulation (Vienna network)	Baseline (no AUSS)	No scenarios	Baseline (no AUSS) % change
	On-demand: Anywhere-to-anywhere	• 250 shuttles • 500 shuttles	Anywhere-to-anywhere: Average % change of all scenarios
	On-demand: Last-mile	• 1118 vehicles • 2338 vehicles	Last-mile: Average % change of all scenarios
System dynamics (Vienna network)	Baseline (no AUSS)	No scenarios	Baseline (no AUSS) % change
	On-demand: Last-mile	No scenarios	Last-mile: % change
Delphi study (expert survey)	Baseline (no AUSS)	No scenarios	Baseline (no AUSS) % change
	Point-to-point	No scenarios	Point-to-point: % change
	On-demand	• Anywhere-to-anywhere • Last-mile on-demand • E-hailing	On-demand: Average % change of all scenarios

- The specific **effect of an AUSS sub-use case** can be determined by comparing the *Baseline* situation at a given penetration rate with the respective SUC results; the difference between the baseline and the SUC is the added effect created by implementing the specific SUC intervention in the simulated network. This represents the present day, so these percentage changes show the combined effect of increasing automation in the background traffic and also the introduction of the AUSS. The nature of the AUSS is that it is introduced completely on day 1 whereas the background traffic changes over increasing penetration.
- To reduce the number of results, for each sub-use case an average (where applicable) is taken of its scenarios in order to derive an **average percentage change** for the respective sub-use case. For example, if the point-to-point "mixed traffic" scenario increases by 20% for a given impact while the point-to-point "dedicated lane" scenario increases by 10%, an average change of 15% is predicted. In Appendix C, the results per scenario can be found. An average was chosen in order to 1) provide a more generalized trend for the sub-use case less specific to certain simulation parameters,

and 2) due to the largely similar results for scenarios within a sub-use case, suggesting an overarching trend regardless of scenario.

In addition, some results have been excluded from the synthesis in order to reduce complexity without affecting the overall outcomes (the excluded results do not add to the insights of the synthesis):

- *Point to point AUSS connecting two modes of transport (small-scale network):* This SUC of microsimulation was performed primarily for model calibration on a smaller section of the Athens network and is less comparable with the other SUCs implemented at the city-scale. It also has a different Baseline, calculated on the smaller network, and is thus not comparable with the Baseline of the other SUCs. These results can be found in Appendix C.
- *Off-peak hour scenarios:* These microsimulation scenarios of the point-to-point SUC are based on different traffic conditions than the Baseline scenario and are therefore not comparable with the Baseline. These results can be found in Appendix C.
- *Delphi results for simulated impacts:* For some impacts both the Delphi method and either micro- or mesosimulation have been used; for these impacts, only the simulation results are reported in this synthesis due to these being considered the more rigorous methods within LEVITATE.

For all the detailed results calculated in Work Package 5, readers are referred to Deliverables D5.2-D5.4 (Roussou et al., 2021a, b, c).

3 Main findings: quantified impacts

This Chapter presents a summary description of the impacts that were quantified in the LEVITATE Deliverables 5.2 to 5.4. The findings are presented for policy domains Environment (Section 3.1), Mobility (Section 3.2), and Society – Safety – Economy (Section 3.3). These sections describe the synthesised results in accordance with the approach described in Section 2.5. The description of summary results is supplemented with a further description of more detailed findings if these more detailed findings offer important additional insights. The detailed findings of D5.2 to 5.4 are presented in full in tables in Appendix C.

3.1 Impacts on the environment

In LEVITATE, four indicators were used to measure impacts on the environment: carbon dioxide (CO_2) emissions, nitrous oxide (NO_x) emissions, particulate (PM_{10}) emissions, and energy efficiency. Their importance for the environment has been widely documented (e.g., EEA, 2020). In this WP5 synthesis report, we describe the environmental impacts using CO_2 emissions and energy efficiency (see *Table 3.1)*. Carbon dioxide emissions are the primary driver of global climate change, and it is widely recognised that in order to decrease the negative impacts on climate change, the world needs to urgently reduce these emissions. Improving the efficiency of services and technologies in urban transport that use energy from fossil fuels will help reduce emissions. Detailed information on the other indicators (NOx and particulate emissions) can be found in the underlying study reports (Roussou et al., 2021a, b, c).

Table 3.1: Environmental impact definitions

Impact	Definition	Methodology
Energy efficiency	*Average rate (over the vehicle fleet) at which propulsion energy is converted to movement (all road traffic)*	Delphi
CO_2 due to vehicles	*Concentration of CO_2 pollutants as grams per vehicle-kilometre (all road traffic)*	Microscopic simulation

Table 3.1 presents an overview of the estimated effects resulting from an introduction of automated urban shuttle services (AUSS) on the CO_2 emissions. These estimates for point-to-point and on-demand AUSS are based on results from the Delphi study and the AIMSUN microsimulation modelling study on the Athens road network. An important assumption underpinning these results is that all CCAMs and shuttles introduced into the network are electric vehicles, and emissions due to electricity generation are outside the scope of this study and therefore excluded. The results are estimated for all motor vehicle road transport within the network, thus including both a shift in the background traffic in the network (private vehicles) as well as the implementation of AUSS.

Delphi results

Based on the Delphi expert consultation the expected impacts of the "point-to-point" and "on-demand" shuttle services on energy efficiency are positive. The results of this study are summarized in Table 3.2, where the units are expressed in % change compared to the Baseline at 100-0-0 scenario (no AUSS; only human-driven vehicles in the network). The Baseline results for energy efficiency indicate that energy efficiency will improve with increasing penetration levels of CAVs.

According to the expert Delphi panel, both forms of AUSS are expected to have an additional benefit for energy efficiency compared to increasing automation alone (Baseline). Point-to-point AUSS is expected to have a larger additional benefit for energy efficiency than on-demand AUSS. Of the different scenarios of on-demand AUSS considered in the Delphi study (see Appendix C.1):

- *Anywhere-to-anywhere* shuttles are expected to offer the largest improvement to energy efficiency at a level similar to point-to-point shuttles (22% increase at 0-0-100)
- *Last-mile* shuttles are expected to have the least positive effect on energy efficiency, slightly lower than the Baseline (12% increase at 0-0-100)

Therefore, experts expect the environmental impact of an automated urban shuttle service to be most likely somewhat positive, but to depend largely on its form of implementation and the types of trips the shuttles replace.

Microsimulation results

The microsimulation results are shown in *Table 3.2.* The Baseline results for CO_2 emissions show large reductions (-40%) when the share of first-generation automated vehicles is at 40% and larger reductions (of-64% to 97%) when the share of second-generation vehicles is above 20%.

The expected improvement in lowering CO_2 emissions due to the introduction of connected and automated vehicles is expected to be large due to the assumption that automated vehicles will also be electric vehicles. However, neither point-to-point nor on-demand shuttle services are predicted to have a large added benefit in terms of lowering CO_2 emissions when compared to the autonomous introduction of connected and automated vehicles (Baseline).

Table 3.2: Estimated impacts of automated urban shuttle services (AUSS) on CO_2 emissions and energy efficiency. Measured in terms of percentage change with respect to the Baseline 100-0-0 scenario.

		Deployment scenarios: Market penetration rate **of CAVs** in **entire** vehicle fleet (Human-driven vehicle - 1st Generation CAV - 2nd Generation CAV)								
		100-0-0	**80-20-0**	**60-40-0**	**40-40-20**	**20-40-40**	**0-40-60**	**0-20-80**	**0-0-100**	
Impact	**Sub-use Case**	%	%	%	%	%	%	%	%	**Method**
Energy efficiency	Baseline (no AUSS)	0,0	3,0	7,1	8,4	15,7	14,1	14,1	14,1	Delphi (expert survey)
	Point-to-point AUSS	0,0	4,2	8,4	15,6	20,8	21,1	21,1	21,1	
	On-demand AUSS	0,0	4,0	5,9	9,5	13,8	16,7	16,7	16,7	
CO_2 emissions	Baseline (no AUSS)	0,0	-16,7	-40,2	-64,3	-81,2	-97,2	-95,5	-95,3	Micro-simulation (Athens)
	Point-to-point AUSS	-0,1	-16,8	-40,3	-64,3	-81,2	-97,2	-95,5	-95,3	
	On-demand AUSS	0,8	-17,1	-40,6	-64,5	-81,2	-97,2	-95,4	-95,3	

3.2 Impacts on mobility

This section presents the main findings of the quantified impacts on mobility, which are a combination of direct and systemic level impacts (see *Table 1.2)*. In LEVITATE, ten mobility impacts (indicators) were used as listed and defined in Table 3.3. Four of these are travel-related indicators, one indicator for congestion, three indicators for modal split, and two indicators for vehicle usage. Of these mobility indicators, travel time and access to travel were considered direct impacts and the rest systemic impacts. The sizes of the impacts are estimated from three methodologies: the Delphi expert panel; microsimulation modelling using the Athens road network, and mesoscopic simulation using the Vienna road network. It should be noted that each impact could be estimated by one or two of the methodologies used (indicated under methodology in *Table 3.3*).

Table 3.3: Mobility impact definitions

Impact	Definition	Methodology
Travel time	Average duration of a 5 Km trip inside the city centre (all traffic) and averaged over all traffic	Mesoscopic simulation*
Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)	Delphi
Amount of travel	Kilometres of travel per person in an area (all traffic)	Mesoscopic simulation*
Total kilometres travelled	Total vehicle kilometres travelled in the network (all traffic)	Microscopic simulation
Congestion	Average delays to traffic (seconds per vehicle-kilometre) as a result of high traffic volume (all traffic)	Microscopic simulation
Modal split using active travel	% change in network trip distance (all traffic) made using active (walking, cycling) transportation	Delphi
Modal split using public transport	% change in network trip distance (all traffic) made using public transportation % of trip distance made using public transportation	Delphi
Shared mobility rate	% change in number of trips made sharing a vehicle with others	Delphi
Modal split Vienna: Active modes	% of Vienna network trip distance (all traffic) made using active transportation (walking, cycling)	Mesoscopic simulation
Modal split Vienna: Public transport	% of Vienna network trip distance (all traffic) made using public transportation	Mesoscopic simulation
Modal split Vienna: AUSS	% of Vienna network trip distance (all traffic) made using automated urban shuttle service	Mesoscopic simulation
Vehicle utilisation rate of AUSS	% of time an AUSS vehicle is in motion (not parked)	Mesoscopic simulation*
Vehicle occupancy of AUSS	% of kilometres an AUSS vehicle is occupied by passengers	Mesoscopic simulation*

* *The Delphi method was also used to estimate a simplified form of these impacts (see Roussou et al., 2021)*

Tables 3.4 and *3.5* present a summary of the estimated effect that the SUC will have on each of the identified indicators.

Table 3.4. Estimated impacts of automated urban shuttle services (AUSS) on mobility, measured in terms of percentage change with respect to the Baseline 100-0-0 scenario and percentage of travel demand.

		Deployment scenarios: Market penetration rate **of CAVs** in **entire** vehicle fleet (Human-driven vehicle - 1st Generation CAV - 2nd Generation CAV)								
		100-0-0	**80-20-0**	**60-40-0**	**40-40-20**	**20-40-40**	**0-40-60**	**0-20-80**	**0-0-100**	
Impact	**Sub use case**	%	%	%	%	%	%	%	%	**Method**
Average travel time (all vehicles)	Baseline (no AUSS)	0	0,2	0,0	-0,1	-0,3	-0,5	-0,4	-0,5	Meso-simulation (Vienna)
	On-demand AUSS: Last-mile	1,3	0,6	0,4	0,1	-0,1	-0,6	-0,2	-0,3	
	On-demand AUSS: A2A	-6,2	-8,1	-8,5	-8,9	-9,1	-9,4	-9,5	-9,5	
Access to travel	Baseline (no AUSS)	0,0	2,6	-1,4	18,8	31,2	33,9	33,9	33,9	Delphi (expert survey)
	Point-to-point AUSS	0,0	6,9	15,2	24,2	32,5	42,1	42,1	42,1	
	On-demand AUSS	0,0	8,4	15,6	23,0	30,6	34,5	34,5	34,5	
Amount of travel (km/person)	Baseline (no AUSS)	0,0	0,0	-0,1	-0,1	-0,2	-0,2	-0,2	-0,2	Meso-simulation (Vienna)
	On-demand AUSS: Last-mile	0,4	0,3	0,3	0,3	0,3	0,2	0,2	0,2	
	On-demand AUSS: A2A	0,9	0,3	0,2	0,2	0,1	0,1	0,1	0,1	
Total kilometres travelled in network	Baseline (no AUSS)	0,0	25,3	25,6	8,0	-10,6	-24,7	53,2	60,0	Micro-simulation (Athens)
	Point-to-point AUSS	-0,9	25,1	25,7	7,0	-10,5	-25,0	52,7	59,9	
	On-demand AUSS	21,0	25,6	27,1	10,5	-8,8	-23,4	56,8	61,2	
Congestion (delay time/ km travelled)	Baseline (no AUSS)	0,0	-11,4	-11,8	-11,6	-9,9	-3,6	-41,9	-45,1	Micro-simulation (Athens)
	Point-to-point AUSS	1,2	-11,2	-12,2	-12,4	-9,0	-3,5	-42,3	-45,0	
	On-demand AUSS	-22,4	-23,6	-25,2	-24,2	-23,2	-21,5	-39,7	-41,8	
Modal split: Active modes	Baseline (no AUSS)	0,0	-3,4	-4,7	-14,9	-16,2	-17,6	-17,6	-17,6	Delphi (expert survey)
	Point-to-point AUSS	0,0	-0,6	-0,6	-3,2	-6,1	-5,4	-5,4	-5,4	
	On-demand AUSS	0,0	-3,9	-8,1	-9,7	-12,9	-14,9	-14,9	-14,9	
Modal split: Public transport	Baseline (no AUSS)	0,0	-3,8	-10,6	-14,9	-25,5	-31,0	-31,0	-31,0	
	Point-to-point AUSS	0,0	0,7	-0,6	0,1	0,9	-0,5	-0,5	-0,5	
	On-demand AUSS	0,0	5,4	3,4	2,5	1,8	4,1	4,1	4,1	
Shared mobility rate	Baseline (no AUSS)	0,0	0,7	5,0	18,0	19,3	21,6	21,6	21,6	
	Point-to-point AUSS	0,0	5,6	11,2	19,1	22,3	23,6	23,6	23,6	
	On-demand AUSS	0,0	2,9	4,0	8,9	10,9	12,1	12,1	12,1	
Vehicle utilization rate of AUSS[2]	On-demand AUSS: Last-mile	0,0	0,1	0,0	0,0	0,1	0,1	0,0	0,1	Meso-simulation (Vienna)
	On-demand AUSS: A2A	6,7	5,2	5,2	4,8	5,0	4,9	4,7	4,9	
Vehicle occupancy of AUSS[2]	On-demand AUSS: Last-mile	0,0	0,8	0,8	0,2	0,4	0,3	0,4	0,4	Meso-simulation (Vienna)
	On-demand AUSS: A2A	16,4	12,8	12,7	12,5	12,4	13,2	13,1	13,1	

[2] Baseline not applicable (measured for shuttles only); percentage change compared to last-mile 100-0-0

Table 3.5. Estimated impacts of automated urban shuttle services (AUSS) on modal split using absolute percentages of total travel demand mobility, measured modal split using absolute percentages of total travel demand in Vienna in terms of percentages change with respect to the Baseline 100-0-0 scenario and percentage of travel demand.

		Deployment scenarios: Market penetration rate **of CAVs** in **entire** vehicle fleet (Human-driven vehicle – 1st Generation CAV – 2nd Generation CAV)								
		100-0-0	**80-20-0**	**60-40-0**	**40-40-20**	**20-40-40**	**0-40-60**	**0-20-80**	**0-0-100**	
Impact	**Sub use case**	%	%	%	%	%	%	%	%	**Method**
Modal split Vienna: Car (HDV & AV)	Baseline (no AUSS)	39,7	40,2	40,6	41,3	42,0	42,5	42,9	43,0	Meso-simulation (Vienna)
	On-demand AUSS: Last-mile	38,9	36,6	37,4	38,1	38,8	39,4	39,6	39,7	
	On-demand AUSS: A2A	38,8	36,8	37,5	38,1	38,8	39,5	39,5	39,8	
Modal split Vienna: Active modes	Baseline (no AUSS)	8,1	8,2	8,3	8,1	8,2	8,2	8,0	8,0	
	On-demand AUSS: Last-mile	7,8	10,5	10,1	10,0	10,0	10,1	9,9%	9,9	
	On-demand AUSS: A2A	8,0	9,8	9,7	9,7	9,6	9,6	9,5%	9,5	
Modal split Vienna: Public transport (excl. AUSS)	Baseline (no AUSS)	52,1	51,6	51,1	50,6	49,8	49,3	49,1	49,0	
	On-demand AUSS: Last-mile	51,7	51,0	50,6	49,9	49,3	48,6	48,7	48,5	
	On-demand AUSS: A2A	50,1	49,7	49,0	48,4	47,8	47,1	47,1	46,8	
Modal split Vienna: AUSS	Baseline (no AUSS)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
	On-demand AUSS: Last-mile	1,6	1,9	1,9	1,9	1,9	1,9	1,9	1,9	
	On-demand AUSS: A2A	3,0	3,7	3,8	3,8	3,8	3,9	3,9	3,9	

The modal split results were calculated using two methods: in the Delphi results, the general expected development (in relative percentages) according to the expert panel has been estimated (see *Table 3.*4). Additionally, the mesosimulation estimated the effects of both the Baseline and on-demand AUSS on the modal split of the city of Vienna, Austria. These results are presented separately in terms of absolute percentage shares of travel demand in *Table 3.5* (instead of the relative percentages used for other impacts).

Delphi results

The Delphi panel was asked to estimate the effect of AUSS, in particular, for the *access to travel* and *modal split* indicators. The results in *Table 3.4* show the following about the developments in *access to travelling* whenever and wherever wanted:

- In the baseline situation, access to travel improves by 19% once second-generation automated vehicles comprise 20% of the vehicle fleet. This increases to 31-34% when the share of second-generation vehicles increases to more than 40% of the fleet.
- Compared to the baseline, both point-to-point and on-demand AUSSs will further improve access to travel across all CCAM penetration levels. At lower penetration levels the estimated effect is similar for both AUSS's but at the highest three penetration levels, the point-to-point AUSS shows larger estimates of improvement in access to travel.
- In all cases, AUSS improves access to travel when compared to the baseline scenario. The experts indicate that AUSSs will improve access to travel between 1% and 15% depending on the level of first- and second-generation CCAM penetration rates.
- Of the on-demand scenarios considered (see *Appendix C.2*), the largest increase in access to travel was expected for anywhere-to-anywhere shuttles and the least for last-mile shuttles.

In the Delphi study, relative developments in *modal split* were also estimated. This showed that experts expect:

- In the Baseline scenario, experts expect increasing penetration of automated vehicles to lead to travellers replacing trips that were previously made by public transport, cycling, or walking with trips using automated vehicles. This is expected to lead to up to a 31% reduction in public transport trips, and 18% reduction in trips using active modes (walking/cycling).
- Both scenarios with AUSS are expected to see a reduction in active transport, although for point-to-point this is to a lesser degree than in the Baseline. Of the on-demand scenarios (see Appendix C.2), anywhere-to-anywhere and e-hailing are expected to result in the largest reduction (up to 20% less) in active transportation. Last-mile shuttles are expected to have a similar reduction in active transport to point-to-point shuttles.
- Both point-to-point and on-demand AUSS are expected to lead to less of a change in public transport (excluding AUSS) usage than in the Baseline. Among the different types of on-demand shuttles considered (see Appendix C.2), an anywhere-to-anywhere service is expected to compete most with public transport (up to a 16% reduction in public transport). Last-mile shuttles are expected to complement public transport to improve its attractiveness, leading to an increase in public transport trips (up to 24%).
- In all scenarios, increasing penetration of automated vehicles as well as AUSS are expected to facilitate an increase (12-24%) in vehicle sharing. An on-demand automated shuttle service is expected to result in less of an increase in sharing than in the Baseline and point-to-point scenarios. Especially the e-hailing (see Appendix C.2) form of on-demand shuttles is expected to be shared less often.

Microsimulation results
The impacts on *total kilometres travelled* and *congestion levels* were estimated using AIMSUN microsimulation software. As can be seen from Table 3.4, the impacts on *total kilometres travelled* show a complex pattern: according to the baseline development, the total kilometres travelled in the simulated network will increase, although it briefly decreases when second-generation CAVs are first introduced (Table 3.4 indicated in red highlights). Once the second-generation CAVs reach penetration levels of 80% to 100%, the total kilometres covered in the network again increase. This development is related to the microsimulation outcomes which suggest that mixed traffic—including human-driven vehicles and first- and second-generation CAVS—leads to increased delays due to less efficient traffic flow. Therefore, during any given simulation period, fewer trips (and fewer network kilometres) can be completed when compared to other mixes where traffic is more homogeneous.

The sub-use cases have little additional impact on the development of total kilometres travelled in the network compared to the Baseline, due to the fact that travel demand remains constant across sub-use cases. The exception is with the introduction of on-demand AUSS in a situation of 100% human driven vehicles. Because the automated on-demand shuttles are modelled to cover 5-10% of the total travel demand, depending on the scenario, their introduction into the network has a similar effect to the Baseline 80-20-0 scenario in which 20% of the vehicle fleet becomes automated. Due to a more efficient traffic flow compared to the Baseline 100-0-0 scenario, more trips are able to be completed in one simulation period. As automation of private vehicles increases in the on-demand scenario, however, the difference between on-demand AUSS and the Baseline or point-to-point SUC become minimal.

Furthermore, it is important to note that while an increase in total kilometres travelled can represent an improvement in mobility and accessibility of the network, such an increase can also bring about negative environmental and/or societal externalities. More kilometres travelled may, for example, use more energy, represent a modal shift from OV/active modes to private vehicles, increase exposure to traffic safety risks, or use more public space.

The microsimulation results for the impacts on *congestion* show that congestion in the baseline scenario will be reduced by 9-12% when 1st generation CAVs make up between 20-40% of the vehicle fleet and may be further reduced (42-45%) when 2nd generation CAVs become dominant in traffic. The point-to-point AUSS has little additional effect on congestion levels, but the on-demand AUSS shows a further reduction in congestion levels compared to Baseline at low penetration rates. This echoes the results of total kilometres travelled, which suggest that implementation of the on-demand AUSS results in a more efficient traffic flow compared to a largely human-driven Baseline most likely due to two factors: a shift in trips from mostly human-driven vehicles to automated shuttles, as well as the shift from private vehicles to a form of shared transport.

Regarding the point-to-point SUC scenarios (see Appendix C.2), the presence of a dedicated shuttle lane had negligible impacts on both the total kilometres travelled and congestion. Only the off-peak hour simulations showed lower levels, due to the reduced amount of traffic on the network. The on-demand SUC scenarios also showed little variation across the different shuttle capacities (8 vs. 15) and shares of demand (5% vs. 10%), with slightly larger effects observed for the 10% demand served scenarios.

Mesosimulation

Mesosimulation was used to estimate impacts of two types of on-demand AUSS on *average travel time*, *amount of travel*, *modal split* and *vehicle utilization* and *usage rate* in the City of Vienna. The two types of on-demand services considered are an anywhere-to-anywhere (A2A) service in the city centre, as well as a last-mile service operating from public transport stops in the city peripheries.

The *average travel time* for all vehicles in the network appears not to change much for the baseline development and the last-mile sub-use case. Compared to the baseline scenario, the introduction of anywhere-to-anywhere AUSS is associated with a substantial reduction in average travel time (6-9%). This reduction increases as the proportion of human-driven vehicles decreases and first- and second-generation automated vehicles increases. The effects of anywhere-to-anywhere shuttles on average travel time also changed in scale depending on fleet size, with a slightly larger effect observed in the larger fleet size scenario compared to the smaller fleet size scenario (see Appendix C.2).

Next, we consider the results for *modal split* in Vienna. The modal split was estimated using mesosimulation of the Vienna network and is reported in terms of absolute percentages of the total travelled distance in *Table 3.5* at each penetration rate (as opposed to percentage change). It should be noted that although AUSS can be considered as a type of public transport, in the model calculations of modal splits these are modelled as separate modes.

The baseline results concerning the *modal split* impacts (private car, active modes, public transport, and automated urban shuttle service AUSS) indicate a gradual reduction in public transport use (from 52% to 49%) and increase in private car use (40% to 43%), while active modes of transport (walking/cycling) remain relatively stable (8,1-8,3%). This suggests that under baseline conditions there is a shift from public transport to private (automated) cars. With the introduction of on-demand AUSS (last-mile and anywhere-to-anywhere urban shuttle services) it is estimated that these could also take a share away (roughly 3%) from initial public transport use. Meanwhile, when AUSS is present, the level of private car use remains relatively constant with increasing automation rates. Both types of the modelled AUSS take up a share of about 2%-3% of trips travelled in the city. For both last-mile and anywhere-to-anywhere, their modal share is expected to be slightly higher for the larger fleet size scenarios (see Appendix C.2).

An interesting result is that the last-mile shuttle service also leads to a small increase in the share of active modes. The last-mile shuttle service is associated with shares of active travel that are about two percentage points higher than under baseline conditions. Also the anywhere-to-anywhere shuttle service corresponds with shares of active travel that are about 1,5 percentage points higher than the baseline. Transport to and from the shuttles is not included in the modal split. A potential explanation for this increase is that travellers who shift trips from a private vehicle to AUSS may be more likely to conduct other trips throughout their day by foot, due to not leaving home with a car. This result is different from the Delphi study, in which experts predicted that automated vehicles and AUSS will take trips away from active modes. Both anywhere-to-anywhere and point-to-point AUSS were estimated to take a share away from short trips which normally would be undertaken on foot or cycling.

For the *vehicle utilization* and *occupancy rate* impacts of automated urban shuttles, a meaningful baseline is not applicable since these rates only apply to the shuttle vehicles themselves. The on-demand anywhere-to-anywhere results in higher shuttle occupancy rates (13-16% higher) than last-mile shuttles and shuttles which drive less kilometres completely unoccupied (utilization of 5-7% higher). The last-mile shuttle service is expected to remain relatively constant across different penetration rates of automated vehicles in the city's vehicle fleet; anywhere-to-anywhere shuttles are expected to decrease slightly as vehicle automation rates increase. Both vehicle utilization rate and occupancy rate are expected to be slightly higher in the scenarios implementing larger shuttle fleets (see Appendix C.2).

3.3 Impacts on society, safety & economy

In this section we discuss the main findings on the (expected) wider impacts of introducing automated urban transport services into city areas that experience increasing levels of CAV penetration. First the definitions of impacts on society, safety and economy are presented in *Table 3.6*.

Table 3.6: Society, safety & economy impact definitions

Impact	Definition	Methodology
Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel and averaged over all traffic	Delphi
Parking space demand	Required parking space in the city centre per person (m2/person)	Delphi
		System Dynamics
Road safety	Number of predicted crashes per vehicle-kilometre driven (all traffic)	Microsimulation (postprocessing with SSAM + Tarko crash prediction method)
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
Average commuting distance	Average length of trips to and from work (added together) in km (all traffic)	System Dynamics

As we have explained earlier, society, safety and economy are highly interrelated policy areas. For example, both road safety and public health have an important social dimension as well as a well-established economic dimension. Economic indicators such as vehicle operating costs and parking space have a direct economic value but will also have an impact on access to mobility and therefore on various social and cultural activities, and collective well-being (and will also have effects that extend to other domains).

Table 3.7 presents the expected wider impacts on the policy domains of society (health, and access to services), as well as road safety and economy. The impacts on road safety are based on results from the AIMSUN microsimulations. System dynamics has been used to estimated impacts on parking space and average commuting distances, and the remaining impacts are based on results from the Delphi study.

Table 3.7: Estimated impacts of automated urban shuttle services (AUSS) on society and economy, measured in terms of percentage change with respect to the Baseline 100-0-0 scenario and percentage of travel demand.

		Deployment scenarios: Market penetration rate **of CAVs** in **entire** vehicle fleet (Human-driven vehicle - 1st Generation CAV - 2nd Generation CAV)								
Impact	**Sub-use Case**	**100-0-0** %	**80-20-0** %	**60-40-0** %	**40-40-20** %	**20-40-40** %	**0-40-60** %	**0-20-80** %	**0-0-100** %	**Method**
Vehicle operating cost (all vehicles)	Baseline (no AUSS)	0,0	-2,7	1,1	-1,8	-8,3	-10,3	-10,3	-10,3	Delphi (expert survey)
	Point-to-point AUSS	0,0	-4,5	-6,2	-11,8	-15,7	-21,6	-21,6	-21,6	
	On-demand AUSS	0,0	0,4	-0,9	-2,8	-4,9	-7,6	-7,6	-7,6	
Parking space demand	Baseline (no AUSS)	0,0	-2,5	-5,5	-14,2	-17,7	-21,1	-21,1	-21,1	Delphi (expert survey)
	Point-to-point AUSS	0,0	0,2	-5,2	-12,3	-17,8	-22,2	-22,2	-22,2	
	On-demand AUSS	0,0	-1,3	-4,0	-9,9	-13,9	-16,4	-16,4	-16,4	
	Baseline (no AUSS)	0,0	2,7	8,0	19,7	34,7	47,3	47,3	47,3	System dynamics (Vienna)
	On-demand AUSS: Last-mile	-0,1	2,6	7,5	18,4	32,9	45,4	45,4	45,4	
Average commuting distance	Baseline (no AUSS)	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,0	System dynamics (Vienna)
	On-demand AUSS: Last-mile	0,0	-1,0	-1,0	-1,0	-1,0	-1,0	-1,0	-1,0	
Road safety: crash rate	Baseline (no AUSS)	0,0	-9,4	-10,2	-20,0	-36,2	-50,1	-58,4	-68,2	Micro-simulation (Athens)
	Point-to-point AUSS	0,2	-10,1	-5,6	-19,6	-35,5	-49,6	-58,5	-68,0	
	On-demand AUSS	-13,6	-10,0	-7,1	-21,1	-37,2	-50,2	-58,4	-68,9	
Public health	Baseline (no AUSS)	0,0	1,0	1,0	3,6	2,2	4,1	4,1	4,1	Delphi (expert survey)
	Point-to-point AUSS	0,0	-0,2	3,7	5,0	8,0	11,9	11,9	11,9	
	On-demand AUSS	0,0	1,9	4,5	4,8	4,4	5,9	5,9	5,9	
Equal accessibility of transport	Baseline (no AUSS)	0,0	4,4	9,7	13,9	19,2	22,5	22,5	22,5	Delphi (expert survey)
	Point-to-point AUSS	0,0	0,3	-3,8	2,0	-3,0	-4,4	-4,4	-4,4	
	On-demand AUSS	0,0	-0,2	-0,2	-2,0	-0,9	2,1	2,1	2,1	

Delphi results
Estimates of impacts on society and economy (namely *vehicle operating cost*, *parking space*, *public health* and *equal accessibility of public transport*) were derived from the Delphi consultation results (see *Table 3.7).*

For the Baseline (No AUSS) condition, experts indicated that an increasing penetration of connected and automated vehicles would lead to:

- A reduction of in *vehicle operating costs* (8-10% less) and required *parking space* (18-21% less), especially at or above a market penetration rate of 80% automated vehicles (from 20-40-40).
- An improvement in *public health* (2%-4%) when the share of automated vehicles is 60% or larger (from 40-40-20). Presumably public health is, in the view of experts, improved by a growing presence of cleaner, safer and quieter vehicles

- The expected improvement in *equal accessibility to transport* in the baseline condition becomes more substantial (19-23% increase) as penetration rates of automated vehicle exceed 80% (from 20-40-40).

Compared to the Baseline development, the introduction of a point-to-point shuttle service is expected to deliver the following:

- Additional *vehicle operating cost* savings of between 8-12% compared to the Baseline (note these are VOC based on total traffic)
- Negligible difference in *parking space* requirements when compared to the Baseline
- Further improvement to *public health* by an additional 8% compared to the Baseline
- A slightly (albeit barely noticeable) negative impact on the equal *accessibility of transport*

Compared to the Baseline development, the on-demand AUSS is not expected to generate additional positive outcomes in terms of lowering *vehicle operating costs*, reducing required *parking space* or improving *equal access to transport*, but it is expected to lead to modestly better *public health* outcomes. Of the on-demand scenarios considered in the Delphi study (see Appendix C.3), the following differences are notable:

- *Vehicle operating cost*: larger reduction expected for anywhere-to-anywhere shuttles than for last-mile or e-hailing
- *Public health:* slightly larger improvement expected for e-hailing
- *Equal accessibility of transport:* anywhere-to-anywhere expected to perform best for accessibility (9% improvement) while last-mile and e-hailing not expected to improve accessibility (-1% change)

In summary, the Delphi consultation reveals that the automated point-to-point shuttle service is expected to deliver extra (benefits above the baseline development) social and economic benefits for the city in terms of additional lower vehicle operating costs, less need for parking space and better public health. The on-demand shuttle service is not believed to generate extra benefits apart from a slightly improved public health, and for an anywhere-to-anywhere service, slight improvements to accessibility and vehicle operating costs.

System dynamics results

In contrast to the Delphi results which showed a development towards lesser demand for *parking space*, the system dynamics result show a development towards increasing demand for parking space with increasing automation. Compared to the baseline, the percentage increase withs implementation of a last-mile shuttle service are slightly lower. Thus, the last-mile shuttle SUC seems to reduce demand for parking space, but the influence is small.

The reason for this contradictory expectation is likely to come from the differences in assumptions with the systems dynamics approach when compared to the Delphi method. In system dynamics, the baseline only considers the increasing market penetration rate of (privately owned) CAVs with no expected simultaneous developments such as policy interventions to restrict individual traffic. This leads to a higher modal share of private cars for increasing CAV penetration rates in the system dynamics model, and consequently the model also estimates an increasing demand for parking space in the absence of further interventions and regulations (Roussou et al., 2021c). As the Delphi method is based on expert consultation, experts may have some assumptions or expectations about the development in private vehicle use which are not considered by the model.

System dynamics was also used to estimate the effect of an on-demand last-mile automated shuttle service on *average commuting distances* for all traffic in the simulation. However, neither the baseline effects of increasing automation nor the implementation of the last-mile shuttles had much effect on the average commuting distance. The last-mile AUSS sub-use case showed a decrease of 1% relative to the starting point, indicating that travellers using the last-mile shuttle may experience a slightly shorter commute.

Microsimulation results
Road safety impacts were estimated from the microsimulation studies in Athens and the results in *Table 3.7* reveal the following:

- The Baseline results indicates that the crash rate of urban transport vehicles improves steadily at higher penetration rates of automated and connected vehicles
- The two sub-use cases, point-to-point and on-demand, have marginal impacts on the crash rate of urban transport vehicles when compared to the baseline. The exception is on-demand AUSS when the rest of the vehicle fleet is 100% human-driven (100-0-0), as the shuttle service essentially replaces 5-10% of human-driven trips with trips in an automated shuttle.
- The presence of a dedicated lane in the point-to-point AUSS scenarios (see *Appendix C.3*) had no effect on crash rates. The simulation on a small-scale network showed a large degree of seemingly random variations, with higher crash rates observed when the shuttles were introduced in an entirely human-driven network. For the on-demand AUSS scenarios, little difference was observed across the fleet sizes and demand served.

In short, the increasing penetration of connected and automated vehicles is predicted to reduce the crash rate of vehicles by up to 69% in the Athens network. The use of a shuttle service for point-to-point or on-demand AUSS is not expected to generate any additional safety benefits over those estimated for the Baseline condition.

The microsimulation software is limited to the simulation of motor vehicles on the road, and therefore does not simulate interactions involving vulnerable road users (VRUs) such as pedestrians and cyclists. As was discussed in Weijermars et al. (2021), increasing penetration levels of CAVs in general is expected to decrease fatalities among VRUs by more than 90% in case of 100% penetration. The sub-use cases on automated urban shuttles are not expected to have a large additional effect specifically on vulnerable road users compared to the baseline scenario, and where larger potential impacts are expected (e.g., on-demand shuttles stopping for boarding/alighting at undesignated stops) it is not possible to quantify the impacts with the available data and simulation methods. Therefore, impacts on VRUs are not quantified for these sub-use cases.

4 Discussion

This chapter discusses the main findings about the expected impacts after introducing of CAVs and automated urban shuttle services (4.1). The strengths and limitations of the theoretical and empirical work underlying these impacts are discussed (4.2), and it adds further insights on policy issues in further developing automated urban transport (4.3).

4.1 Main findings

In this section, the results are summarised and discussed regarding the impacts of deploying connected and automated vehicles (CAVs) in urban environments on the policy areas (environment, mobility, and society-safety-economy). In addition to the general impacts, the effects of the Automated Urban Shuttle Services (AUSS) interventions are discussed.

4.1.1 Impacts on Environment

As mentioned in Section 3.1, CO_2 emissions and energy efficiency indicators are used to summarise the environmental impacts.

The results in Table 3.2 show that the expected reduction in CO_2 emissions (per vehicle kilometre) with increasing market penetration rates is largely proportional to the percentage of the vehicle fleet which becomes an automated vehicle (e.g., a 40% reduction in CO_2 emissions when the vehicle fleet is 40% first-generation automated vehicles; a 64% reduction when an additional 20% become second-generation automated vehicles). These estimated reductions are largely attributed to the fact that in the simulation models, automated vehicles were defined as electric vehicles with minimal emissions.

Furthermore, neither point-to-point nor on-demand AUSS are predicted to further reduce CO_2 emissions per vehicle kilometre when compared to the introduction of connected and automated vehicles (baseline, shown in Table 3.2). The microsimulation scenarios considering the effects of a dedicated lane and fleet size also showed negligible effects on emissions. It is possible, however, that a change in the total vehicle kilometres travelled per transport mode may affect the total environmental impact. If an automated urban shuttle system is able to capture some of the projected increase in automated private vehicle use (from mesosimulation results, Table 3.5), this shared form of travel may reduce total vehicle kilometres travelled and therefore electricity demands.

The Delphi study found a moderate improvement expected in energy efficiency for both the Baseline and AUSS scenarios. The largest improvements to energy efficiency are expected from the point-to-point shuttle service or the on-demand: anywhere-to-anywhere scenario.

4.1.2 Impacts on Mobility

The mobility impacts are, for the largest part, system-wide impacts within the transport system. The ten mobility indicators used to evaluate the impacts of mobility were presented in Section 3.2.

Access to travel

According to the Delphi panel, positive effects are to be expected for *access to travel* (the opportunity of taking a trip whenever/wherever wanted). According to the baseline development, access to travel will be improved substantially once automated vehicles make up more than half of the vehicle fleet (19-34% improvement). Compared to the baseline, both point-to-point and on-demand AUSSs are expected to further improve access to travel across all CAV penetration levels (1-15% higher than baseline). Especially a point-to-point shuttle service and the anywhere-to-anywhere variant of on-demand AUSS are expected to make travel more accessible than in baseline conditions.

Traffic conditions

The impacts on *total kilometres travelled* and *congestion levels* were estimated using AIMSUN microsimulation. The impacts on total kilometres travelled show a complex pattern: according to the baseline development, the kilometres travelled will increase at most penetration rates but will decrease once human-driven vehicles reach 20% and lower, and second-generation CAVs reach penetration levels of between 40 and 60%. At penetration levels beyond 60% for second-generation CAVs, the total kilometres covered in the network again increases significantly. This development is related to the microsimulation outcomes which suggest that mixed levels of human, first- and second-generation CAVs lead to increased congestion levels and therefore, during any given simulation period, less trips (and therefore fewer network kilometres) are completed when compared to other mixes where less human or fewer automated vehicles are present. The point-to-point and on-demand scenarios (see Appendix C.2) involving a dedicated shuttle lane or variations in shuttle fleet capacity, had little additional impact on kilometres travelled or congestion beyond those effects seen in the baseline.

The effects on *kilometres travelled* is one of the more complex and perhaps ambivalent findings discussed in this synthesis. Increased penetration levels of CAVs leads to more kilometres travelled in the simulation. This generally relates to improved traffic conditions, less congestion and less delay and therefore more trips can be completed within the same simulation time frame. With mixed traffic (mixed human and CAV) however, there are more interactions which lead to more delay and congestion, and therefore fewer trips and kilometres travelled within the modelled timeframe. It should be noted that for this synthesis the kilometres travelled increase is assumed to be a favourable mobility outcome since it indicates both an increase of completed trips within the simulated time frame as well as a decreased delay time in the city network. However, it is not clear that these effects are only positive. On the one hand, more kilometres travelled indeed signifies higher accessibility and lower delay times. On the other hand, more kilometres travelled can also mean more energy usage, shift trips from public transport/active modes to private vehicles, higher exposure to traffic safety risks, and may use up more public space. It should be noted that the microsimulation is not necessarily predicting more private vehicle travel in total but just that more car travel "fits" efficiently in the network as CAV penetration increases.

Mesosimulation was used to estimate the impact of on-demand last mile and on-demand anywhere-to-anywhere AUSS on *average travel times* in the city of Vienna. The *average* *travel time* for all vehicles in the network appeared not to change much under baseline development or under the last-mile sub-use case. Compared to the baseline scenario, the introduction of an anywhere-to-anywhere automated urban shuttle service is associated with a reduction in average travel time (6-9% on average per vehicle, calculated over all traffic). This reduction increases as the proportion of human-driven vehicles decreases and first- and second-generation automated vehicles increases.

Modal split

The baseline results concerning the *modal split in Vienna* estimated using mesosimulation indicate a shift of about 3% of the total travel demand from public transport to the private (automated) car, while walking and cycling remain relatively constant. When on-demand shuttle services are introduced into the network, roughly the same portion (3%) shifts from public transport to automated shuttles, rather than to a private automated vehicle. Last-mile and anywhere-to-anywhere on-demand shuttle services each take up a share of about 2%-3% of the travelled distance, and also appear to facilitate a small increase of up to 2% in active (walking/cycling) travel.

These mesosimulation results for *modal split* are different than those found in the Delphi study, which show that experts expect both automated vehicles and an automated shuttle system to be more competitive with active travel and public transport. While increasing penetration of CAVs (without a shuttle system) is expected by both methods to draw some trips away from public transport, in the Delphi study experts also expected a decrease in walking and cycling. This impact on public transport is largely in line with other studies, which also expect the introduction of automation to reduce public transport trips (Correia & van Arem, 2016; Kim et al., 2015a; Kröger et al., 2018; Martin & Shaheen, 2011). The impact on active modes of travel is in the literature again more mixed, with some studies finding a decrease in cycling and walking when CAVs are introduced (Correia & van Arem, 2016; Kim et al., 2015a; Kröger et al., 2018) and others finding an increase (Martin & Shaheen, 2011). The increase in private car use predicted by the mesosimulation is in line with Soteropoulos et al. (2019), who conclude that the increased availability of private automated vehicles for all (even people without a driving license, children, elderly and mobility-impaired people) may lead to an increase in the share of private car trips.

The degree to which also adding an automated urban shuttle service is predicted to affect these changes in modal split depends on the type of shuttle system considered as well as the methodology. Compared to the mesosimulation, which predicts a small increase in active travel, the Delphi method predicts a decrease: for anywhere-to-anywhere and e-hailing, this decrease is even more than in the baseline. Last-mile and point-to-point AUSS, on the other hand, are expected by experts in the Delphi study to complement active travel, leading to higher active mode shares than in the baseline development. In addition, while anywhere-to-anywhere shuttles are seen as larger competitors to public transport (leading to a decrease in mode share), last-mile shuttles are seen as a complementary service which can increase the share of public transport in the overall modal split. This is in line with the mesosimulation finding that anywhere-to-anywhere shuttles would reduce public transport usage more than last-mile, although last-mile shuttles did also result in a slight decrease. In the literature, the introduction of automated shuttle services such as the anywhere-to-anywhere AUSS are expected to lead to the reduction of the use of public transport and also lower the private car modal split (Boesch et al., 2018).

Shuttle utilization

Vehicle utilization and *occupancy rates* of automated urban shuttles were also calculated using mesosimulation of the Vienna network. The on-demand anywhere-to-anywhere AUSS results in higher shuttle occupancy rates (13-16% higher) and shuttles which drive less kilometres completely unoccupied (utilization of 5-7% higher) when compared to the last-mile shuttle service. In addition, the scenarios with larger shuttle fleets sizes (see Appendix C.2) show slightly higher utilization and occupancy rates due to the better availability of AUSS vehicles, which leads to a higher number of service trips. Both occupancy and utilization rates decrease slightly when a larger share of connected and automated vehicles become part of the city vehicle fleet.

4.1.3 Impacts on Society, safety & economy

Road safety

Road safety impacts were estimated from the microsimulation studies in Athens. The crash rate of all vehicles in the network improves steadily at higher penetration rates of connected and automated vehicles; when the share of second-generation vehicles is at 20% the crash rate is reduced by 20% and when the share is at 40% the crash rate is reduced by 36%. At larger shares of second-generation vehicles (60-100%) the crash rate of urban transport vehicles is reduced by 50% to 69%. The point-to-point and on-demand sub-use cases, as well as the scenarios involving a dedicated shuttle lane or variations in shuttle fleet capacity, had little impact on road safety beyond those effects seen in the baseline.

The microsimulation software is limited to the simulation of motor vehicles on the road, and therefore does not simulate interactions involving vulnerable road users (VRUs) such as pedestrians and cyclists. As was discussed in Weijermars et al. (2021), increasing penetration levels of CAVs in general is expected to decrease fatalities among VRUs by more than 90% in case of 100% CAV penetration. Compared to the baseline scenario, the sub-use cases on automated urban shuttles are not expected to have large additional effects on specifically vulnerable road users. Where larger potential impacts are expected (e.g., on-demand shuttles stopping for boarding/alighting) it was not possible to quantify the impacts on VRU with the available data and simulation methods. Therefore, impacts on VRUs were not quantified for these sub-use cases.

Societal & economic impacts

Estimates of the impacts on society and economy - *vehicle operating cost, parking space, public health* and *accessibility of public transport* - were derived from the Delphi study. In addition, the system dynamics method was used to estimate impacts for both *parking space* demand and *average commuting distances* within the city of Vienna. Increased penetration of connected and automated vehicles in the Baseline scenario is predicted to lead to a reduction in vehicle operating costs while improving public health and the equal accessibility of transport. The predictions for parking space differ greatly per method: in the system dynamics model, an increase in private car use is associated with an increase in the demand for parking space, while in the Delphi method, seem to have based their expectations on a different set of assumptions (e.g., future policies/services to limit private vehicle usage) and therefore predict a decrease in the demand for parking space. When penetration rates of automated vehicles reach 80-100% in the baseline scenario, the following effects are expected compared to the situation with only human-driven vehicles and no CAVs:

- Vehicle operating cost: 8%-10% reduction
- Parking space: 18%-21% reduction (Delphi), 35-47% increase (System dynamics)

- Public health: 2%-4% increase
- Equal accessibility of transport: 19%-23% increase
- Average commuting distance: 1% increase

According to the Delphi consultation, the automated point-to-point shuttle service is expected to deliver extra benefits (benefits above the baseline development) for the city in terms of (reduced) vehicle operating costs, (less)parking space and (better)public health. The on-demand shuttle service is not believed to generate extra benefits apart from slightly improved public health. The anywhere-to-anywhere service, slight improvements to accessibility and vehicle operating costs are estimated. The system dynamics model predicts that last-mile AUSS can help reduce the increase in parking space demands (lower than the baseline), and results in a slightly lower average commuting distance.

4.2 Strengths and Limitations

Like most projects of this type, LEVITATE has strengths and limitations. A potential strength of the LEVITATE project is that both smart city transport policy interventions and the associated impacts have been selected by a diverse group of stakeholders. A wide variety of impacts were studied at the same time and the project tried to capture interdependencies. The best available methods, microsimulation, mesosimulation, Delphi, and other complementary methods such as system dynamics and operations research, were used to study and quantify the expected impacts of mobility interventions intended to support CAV deployment and sustainable city goals. These impacts provide essential input for developing a practical Policy Support Tool for city policy makers. Above all, the knowledge from LEVITATE is intended to contribute and support future policy development and policy-making for smart city transport and traffic. Finally, a strong point of LEVITATE is that a consistent framework for assessing impacts across the project was used so that impacts may be more comparable across all use cases.

However, we also recognize that LEVITATE has limitations and these are described below. Firstly, we discuss some general limitations or difficulties concerning predicting future trends and, secondly some limitations that are more specifically related to the methods used in deriving the estimates.

Limitations in predicting future trends
Research evidence is not available for all potential impacts of connected and automated vehicles identified in LEVITATE. Specific potential impacts of CAV that are difficult to predict with any confidence are the following (Elvik et al., 2020; Bin, 2021[1]):

- Whether there will be a widespread transition from individual to shared mobility. There is no consensus on whether individual use of motor vehicles will continue at present levels or be replaced by various forms of shared mobility. This will largely be impacted by the policy measures of the city and national authorities. Therefore, the LEVITATE project aims to support the authorities finding the most beneficial policies on the way towards an automated transport system.

1. Personal communication from colleague Hu Bin on this report.

- It is not clear what type of propulsion energy connected and automated vehicles will use. Some researchers expect the introduction of connected and automated vehicles to be associated with a transition to electric propulsion. In LEVITATE project the assumption has been made that all CAVs are electric vehicles. This raises additional important questions including whether the electric power grid is able to keep up with the demand of the CAV/EVs, and whether the electric energy comes from sustainable sources. These aspects fall beyond the immediate scope of LEVITATE and have not been considered.
- Connected and automated vehicles are vulnerable to cyber-attacks. However, the risk of such attacks cannot be quantified. Only potential scenarios can be described. This is an aspect which has not been explicitly considered in the impact estimations.
- The costs of operating CAVs are highly uncertain. It is not clear whether CAVs will be as affordable as current motor vehicles. The costs of automation technology may influence the level of inequality in access to transport. However, there is a broad consensus that a significant cost reduction in urban transport will be realized when human drivers are no longer required to operate road-based vehicles.
- Behavioural adaptation to connected and automated vehicles, in particular during the transition period before full market penetration, remains uncertain. While some studies suggest various forms of behavioural adaptation, predicting its form and impacts is impossible and highly speculative.
- Changes in employment are difficult to predict. While full automation will eliminate the need for drivers, other potential impacts affecting changes in employment are less known.

Specific method-related limitations
There are some further remarks to be made about the possible limitations of the methods used in WP5:
- The results of the microsimulation models are dependent upon specific assumptions (summarised in Appendix B of this report), applying a different set of assumptions may lead to other outcomes.
- Each quantitative simulation method has different parameters and is applied to a different city model, for example the mesoscopic simulation uses the MATSim model for Vienna and the microscopic simulation considers the AIMSUN model for Athens
- The simulation modelling was based on the Athens and Vienna city networks and therefore the results cannot be immediately generalized. In both cases results are most transferable to those urban conglomerates which have structural and dynamic characteristics that are similar to those of the city networks modelled in LEVITATE.
- The simulation models used examined only two CAV profiles; future work may extend the number of profiles
- The safety results of the microsimulation do not include crashes where vulnerable road users are involved
- As with microsimulation, system dynamic and mesosimulation models are based on assumptions that may not always reflect the full complexities of reality.
- The Delphi method is based on human judgement which can be insightful but also be fallible.

4.3 Policy issues concerning implementation

In *Section 4.1* the possible impacts of automated urban transport were described. In the various models it is assumed that automated urban transport will function smoothly and that it will be accepted and used by the larger public. In practice, the use and acceptance of automated urban transport will depend very much on how well it is planned and governed and how well public demands or needs concerning transport have been taken into account. In this section we will reflect on a number of broader policy issues surrounding the introduction of automated transport systems in urban areas.

In this section we will first look at recent literature on the governance of future urban transport systems. The sub use cases, or policy interventions (or sub-use cases) studied in the LEVITATE project are part of a wider transition to smart mobility and smart cities. It is good to have insight into governance issues. Secondly, we describe findings from specific studies on urban shuttle system pilots. Issues identified from the literature and related to governing and planning new automated urban transport services may be relevant to the outcomes of Levitate and will be discussed in *Section 5.2* on **Policy recommendations**.

4.3.1 Governance of automated mobility in urban environments

Implementing new forms of connected and automated mobility is a highly complex process, particularly in the urban environment. Many different actors in city governance, industry and the general population will need to come together to deal with these challenges. Although there may be a strong push from industry to implement new smart mobility services, there are still many uncertainties that lie beyond the powers or competence of any one single actor to fully control or address. Adequate legislation and technical standards are expected to lag behind CAV deployment trials and pilots (in other words, technology develops faster and legislation and standards etc. have to follow). It is important to anticipate these developments and to start the processes necessary for adopting standards and legislation that will be necessary to regulate large scale CAV deployment. An example we can learn from is the advent of the motor car in a largely unregulated transport environment and which introduced many negative impacts which in time, and to this day, need mitigation. However most modern road safety policies are based on the concept of a Safe system which is about prevention, and this pleads for a pro-active approach, also with respect to standards, legislation and regulation.

There is enthusiasm about the transition towards smart mobility, but not surprisingly opinions vary. Fraedrich et al. (2018) carried out a survey among city planners in 24 German cities. Half of the respondents believed that shared autonomous vehicles could positively contribute to urban planning objectives, but only 10% reported that private autonomous cars could contribute to those objectives. According to the respondents, implementation of automated vehicles would require preparatory action in the fields of transportation planning, traffic control, road infrastructure, urban planning, citizen participation, test fields and data standards and requirements. Additional interviews with city planning experts led to four major insights namely

- cities themselves are a major driving force.
- for city renewal or redevelopment, public transport is a major goal.
- there is concern about the possibility of an increase of private car use in cities.
- city goals are not always directly aligned with other stakeholders seeking to push automated vehicle technology.

In the USA, McAslan et al. (2021) have looked at plans for autonomous vehicles amongst Metropolitan Planning Organizations (MPOs). One key area that requires attention is public engagement in the management of emerging technologies. This element seems critical to advancing CAVs in a way that addresses issues of equity and mobility justice (and others). Equity, accessibility, and other such goals are often promoted by industry, but ultimately the realization of these is ultimately a planning and policy decision (McAslan et al., 2021). Several of the studied Regional Transportation Plans did have policies to address issues of equity and accessibility. However, MPOs need to engage stakeholders (e.g., the public, industry, etc.) and make issues such as equity or other valued public goals a priority. Left to market forces alone, it is likely that these potential benefits will not be realised and could even worsen (McAslan et al., 2021).

Many authors have stressed that the industry and economy forces that tend to push towards implementation of automated driving, should be balanced by an equally strong orientation on the social-ethical (or the non-technical) dimension of the new technology. In other words, how it is governed, how it is perceived by citizens from various social strata, whether it complies with ethical guidelines and whether it really provides the expected benefits for the city (Fraedrich et al., 2018; McAslan et al., 2021; Habibzadeh et al., 2019, Milakis & Muller, 2021). In recognition of this, authors have suggested that new types of national, local or city governance (or management) are needed to steer the transition towards automated mobility in a responsible way (e.g., Aoyama & Leon, 2021; McAslan et al., 2021; Milakis & Muller, 2021).

Milakis & Muller (2021) suggest that policy makers need new tools for long term planning to accommodate uncertain urban futures. They argue in favour of new participative anticipatory governance instead of traditional governance which is typically supported by forward looking exploratory deployment scenarios with short term implications. They suggest a research agenda that is more oriented on citizens than consumers, more focused on long term than only short term and more based on citizen participation than traditional short-sighted scenario analysis. Their emphasis on normative scenario analysis (i.e., back casting) aligns well with the LEVITATE project.

McAslan et al. (2021) argue for anticipatory governance looking at future scenarios, using flexible planning mechanisms, and where monitoring and learning are built in the planning process, and the public is actively engaged.

Aoyama & Leon (2021) conclude that cities are part of multi-scalar governance frameworks where new rules, regulations, strategies, and standards are negotiated and enacted. They identified four key roles for cities in the governance of the emerging autonomous vehicle economy: regulator, promoter, mediator, and data catalyst. They cite the example of the city of Pittsburgh which, in recent years, has shifted away from a role of being promotor to a new role of being mediator. The initial emphasis of the city government on the promotion of the autonomous vehicle economy has decreased and has given way to an acknowledgment of the need to build more equitable relationships between various stakeholders in the city area. Another example of a city taking up a different governance role is Boston. In recent years, Boston's city government has become very active as a data catalyst; the city takes an active approach in exploring partnerships on data collection and developing a shared research agenda that includes not only vehicle testing, but also business model exploration, experiments with connected transportation infrastructure, and research on autonomous mobility and its implications on Boston's workforce.

On the city level, policy makers and planners face four major areas where preparation is needed to enable future use of CAVs (Alawadhi et al., 2020).

1. the road infrastructure needs to be adapted in order to facilitate proper functioning of automated vehicle systems.
2. the digital infrastructure needs to be set in place, including a framework, technical standards and procedures for cybersecurity and data privacy.
3. there needs to be clarity about how legal responsibilities and liabilities may be solved and how problems in this area may be avoided.
4. the social understanding, acceptance and approval of the new forms of mobility amongst various citizen groups and stakeholders in the urban area seems critical.

In many publications on smart mobility in the smart city it has been emphasised that active education and engagement of citizens in policy development and decision making is crucial for the successful implementation of CAVs and CCAM (e.g., Alawadhi et al., 2020; Bezai et al., 2021; Briyik et al., 2021; Chng et al., 2021; Horizon 2020 Commission Expert Group, 2020; McAslan et al. 2021; Milakis & Muller, 2021; Ayoma & Leon, 2021). User acceptance of automated vehicles will depend upon how the new automated mobility is perceived, how it will be used (shared or not, handling of privacy etc.) and what it will cost (Bezai et al., 2021). The city management has to provide and manage new technology that serves the needs of the city, i.e., the needs of its citizens: “New technologies are not ends in themselves but have to adapt to what serves the city. In the end, it is the municipalities that have to implement it” (Freadrich et al., 2018; p. 8).

The Horizon 2020 report on Ethics of connected and automated vehicles gives the following recommendations for preparing and engaging the public for CAVs (Horzon, 2020; p. 68):

- inform and equip the public with the capacity to claim and exercise their rights and freedoms in relationship to AI in the context of CAVs
- ensure the development and deployment of methods for communication of information to all stakeholders, facilitating training, AI literacy, as well as wider public deliberation
- investigate the cognitive and technical challenges users face in CAV interactions and the tools to help them surmount these changes

Chng and colleagues (2021) have investigated citizen perceptions on driverless mobility by performing Citizen Dialogues, these are structured discussion meetings using both qualitative and quantitative methods, designed to be informative, deliberative and neutral to generate critical but unbiased insights. These dialogues were attended by more than 900 citizens in 15 cities across North America, Europe and Asia and the following was concluded:

- public transport was the preferred implementation model for driverless mobility, followed by ride-sharing and private car ownership
- the levels of trust and acceptance of automated vehicles tended to be lower at higher levels of vehicle automation
- citizens have reservations about whether industry will sufficiently safeguard citizens’ interests; government should seek to support trust in industrial developments through regulation and oversight

- the citizens prefer their government to take active roles in driverless mobility and to set standards and regulations that safeguard and promote their interests

4.3.2 Experiences with urban shuttle services

In 2021, there were over 70 completed or ongoing driver shuttle pilots in several cities around the world, with more agencies planning to launch future trials (Nesheli et al., 2021). Some transportation experts are bold enough to make some predictions on new urban transport services. For example, Litman (2021) predicts: "Shared autonomous vehicles (self-driving taxis) and rides (micro-transit services) may be widely available by the 2030s. Shared vehicles have moderate operating costs, and offer moderate convenience and comfort. They should be cheaper than current taxi and ridehailing services but offer lower quality service since no driver will be available to assist passengers, provide security, or clean vehicles. Vehicle dispatching will sometimes be slow and unpredictable, particularly in suburban and rural areas. Shared rides will have the lowest costs but the least convenience and comfort. Because of their high labor costs and predictable routes, long-haul buses and freight trucks are particularly appropriate for autonomous operation, so self-driving buses and trucks may become common in the 2030s and 2040s." (Litman, 2021; p. 5).

Without pretending to be complete, we present a number of recent findings on shuttle projects below, starting with specific, independent studies and ending with general reviews.

Germany
Nordhoff et al. (2019) conducted an interview study among users of an automated shuttle on the EUREF campus in Berlin-Schönerberg. They classified people's statements on the acceptance of a driverless shuttle in terms of technological expectations, shuttle performance, service quality, risk and benefit perception, travel purpose, and trust. It was found those respondents had idealized expectations regarding the technical capabilities of an automated shuttle, which did not correspond with the actual technological capabilities of the shuttle. These idealized expectations were partly the result of the ambitious portrayal of automated driving in the media. A large number of respondents reported that they found the current shuttle speed too slow to be of real use on their daily mobility trips. Respondents regarded service quality as a particularly important determinant of the acceptance of automated shuttles. Most respondents were positive towards the future use of automated shuttles in public transport. A number of respondents reported to prefer having a steward onboard or in a control room and they did not think that the shuttle allowed them to engage in cognitively demanding tasks such as working. The authors recommended to improve the technological capabilities and service quality of automated shuttles in order to be accepted. This study provides a somewhat sobering outlook on the hype that may surround automated public transport.

Norway
In Norway, the **SmartFeeder research** project (2017-2020) studied the introduction of automated shuttle buses in order to build knowledge on how automated mobility services should be implemented in the future transport system (Lervåg, 2020). In the course of this project five automated shuttle service pilots were performed in mixed traffic on public roads. Lervåg (2020) presents lessons learned on *technological performance*,

traffic safety, *user acceptance* and *business models.* Given the subject of this chapter, we will focus on the last two aspects as the other two have been discussed at length in the rest of this report:

User acceptance
The research reports a positive development in terms of increasing user acceptance and trust in automated mobility services. Passengers were overall satisfied and felt safe – even in pilots without a host on board. There is reason to assume that automated mobility services that are perceived to be beneficial and simplify people's everyday travels, will be utilized. Current restrictions in vehicle speed and capacity are however limiting the present transport benefits for users today.

Business
The SmartFeeder project developed a generic model of the value network of automated shuttle services, followed by specific descriptions of value networks and supplementary ITS services for the various pilots. The value network is defined as a web of relationships that generates economic value and other benefits through complex dynamic exchanges (both tangible and intangible) between individuals, groups, or organisations. In all this there is a need for collaboration between complementary actors and services, and between private industry, government, city planners and public transport authorities.

Sweden
In a case study on the introduction of driverless shuttles in Stockholm, Oldbury & Isaksson (2021) studied governance arrangements. The found that public institutions were closely involved in the process of automation. The relationship between the Regional Public Transport Authority (RPTA) and the private bus operator was formally regulated by an already established procurement contracts. Plans for large-scale urban development were taken into account in the contract specifications, and the contracts served as entry point for piloting driverless shuttles as part of public transport in Stockholm. In this case an existing tool was used to introduce innovation. The analysis further found that the bus operating company had clear ambitions to develop driverless shuttles as part of a wider offering of services and the operator's role substantially informed and influenced governance arrangements. In contrast to other literature, the case shows how public and private roles overlap in the provision of a public service. This case study shows both the importance of established public authorities in creating the possibilities for automated forms of public transport, and the influential role of the private company in further shaping this process. The authors recommend that public authorities set a strategic agenda on an overarching level. There is a need for more clearly articulated policy and planning agenda clarifying the long-term public stance regarding automation in infrastructure and transport planning (and smart mobility more generally). (Oldbury & Isaksson, 2021).

Europe
Boersma et al. (2021) studied results from pilots with automated shuttles in Europe and the USA. For pilots in Europe, they found that most pilots were carried out in reasonably controlled environments and not on typical public road environments. Also, most pilots with automated shuttles, with one exception, the vehicles were manned by a conductor. A few shuttle services operated in mixed traffic situations with some infrastructural changes such as a changed priority situation and temporary markings on the road. The speed of the shuttle vehicles during the pilots were low, respectively 8 km/h until a maximum of 40 21 km/h, with most vehicles operating below 21 km/h.

The pilots in the Europe show a broad interest in implementing automated vehicles in public transport. According to the authors, technical issues are being fixed with every new pilot and the technology is improving fast. In the Netherlands, there is a shift from focussing on technical aspects to focusing on fulfilling a public transport gap and offering a service with AVs. In general, the goals of the pilots are shifting from short-term experiments to long-term pilots or even permanent applications. The experimental law in the Netherlands creates the opportunity to experiment with AVs without on-board steward. This could potentially stimulate the transition to operating AVs without steward on-board, which might make operating AVs in PT more attractive for PT companies/ authorities due to the absence of a driver and thereby an expected reduction in total cost of ownership.

The **AVENUE** project (2018–2022) operates pilot projects in four European demonstrator cities: Geneva, Lyon, Copenhagen, and Luxembourg (AVENUE, 2018; Nemoto et al., 2021). As a first step, automated shuttles are integrated into the public transport system using fixed routes on mixed traffic. In the project the pilot trials concerning automated shuttles in public transport are limited to special conditions such as (Nemoto et al., 2020):

- The tests are limited to fixed routes or offering on-demand services in a specific and limited area.
- The vehicles drive at low speeds (avg. 18 km/h and max. 25 km/h).
- A safety driver on board of the automated shuttle is required by law (human intervention may is some cases be necessary).
- The cities' infrastructure and regulations need to be developed in order to deploy AVs.
- The ride in the automated shuttles is currently free of charge.

Nemoto et al. (2021) looked at the impacts of Shared Automated Electric Vehicles (SAEV) which may include different types of vehicles, such as robo-taxis and automated shuttles integrated into public transport. The business models of these different types of vehicles may vary based on vehicle ownership (public or private) and who controls the network operations. To guide future implementation of SAEV, Nemoto et al. (2021) propose a set of 20 indicators that are broadly applicable and may help to enable the impact assessment stemming from the integration of SAEV in the cities' mobility system.

In the assessment phase of AVENUE, data quality and data availability varied according to the different cities and transport operators, posing challenges to compare the results and performance in different cities (Nemoto et al., 2021). Limitations also concerned asymmetry in data availability from governments, Public institutions' reporting and businesses reporting (e.g., private mobility providers, transport operators), and therefore, dealing with missing or incomplete data (Nemoto et al., 2021). The economic feasibility to deploy SAEV may face challenges in the short term due to the high investments in research and development, continuous improvement, and high costs to purchase and operate SAEV (Nemoto et al., 2021).

USA - Nebraska

During an autonomous shuttle pilot in Nebraska, Piatkowski (2021) studied three subjects: 1. perceptions and expectations regarding the service, 2. potential use of an autonomous shuttle, and 3. individual willingness to substitute other modes of travel for an autonomous shuttle. The pilot was conducted at a University of Nebraska facility in which participants had the opportunity to ride the shuttle on a closed course set up in a parking lot (an approximately 10-minute demonstration) and take a brief survey about their experience.

The findings demonstrated the presence of an early-adopter population, enthusiastic about a potential shuttle service, regardless of its potential transportation implications (Piatkwoski, 2021). Respondents considered the technology safe, but also had high expectations for the service (including stop and mobile app amenities).Findings further demonstrated that (younger) age, working downtown, and (negative) perceptions of bus service are associated with willingness to substitute car travel for shuttle travel. The more walking is perceived as increasingly inconvenient, the higher the willingness to substitute travel by foot for travel by autonomous shuttle. Perceptions that driving and existing transit services are inconvenient in turn each increased the willingness to use the shuttle. Findings suggested complex potential substitution effects of the technology, wherein there is interest in substituting both foot and car travel for an autonomous shuttle service. Finally, the findings showed that there are concerns that the absence of a driver will reduce rider safety, marginalize disabled individuals, and delay or ignore cleaning or maintenance in the passenger area. The survey findings underscored the importance that potential riders place on safety and security when asked about the importance of relevant shuttle stop amenities (e.g., lighting and security cameras at the stop).

International reviews

Golbabaei et al. (2021) conducted a systematic review of the literature to address the research question: 'What roles could shared autonomous vehicles play in delivering smart urban mobility?' They identified 81 recent and relevant articles on the topic. Important findings of their review on factors that influenced usage were the following (Golbabaei et al (2021):

- The number and position of pick-up and drop-off areas may impact SAV usage compared to other transportation modes. Pick-up and drop-off areas may be concentrated well at particular spots city-wide, aimed to encourage wider adoption of SAV use as well as active modes.
- SAVs will be able to counterpart public transport system, through providing convenient first/last-mile solutions as well as offering services on less frequently used routes.
- Waiting time, travel time and travel cost are critical in people's decision to choose using SAVs.
- Autonomous Mobility on Demand services can be employed as a complement of existing public transport services, they might be utilized as first/last mile solutions, henceforth enhancing the convenience of mass transport system for citizens. Thus, impact studies should focus on evaluating integrated PTSAV systems including the operational and demand sides.

Nesheli et al. (2021) reviewed over 30 completed or ongoing Driver Shuttle (DS) deployments to identify factors that contribute towards a successful pilot program. Thirty-three pilot projects were evaluated: 4 from Canada, 8 from the U.S., 13 from Europe, 2 from Australia, and 6 from Asia. Agencies selected routes for pilots based on one or more of the following 4 criteria – technical feasibility, public education, transportation gaps, and meeting specific testing requirements. In nine of the reviewed pilot projects, shuttle routes were partly determined by the limitations of automated technology. Given the current state of technology, DSs face issues associated with identifying and responding appropriately to obstacles and accurate localization, thus restricting their operating path. Thirteen pilot programs explicitly stated that their route locations were based on where they could generate the most amount of public attention. A common use of DSs is to connect neighbourhoods to the existing transit network, thus addressing the first- and last-mile problem in public transport. 14 cities opted to place pilot routes in locations without any existing transit service available to test whether DSs are a feasible solution. Some pilot projects placed special attention on ensuring that shuttles had sufficient interactions with its environment and selected routes that are representative of reality to collect meaningful data.

Nesheli et al. (2021) present a number of lessons learned about increasing acceptance of shuttle services*.* A primary goal expressed in virtually all pilot programs was to evaluate the acceptance of automated technology. Across most pilots' respondents expressed positive sentiments regarding traffic safety in DSs, but there were concerns about in-vehicle security and emergency management. Other common criticisms made by the public included slow shuttle speeds and unexpected brake actions. The low shuttle speeds also led to other issues such as long wait and travel times, as well as unreliable services Study approaches, such as Stated Preference surveys, virtual reality and social network analysis) may be used to measure public acceptance of DSs.

Other lessons learned include the importance of raising public awareness before starting a pilot. Doing so seems to attract public attention and inform road users how to behave around the shuttle. A driverless shuttle may confuse other road users because it is unable to indicate signal changes in advance and it can travel in the opposite direction without turning around. Having clear signage and pavement markings is also needed to reduce confusion, and continuous communication should be maintained throughout the pilot, especially if there is a service interruption. Furthermore, technical issues should be anticipated as many of the pilots experienced localization problems during the trial. Finally, a common approach that has seen success in several pilots is dividing it into multiple phases (e.g., starting in simple traffic environments and moving to more complex environments in late stage).

For designing future pilot applications Nesheli et al. provide a number of valuable guidelines (Nesheli et al., 2021; Table 2):

- Provide detailed cost breakdown of pilot programs to the public
- Analyse the costs and benefits of pilots based on real data
- Plan pilot projects in a way that participants in the study will be representative of the actual demographics the service is intended for (e.g., by conducting surveys before deployment)
- Establish clear measures of effectiveness and test scenarios (e.g., crossing an intersection, manoeuvring a roundabout, etc.) for the DS beforehand
- Select locations that will improve accessibility and move away from testing on enclosed routes
- Provide detailed reporting on how routes were planned and selected
- Provide all stakeholders access to real-time data for planning the service and selecting the route
- Plan and equip the DS with the necessary sensors (e.g., cameras, automatic passenger counts, etc.) and data acquisition system to achieve specific research goals
- Design a survey to evaluate user experiences during and after the pilot
- Notify the public when an unexpected event occurs (e.g., service suspension, accident, etc.)
- Provide communication with the public before, during and after the pilot program

- Denote the shuttle’s route using pavement markings and signs and indicate the vehicle is autonomous

5 Conclusions and Recommendations

This chapter presents conclusions on the main impacts of CAVs and automated urban transport on environment, mobility, and society-safety-economy and it presents challenges (Section 5.1). In Section 5.2 general policy recommendations are given to help steer successful implementation of automated urban transport in the near future.

5.1 Conclusions

Increasing penetration levels of connected and automated vehicles in the urban city area are estimated to have mostly positive impacts on the **environment** (less emissions, higher energy efficiency), on **mobility** (more access to travel and less congestion), and on **society** and **economy** (improved road safety and public health, and lower vehicle operating costs). The following conclusions, given the underlying modelling assumptions and limitations and overall scope of the LEVITATE project, can be drawn from the results derived by the work done in WP5:

Environment
Electric automated vehicles (private & AUSS) are expected to have a positive environmental impact in the form of reduced emissions and higher energy efficiency. Assuming all private automated vehicles as well as all shuttles are electric vehicles, the implementation of an automated shuttle system is not predicted to have a large additional impact on emissions per vehicle-kilometre. However, the modal split (private vehicles vs. other forms of shared/active transport) will likely have an impact on the total electricity demand of the mobility system. Therefore, the private vehicle trips which are replaced by an automated urban shuttle service are expected to provide additional environmental gains.

Autonomous public shuttles and other new mobility services can provide increased freedom of choice of the most suitable mobility mode for each individual trip. By providing a wider palette of mobility solutions, users can in the long term lower their dependency on private cars and start using a wider spectrum of services. This can improve the resource efficiency and have a self-reinforcing effect on the popularity of the active travel modes, such as walking and cycling.

Mobility
At high penetrations, automated vehicles and an automated urban shuttle service (AUSS) are expected to improve the ease of travelling (access to travel) and reduce congestion. Especially when the majority of the fleet is a connected and automated vehicle, traffic is expected to flow more smoothly and efficiently. This can result in shorter average travel times, reduced congestion delays, and the possibility to travel more kilometres within a certain time frame. The addition of automated urban shuttles to the network appears to have little influence on the overall traffic flow (congestion), primarily due to the small number of shuttles compared to the rest of the vehicle fleet. However, due to serving a larger portion of the travel demand, anywhere-to-anywhere on-demand shuttles are

expected to provide some additional benefits in travel time and congestion reductions, especially when the rest of the vehicle fleet is still largely human-driven.

Regarding potential changes in the modal split, without additional policy measures an increased penetration rate of automated vehicles may lead to a modal shift away from public transport (according to both mesosimulation and the Delphi study) and walking/cycling (according to the Delphi experts) towards automated vehicle use. The automated urban shuttle services are expected to redirect some of this shift to AUSS rather than private automated vehicles. The form of AUSS is also important: last-mile shuttles are expected to compliment public transport making it more attractive to travellers, and anywhere-to-anywhere shuttles are expected to replace more public transport and active mode trips. A point-to-point shuttle service is expected to compete less with existing public transport or active modes, with less decrease expected than in baseline conditions.

Safety
Especially at high penetration rates, automated vehicles are expected to have a positive effect on road safety by reducing the crash rates between motor vehicles as well as between motor vehicles and vulnerable road users (e.g. pedestrians and cyclists). Similarly to in the mobility impacts, the addition of an automated shuttle service does not have a large effect on the overall crash rate due to the small number of shuttles compared to the rest of traffic in the network.

Society & economy
Increasing penetration rates of automated vehicles are expected by experts to have some beneficial effects on public health, presumably due to reduced local emissions, improved vehicle safety and lower noise pollution. Point-to-point shuttles are expected to bring some additional benefits for public health, likely due to encouraging active transportation between shuttle stops and the origin/destination.

According to experts in the Delphi study, automation is expected to improve the equal accessibility of transport to people of all means and abilities. The use of automated vehicles may make vehicle transport possible for travellers who do not drive, such as children, the elderly, those with a disability, or others without a driver's license.

The effect of automated vehicles & AUSS on parking space demands varied based on the methodology, and assumptions underpinning the estimations. If a substantial modal shift towards the private vehicle with increasing automation is realized without further policy intervention, this may correspond to a large increase in parking demand (as system dynamics predicts). However, if this trend is not realized and other policy measures are taken to either limit growth in private vehicle use or restrict/reorganize parking space allocation, then there could be a reduction in parking space demands.

Automated urban shuttle service: different implementations
The different forms of automated urban transport considered—including point-to-point, anywhere-to-anywhere, and last-mile AUSS—each have strengths and weaknesses:

- Point-to-point shuttles: expected to be more energy efficient, less accessible to disadvantaged groups, more beneficial for public health and active transport, more cost efficient (lower vehicle operating cost), possibility to implement on dedicated lane
- Compared with the baseline, the on-demand AUSS is associated with shorter travel time, better access to travel, and less congestion. According to the experts

consulted in the Delphi study, on demand AUSS will yield lower benefits than the point to point AUSS when it comes to access to travel, parking space, public health, shared mobility, and vehicle operating costs.

- With respect to different types of on-demand shuttles the following may be observed:
  - *Anywhere-to-anywhere* shuttles: most accessible (door-to-door), large potential to replace public transport and/or active mode trips, larger reduction in average travel time than last-mile shuttles, predicted to be used more resulting in lower empty kilometres (higher utilization) and higher vehicle occupancy
  - *Last-mile shuttles*: less influence on most impacts (smaller scale), smaller environmental and health benefits, potential for synergistic relationship with public transport to increase share of public transportation

Challenges

The findings point out a number of challenges for urban transportation planners and managers:

1. Modal split of private vehicle transport: an increase in private vehicle transport can have undesirable environmental, spatial, health and social effects. The results suggest that increasing automation may attract some public transport users and/or pedestrians/cyclists to switch to a private automated vehicle
2. Effect on physical activity: door-to-door, on-demand transport has the potential to replace a share of walking/cycling trips as well as public transport trips where first- and last-mile transport is done by an active mode. However, if many private vehicle trips are replaced by AUSS, the overall effect on active transportation may be positive.
3. Mixed traffic: During the transition phases, when traffic is still mixed between human-driven vehicles and different generations of automated vehicles, differences in driving behaviour between different types of vehicles can slow down, or temporarily negate, some of the expected improvements in mobility (traffic flow/congestion) and road safety. Benefits are expected to be largest once the vehicle fleet reaches a more homogeneous state (mostly/completely automated).
4. Increase in vehicle kilometres: automation (possible increased private transport) combined with more efficient traffic flow may make an increase in road traffic possible. While this can signify an increase in accessibility, higher levels of traffic can also put a heavier burden on the electricity grid, increase exposure to traffic safety risks and use more public space.

In brief, the LEVITATE results confirm the results of other studies, showing that positive impacts on environment, economy, society and safety are to be expected when larger shares of first- and second-generation connected and automated vehicles are introduced in the traffic system. Additional benefits (higher energy efficiency, better access to travel, improvement public health, and lower vehicle operating costs) have been estimated from the introduction of point-to-point automated urban shuttles and, to a lesser degree, from on demand shuttles. Both point-to-point and on demand AUSS seem to have no additional effects on emissions and the number of kilometres travelled in the network.

5.2 Policy recommendations

In the previous section it was concluded that AUSS, and especially point to point version, is likely to result in additional positive benefits for. The successful implementation of AUSS transition will largely be impacted by the policy measures of the city, local and national authorities. Therefore, the LEVITATE project aims to support the authorities finding the most beneficial policies on the way towards an automated transport system. In this section we provide policy recommendations in this area that were based on a scan of the recent literature on smart mobility and shuttles services (described in *Section 4.3*).

In the previous section it was concluded that AUSS, and especially point to point version, is likely to result in additional positive benefits (higher energy efficiency, better access to travel, improvement public health, and lower vehicle operating costs). The successful implementation of AUSS will largely be impacted by the policy measures of the city, local and national authorities. Therefore, the LEVITATE project aims to support the authorities finding the most beneficial policies on the way towards an automated transport system. In this section we provide policy recommendations that were based on a combination of the work conducted in Levitate WP5 and a scan of the recent literature on smart mobility and shuttles services (described in *Section 4.3*). The following recommendations are relevant for the future development and implementation of automated urban transport systems:

1. To **Govern** new forms of smart mobility and automated urban transport, public authorities will need to cooperate with many new partners and assume **new roles** in the process of governance. Although many ideas and plans for new forms of mobility may come from private companies, public authorities should help steer the process of innovation by setting up **strategic agendas** and **by setting standards** and **guidelines**.
2. The automated urban shuttle services studied in LEVITATE have been shown to have the potential to generate extra benefits for the city, over and above those of growing vehicle automation. However care should be taken to prevent the anticipated unwanted impacts of these services, for example on equal accessibility of travel and on modal split use of active travel forms. Anticipatory **research** and anticipatory and flexible **planning** approaches are recommended to prevent these negative developments.
3. Given the potential that increasing automation may attract part of public transport users and/or pedestrians/cyclists to switch to a private automated vehicle it is recommended that city planners and managers **plan and stimulate multi-modal transportation networks** for the city.
4. **Clear communication** to transport users and other road users is necessary to clearly explain new transport operations, to explain what users and other road users can expect and to prevent idealised expectations.
5. In decisions about new forms of automated transport **waiting time**, **travel time**, **travel costs**, **comfor**t, **safety** and **security** should play a dominant role in setting policy goals as these are likely to determine long term and wider acceptance once the novelty value wears off.
6. In future projects the **long-term planning** of successive implementation phases is recommended, for example going from operator to remote operator operations, and from simple to complex traffic environments.
7. Although new forms of automated urban transport may be operated and controlled by private companies, it is recommended that these are developed to preferably **complement the public transport** system in useful ways, for example by providing

convenient first/last-mile solutions as well as offering service on less frequently used routes.
8. **Guidelines** - including ethical guidelines - and **lists of impacts** for future automated urban mobility and transport have been formulated and should be partly or fully adopted in strategic plans to facilitate successful implementation of new transport services.

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Appendix A Methods and operationalisation

In this Appendix we describe the main methods used to estimate the impacts within WP5, namely traffic microsimulation, Delphi and mesosimulation.
In essence, *microscopic traffic simulation models* simulate the movement of individual vehicles on a pre-defined road network using a combination of vehicle and driver models that approximate car-following and lane-changing theories and thereby allowing the forecasting of traffic-related impacts. Traffic simulations are the most commonly applied method for predicting the impacts of connected and automated vehicles (Elvik et al., 2020). Traffic simulations have been used to study several potential impacts of connected and automated vehicles, including impacts on road capacity, intersection capacity and performance (stops and delays), traffic volume, travel time, fuel consumption, road accidents etc. The results of most microsimulation studies show potential impacts of connected and automated vehicles as a function of their market penetration rate (Elvik et al., 2020).

In WP5, microscopic simulation was used to study the impacts of three policy interventions (sub-use cases) on CO_2-emission, congestion, amount of travel and traffic safety. The three policy interventions were: point-to-point automated urban shuttle service (AUSS) connecting two modes of transport, point-to-point AUSS (in a large-scale network and on-demand AUSS. Within LEVITATE, AIMSUN Next software was used for microsimulation modelling and used the road network and traffic situation in the city of Athens as the basis to estimate the impacts of the three SUCs (Roussou et al., 2019; Sha et al., 2021a).

In WP5 of LEVITATE the *Delphi method* was also used to estimate the effects of the three SUC's and to identify the experts' vision of the future related to CATS. The Delphi method is a systematic and qualitative method of forecasting which is based on collecting opinions from a group of experts by means of a series of related questions. The questions were related to the specific three policy interventions (sub-use cases (SUCs) and experts were asked to give their opinion on the effect of these SUCs on the different impact areas. The Delphi uses a process of repeated testing whereby results of a first round of questions are communicated back to the group and the questions repeated at a later stage in a second round to see if respondents change opinions. In WP5 fourteen experts participated in the 1st round and nine in the 2nd (achieved participation rate 64%). The majority of experts agreed strongly or moderately with the expected trends for all the impacts and all studied SUCs, suggesting that the obtained results are a reasonable estimate of the effect size. However, it must be pointed out that the number of consulted experts in WP5 is modest and that averaging their responses is, in this instance, a defensible approach although it does not necessarily provide the best estimate.

Mesoscopic simulation is a supplemental method within the group of simulation

approaches which emphasise the modelling of behaviours and choices of individuals (Elvik et al., 2020). Such an activity-based-modelling (ABM) framework is realised by the mesoscopic traffic simulation tools of MATSim. "Mesoscopic" in this context underlines the fact that the method is less focussed on immediate interactions between road users, thus reducing the level and complexity of these details, but rather on the choices people (represented as agents is a mesoscopic model) make to re-arrange their daily routes and schedules of activities. Each of the activities within a complete daily chain or "plan" are preferably reached in time by the means of transport available to each person (agent) within the simulated area under investigation. The major conclusions that can be extracted from such models refer to changes in modal split, as well as differences in road network loads and vehicle utilization (Elvik et al., 2020).
Mesoscopic simulation and activity-based-modelling are well-suited for assessing modal split, road network loads and vehicle utilisation rate (Elvik et al., 2020).

The types of impacts studied within LEVITATE have been estimated and forecasted using various assessment methods, such as traffic microsimulation, system dynamics and the Delphi panel method. In the study design it was anticipated to use traffic microsimulation to estimate direct impacts and mesosimulation for the systemic impacts whereas the Delphi would supplement these and together with systems dynamics would also provide estimates for the wider impacts. Traffic microsimulation can be used to forecast direct impacts (which have an immediate to long term effect) and are suitable to develop relationships that can infer dose (in terms of introduction of sub-use case) and response (selected impact). Traffic microsimulation also provides further input to assess medium-term impacts by processing those results appropriately to infer such impacts.

The mesoscopic simulation is used as a method to estimate the impacts of AUSS on the travel time and other direct and systemic impacts such as access to travel, delay and total kilometres travelled (Table 2.3 and Deliverable D5.3)

In addition, the Delphi method was used within LEVITATE to identify the experts' vision of the future related to CATS. The questions included various policy interventions, called sub-use cases (SUCs) and experts were asked to give their opinion on the impact of these SUCs on different impact areas.

System level analysis (such as by tools found within system dynamics) can provide measure of long-term impacts. System dynamics is a modelling technique where the whole system is modelled at an abstract level by modelling the sub-systems at component level and aggregating the combined output (Boghani & Zach, 2020). This allows researchers to use feedback/feedforward from one component to another within the system, which unfolds when output is viewed against time. System dynamics is a powerful way of modelling a system at an abstract level. Final points on its strengths and usefulness can be summarised as below (Boghani & Zach, 2020):
• Feedback within the system can be handled easily and one can see the effect of complex feedback via numerical simulations.
• Interconnected systems can be integrated very well and allows one to extend the model as well.
• Structure determines behaviour – same model, different behaviours due to states of sub-systems/constituents.
• Future values depend on past values.
• Mathematical complexity of large complex system does not hinder modelling, as the system is solved by using solvers using discretised system.

• Allows one to play with 'what if' scenarios easily and faster. It allows one to change the strength and timing of external disturbances as well as of policy measures that might be applied.
• Provides a deeper understanding of the system, as one knows what effects are generated in the system, due to a particular cause presented to it

For the sake of simplicity and applicability of these 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 implementing 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).

Table A.1 shows an overview of the automated urban transport impacts covered in WP5 for the five policy domains, along with a short description and the unit of measurement.

Table A.1: *Overview of the estimated automated urban transport impacts in WP5.*: *Overview of the estimated automated urban transport impacts in WP5*.

Policy domain	Impact	Description / measurement	Unit of Measurement
Direct impacts			
Mobility/Economy	Travel time	*Average duration of a 5Km trip inside the city centre*	*Min/5km*
Economy	Vehicle operating cost	*Direct cost of operating a vehicle per kilometre of travel*	*€/km*
Systemic impacts			
Mobility /Economy	Congestion	*Average delays to traffic (seconds per vehicle-kilometre) as a result of high traffic volume*	*s/veh-km*
	Total km travelled in the network	*Number of kilometres by mode and total*	*km*
	Modal split using public transport	*% of trip distance made using public transportation*	*%*
	Modal split using active travel	*% of trip distance made using active transportation (walking, cycling)*	*%*
	Shared mobility rate	*% of trips made sharing a vehicle with others*	*%*
	Vehicle utilisation rate	*% of time a vehicle is in motion (not parked)*	*%*
	Vehicle occupancy	*average % of seats in use*	*%*
Wider impacts			
Safety	Road safety	*Number of traffic conflicts per vehicle-kilometre driven (temp. until crash relation is defined).*	*Conflicts/veh-km*
Environment/economy	Parking space	*Required parking space in the city centre per person*	*m^2/person*
Environment	Energy efficiency	*Average rate (over the vehicle fleet) at which propulsion energy is converted to movement*	*%*

Policy domain	Impact	Description / measurement	Unit of Measurement
	CO_2 due to vehicles	*Concentration of CO_2 pollutants as grams per vehicle-kilometre (due to road transport only)*	*g/veh-km*
	NO_X due to vehicles (not further discussed in this report)	*Concentration of NO_x pollutants as grams per vehicle-kilometre (due to road transport only)*	*g/veh-km*
	PM_{10} due to vehicles (not further discussed in this report)	*Concentration of PM_{10} pollutants as grams per vehicle-kilometre (due to road transport only)*	*g/veh-km*
Society	Public health	*Subjective rating of public health state, related to transport (10 points Likert scale)*	*Point score*
	Commuting distances	*Average length of trips to and from work (added together) in km*	*km*

Appendix B CAV parameters in microsimulation

Table 5 CAV parameters used in traffic microsimulation within LEVITATE

Parameter	Human-Driven Vehicle	1st Generation CAV	2nd Generation CAV	Comment
Reaction time in car following (Reaction Time)	0.8 sec	0.9 sec	0.4 sec	This parameter, along with sensitivity factor, affects time headway. This can be set under Experiment >> Reaction Time tab >> Reaction Time Settings. Be sure to choose option 'Variable (Different for Each Vehicle Type).
Max. acceleration	5 (3, 0.2, 7) Mean (min, dev, max)	4.5 (3.5, 0.1, 5.5) Mean (min, dev, max)	3.5 (2.5, 0.1, 4.5) Mean (min, dev, max)	This can be set for Vehicle type under Microscopic Model >> Main tab.
Normal deceleration	3.4 (2.4, 0.25, 4.4) Mean (min, dev, max)	4 (3.5, 0.13, 4.5) Mean (min, dev, max)	3 (2.5, 0.13, 3.5) Mean (min, dev, max)	Same as above.
Max. deceleration	5 (4.0, 0.5, 6.0) Mean (min, dev, max)	7 (6.5, 0.25, 7.5) Mean (min, dev, max)	9 (8.5, 0.25, 9.5) Mean (min, dev, max)	Same as above.
Clearance	1 (0.5, 0.3, 1.5) Mean (min, dev, max)	1 (0.8, 0.1, 1.2) Mean (min, dev, max)	1 (0.8, 0.1, 1.2) Mean (min, dev, max)	Minimum gap at standstill. This can be set for vehicle type under Dynamic Models >> Main tab.
Safety margin factor	1	[1;1.25]	[0.75;1]	This generates give-way behaviour at unsignalised junctions.
Look ahead distance factor	[0.8;1.2]	[1.1;1.3]	[1;1.25]	Also known as Distance Zone Factor. This is changed to emulate connectivity in the sense that AVs will have better knowledge of junctions and turnings so they will consider changing lanes earlier than human-driven vehicles.
Overtaking	Begin at 90%, Fall back at 95%	Begin at 90%, Fall back at 95%	Begin at 85%, Fall back at 95%	

Appendix C Full results

C.1 Environmental impacts

			Market penetration rate: AVs in Background vehicle fleet (Human-driven vehicle - 1st Generation AV - 2nd Generation AV)								
Impact	**Sub-use Case**	**Scenario**	**100-0-0**	**80-20-0**	**60-40-0**	**40-40-20**	**20-40-40**	**0-40-60**	**0-20-80**	**0-0-100**	**Method**
Energy efficiency	Baseline	(no AUSS)	0,0%	3,0%	7,1%	8,4%	15,7%	14,1%	14,1%	14,1%	Delphi (expert survey)
	Point-to-point AUSS	Point-to-point	0,0%	4,2%	8,4%	15,6%	20,8%	21,1%	21,1%	21,1%	
	On-demand AUSS	Anywhere-to-anywhere	0,0%	5,2%	9,3%	14,2%	18,6%	22,1%	22,1%	22,1%	
		Last-mile	0,0%	4,2%	5,6%	8,4%	11,5%	11,5%	11,5%	11,5%	
		E-hailing	0,0%	2,7%	2,7%	5,8%	11,3%	16,5%	16,5%	16,5%	
CO_2 emissions	Point-to-point AUSS connecting two modes (small-scale network)	Baseline (small-scale; peak hour)	0,0%	-34,7%	-60,4%	-82,0%	-90,8%	-99,4%	-99,4%	-99,5%	Micro-simulation (Athens)
		Peak hour - Mixed traffic	-2,9%	-10,1%	-48,6%	-81,7%	-90,8%	-99,4%	-99,4%	-99,4%	
		Peak hour - Dedicated lane	1,0%	-11,8%	-56,4%	-82,5%	-91,2%	-91,2%	-99,4%	-99,4%	
		Peak hour - Incident	0,3%	-12,2%	-51,5%	-82,2%	-91,2%	-99,4%	-99,4%	-99,4%	
		Off Peak hour - Mixed traffic	-51,2%	-57,9%	-72,9%	-89,9%	-94,7%	-99,5%	-99,5%	-99,5%	
		Off Peak hour - Dedicated lane	-53,7%	-57,0%	-72,9%	-89,8%	-94,7%	-99,5%	-99,5%	-99,5%	
	Point-to-point AUSS (large-scale network)	Baseline (large-scale; peak hour)	0,0%	-16,7%	-40,2%	-64,3%	-81,2%	-97,2%	-95,5%	-95,3%	
		Peak hour - Mixed traffic	0,1%	-16,7%	-40,4%	-64,4%	-81,2%	-97,2%	-95,5%	-95,3%	
		Peak hour - Dedicated lane	-0,3%	-16,8%	-40,1%	-64,3%	-81,2%	-97,2%	-95,5%	-95,3%	
		Off Peak hour - Mixed traffic	-36,0%	-47,2%	-62,0%	-75,9%	-85,9%	-95,8%	-94,6%	-94,6%	
	On-demand AUSS	Baseline (large-scale; peak hour)	0,0%	-16,7%	-40,2%	-64,3%	-81,2%	-97,2%	-95,5%	-95,3%	
		8 pax - 5% demand served	-6,7%	-17,0%	-40,6%	-64,4%	-81,3%	-97,2%	-95,5%	-95,3%	
		15 pax - 5% demand served	3,7%	-16,7%	-40,4%	-64,4%	-81,2%	-97,2%	-95,5%	-95,3%	
		8 pax - 10% demand served	3,0%	-17,3%	-40,7%	-64,5%	-81,2%	-97,2%	-95,4%	-95,3%	
		15 pax - 10% demand served	3,0%	-17,4%	-40,7%	-64,6%	-81,1%	-97,2%	-95,4%	-95,3%	

C.2 Mobility impacts

Impact	Sub-use Case	Scenario	100-0-0	80-20-0	60-40-0	40-40-20	20-40-40	0-40-60	0-20-80	0-0-100	Method
			Market penetration rate: AVs in Background vehicle fleet (Human-driven vehicle - 1st Generation AV - 2nd Generation AV)								
Average travel time	Baseline	(no AUSS)	0,0%	0,2%	0,0%	-0,1%	-0,3%	-0,5%	-0,4%	-0,5%	Meso-simulation (Vienna)
	On-demand: Last-mile AUSS	1118 shuttles	1,3%	0,5%	0,4%	0,1%	0,0%	-0,6%	-0,2%	-0,3%	
		2338 shuttles	1,4%	0,6%	0,3%	0,1%	-0,3%	-0,5%	-0,2%	-0,2%	
	On-demand: Anywhere-to-anywhere AUSS	250 shuttles	-4,4%	-6,2%	-6,5%	-6,9%	-7,1%	-7,3%	-7,4%	-7,4%	
		500 shuttles	-8,1%	-10,1%	-10,5%	-10,8%	-11,2%	-11,4%	-11,5%	-11,6%	
Access to travel	Baseline	(no AUSS)	0,0%	2,6%	-1,4%	18,8%	31,2%	33,9%	33,9%	33,9%	Delphi (expert survey)
	Point-to-point	Point-to-point AUSS	0,0%	6,9%	15,2%	24,2%	32,5%	42,1%	42,1%	42,1%	
	On-demand AUSS	Anywhere-to-anywhere	0,0%	9,7%	18,8%	28,7%	40,3%	43,8%	43,8%	43,8%	
		Last-mile	0,0%	8,2%	15,2%	20,1%	27,6%	28,7%	28,7%	28,7%	
		E-hailing	0,0%	7,3%	12,8%	20,1%	23,8%	31,1%	31,1%	31,1%	
Amount of travel (km/person)	Baseline	(no AUSS)	0,0%	0,0%	-0,1%	-0,1%	-0,2%	-0,2%	-0,2%	-0,2%	Meso-simulation (Vienna)
	On-demand: Last-mile AUSS	1118 shuttles	0,4%	0,3%	0,3%	0,3%	0,2%	0,1%	0,2%	0,2%	
		2338 shuttles	0,4%	0,4%	0,4%	0,3%	0,3%	0,3%	0,3%	0,3%	
	On-demand: Anywhere-to-anywhere AUSS	250 shuttles	0,7%	0,0%	0,0%	-0,1%	-0,2%	-0,2%	-0,2%	-0,2%	
		500 shuttles	1,0%	0,7%	0,5%	0,5%	0,5%	0,4%	0,4%	0,4%	
Total kilometres travelled in network	Point-to-point AUSS connecting two modes (small-scale network)	Baseline (small-scale; peak hour)	0,0%	-1,1%	-4,3%	2,9%	0,5%	-1,1%	2,9%	-10,6%	Micro-simulation (Athens)
		Peak hour - Mixed traffic	-1,9%	12,4%	6,5%	2,3%	0,4%	-1,6%	0,4%	1,2%	
		Peak hour - Dedicated lane	-9,0%	10,9%	-27,4%	-3,7%	2,1%	2,1%	-5,0%	-0,6%	
		Peak hour - Incident	1,3%	14,3%	3,9%	5,0%	4,0%	2,7%	4,9%	5,5%	
		Off Peak hour - Mixed traffic	-27,0%	-19,1%	-22,8%	-23,3%	-22,8%	-23,7%	-22,7%	-20,4%	
		Off Peak hour - Dedicated lane	-25,7%	-19,4%	-22,3%	-23,6%	-23,4%	-24,1%	-22,7%	-20,6%	
	Point-to-point AUSS	Baseline (large-scale; peak hour)	0,0%	25,3%	25,6%	8,0%	-10,6%	-24,7%	53,2%	60,0%	
		Peak hour - Mixed traffic	-0,4%	25,1%	24,8%	7,0%	-10,0%	-24,8%	52,2%	59,6%	

	(large-scale network)	Peak hour - Dedicated lane	-1,4%	25,1%	26,6%	7,0%	-10,9%	-25,1%	53,1%	60,2%	
		Off Peak hour - Mixed traffic	-2,4%	17,8%	20,0%	21,6%	12,4%	-0,8%	29,3%	30,1%	
	On-demand AUSS	Baseline (large-scale; peak hour)	0,0%	25,3%	25,6%	8,0%	-10,6%	-24,7%	53,2%	60,0%	
		8 pax - 5% demand served	10,8%	23,5%	24,8%	9,1%	-9,8%	-23,5%	57,1%	60,7%	
		15 pax - 5% demand served	23,6%	25,9%	25,9%	9,9%	-9,6%	-23,8%	56,6%	60,5%	
		8 pax - 10% demand served	24,9%	26,6%	28,0%	12,4%	-8,7%	-23,2%	56,6%	62,3%	
		15 pax - 10% demand served	24,7%	26,6%	29,5%	10,8%	-7,2%	-22,9%	56,7%	61,3%	
Congestion (delay time/km travelled)	Point-to-point AUSS connecting two modes (small-scale network)	Baseline (small-scale; peak hour)	0,0%	-32,7%	-28,4%	12,8%	9,4%	0,6%	-9,4%	-43,2%	Micro-simulation (Athens)
		Peak hour - Mixed traffic	3,6%	-5,0%	5,3%	13,9%	10,4%	4,5%	-3,1%	-12,4%	
		Peak hour - Dedicated lane	10,5%	-5,7%	59,0%	31,8%	4,0%	4,0%	1,0%	-11,3%	
		Peak hour - Incident	0,1%	-10,9%	1,4%	7,3%	-3,7%	-6,7%	-13,3%	-17,0%	
		Off Peak hour - Mixed traffic	-61,0%	-60,4%	-51,5%	-51,7%	-52,3%	-53,3%	-58,8%	-62,2%	
		Off Peak hour - Dedicated lane	-63,6%	-57,7%	-50,0%	-49,0%	-50,9%	-51,7%	-57,7%	-61,5%	
	Point-to-point AUSS (large-scale network)	Baseline (large-scale; peak hour)	0,0%	-11,4%	-11,8%	-11,6%	-9,9%	-3,6%	-41,9%	-45,1%	
		Peak hour - Mixed traffic	0,8%	-11,2%	-12,5%	-13,1%	-9,4%	-3,4%	-42,1%	-45,3%	
		Peak hour - Dedicated lane	1,6%	-11,2%	-12,0%	-11,7%	-8,7%	-3,7%	-42,5%	-44,7%	
		Off Peak hour - Mixed traffic	-43,5%	-53,3%	-56,1%	-56,0%	-52,8%	-48,7%	-69,5%	-71,3%	
	On-demand AUSS	Baseline (large-scale; peak hour)	0,0%	-11,4%	-11,8%	-11,6%	-9,9%	-3,6%	-41,9%	-45,1%	
		8 pax - 5% demand served	-19,2%	-22,3%	-23,9%	-21,9%	-21,9%	-19,9%	-39,6%	-40,9%	
		15 pax - 5% demand served	-21,5%	-22,1%	-23,3%	-22,5%	-21,9%	-19,5%	-38,1%	-40,0%	
		8 pax - 10% demand served	-25,4%	-26,0%	-27,5%	-26,7%	-24,7%	-24,1%	-41,4%	-44,2%	
		15 pax - 10% demand served	-23,6%	-23,9%	-26,3%	-25,7%	-24,1%	-22,5%	-39,7%	-42,1%	
Modal split: Active modes	Baseline	(no AUSS)	0,0%	-3,4%	-4,7%	-14,9%	-16,2%	-17,6%	-17,6%	-17,6%	Delphi (expert survey)
	Point-to-point	Point-to-point AUSS	0,0%	-0,6%	-0,6%	-3,2%	-6,1%	-5,4%	-5,4%	-5,4%	
	On-demand AUSS	Anywhere-to-anywhere	0,0%	-1,7%	-8,5%	-14,3%	-16,4%	-20,2%	-20,2%	-20,2%	
		Last-mile	0,0%	-4,5%	-6,1%	-3,5%	-3,8%	-4,1%	-4,1%	-4,1%	
		E-hailing	0,0%	-5,6%	-9,7%	-11,4%	-18,6%	-20,3%	-20,3%	-20,3%	
	Baseline	(no AUSS)	0,0%	-3,8%	-10,6%	-14,9%	-25,5%	-31,0%	-31,0%	-31,0%	

Modal split: Public transport	Point-to-point	Point-to-point AUSS	0,0%	0,7%	-0,6%	0,1%	0,9%	-0,5%	-0,5%	-0,5%	
	On-demand AUSS	Anywhere-to-anywhere	0,0%	1,4%	-6,8%	-13,6%	-21,1%	-16,3%	-16,3%	-16,3%	
		Last-mile	0,0%	11,1%	15,9%	17,7%	22,1%	23,5%	23,5%	23,5%	
		E-hailing	0,0%	3,7%	1,1%	3,4%	4,5%	5,1%	5,1%	5,1%	
Shared mobility rate	Baseline	(no AUSS)	0,0%	0,7%	5,0%	18,0%	19,3%	21,6%	21,6%	21,6%	
	Point-to-point	Point-to-point AUSS	0,0%	5,6%	11,2%	19,1%	22,3%	23,6%	23,6%	23,6%	
	On-demand AUSS	Anywhere-to-anywhere	0,0%	4,3%	4,7%	10,2%	13,0%	14,8%	14,8%	14,8%	
		Last-mile	0,0%	4,2%	5,7%	13,3%	16,7%	18,4%	18,4%	18,4%	
		E-hailing	0,0%	0,2%	1,6%	3,1%	3,1%	3,1%	3,1%	3,1%	
Modal split[1] Vienna: Private vehicle (HDV & AV)	Baseline	(no AUSS)	39,7%	40,2%	40,6%	41,3%	42,0%	42,5%	42,9%	43,0%	Meso-simulation (Vienna)
	On-demand: Last-mile AUSS	1118 shuttles	38,9%	36,7%	37,4%	38,2%	38,9%	39,5%	39,6%	39,8%	
		2338 shuttles	38,9%	36,5%	37,3%	38,1%	38,7%	39,4%	39,5%	39,7%	
	On-demand: Anywhere-to-anywhere AUSS	250 shuttles	39,1%	37,2%	37,8%	38,4%	39,1%	39,8%	39,8%	40,1%	
		500 shuttles	38,6%	36,4%	37,3%	37,9%	38,5%	39,2%	39,2%	39,6%	
Modal split[1] Vienna: Active modes	Baseline	(no AUSS)	8,1%	8,2%	8,3%	8,1%	8,2%	8,2%	8,0%	8,0%	
	On-demand: Last-mile AUSS	1118 shuttles	7,8%	10,6%	10,2%	10,1%	10,0%	10,1%	9,9%	10,0%	
		2338 shuttles	7,8%	10,5%	10,1%	10,0%	10,1%	10,1%	9,9%	9,8%	
	On-demand: Anywhere-to-anywhere AUSS	250 shuttles	8,1%	9,9%	9,9%	9,8%	9,7%	9,7%	9,6%	9,6%	
		500 shuttles	7,8%	9,6%	9,5%	9,6%	9,4%	9,4%	9,4%	9,3%	
Modal split[1] Vienna: Public transport (excl. AUSS)	Baseline	(no AUSS)	52,1%	51,6%	51,1%	50,6%	49,8%	49,3%	49,1%	49,0%	
	On-demand: Last-mile AUSS	1118 shuttles	51,7%	51,0%	50,6%	49,9%	49,4%	48,8%	48,8%	48,5%	
		2338 shuttles	51,6%	51,0%	50,6%	49,9%	49,2%	48,5%	48,6%	48,4%	
	On-demand: Anywhere-to-anywhere AUSS	250 shuttles	50,5%	49,9%	49,4%	48,8%	48,2%	47,4%	47,5%	47,2%	
		500 shuttles	49,8%	49,5%	48,6%	47,9%	47,4%	46,7%	46,7%	46,4%	
Modal split[1] Vienna: AUSS	Baseline	(no AUSS)	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	
	On-demand: Last-mile AUSS	1118 shuttles	1,5%	1,8%	1,8%	1,8%	1,8%	1,7%	1,7%	1,8%	
		2338 shuttles	1,8%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	
		250 shuttles	2,3%	2,9%	3,0%	3,0%	3,0%	3,0%	3,0%	3,0%	

	On-demand: Anywhere-to-anywhere AUSS	500 shuttles	3,8%	4,5%	4,6%	4,6%	4,7%	4,7%	4,7%	4,7%	
Vehicle utilization rate of AUSS[2]	On-demand: Last-mile AUSS	1118 shuttles	0,0%	0,4%	0,3%	0,2%	0,3%	0,3%	0,2%	0,3%	Meso-simulation (Vienna)
		2338 shuttles	0,0%	-0,2%	-0,4%	-0,2%	-0,2%	-0,2%	-0,2%	-0,2%	
	On-demand: Anywhere-to-anywhere AUSS	250 shuttles	0,0%	-1,6%	-1,6%	-2,2%	-1,9%	-1,9%	-2,3%	-2,1%	
		500 shuttles	0,0%	-1,0%	-1,1%	-1,2%	-1,2%	-1,3%	-1,2%	-1,0%	
Vehicle occupancy of AUSS[2]	On-demand: Last-mile AUSS	1118 shuttles	0,0%	1,0%	0,9%	0,2%	0,6%	0,1%	0,3%	0,4%	Meso-simulation (Vienna)
		2338 shuttles	0,0%	0,6%	0,7%	0,3%	0,2%	0,4%	0,5%	0,3%	
	On-demand: Anywhere-to-anywhere AUSS	250 shuttles	0,0%	-4,2%	-3,5%	-3,9%	-3,7%	-3,4%	-2,9%	-3,5%	
		500 shuttles	0,0%	-2,0%	-2,9%	-3,0%	-3,1%	-2,0%	-2,7%	-2,1%	

[1] Modal split values are given in terms of percentage of the total travel demand (trips)

[2] Baseline not applicable (measured for shuttles only)

C.3 Societal impacts

			Market penetration rate: AVs in Background vehicle fleet (Human-driven vehicle - 1st Generation AV - 2nd Generation AV)								
Impact	**Sub-use Case**	**Scenarios**	**100-0-0**	**80-20-0**	**60-40-0**	**40-40-20**	**20-40-40**	**0-40-60**	**0-20-80**	**0-0-100**	**Method**
Vehicle operating cost	Baseline	(no AUSS)	0,0%	-2,7%	1,1%	-1,8%	-8,3%	-10,3%	-10,3%	-10,3%	Delphi (expert survey)
	Point-to-point AUSS	Point-to-point AUSS	0,0%	-4,5%	-6,2%	-11,8%	-15,7%	-21,6%	-21,6%	-21,6%	
	On-demand AUSS	Anywhere-to-anywhere	0,3%	0,3%	-4,1%	-8,4%	-11,7%	-17,2%	-17,2%	-17,2%	
		Last-mile	0,0%	0,7%	-1,1%	-3,1%	0,5%	-3,1%	-3,1%	-3,1%	
		E-hailing	0,0%	0,3%	2,4%	3,0%	-3,5%	-2,6%	-2,6%	-2,6%	
Parking space required	Baseline	(no AUSS)	0,0%	-2,5%	-5,5%	-14,2%	-17,7%	-21,1%	-21,1%	-21,1%	Delphi (expert survey)
	Point-to-point AUSS	Point-to-point AUSS	0,0%	0,2%	-5,2%	-12,3%	-17,8%	-22,2%	-22,2%	-22,2%	
	On-demand AUSS	Anywhere-to-anywhere	0,0%	-1,1%	-3,8%	-9,9%	-15,7%	-18,9%	-18,9%	-18,9%	
		Last-mile	0,0%	-0,6%	-4,6%	-10,4%	-13,9%	-16,6%	-16,6%	-16,6%	
		E-hailing	0,0%	-2,2%	-3,5%	-9,3%	-12,0%	-13,7%	-13,7%	-13,7%	
	Baseline	(no AUSS)	0,0%	2,7%	8,0%	19,7%	34,7%	47,3%	47,3%	47,3%	System dynamics (Vienna)
	On-demand AUSS	Last-mile	-0,1%	2,6%	7,5%	18,4%	32,9%	45,4%	45,4%	45,4%	
Average commuting distance	Baseline	(no AUSS)	0,0%	0,0%	0,0%	0,0%	0,0%	1,0%	1,0%	1,0%	System dynamics (Vienna)
	On-demand AUSS	Last-mile	0,0%	-1,0%	-1,0%	-1,0%	-1,0%	-1,0%	-1,0%	-1,0%	
Road safety: crash rate	Point-to-point AUSS connecting two modes (small-scale network)	Baseline (small-scale; peak hour)	0,0%	-37,4%	5,1%	-75,8%	-71,9%	-62,0%	-52,2%	-66,0%	Micro-simulation (Athens)
		Peak hour - Mixed traffic	66,6%	-60,2%	-51,6%	10,8%	-83,0%	-83,9%	-90,5%	-90,4%	
		Peak hour - Dedicated lane	78,2%	-80,9%	5,7%	-52,0%	-41,9%	-69,8%	-80,5%	-88,3%	
		Peak hour - Incident	65,4%	30,5%	-49,6%	14,5%	-59,7%	-33,0%	-51,3%	-61,1%	
		Off Peak hour - Mixed traffic	-64,8%	-71,1%	-61,8%	-45,8%	-78,0%	-82,6%	-89,1%	-91,8%	
		Off Peak hour - Dedicated lane	-47,9%	-69,9%	-63,8%	-71,6%	-77,6%	-82,4%	-89,3%	-92,0%	
	Point-to-point AUSS (large-scale network)	Baseline (large-scale; peak hour)	0,0%	-9,4%	-10,2%	-20,0%	-36,2%	-50,1%	-58,4%	-68,2%	
		Peak hour - Mixed traffic	0,4%	-10,6%	-6,0%	-19,4%	-35,6%	-49,6%	-58,5%	-68,0%	

		Peak hour - Dedicated lane	-0,1%	-9,7%	-5,2%	-19,9%	-35,4%	-49,6%	-58,5%	-68,0%	
		Off Peak hour - Mixed traffic	-49,1%	-51,3%	-50,3%	-57,9%	-64,0%	-69,4%	-74,7%	-78,7%	
	On-demand AUSS	Baseline (large-scale; peak hour)	0,0%	-9,4%	-10,2%	-20,0%	-36,2%	-50,1%	-58,4%	-68,2%	
		8 pax - 5% demand served	-4,8%	-8,9%	-6,6%	-19,7%	-38,3%	-50,5%	-58,5%	-69,0%	
		15 pax - 5% demand served	-14,6%	-9,2%	-6,6%	-20,6%	-37,2%	-50,8%	-58,7%	-68,5%	
		8 pax - 10% demand served	-17,7%	-10,8%	-7,7%	-22,1%	-36,9%	-49,8%	-58,1%	-68,9%	
		15 pax - 10% demand served	-17,3%	-11,2%	-7,6%	-22,2%	-36,2%	-49,6%	-58,3%	-69,1%	
Public health	Baseline	(no AUSS)	0,0%	1,0%	1,0%	3,6%	2,2%	4,1%	4,1%	4,1%	Delphi (expert survey)
	Point-to-point AUSS	Point-to-point AUSS	0,0%	-0,2%	3,7%	5,0%	8,0%	11,9%	11,9%	11,9%	
	On-demand AUSS	Anywhere-to-anywhere	0,0%	2,8%	4,1%	5,1%	2,5%	5,5%	5,5%	5,5%	
		Last-mile	0,0%	3,0%	7,0%	4,4%	4,4%	4,1%	4,1%	4,1%	
		E-hailing	0,0%	-0,2%	2,4%	5,0%	6,4%	8,0%	8,0%	8,0%	
Equal accessibility of transport	Baseline	(no AUSS)	0,0%	4,4%	9,7%	13,9%	19,2%	22,5%	22,5%	22,5%	Delphi (expert survey)
	Point-to-point AUSS	Point-to-point AUSS	0,0%	0,3%	-3,8%	2,0%	-3,0%	-4,4%	-4,4%	-4,4%	
	On-demand AUSS	Anywhere-to-anywhere	0,0%	0,3%	-1,1%	-1,0%	-0,3%	8,6%	8,6%	8,6%	
		Last-mile	0,0%	-1,1%	-1,1%	-3,8%	-1,8%	-0,8%	-0,8%	-0,8%	
		E-hailing	0,0%	0,2%	1,7%	-1,1%	-0,7%	-1,4%	-1,4%	-1,4%	