Policy Recommendations for Connected, Cooperative, and Automated Mobility

LEVITATE Policy Recommendations Deliverable D 8.4

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Executive summary

This deliverable presents the summary of key findings based on the impact assessment of Cooperative, Connected, and Automated Mobility (CCAM) technologies and services, performed within the Levitate project. Based on these findings this Deliverable identifies key factors with implications for future policy making and recommends areas for deeper consideration to policymakers. To build the background, a brief summary of the impact assessment framework within Levitate and discussion is presented on the vision of the two city project partners 'Transport for Greater Manchester' and 'City of Vienna'.

The details of the results can be found in the following Levitate Deliverables

- 5.2-5.4 (Roussou et al, 2021a; Roussou et al., 2021b; Roussou et al., 2021c),
- 6.2-6.4 (Haouari et al., 2021; Sha et al., 2021; Chaudhry et al., 2021),
- 7.2-7.4 (Hu et al, 2021a; Hu et al, 2021b; Hu et al, 2021c),
- Weijermars et al, 2021
- Deliverables 5.5 (Goldenbeld et al., 2021a), 6.5 (Gebhard et al.,2022), and 7.5 (Goldenbeld et al., 2021b),
- Case Studies documents (Hu et al., 2022, Johannes et al., 2022, Richter, G., 2022, Singh et al., 2022, Haouari et al., 2022),
- Transferability Working Paper (Sha et al., 2022).

Various impacts (studied within Levitate) of CCAM are discussed both under baseline conditions (i.e., with increasing penetration of CAVs without any policy intervention) and then with the implementation of various policy measures. Findings from cost and benefit analyses (D3.4 Hartveit and Veisten, 2022) have also been presented.

The deliverable presents the broader implications of various CCAM related policy measures, the key influencing factors for ensuring the effective and sustainable implementation, and hence, enables the selection of suitable policy options while minimising any adverse impacts.

Key highlights based on the consolidated findings on broader impact dimensions are as follows:

General issues

- CCAM services with similar names and broad approach may have very different impacts depending on the manner in which they are implemented.
- Future CCAM services and technologies may have a mixture of positive and negative societal impacts. Policy measures should be based on a full impact assessment in order to identify improved opportunities to achieve city policy goals or set measures to mitigate negative impacts. Depending upon network characteristics and fleet compositions, the early phases of CAV deployment with a mixed fleet of automated vehicles and vehicles with human drivers in the transport system can result in marginal decrease and in some cases increased conflicts and collisions. Local and national policies will be essential to monitor and mitigate these detrimental impacts during the transition phase.
- As advanced automated vehicles form the largest part of the vehicle fleet, it is anticipated that crash rates will reduce substantially below the current levels. When

these vehicles meet or exceed the performance of humans it is expected that traffic impacts may improve beyond existing levels.

- Early generations of automated vehicles, which operate below the level of human driven vehicles with increased headways, highly cautious sensitivity to the detection of other road users– so increased stops - and therefore slower travel and increased delays, are expected to reduce the capacity of cities for traffic. City policies will be required to mitigate these impacts.
- The magnitude of the impacts of CCAM services and technologies is broadly in line with the fleet penetration. Small scale deployments are unlikely to result in a large impact at network level as these impacts remain dominated by the background traffic.
- Several policy measures that have been examined can bring positive environmental impacts; however, powertrain electrification has an overwhelmingly larger impact on emissions compared to the studied policy interventions
- Commonly any improvement in passenger car mobility through the increased automation will have the effect to reduce the use of public transport and active travel. Similarly, improvements in public transport will reduce personal car use and active travel. Automated ride sharing as well as last mile shuttle services are likely to negatively impact active travel with respect to the baseline scenario due to providing pick-ups and drop-offs closest to the origins and destinations of passengers, where last mile shuttles can potentially have much stronger impact on active travel than automated ride sharing.
- Close monitoring of the manner in which CAVs moved, their interactions within the transport network and a calibration of the societal impacts is essential to improve future impact forecasts and to prepare more effective interventions so that city goals can be achieved.
- The Levitate project has shown the benefits of conducting detailed impact forecasts based on a broad spectrum of modelling methods. The methods can be applied to other CCAM interventions and can also be adapted to evaluate real-world trials of CCAM services and technologies.

Economic cost-benefit analysis
All single interventions have been tested in cost-benefit analysis, applied to a hypothetical case area. Although lacking input about the costs of implementing the policy interventions, the following summarises the overall results in net present value (NPV).

- There is a considerable variation in NPV between the interventions and between the various implementation methods.
- Automated urban shuttle services, automated freight delivery and the implementation of GLOSA show routinely positive NPV, given relatively limited costs of implementation.
- Automated ride sharing (ARS) and the replacement of on-street parking show variable NPV results, in the case of ARS the proportion of the total demand and the willingness to share are critical factors.
- The introduction of road pricing within a CAV traffic environment will result in negative NPV; the gains in external environment and health impacts do not outweigh the increased costs to private car users, under the given assumptions.
- Even without policy measures, automation in freight transport will likely gain popularity once the technology is mature and the operating costs become cheaper than the costs nowadays.

Specific interventions

- **Road use pricing** can be a promising option for improving use of active modes and public transport with increasing prevalence of CAVs. The benefits from Road Use Pricing policy may be slower but will potentially lead to sustainable benefits. It is expected to lead to a number of additional benefits over the baseline impacts: better energy efficiency (dynamic toll more than static toll or empty km pricing), higher vehicle occupancy rate, and lower parking space demand.
- The implementation of **Dedicated Lanes for CAVs** shows small benefits for traffic until CAVs comprise the majority of vehicles in the fleet. The use of the innermost lane provides the greatest traffic and safety benefits.
- The optimum parking behaviour of CAVs can be managed by adjusting the **price of parking**. The scenario where a CAV drops passengers off then parks locally minimises impacts on travel time and congestion. Other scenarios where a CAV may return to base or park remotely will increase impacts because of the additional distance travelled.
- CAV parking that is remote from the drop-off location enables **on-street parking** to be replaced by public spaces or cycle lanes with associated benefits to travel delay and speed.
- **Green Light Optimised Speed Advisory (GLOSA)** systems in general showed small improvements in traffic impacts when used with fixed time controllers. Increasing the number of GLOSA controlled intersections on arterial roads resulted in small additional improvements in traffic impacts. The impacts need to be carefully assessed when human-driven vehicles comprise the largest proportion of traffic.
- The impact of **Automated Rideshare Services** depends heavily on the proportion of total demand fulfilled by the service and also the passengers' willingness to share with others. When fulfilling low levels of demand there are low, adverse impacts on traffic indicators and there are many empty journeys but, when there is a high willingness to share and a large part of the total demand are covered, traffic impacts become positive.
- Under all of the deployment scenarios examined the impacts of **Automated Urban Shuttle Services** were relatively low as the vehicles routinely formed only a small part of the total fleet. Most societal impacts were positive. However, care should be taken to prevent the anticipated unwanted impacts of these services, for example on the use of active travel modes. Anticipatory research and anticipatory and flexible planning approaches are recommended to prevent these negative developments.
- Freight vehicles also tend to be a small proportion of the total fleet nevertheless **Automated Urban Freight Delivery** services provide many positive benefits. Automated freight vehicles that enable night-time deliveries to be made produce additional benefits to travel time and congestion. Automation alone will most likely lead to an increase in freight mileage (because of smaller and cheaper freight vehicles), so corresponding policy measures in favour of freight consolidation should be considered to mitigate this trend. Fortunately, automation is expected to facilitate the consolidation process.
- A focused assessment of the impact on bridges of truck platooning has identified the need to improve the structural resistance of bridges over 55m span in bending and over 60m span in shear. Alternatively, increased forward headways must be imposed.

Other key remarks

- 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 promote preferred directions of innovation by setting up strategic agendas and by establishing suitable standards, regulations and guidelines.
- However, care should be taken to prevent the anticipated unwanted impacts of these services, for example on equal accessibility of travel and on the use of active travel modes. Anticipatory research and anticipatory and flexible planning approaches are recommended to prevent these negative developments.
- 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 enhance the public transport network, by providing point-to-point Automated Urban Shuttle Services as well as on-demand AUSS, in order to promote the reduction of the use of private cars.
- 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. The effectiveness of specific interventions may be very sensitive to changes in mobility behaviour.
- In decisions about new forms of automated transport, waiting time, travel time, travel costs, comfort, 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.
- 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.
- Although new forms of automated urban transport may be operated and controlled by private companies, it is recommended that these are developed to complement the public transport system in useful ways, for example by providing their services in regions not served by the public transport, usually outside the city center, or by providing automated shuttles connecting different existing public transport stations.
- Guidelines - including ethical guidelines - and lists of impacts for future automated urban mobility and transport have been formulated, within LEVITATE and generally by the transport research community, and should be partly or fully adopted in strategic plans to facilitate successful implementation of new transport services.
- Multimodality and synchro modality are important factors to aim towards a sustainable logistic supply chain.
- All the above points require homogenous and shared data among operators, which is perhaps the most difficult challenge due to the competition between service providers as well as freight operators.

The many different scenarios of CCAM, the many different potential policy options and its interdependencies show a very complex pattern of effects. However, the effects of CCAM on cities and society largely depend on the regulatory framework in which CCAM is deployed. It is up to policy makers to define a regulatory framework supporting the goals of the respective Smart City Strategies, SUMPs (Sustainable Urban Mobility Plans), Climate Strategies etc. while avoiding adverse effects.

1. Introduction

Connected, cooperative, and automated mobility (CCAM) services and technologies 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 safety, mobility, environment and economic growth. With such systems not yet in widespread use, there is a lack of data and knowledge about impacts.

Furthermore, 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 forecast the impact of future systems represents a major challenge.

Finally, the dimensions for assessment are themselves very diverse, including safety, mobility and environment but with many sub-divisions adding to the complexity of future mobility forecasts.

The aim of the LEVITATE project is to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives.

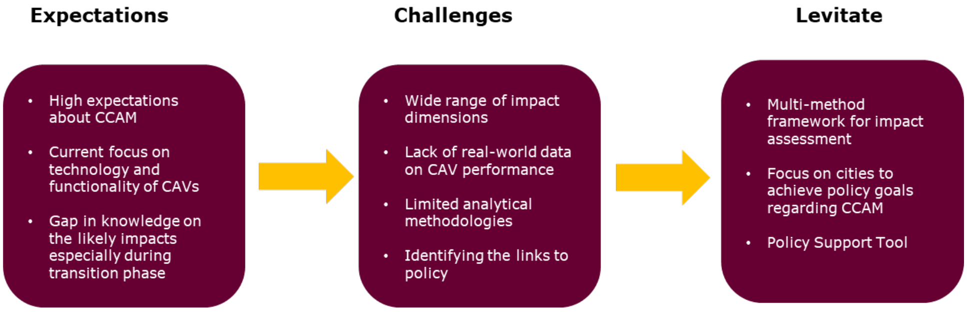


Figure 1.1: Motivation and scope of the Levitate project

1.1 LEVITATE Project

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

Specifically LEVITATE has four key objectives:

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

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 on these city goals have been studied by various methods and for different policy interventions (sub-use cases). This Chapter describes the major policy goals towards which cooperative, connected, and automated transport may contribute and how the various distinct impacts on transport system are interrelated and related to the policy goals.

2.1 Urban mobility and transport goals

To date, there is no standard European approach for defining goals and indicators for the further development of smart cities. Within the Levitate project, 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 (LEVITATE deliverables D4.1-4.3, Zach et al., 2019). The analysis conducted within the Levitate project covers the effects of autonomous vehicle share on the goals set out by policymakers of these cities (Papazikou et al., 2020a). 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 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 the 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 and other emissions	CO2 and NOx, PM10 and PM2.5emissions
	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 (walking, cycling, public transport and shared mobility modes) (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 relevant transport strategy for Levitate WP7 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 ecomobility 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 (Table 2.2), each with its own impact measure.

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

Policy domain	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 goals although specific policies must 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.

The process of starting with quantified goals and deriving the most suitable supporting policy interventions to achieve these goals in a systematic way is referred to as backcasting which has been one of the methodological pillars of LEVITATE. This approach and its application in the Policy Support Tool is summarized in section 4.4.

2.2 LEVITATE Impact Assessment Framework

Developing methods for assessing and predicting the impacts of CCAM involved the following main stages:

1. Identification and classification of the impacts of connected and automated driving
2. Description and measurement of the impacts of connected and automated driving
3. Development of methods of back casting and forecasting of the impacts of connected and automated driving
4. Evaluation of comparability and amenability to monetary valuation of the impacts of connected and automated driving
5. Method for analysing the costs and benefits of connected and automated driving

6. Methods for generating options and scenarios for policy at the city level with respect to the introduction of connected and automated driving

Figure 2.1 presents an overview of the project components and workflow. It is envisaged that forecasting will concentrate on those impacts that are regarded as most important and relevant from the stakeholder perspective of policy makers.

With regard to identifying potential impacts of CCAM, a wide net was cast through the available knowledge in the literature and the causal pathways connecting these impacts to each other.

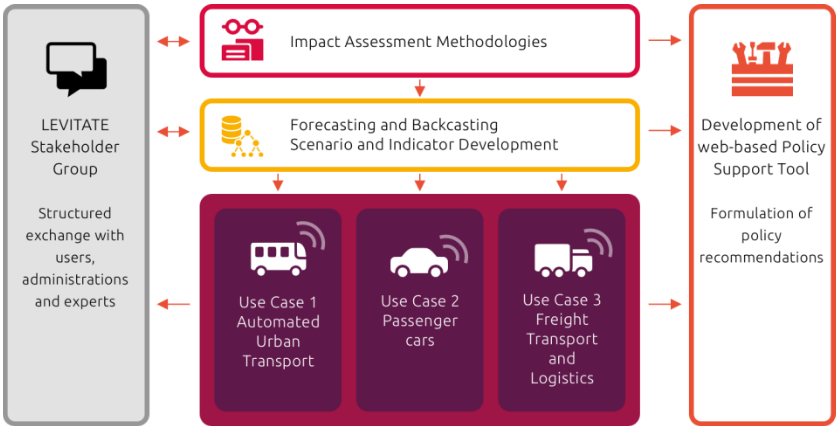


Figure 2.1: Overview of project components and workflow

2.3 Impact Dimensions— Expected impacts of automation

It is expected that CCAM will have substantial impacts on road transport. Deliverable D3.1 (Elvik et al., 2019) presented a taxonomy of potential impacts of CCAM 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).

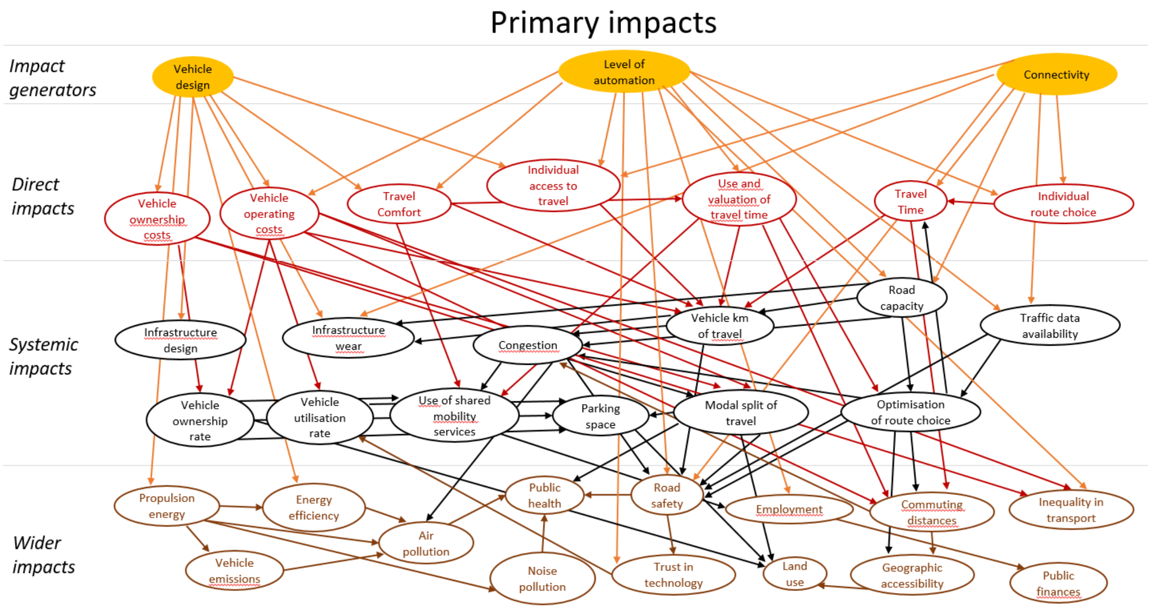


Figure 2.2: Taxonomy of impacts generated by transition to connected and automated vehicles (LEVITATE D3.1, Elvik et al., 2019)

Figure 2.2 shows the different paths by which impacts are generated by automation technology. Three aspects of it are identified in Figure 2.2.: 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 ability 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 2.2 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 nonautomated road users, 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 in the level of congestion, vehicle kilometres of travel, changes in the modal split of travel and optimisation of route choice. (Elvik et al., 2019).

Expected impacts, reported by the previous literature, under passenger, freight, and public transport services can be found in the following LEVITATE Deliverables.

- Deliverables 5.1-5.5 (Papazikou et al.,2020b; Roussou et al., 2021a; Roussou et al., 2021b; Roussou et al., 2021c; Goldenbeld et al.,2021),
- Deliverables 6.1-6.5 (Boghani et al., 2019; Haouari et al., 2021; Sha et al., 2021; Chaudhry et al., 2021; Gebhard et al.,2022), and
- Deliverables 7.1-7.5 (Hu et al., 2019; Hu et al., 2021a; Hu et al., 2021b; Hu et al., 2021c; Goldenbeld et al., 2021b).

There is considerable overlap among the lists of impacts presented by the studies, suggesting a high level of scientific consensus about the potential impacts of CCAM. Figure 2.3 below presents an overview of the list of impacts considered in the project.

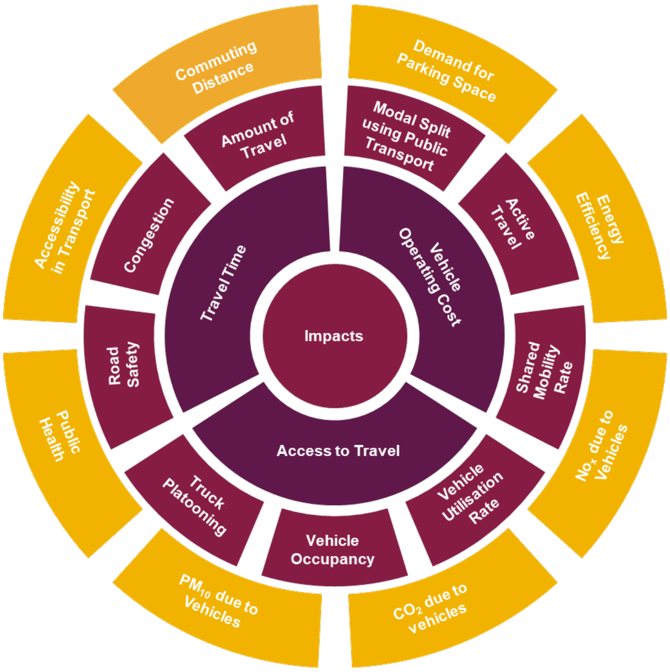


Figure 2.3: Impacts Dimensions of CCAM studied within LEVITATE; Direct (inner circle), systemic (middle circle), and Wider Impacts (outer circle)

Some impacts are nested within each other. For example, lower operating costs, improved travel comfort and reduced travel time all contribute to reducing the generalised costs of travel. Table 2.3 further provides the description on each impact variable.

Table 2.3: Description of impact variables

Impact	Description
Travel time	Average duration of a 5Km trip inside the city centre
Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel
Freight Transport Cost	Direct outlays for transporting a tonne of goods per kilometre of travel
Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)
Congestion	Average delays to traffic (seconds per vehicle-kilometre) as a result of high traffic volume
Amount of travel	Person kilometres of travel per year in an area
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
Truck Platooning	Impacts of truck platooning on highway bridges
Road safety	Number of traffic conflicts per vehicle-kilometre driven (temp. until crash relation is defined).
Parking space	Required parking space in the city centre per person (m2/person)
Energy efficiency	Average rate (over the vehicle fleet) at which propulsion energy is converted to movement
NO_X due to vehicles	Concentration of NOx pollutants as grams per vehicle-kilometre (due to road transport only)
CO_2 due to vehicles	Concentration of CO2 pollutants as grams per vehicle-kilometre (due to road transport only)
PM10 due to vehicles	Concentration of PM10 pollutants as grams per vehicle-kilometre (due to road transport only)
Public health	Subjective rating of public health state, related to transport (10 points Likert scale)
Accessibility in transport	The degree to which transport services are used by socially disadvantaged and vulnerable groups including people with disabilities (10 points Likert scale)
Commuting distances	Average length of trips to and from work (added together)

2.4 Identified Policy Interventions and Analysis Scenarios

Several potential policy interventions (named as sub-use cases) to support or mitigate policy goals based on impacts of CCAM were identified through meetings with the stakeholders. In this regard, a stakeholder reference group (SRG) workshop, detailed in D 6.1 (Boghani et al., 2019) was conducted where consultation was obtained from the experts from city administrations and industry on the generation and prioritization of the sub-use cases. Within LEVITATE, this list has been prioritized and refined within subsequent tasks in the project to inform the interventions and scenarios related to passenger, urban, and freight transport. In turn, these policy interventions have been included in the LEVITATE Policy Support Tool (PST).

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

- SRG Workshop: Containing first-hand feedback for the sub-use cases but might only reflect the opinions of organisations and people who participated.

- Scientific literature: Indicating the scientific knowledge and the available assessment methodologies for the sub-use cases. However, this might not be directly linked to their importance / relevance for practice.

- Roadmaps: Indicating the relevance of sub-use cases from the industrial/ political point of view, independent of available scientific methodologies.

- Results of the backcasting city dialogues conducted in LEVITATE WP4 for Vienna, Greater Manchester, and Amsterdam (Zach, Sawas, Boghani, & de Zwart, 2019; Papazikou et al., 2020a).

Considering the suggestions from SRG and existing knowledge through literature, the following sub-use cases (SUC) have been defined within the project based on the transport mode.

Passenger Transport
- Road use pricing (RUP)
- Provision of dedicated lanes (DL) on urban highways
- Parking price polices
- Parking space regulations
- Automated ride sharing (ARS)
- Green light optimal speed advisory (GLOSA)

Urban Transport
- Point-to-Point Automated Urban Shuttle Service (AUSS)
- On-demand Automated Urban Shuttle Service (AUSS)

Freight and Logistics
- Automated urban delivery
- Automated consolidation
- Hub-to-Hub automated transport
- Platooning on urban highway bridges

Table 2.4: Analysis Scenarios within various Sub-use Cases

Passenger Transport						**Urban Transport**		**Freight Transport**			
RUP	Provision of DLs on urban highways	Parking Price	Parking space regulations	Automated Ride Share	GLOSA	Point-to-Point AUSS	On-demand AUSS	Automated urban delivery	Automated consolidation	Hub-to-Hub automated transport	Platooning on urban highway bridges
Dynamic Toll	DL on A Road and motorway (left most lane placement)	Enter, drop-off passengers and return to origin	Removal of parking spaces to 50%	5% demand with varying WTS (20-100%)	Implementation on 1 intersection	Point-to-point AUSS connecting two modes of transport	Anywhere-to-anywhere AUSS	Semi-automated delivery	Manual delivery with bundling at city hubs	Operation via transfer terminal	Structural reinforcement
Static Toll	DL on Motorway (left most lane placement)	Enter, drop-off passengers and return to outside parking	Conversion to driving lanes	10% demand with varying WTS (20-100%)	Implementation on 2 intersections	Point-to-point AUSS in a large-scale network	Last-mile AUSS	Automated delivery	Automated delivery with bundling at city hubs		Intelligent access control
	DL on A road with right most placement	Enter, drop-off and drive around while waiting for the passenger	Conversion to cycle lanes	20% demand with varying WTS (20-100%)	Implementation on 3 intersections		E-hailing	Automated night delivery			
	DL on A road with left most lane placement		Replacement with pick-up/drop-off spaces								
			Conversion to public spaces								

2.5 Methods within LEVITATE

It was envisaged that a broad range of methods must be used in order to adequately quantify as many of the potential impacts as possible. The types of impacts that are presented in LEVITATE Deliverable 3.1 (Elvik et al., 2019): A taxonomy of potential impacts of connected and automated vehicles at different levels of implementation (Elvik et al., 2019) have been estimated and forecast using appropriate assessment methods, such as traffic simulation, system dynamics and Delphi panel method. For example, traffic simulation can directly provide short-term impacts. Therefore, it (microscopic and mesoscopic simulation) was used to forecast short-term impacts regarding dose (in terms of introduction of sub-use case) and response (selected impact). Traffic simulation also provides further input to assess other types of impacts by processing those results appropriately to infer such impacts, such as safety impacts through identification of traffic conflicts which involves processing of vehicular trajectories through a surrogate safety assessment model.

With incremental development towards perfection in automation, the concept of first and second generation systems was introduced in traffic simulation modelling. Both types are assumed to be fully automated vehicles with level 5 automation. The main idea behind modelling these two types is based on the assumption that technology will advance with time. Therefore, 2nd Gen CAVs will have improved sensing and data handling capabilities, decision making, driver characteristics, and anticipation of incidents etc. In general, the main assumptions on CAVs characteristics are as follows:

- 1st Generation: Sensing and computational capability is limited. These vehicles are considered to be conservative in their driving characteristics whereby they leave larger gap, have higher anticipation of lane change and incidents etc. (relating to connectivity) than human driven vehicles and takes more time during give way situations.
- 2nd Generation: Sensing and computational capability is advanced, can use data fusion and is more confident in taking decisions. These vehicles are considered to appear more aggressive in their driving characteristics whereby they leave smaller (compared to human driven vehicles) headway to preceding vehicle, have higher anticipation of lane change or incidents etc. (relating to connectivity) than human driven vehicles and 1st Generation CAVs, and takes less time during give way situations.

It is considered that all AVs will be connected. Decision-making by using information received using connectivity in 1st generation would be limited so some behaviours will be limited due to this. 2nd generation vehicles are considered to be advanced in decision-making by using information using connectivity and so, this will be reflected in their driving behaviours. The CAV driving behaviours developed in the LEVITATE project are presented in detail in Chaudhry et al., 2022.

System level analysis (such as by tools found within system dynamics) can be used to measure long-term impacts. For the sake of simplicity and applicability of assessment methods, it is assumed that for the appropriate level of automation, adequate infrastructure exists. It is also assumed that the pure technological obstacles for the sub-use cases in consideration are solved. All results relating to the relationships between sub-use cases, impacts and any intermediate parameters have been used for the development of the LEVITATE Policy Support Tool (PST). The results are integrated within the PST modules and functionalities so that impact assessment can be carried out by the user.

Figure 2.3 presents an overview of various methods used within the project to estimate the various impact indicators.

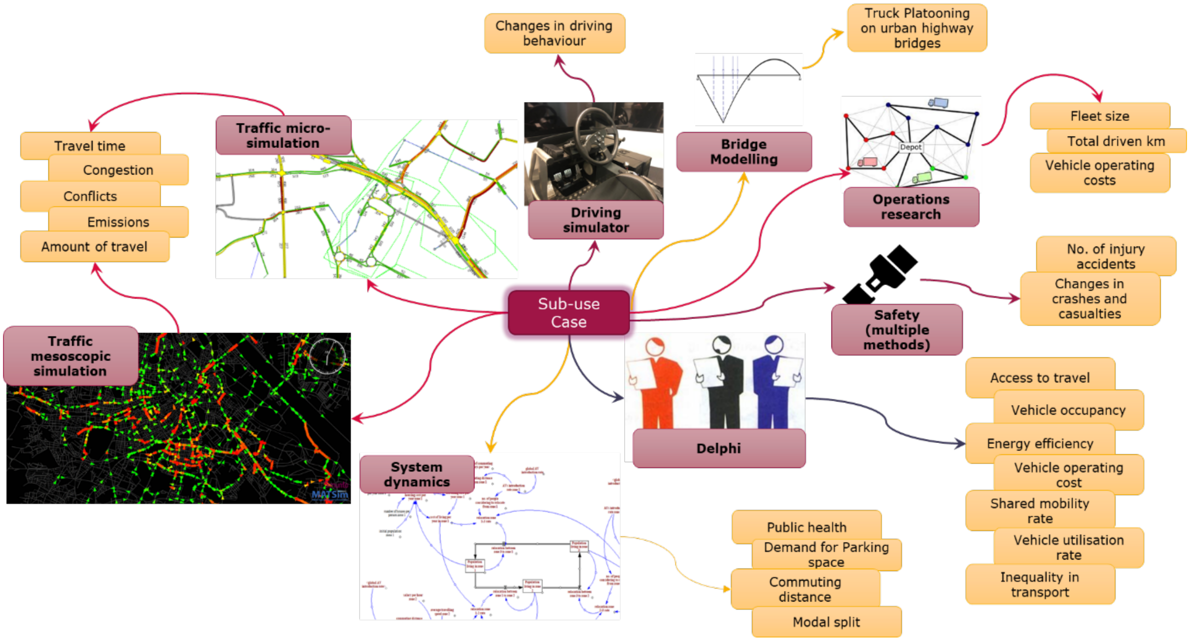


Figure 2.4: Multi-method framework within LEVITATE

3. Policy Considerations and Discussion

The policy interventions studied in the LEVITATE project are part of a wider transition to smart mobility and smart cities. In this section we will reflect on a number of relevant broader policy issues surrounding the introduction of Cooperative, Connected and Automated Mobility (CCAM) in urban areas. Planning and governance of new forms of CCAM 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 tested in 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 CCAM deployment. An example we can learn from is the advent of the motor car in a largely unregulated transport environment, which introduced many negative impacts which in time, and to this day, need mitigation. The Safe System approach to traffic safety focuses on prevention, pleading for a pro-active approach to not only road and vehicle design but also with respect to standards, legislation and regulation (ITF, 2016).

There is enthusiasm about the transition towards smart mobility, but not surprisingly opinions vary. Fraedrich et al. (2019) 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:

- cities themselves are a major driving force
- for city renewal or redevelopment, promoting public transport is a major policy measure
- 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 similar public goals are often promoted by industry, but the realization of these is ultimately a policy decision (McAslan et al., 2021). Several of the studied Regional Transportation Plans did have policies to address equity and accessibility. However, MPOs need to engage stakeholders, both from the public sector and industry, to ensure that public goals like equity, accessibility etc. are prioritised in addition to safety and mobility goals in the transportation decision making process. 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., 2019; 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 for Boston's workforce. In planning for future urban city mobility, 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.

Legal readiness

The EU has not yet amended its legal framework to incorporate AV-related liability and insurance risks, but it is exploring solutions to these issues. In 2016 the European Commission launched GEAR 2030 in order to explore solutions to AV-related liability issues. In May 2016 European Parliament Members recommended that the EC should create a mandatory insurance scheme and an accompanying fund to safeguard full compensation for victims of AV accidents and a legal status should be created for all robots to determine liability in accidents (Taeihagh & Lim, 2019).

Looking at recent developments in the six major areas for legal reform the following conclusions can be drawn:

- **Admission and testing:** various countries and states have applied different legal rules for admission and testing of automated vehicles; in the future comparative review of these regulations and associated experiences and outcomes should lay the groundwork for a more uniform approach in the EU and internationally (Lee & Hess, 2020). Technical standards for vehicles are at an early stage of development across the EU, UK and US. The current approach is to develop a method to specify vehicle performance requirements for specific operational design domains however fully automated systems will potentially be used across a very large range so new virtual approaches to vehicle safety assurance are required.
- **Liability**: the possible theoretical and legal solutions to liability and insurance have been outlined by various authors (Evas, 2018; Mardirossian 2020; Bertolini & Ricaboni, 2021; Vellinga, 2019) and further discussion between stakeholders and the development of specific cases of litigation will determine the legal option that is chosen
- **Human-machine interaction:** in this particular area a lot of research is still needed to answer questions on the design of the human-machine interface that will allow safe and reliable control of the vehicle, in all possible circumstances and involving different traffic situations and different internal states of the driver. This is particularly important for the earlier phases of automation (e.g. level 3) where the driver is still expected to perform some tasks. Uniform standards can only be formulated once this research has been carried out and main conclusions have been agreed upon by all stakeholders involved (Kyriakidis et al., 2017; Morales-Alvarez et al., 2020; Carsten & Martens, 2019)
- **Road infrastructure:** both within EU and USA work has been done to formulate general definitions of the new road classes that are needed to support automated and autonomous vehicles (Rendant & Geelen, 2020; Liu et al., 2019; Saeed et al., 2020). In the Inframix project, so-called ISAD levels (Infrastructure Support Levels for Automated Driving) were developed in which an impetus is given to define the minimum infrastructure (physical and digital) required to enable certain self-driving functions (Rendant & Geelen, 2020). For conventional road infrastructure, automated recognition of road geometry and signs is important and maintenance will be crucial for this. As of yet there are no norm or standards in the EU referring to traffic sign machine readability (Lytrivis et al., 2019).
- **Digital infrastructure:** connected cars require that every vehicle’s location and journey history be recorded and saved, but the current level of IT security cannot guarantee that data might be accessed by unwanted third parties. Thus, the

  development of cybersecurity is of the utmost importance for the development of connected and autonomous driving (Medina et al., 2017). At the moment the automotive industry lacks a standard approach for dealing with cybersecurity (Burkacky et al., 2020). The EU, through the European Union Agency for Network and Information Security (ENISA) had proposed good practices that should be considered (Medina et al., 2017).
- **Specific issues concerning electric vehicles:** The costs of battery technology, the number of charging stations and the charging wait time are main variables that will influence electrification of vehicle fleet (Mahdavian et al., 2021). It has been estimated that converting all passenger cars in USA to electric vehicles would consume 28% more power than the US currently produces (Mahdavian et al., 2021).

Road infrastructure readiness

Road infrastructures will have to be adapted in order to be ready, readable, and cooperative in all situations and weather conditions (Gruyer, 2021). CAVs require highly visible road edges, curves, speed limit and other signage (Liu et al.,2019). For the EU it is important to have uniform road markings. The roadside digital infrastructure also needs to meet various connectivity requirements. The lack of sufficiently visible road markings is at the moment an obstacle for some manufacturers for the reliable functioning of autonomous vehicles (Rendant & Geelen, 2020). The reliability of systems such as Intelligent Speed Adaptation and Lane Departure Warning Assistant, are dependent on legible road markings for reliable functioning (Korse et al., 2003; Eurorap, 2013). Other infrastructural aspects deal with the harmonisation of the road infrastructure (colour, reflective materials, etc.). In Europe this will likely have a positive influence on the roll-out of CAVs (Rendant & Geelen, 2020). The development of camera technology and image processing algorithms is so fast that future systems will likely be able to deal with lower quality markings, in which case upgrading road markings to support self-driving vehicles may not be necessary (Rendant & Geelen, 2020). In the Inframix project, so-called ISAD levels ("Infrastructure Support Levels for Automated Driving") were developed in which an impetus is given to define the minimum infrastructure (physical and digital) required to enable certain self-driving functions. Such an approach makes sense to clarify what level of automation is possible on a given road section (Rendant & Geelen, 2020)

Readiness to address cybersecurity and data privacy concerns

The successful operation of CAVs and their expected impact depend significantly on their management (as part of the greater traffic network and as data carriers and providers) and addressing risks associated with them (Lim & Taeihagh, 2018). Two of these risks are privacy and cybersecurity. The ability of CAVs to store and communicate personal data may conflict with data privacy laws. Cybersecurity is at stake when communication networks crucial for safe operation of CAVs can be hacked. Lim & Taeihagh (2018) conclude that within the EU a proper implementation of the General Data Protection Regulation (GDPR) can ensure privacy protection. These researchers argue that CAVs are especially vulnerable to cyber-attacks due to their ability to store highly sensitive data and transmit such data on external communication networks. The GDPR also provides guidance on how organisations can comply with legal requirements (Mulder & Vellinga, 2021). These authors emphasize a three-step approach to cyber-security based on GDPR: first a data protection impact assessment (DPIA), secondly data protection by design, and finally data protection by default. Data protection by design and by default are legal obligations set in Article 25 of the GDPR. A DPIA can contribute to, amongst others, complying with these two obligations. To address cybersecurity the EU enacted the first EU-wide legislation on cybersecurity, the NIS directive in August 2016 and has also released voluntary cybersecurity guidelines. In December 2016 the EU agency for Network and Information Security released best practices guidelines for the cybersecurity of connected vehicles. Cybersecurity and security concerning private data are important for building trust in and social acceptance of CAVs (Lim & Taeihagh, 2018; Seetharaman et al., 2021). The GDPR also provides guidance on how organisations can comply with legal requirements (Mulder and Vellinga, 2021). Vitunskaite et al. (2019) studied practices of cybersecurity in the cities of Barcelona, London and Singapore. They observe the following:

> *"The real difficulty for observing security stems from the complexity of the smart city ecosystem and involvement of a high number of competing actors and stakeholders. As the cities are still developing, many fail to take these risks into account and develop an appropriate third-party management approach. One of the key symptoms of this deficiency is lack of appropriate standards and guidance, clearly defined roles and responsibilities and a common understanding of key security requirements. The case studies of Barcelona, Singapore and London have emphasised and corroborated the importance of technical standards, cyber security measures and an effective third-party management approach" (Vitunskaite et al., 2019).*

In another paper on cybersecurity in the smart city, Habibzadeh et al. (2019) observe that it is common knowledge in the literature about public administration that information technology implementation projects are often derailed by non-technical challenges; issues of politics, bureaucracy, liability and other non-technical factors slow down the implementation of technology that is available. Also, with respect to security in the smart city it is often the case that new technologies have arrived and are deployed whereas personnel practices, security policies, and other agency and municipal practices tend to lag behind - resulting in a so called "security debt" (Habibzaheh et al., 2019; p. 4). These authors recommended that cities unambiguously define security roles of individuals in city administration, that they actively value security leadership, and that the cities form and maintains specialised security teams to carry out routine security measures such as training, firmware updates, developing emergency response plans, maintaining communications with different vendors and service provider. Khan et al. (2020) have studied the various cyber-attacks on automated vehicles and possible mitigation strategies from a perspective of the communication framework of CAVs. Based on the literature review, the leading automotive company reports, and the study of relevant government research bodies, Khan et al. (2020) have described the CAVs communication framework for all possible interfaces in the form of a flow-chart. The authors argue that this description has a three-fold value: first, it is imperative to have a systematic understanding of the CAVs communication framework; second, it is beneficial for monitoring, assessing, tracking, and combating potential cyber-attacks on various communication interfaces; third, it will facilitate the development of a robust CAVs cybersecurity-by-design paradigm by application developers. Important recommendations from their analysis are (Khan et al., 2020):

- CAVs and connected infrastructure require a continuous surveillance system to alert relevant operation centres immediately about any data or vehicle breaches
- system designers need to stay up to date with the advances in attacks on the CAV embedded system

- manufacturers need to integrate security into every part of their designs
- in a coordinated approach to CAV cybersecurity ideally a shared problem-solving approach involves both road operators (as customers) and suppliers such as automotive manufacturers, equipment manufacturers, data aggregators and data processors

Readiness to engage social and ethical concerns

Introducing automated mobility will raise important social and ethical questions. 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 more broadly of CCAM (e.g., Alawadhi et al., 2020; Bezai et al., 2021; Briyik et al., 2021; Chng et al., 2021; Horizon 2020, 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 (Horizon 2020, 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

Interestingly, Chng et al. (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 found:

- 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 steering the development and deployment of driverless mobility and to set standards and regulations which safeguard their interests

4. Policy Recommendations

This section presents first an overview of recommendations from available literature, and then discusses recommendations based on the findings from LEVITATE. The detailed results are presented and discussed in the following LEVITATE Deliverables and working papers.

- D5.2-5.4 (Roussou et al, 2021a; Roussou et al., 2021b; Roussou et al., 2021c),
- D6.2-6.4 (Haouari et al., 2021; Sha et al., 2021; Chaudhry et al., 2021),
- D7.2-7.4 (Hu et al, 2021a; Hu et al, 2021b; Hu et al, 2021c),
- Working paper on road safety related impacts (Weijermars et al, 2021), and
- Syntheses of results presented in D5.5 (Goldenbeld et al., 2021a), D6.5 (Gebhard et al.,2022), and D7.5 (Goldenbeld et al., 2021b).

Various impacts (studied within Levitate) of CCAM are discussed both under baseline conditions (i.e., with increasing penetration of CAVs without any policy intervention) and then with the implementation of various policy measures. Findings from cost and benefit analyses (D3.4, Hartveit and Veisten, 2022) are presented too.

4.1 Main Findings from Levitate and Potential Policy Options

The impacts for the CCAM technologies investigated within the Levitate project are measured relative to the baseline starting point: the situation with no intervention or presence of CAVs only.

Important to note is that the baselines estimated vary across methods and the city networks to which CAVs and the policy interventions (sub-use cases) were applied. In the microsimulation, results for the baseline estimates differ between SUCs due to different networks being studied for each SUC. For the mesosimulation and system dynamics impacts, one baseline was calculated for the entire city of Vienna, which may also show different effects from the networks used in the microsimulation. Also, the baseline estimates in the Delphi method differ across SUCs because different expert groups evaluated different SUCs. The results therefore reflect the implementation of CAVs under a wide range of conditions, networks, and methodologies. The results serve as indicative of impact ranges rather than definitive estimates, which would have required a much larger study as well as more observational data which is unavailable due to the early stages of automated technology. Care must be taken in generalising the results to situations to those which are comparable to those modelled in Levitate. The results are transferable in as far as they are applied to networks that are comparable to those used in Levitate.

The many different scenarios of CCAM, the many different potential policy options and their interdependencies show a very complex pattern of effects. Anyhow the effects of CCAM on cities and society largely depend on the regulatory framework in which CCAM is deployed. It is up to policy makers to define a regulatory framework supporting the goals of the respective Smart City Strategies, SUMPs, Climate Strategies etc. while avoiding adverse effects.

The following consolidation of results from the impact assessment performed within Levitate project should help identifying factors which are important for the informed and effective policy making and facilitate choosing adequate policy options.

4.1.1 General Considerations

- **Policy measures should be identified with consideration for the many critical impact dimensions**
  - LEVITATE results have demonstrated the importance of evaluating wider societal impacts of CCAM and identified and analyzed various critical impact dimensions leading to broader implications of CCAM technologies and thus provide useful insights for future policy discussions and decisions. There are broader implications of CCAM services. For example, to increase access of travel and shared mobility rate, automated ride sharing services can potentially be a supportive measure; however, the mobility (travel time, congestion) and safety may be negatively impacted especially if willingness to share remains low. Policy on parking space regulations can potentially have a strong impact on changes in modal split. In particular, replacing on-street parking with driving lanes would encourage more vehicles on the roads potentially reducing share of public transport users, with increasing market penetration rate. Road use pricing and some parking pricing policies can significantly increase active travel, meaning reduced adoption/use of CAVs. Meanwhile, services like last mile shuttles and automated ride sharing can significantly increase public transport modal split and reduce active travel.

- **The manner (policy decisions) in which CCAM services and technologies are implemented can be critical for managing potential adverse impacts.**

  - The policy decisions for implementing CCAM services can be critical for any adverse side effects. Cities cannot control the development in the introduction of advanced automation in vehicles, which is determined by manufacturers and national governments. They can manage the consequences through the manner in which the CCAM services will be implemented and control CAV access to the road network. The LEVITATE impact assessment framework and Policy Support Tool can help in analyzing potential outcomes due to various policy measures and can provide guidelines towards suitable options.

  - For example, to control a potential increase in the use of private vehicles with increasing MPR of CAVs and to help mitigate an increase in congestion, road use pricing or congestion pricing schemes are a potential policy measure to limit congestion and increase public transport usage and active travel. Dedicated CAV lanes can also be a potential policy option; however, our results on Dedicated CAV lanes indicate a reduction in congestion primarily when there is a large share of both human-driven vehicles (60%) and 1st generation CAVs (40%) in the network. Section 4.2.2 further presents specific findings on the broader implications of various policy measures studied within LEVITATE.

- **The transition phase to full fleet penetration is highly important and cities need to prepare to manage potentially adverse impacts**

  - First generation CAVs are anticipated to be less capable than human drivers; this adversely affects many traffic indicators (e.g., travel time, congestion). Therefore, during the transition phase the findings forecast an uncertain or inconsistent balance of benefits and disbenefits according to the fleet penetration of CAVs.

  - However, higher penetration levels of CAVs in the urban area are estimated (for most baselines) to have a positive impact on the environment (less emissions, higher energy efficiency), on society, safety & economy (improved road safety, public health, and lower vehicle operating costs) and on most mobility indicators (more access to travel and less congestion). In the absence of policy interventions, some potentially negative effects could be realised if private automated vehicle transport leads to a decline in walking, cycling, and/or public transport trips.

- **The early phase of CAV deployment (low MPR) in the transport system can be challenging towards improving road safety. Policy making is critical in influencing the road safety impacts**

  - In the microsimulation, results for the baseline scenario differ between different city road networks being studied for each policy intervention within Levitate. Overall, increasing penetration levels of CAVs lead to decreasing crash rates (number of crashes per simulated km travelled). At lower penetration rates when there is still mixed traffic on the road, the impact on crash rates is more gradual and some modelled road networks even show an increase in crash rates at low penetration levels of CAVs. This is likely due to interactions between human-driven vehicles and CAVs (Weijermars et al., 2021). The implementation of CAVs should ideally lead to prevention of all crashes involving human errors, particularly at higher to full penetration rate; however, as indicated by our analysis results and also reported by several other studies (Shi, Li, Cai, Zhang, & Wu, 2020, Yu, Tak, Park, & Yeo, 2019, Favaro, 2017; Petrovic, 2020), the early and interim phases of implementation could be challenging for the improvement in safety and therefore require substantial research and testing for safe operations.

  - Table 4.1 summarizes the results for various policy interventions based on their implementation schemes that were studied within LEVITATE (Roussou et al., 2021; Chaudhry et al., 2021; Hu et al., 2021). For each policy intervention, the road safety impacts were compared to the baseline scenario which represents the situation without any intervention but with increased penetration rates of 1st and 2nd generation CAVs.

Table 4.1: Summary of road safety impacts for the different SUCs.

Policy Interventions studied within LEVITATE	**Description of expected road safety impacts (compared to baseline scenario)**
Point-to-point automated urban shuttle	No clear additional impact on crash rate
On demand automated urban shuttle	No clear additional impact on crash rate
Dedicated lanes for CAVs	No clear additional impact on crash rate
Parking price regulation	Increase in crash rate expected
Replacing on-street parking	Further decrease in crash rate expected
Automated ride sharing	Increase in crash rate expected
Green Light Optimised Speed Advisory (GLOSA)	No clear additional impact on crash rate
Automated delivery	Decrease in crash rate especially at lower penetration rates of CAVs
Automated consolidation	
Hub-to-hub with transfer hub	

- Some rebound effects can be expected; mobility behaviour (distance travelled, mode choice, route choice) will likely be affected by the introduction of CAVs and this subsequently influences road safety. Other rebound impacts concern infrastructural changes and changes in travel behaviour of other road users.

- It should be noted that policy makers can influence the road safety impacts of CAVs, for example by regulations concerning the conditions that must be met by CAVs to be allowed on the public roads. Moreover, it should be stressed that not all safety related impacts are quantified within LEVITATE and many assumptions were needed for the estimation of impacts. For example, possible new risks are not taken into account in the impact estimates as not all new risks may have been identified yet and for others the size of the impact cannot be estimated. Finally, it should also be stressed that, even if CAVs function perfectly and are not at all involved in crashes, crashes among non-CAV road users would still happen. For example, in the Netherlands more than half of the serious injuries are due to bicycle crashes in which no motorised vehicles are involved (Aarts et al., 2021). These crashes cannot be prevented by CAVs.

- **Impacts on vulnerable road users:**
  Unmotorized vulnerable road users (VRUs), comprised of pedestrians and cyclists, are not included in the microsimulation model and therefore, crashes involving VRUs are not taken into account in the impacts discussed above. As developments related to CCAM are expected to impact road safety of VRUs as well, another approach based on crash statistics was taken to estimate the impacts on crashes with VRUs. This approach is based on two main assumptions: 1. It is assumed that all crashes that were caused by human-driven vehicles (car is ‘at fault’) can be prevented by CAVs, and 2. as CAVs are expected to have lower reaction times than human-driven vehicles, it is assumed that the remaining crashes (VRU is ‘at fault’) are less severe when CAVs are involved instead of human-driven vehicles.

The share of crashes for which the pedestrian or cyclist is registered to be 'at fault' differs between cities and countries.

4.1.2 Policy Intervention Specific Recommendations for Passenger Cars

- **Policies for introducing shared automated mobility services should consider minimising the empty vehicle-kilometres travelled (VKT) and maximising the willingness to share**

  - LEVITATE results indicate negative impacts on mobility (increase in travel time and congestion) with the introduction of automated ride sharing services as compared to the baseline conditions. The results suggest that the willingness of users of automated ride sharing to share trips with other travellers can have a strong effect on the traffic situation by reducing the number of automated taxi vehicles and trips present in the network. For example, when shared CAVs account for 20% of the travel demand, the increase in congestion was found to be higher with "20% willing to share" as compared to the "100% willing to share" scenario. (Haouari, et al., 2021 and Sha et al., 2021). The results were found to be consistent with previously reported findings by Overtoom et al. (2020). One of the most important potential reasons for the increasing impact on congestion (delays) is the increased number of trips and the empty VKT caused by making repositioning trips to reach new travellers. The circulating behaviour of shared automated vehicles (SAV) could also explain this increasing trend since they tend to use low capacity and/or secondary roads to reach their destinations, causing more traffic congestion (Overtoom, Correia, Huang, & Verbraeck, 2020). This suggests implementing such services in a manner which can minimise empty VKT (e.g., 'empty km pricing') of vehicles and increase willingness to share (e.g., sharing incentives).

  - With regard to environmental impacts, the introduction of automated ride sharing services in the studied networks showed an increase in emissions under mixed fleet scenarios, as compared to the baseline scenario. Important to note is that all personal and shared CAVs were modelled as electric vehicles so the impact on emissions under the mixed fleet scenarios with human-driven vehicles is due to changes in traffic flow within the network. The increase in overall network level emissions was found to be mainly due to circulating movements of shared automated vehicles (especially under low willingness to share) leading to congestion and interrupted flow in the network (D6.4, Chaudhry et al., 2021). The rate of shared trips was found to be a crucial factor in counteracting the effects of empty VKT due to empty pick-up trips.

  - Introduction of automated ride sharing vehicles in the study networks within Levitate were also found to slightly increase crash rates of car-car crashes compared to the baseline scenario, although the differences are small and appear to show some random variation. Neither the percentage of demand served nor the willingness of passengers to share trips showed a clear relationship with the crash rate.

  - Almost no change in parking demand is predicated as compared to the baseline, from system dynamics analysis within Levitate considering 20% share of total demand and 100% willingness to share. Intuitively, more demand served by shared CAVs would reduce the number of personal vehicles cars on the road. However, due to pick-ups, drop-offs, and waiting for passengers, the requirement for parking spaces may not significantly reduce. Commuting distances were also estimated to increase with the inclusion of automated ride sharing services as such service would provide access and serve customers anywhere to anywhere. In addition, the option to share a ride with others would add to the total distance travelled per person.

- Majority of the experts in the Delphi study within Levitate predict positive implications of automated ride sharing services on access to travel, vehicle operating cost, vehicle utilisation rate, vehicle occupancy, energy efficiency, public health, and accessibility in transport.

- In order to have beneficial policy effects, the policies for automated ride hailing services should promote the usage of such services as shared rides (high willingness to share) and not only as shared vehicles. Carpooling incentives can also be tested. Another aspect to consider is, that as suggested in a study by Hall (2018), the effects of ride-hailing services can vary based on the state of public transit of a city. Therefore, the most optimal policy can likely differ from one city to the other. Their investigations revealed that Automated Ride Sharing services are a complement to small transit agencies and to agencies in large cities.

- The benefits of an automated ride sharing system highly depend on the users' willingness to combine trips and it has the potential to increase congestion due to empty repositioning trips. Therefore, the suitability of local conditions for an automated ride sharing system should first be studied before its implementation.

The potentially negative impacts on traffic indicators and safety can be minimized with limiting their service routes/areas.

➢ **Parking pricing schemes can potentially have a trade-off between different positive and negative societal impacts. Depending on the study area, the most optimal parking price policy may require a combination of different parking options.**

- Within LEVITATE, increased parking prices are assumed to influence the parking behaviour of CAVs. Instead of paying a higher price to park at the destination, CAVs were simulated to either: drive around, return to the origin or park outside the centre, or show balanced parking behaviours (combination of driving around, return to origin, park outside, and parking inside the centre) while waiting to pick up passengers. With the implementation of these parking price policies, the travel time and delay were found to considerably increase with increasing MPR of CAVs as compared to the no-policy intervention scenario (baseline). The main reason is that most of the vehicles either drive around or return to their origin instead of parking at the destination under the tested policies, which can lead to a higher traffic volume within the network, causing congestion on the roads. The maximum delays were found with 'drive around' behaviour whereas, lesser delays were found in the case of a balanced parking scenario as compared to 'drive around' and 'heavy return to origin and park outside' scenarios, meaning a strategy creating balanced parking behaviours, as opposed to only drive around or return to origin policies, can potentially minimise the negative impacts on congestion.

- Balanced parking scenario in LEVITATE has been identified to be most optimal strategy, as compared to the other analysis scenarios, with respect to minimising negative impacts on mobility. Under this strategy, a significant increase in active travel has also been estimated by the system dynamics analysis within Levitate; however, a slight reduction in public transport modal split may be expected under the mixed fleet scenarios.

- The road safety analysis within Levitate show that crash rates might increase at lower MPRs, with 20-40% of the vehicle fleet being automated. This is primarily due to interactions between human-driven vehicles and automated vehicles, which are expected to have different driving styles and capabilities. This increased risk due to mixed traffic is particularly visible in the “drive-around” scenario, where the automated vehicles cause additional congestion on the road—and therefore, additional opportunities for conflicts.

- Depending upon the implementation strategy, there can potentially be various positive implications due to parking pricing policies as predicted by the Delphi panel study such as increase in vehicle occupancy, vehicle operating cost, access to travel, active travel, public health, and accessibility in transport. Parking demand under the 'balanced scenario' was estimated to significantly reduce as compared to the baseline scenario. However, the impact outcome is highly dependent on the implementation scheme (D6.2, Haouari et al., 2021; D6.3, Sha et al., 2021; D6.4, Chaudhry et al., 2021). For example, policies that encourage vehicles to drive around can negatively impact mobility, energy efficiency, vehicle operating cost, and accessibility in transport.

➢ **Various on-street Parking Space management options can have both positive and negative aspects which should be carefully assessed based on the local transport policy goals**

- LEVITATE results on the analyses of interventions of replacing on-street parking with driving lane, cycle lane and public spaces have shown a significant improvement in reducing the delay time compared to the baseline scenario. Whereas, the interventions of removing half of the on-street parking spaces and replacing them with pick-up/drop-off points have been found to have comparatively less impact on delay time. This is mainly because replacing the existing on-street parking with pick-up/drop-off points can generate queues in the traffic stream while vehicles pick up and drop off passengers, and eventually cause congestion to build up in the network. This finding is in line with other previous studies that indicated replacing on-street parking with pick-up/drop-off points could lead to excessive delays and increased travel times, which in turn would add more traffic congestion to the road network (Winter et al., 2021; Chai et al., 2020; ITF, 2018).

- Dynamic pick-up/drop-off points could be introduced in the network to mitigate this impact as an improvement measure. The results also suggest that replacing half of the on-street parking spaces may not provide the expected improvement to the traffic conditions in the city centre, especially with a congested network.
- Policy makers must carefully analyse potential benefits and disbenefits due to parking space management strategies. An overview of the positive and negative impacts due to various on-street parking strategies tested within Levitate is provided in Table 4.2, which can help towards this assessment.

Table 4.2: Summary of Key Impacts due to various On-Street Parking Space Regulations

Implementation Schemes	**Potential Implications**
Removal of 50% of on-street parking spaces	reduction in delays increase in active travel up to 70% MPR reduction in the demand for parking spaces reduction in emissions
Replace with Driving Lanes	stronger reduction in delays increase in vehicle operating costs reduction in public transport usage increased access to travel decrease in vehicle occupancy negative impact on public health positive impact on accessibility in transport increased demand for parking with increasing MPR above 50% reduction in emissions
Replace with Cycle Lanes	stronger reduction in delays *potential impacts on VRUs accidents reduction in emissions
Replace with Public Spaces	stronger reduction in delays reduction in access to travel increase in vehicle occupancy positive impact on public health reduction of accessibility in transport *potential impact on VRUs accidents reduction in emissions
Replace with Pick-up/Drop-off spaces	reduction in delays increase in vehicle operating costs increase in access to travel increase in vehicle occupancy positive impact on accessibility in transport impacts on pedestrians' safety reduction in emissions

* speculation (specific analyses including VRU's was not studied within the simulation modelling approaches)

- **<u>Road use pricing</u> can be a promising option for improving use of active modes and public transport with increasing MPR of CAVs. The benefits from Road Use Pricing policies may be slower but will potentially lead to sustainable benefits.**

  - Tolling policy with increasing automated vehicles can have positive impacts on travel time; however, increasing automation alone without any road use pricing policy was found to cause no significant improvement.

  - When vehicle automation becomes more widely available, public transport usage and active travel is predicted to decline. Implementation of road use pricing can be a potential option which can strongly impact shift to active modes and public transport.

  - Road use pricing (RUP) is expected to lead to a number of additional benefits over the baseline impacts: better energy efficiency (dynamic toll more than static toll or empty km pricing), higher vehicle occupancy rate, and lower parking space demand. On the negative side, road use pricing is expected to lead to increase in vehicle operating costs, and less equal accessibility of transport. The scenario "empty km pricing" is expected to contribute more positively towards keeping vehicle operating costs within bounds compared to the "static toll" and "dynamic toll" scenarios. The "static toll" scenario is expected to result in the highest shares in active transport modes and public transport. The "dynamic toll" scenario is expected to lead to the highest vehicle occupancy rates.

  - **Road use pricing implementations:** A more detailed analysis (Richter & Müller, 2022) of the RUP implementation possibilities shows for the investigated scenarios, that the RUP measure implementation has a uniform transfer effect on the direct vicinity of the tolling area, where the modal shift changes affect the environment in a positively correlated manner. One could also say the tolling area stretches its effects outwards similarly, which differs in behaviour from e.g., parking fees, where resource problems are condensed at the boundaries of implementation areas. While RUP introduction encourages a modal shift away from passenger car use to more sustainable modes of transport, it does slightly less so for the more attractive CAVs.

  - **Tolling exemption for residents:** RUP exemption of the residents leads to considerable rebounds from the no-exemption scenarios, depending on the initial extent level of implemented tolling (higher tolling levels have more pronounced effects). For the maximum tolling levels tested, about 30 % of cycling trips (which are a small part of all trips) revert to passenger car trips. Interestingly however, a considerable part of cycling trips changes to public transport, when residents are exempt from RUP. This surprising effect also happens for car trips at a maximum level of ~12 % changing to public transport, which indicates avoidance of re-emerging travel-time costs (i.e., due to congestion) within and around the tolling area.

  - **Road-class based tolling:** Due to the implementation by dynamic tolling per travelled distance, effects are comparable, but slightly weaker than in the case of

static tolling. Once the technical hurdles of real-life applications have been overcome, effects of this RUP implementation can be better tailored to given geographical conditions. The measure leaves more flexibility for the passenger car users.
However, applying additional tolls to side-roads results in another considerable amplification of the modal shifts towards desired and more sustainable modes of transport. Investigated realistic application scenarios do significantly exhibit the effects intended by the RUP policy measure.

- **GLOSA system implementation can potentially bring mobility and environmental benefits; however, implications need to be carefully assessed especially when human-driven vehicles comprise the largest proportion of traffic**

  - GLOSA system when tested on automated vehicles only and under fixed time traffic signals was found to have positive impacts on traffic efficiency; however, considering the application for human-driven vehicles, various human factors related aspects (e.g. compliance rate, response delay) are predicted to play an important role with regard to the impacts on mobility and environment (Singh et al, 2022), and potentially can impact safety as well.

  - Evaluations from field trials are needed to assess the safety implications of GLOSA system especially when human-driven vehicles make the larger proportion of traffic. Previous surrogate safety evaluation with different signal timing schemes (Stevanovic et al., 2015) has shown that the number of conflicts only significantly decreases when GLOSA is applied with fixed time signal controllers, and the GLOSA equipped vehicles penetration rate is 100%.

- **Some policy measures can bring positive environmental impacts; however, powertrain electrification has an overwhelmingly larger impact on emissions compared to the studied policy interventions**

  - Within LEVITATE, all CAVs (1st and second generation) were assumed to be electric vehicles. During the transition phase, under mixed traffic conditions with human-driven vehicles, some policy measures such as "On-street parking management" through various regulations analysed within Levitate including removing half on-street parking spaces, replacing with driving lanes, replacing with pick-up/drop-off points, replacing with public spaces, and replacing with cycling lanes have been identified to bring positive benefits on environment by decreasing CO_2 emissions when human-driven vehicles are still in the network.

4.1.3 Policy recommendations for Automated Urban (Public) Transport

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: o 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 of 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 increase 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.

In addition to the above discussions on policy development, the following points are also important for the future development and implementation of automated urban transport systems:

- As mentioned already for other policy measures, in order 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.

- The automated urban shuttle services studied in LEVITATE provide 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 the use of active travel modes. Anticipatory research and anticipatory and flexible planning approaches are recommended to prevent these negative developments.

- 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 enhance the public transport network, by providing point-to-point AUSS as well as on-demand AUSS, in order to promote the reduction of the use of private cars.

- 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.

- In decisions about new forms of automated transport, waiting time, travel time, travel costs, comfort, 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.

- 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.

- Although new forms of automated urban transport may be operated and controlled by private companies, it is recommended that these are developed to complement the public transport system in useful ways, for example by providing their services in regions not served by the public transport, usually outside the city center, or by providing automated shuttles connecting different existing public transport stations.

- Guidelines - including ethical guidelines - and lists of impacts for future automated urban mobility and transport have been formulated, within LEVITATE and generally by the transport research community, and should be partly or fully adopted in strategic plans to facilitate successful implementation of new transport services.

- Automated ride sharing as well as last mile shuttle services are likely to negatively impact active travel with respect to the baseline scenario due to providing pick-ups and drop-offs closest to the origins and destinations of passengers, where last mile shuttles can potentially have much stronger impact on active travel than automated ride sharing

4.1.4 Policy recommendations for automated freight transport

Effects of SUCs: automated delivery, consolidation and hub-to-hub transport

On top of the baseline impacts of increasing CAV penetration, the automated freight sub-use cases yielded some additional effects:

- The automated delivery sub-use case is associated with additional benefits for energy efficiency, CO2 emissions, road safety, congestion, public health and vehicle operating costs. The night-time-only automated delivery scenarios show additional benefits particularly for the two mobility indicators (travel time and congestion), due to less interaction with the larger daytime traffic volumes.
- The automated consolidation sub-use case is associated with additional benefits for energy efficiency, CO2 emissions, road safety, congestion, travel time, public health and vehicle operating costs. Compared to automated delivery without consolidation at city hubs (the first sub-use case), further improvements in energy efficiency, operating costs, and a large reduction in total kilometres travelled are expected. This suggests that centrally located city-hubs can help to realise a more efficient allocation of resources.
- The hub-to-hub sub-use case is expected to deliver additional benefits for energy efficiency, CO2 emissions, road safety, congestion, travel time, public health, and freight vehicle operating costs.
- All three automated freight SUCs are predicted to (marginally) improve road safety compared to the baseline, particularly at lower penetration rates when less of the remaining vehicle fleet is automated.
- At the higher-level CAV penetration rates (above 80%), all three automated freight SUCs are expected to require slightly more parking space (less reduction) than in the baseline without automated delivery. The hub-to-hub SUC is even expected to slightly increase parking space requirements at 100% CAV penetration compared to the current situation (with 100% human-driven vehicles).
- The sub-use cases of automated delivery, hub-to-hub and especially automated consolidation are predicted positively impact public health compared to the baseline. This positive expectation is likely based on the expected additional benefits of these sub-use cases for both road safety and emissions.
- Using data on freight delivery trips in Vianna, it was estimated that compared to manual freight delivery, completely automated delivery and automated delivery with city-hubs will substantially reduce annual fleet costs (-68%).

Effects of truck platooning on bridges

Connected and automated freight vehicles are expected to facilitate truck platooning, and as a result potentially test the strength of bridges. The study of truck platooning on bridges yielded the following main conclusions:

- The largest effect of truck platooning on simple single span (beam) bridges as modelled in LEVITATE is observed for the criteria of braking forces. For bridges above 80m length, it has been estimated that the braking force is at least double of the baseline scenario.
- According to standard bridge models and standard traffic simulations within LEVITATE, the need for strengthening structural resistance of bridges arises for existing bridges with $\alpha\alpha QQ$ = 1 starting from span length of 55 m for bending moment and 60 m for shear force ULS; for existing bridges with resistance at resistance level of $\alpha\alpha QQ$ = 0.8, strengthening needs would arise sooner – starting from bridge spans of 40 m.
- For bridge strengthening, a model and guidelines for estimating the costs in relation to the initial construction costs have been developed (D7.3) (Hu et al., 2021b).
- As an alternative to strengthening bridges, intelligent access control can be used to arrange the increase of inter-vehicle distances for the bridge section to meet the code level and prevent. Headway has been recommended and is presented in LEVITATE D7.3 (Hu et al., 2021b). Forcing an increased inter-vehicle distance by intelligent access control will not diminish the ecological and economic benefits of truck platoons.

The following recommendations are relevant for the future development and implementation of automated freight transport systems:

- Even without policy measures, automation in freight transport will likely gain popularity once the technology is mature and the operating costs become cheaper than the costs nowadays.

- Automation alone will most likely lead to an increase in freight mileage (because of smaller and cheaper freight vehicles), so corresponding policy measures in favor of freight consolidation should be considered to mitigate this trend. Fortunately, automation is expected to facilitate the consolidation process.

- During the transition phase, truck platooning enabled by automated freight traffic may increase the burden on the infrastructure. Especially critical parts such as bridges should be under attention. Structural strengthening in the long term or mitigation measures such as access control should be considered.

- All the above points require homogenous and shared data among operators, which is perhaps the most difficult challenge due to the competition between service providers as well as freight operators. National governments or municipalities can act as a neutral, credible party to collect and process these data.

Table 4.3 provides a summary of the potential policy options for supporting or mitigating a particular impact based on the policy goal.

Table 4.3: Expected Impacts of CCAM and recommended policy interventions

Impact variable	CCAM impact	Policy Goal	Potential policy interventions (SUC) to support or mitigate
Travel time	Mixed findings based on the method used, network and fleet composition. (In some cases, increase in transition phase)	decrease travel time	• dedicated Lanes at moderate MPR • on-street parking replacement with driving lanes, cycle lanes, and public spaces • GLOSA • automated urban delivery • automated consolidation • hub-to-hub automated transport • On-demand AUSS
Vehicle operating cost	increase in short-term	reduce vehicle operating cost	• Dedicated AV Lanes • automated urban delivery • automated consolidation
Access to travel (opportunity to travel from anywhere to anywhere)	increase	increase access to travel	• automated ride sharing services • point-to-Point AUSS • on-demand AUSS • parking price policies • on-street parking replacement with driving lanes or pick-up/drop off spaces
Congestion	increase in short term (transition phase)	decrease congestion	• dedicated CAV lanes on highways • replacing on-street parking with driving lanes, cycle lanes, and public spaces • GLOSA
Amount of travel (passenger cars VKT)	increase	reduce amount of travel	• road use pricing • replacing on-street parking with driving lanes • automated ride sharing services
Modal split using public transport	decrease	increase modal split using public transport	• road use pricing • parking price policies • automated ride sharing
Modal split using active travel	decrease (or neutral)	increase active travel	• parking price policies • road use pricing • parking space regulations
Shared mobility	increase	increase shared mobility	• road use pricing • parking price policies • parking space regulations (public use, driving lanes, pick-up/drop-off) • automated ride sharing • Point-to-Point AUSS • On-demand AUSS

Impact variable	**CCAM impact**	**Policy Goal**	**Potential policy interventions (SUC) to support or mitigate**
Vehicle utilisation rate	increase	Decrease vehicle utilization rate	• parking price policies • road use pricing • increased shared mobility (automated ride sharing)
Vehicle occupancy	decrease (or neutral)	increase	• road use pricing • parking space regulations (public spaces, pick- up/drop-off) • automated ride sharing • point-to-Point AUSS • on-demand AUSS
Road safety (number of crashes)	reduction in crashes	increase road safety by reducing number of crashes	• point-to-Point AUSS • on-demand AUSS • automated urban delivery • automated consolidation • hub-to-hub automated transport • Dedicated CAVs lanes (on A road left-most lane placement)
Parking space (demand for parking)	increase	decrease the demand for parking	• Removing 50% of the on-street parking • Road use pricing
Energy efficiency	increase	increase energy efficiency	• GLOSA • Automated ride sharing services
Emissions	reduce (considering electrification)	reduce emissions with presence of HDVs	• Replacing on-street parking
Public health	Mixed predictions	Improve public health	• Replacing on-street parking with public spaces • Automated ride sharing services • Automated urban delivery • Automated consolidation
Accessibility in transport (equality in access to transport)	increase	increase	• automated ride sharing services up to moderate fleet penetration • replace on-street parking with driving lanes and pick-up/drop off spaces
Commuting distances (considering household relocation)	small increase	Based on city's policy on urban sprawl and distance travelled	• Marginal difference was found on commuting distances with the studied policy interventions. (Note: Automated ride sharing services can potentially increase commuting distances.)

4.2 Cost-benefit analysis

4.2.1 What the cost-benefit analysis does

Cost-benefit analysis (CBA) is included in the PST as an add-on module. The CBA module applies the PST information, the matrices of initial impact values and annual changes over the period of 2020-2050; the matrices produced for the PST user-selected deployment scenario and its baseline scenario. The CBA adds monetary valuations to changes in impacts, valuing the changes from baseline to policy (Hartveit & Veisten, 2022).

Transport kilometrage is a key driver of the CBA module; the CBA does not work without it. All valuations of impacts are either stated originally as €/km (most often €/vkm), or they are transformed from, e.g., original €/hour to €/km.

The CBA module estimates the valuation of changes per "agent"; these agents comprise transport mode users, transport service providers, external effects (other infrastructure users and the community), and a "policy entity" to which the costs of policy implementation are allocated. The policy entity also collects tolls/fees and administrates land use. The calculations per agent and transport mode is a necessity, as all valuations are transport-mode specific and often different for consumers and providers. It adds complexity to the module, but it also adds more information about distributional effects of the selected scenario deployments.

The CBA module yields monetised assessment of single impacts, e.g., the net present value (NPV) of travel time and delay changes. It also produces NPV for each specified agent. A virtue of the CBA is that it also estimates the overall NPV of the deployment scenario, for a given set of inputs, predicted changes, and valuations. Hence, the CBA can assess all impacts together on a common monetary scale. The overall NPV of a project can be stated in a simplified way as:
"The present value is a sum over the project period, in which the benefits and costs in future years are discounted. If the discounted monetised impacts are positive and greater than the discounted implementation costs, the NPV of the project is positive. The NPV expression above is for the whole period, but NPV can also be calculated per year or, in our transport project case, per vehicle km (vkm)."

As indicated, when the PST user initiates the CBA module, it will provide a CBA for the selected deployment scenario in the PST (a single scenario or a combined scenario). Firstly, the CBA will present a simple NPV result emphasizing the agent(s) that the deployment scenario targets, e.g., automated urban shuttles, passenger cars, and/or freight delivery vehicles. The next result is a break-even analysis, showing how annual net benefits and cumulative net benefits develop over the period. Finally, the CBA module shows the distributional NPV results, per year and per vkm, distributed across impacts and across agents.

The CBA module includes most of the impacts described in sub-chapter 4.1. But some impacts present in the PST are not quantified in a manner easily applicable to monetisation; e.g., access to travel, public health, and accessibility in transport. These impacts, and possibly others, might have had some weight in the CBA if included in monetary terms.

When looking at the NPV for particular impacts, we will expect that the CBA shows a fairly similar pattern to those presented in sub-chapter 4.1. Yet, the relative valuations of the different policy impacts, as well as the costs of implementing the deployment scenarios, will be of importance for the CBA results. Even if various impacts show a positive NPV, their relative value can be outweighed by other negative NPV impacts; and vice versa. And even if all impacts of a deployment scenario are positive, the costs of implementing the scenario might surpass the present value of all the benefits.

The CBA module does not include a complete set of default costs of implementation; what is included comprises the hub costs for freight consolidation and hub-to-hub. Costs of implementation are not the same as negative impacts, the "negative benefits". Implementation costs are the costs of initiating the policy, e.g., the planning and preparation (labour costs) and, for some deployments, technical installations. In hypothetical examples shown below, most scenarios include a fixed start-up (investment) cost of €1 million and annual management/monitoring costs of €10,000 (in the EU-28 Euro value of 2020, EUR_{2020}, 30,500 GDP/capita). The implementation costs do not comprise costs of vehicles; these are part of the impacts, more precisely the vehicle operating and ownership costs (voc).

4.2.2 Cost-benefit analysis results for a hypothetical case area

Although somewhat hypothetical, CBA has been estimated for all 54 deployment scenarios (Hartveit & Veisten, 2022). The common hypothetical case area has a population size of 500,000 and, for passenger transport scenarios, an annual amount of person travel of 2 billion pkm, initially distributed 40% public transport (55% road-based), 3% active transport (50% cycle vkm), and 57% car transport. The scenarios for AUSS are scaled with respect to the amount of travel; and automated ride sharing is scaled with respect to the pkm by automated cars. For freight transport scenarios, scaling with respect to the city population is applied. Beyond that, the CBA applies defaults from the PST development version (Ziakopoulos et al., 2022).

The impacts are distributed as follows (Hartveit & Veisten, 2022):

- Travel time & internal delay impact: a weighted average of individuals' valuation of travel time saving in "free flow" and in congestion is applied to travel time changes and delay changes.
- Vehicle operating and ownership: All transport modes' voc is derived applying multiplicators to the PST voc for passenger cars; for freight vehicles the voc is primarily based on Hu et al. (2021a; 2021b).
- Parking space (fares & fees): A hypothetical parking space value is derived from changes in the populations' required parking space and a valuation of undeveloped land. (Fares paid by public transport and shared vehicle users, as well as fees paid for parking or driving in the city centre are also channelled into this impact category, but the payments are cancelled out by the incomes for transport service providers and the policy entity.)
- Internal crash risk impact: The share of a cost of crash that a transport mode user will suffer himself/herself (injury and/or payment).
- External crash risk impact: The share of a cost of crash that is charged on collision adversaries and the rest of society (injury and/or payment).
- External delay impact: The share of the cost of delay that other infrastructure users and the rest of society will bear.
- Emissions, NO_X & PM_{10}: The local air pollutants with valuations.
- Emissions, CO_2: The global greenhouse gas with valuations.

- Policy implementation: The cost of implementing the policy, the deployment scenario (always zero or negative).

Table 4.4 shows the NPV/vkm for the 17 deployment scenarios, from all three use cases, representing discounted average changes for a project period from 2025 to 2050. The Euro values in the tables represent EUR_{2020} for GDP/capita equal to 17,000, following the PST default.

In the table, negative figures are red and indicate an NPV loss from baseline to policy. Thus, if the travel time and internal delay impact has negative value, it reflects travel time increase and/or increased delay. Equivalently, if the external crash risk impact has a positive value, it indicates a reduction in crash risk (improved road safety). These results might also follow from fluctuations in these impacts, such that, e.g., there is an increase in travel time early in the period and a subsequent decrease later, and vice versa for crash risk; the CBA puts relatively more weight on impacts earlier in the project period.

Table 4.4: CBA module, summary of results based on hypothetical case area, all three use cases, NPV/vkm distributed according to the type of impact

Impact variable	**Potential policy intervention, monetised impacts, € (GDP/capita 17,000), NPV/vkm**																
	Passenger car transport										**Automated urban shuttle service**				**Freight transport**		
	Road-use pricing		Dedicated lanes		Parking behav-iour, (balanced)	Parking space regulation		GLOSA	Automated ride sharing		Point-to-point, 2 hubs	Point-to-point, network	On-demand		Automated urban delivery	Automated consoli-dation	Automated hub-to-hub
	Static fee (€5)	Dyna-mic fee (€0.7)	A road, left-most	Motor-way, left-most		Replac-ing with driving lanes	Remov-ing 50% parking space	On 2 intersections	5%, 100% wts	20%, 100% wts	Peak, mixed	Peak, mixed	10%, 8 pax	10%, 15 pax			
Travel time & internal delay impact	-0,0754	-0,0907	-0,0197	-0,0337	0,0078	0,0264	0,0030	-0,0095	-0,0558	-0,0573	0,0012	0,0103	0,0345	0,0334	0,0424	0,0456	0,0163
Vehicle operating & ownership	-0,0562	-0,0511	0,0198	0,0254	-0,0150	-0,0224	0,0078	0,0333	0,0244	0,0217	0,0118	0,0118	0,0112	0,0113	0,0844	0,0909	0,0625
Parking space (& fares, fees)	-0,0017	-0,0019	-0,0035	-0,0044	0,0633	-0,0352	0,0108	-0,0087	0,0462	0,2218	0,0098	0,0096	-0,0305	-0,0300	0,0366	0,0018	-0,0183
Internal crash risk impact	0,0014	0,0013	0,0001	0,0001	-0,0002	-0,0000	0,0002	0,0002	0,0001	-0,0002	0,0008	0,0007	0,0001	0,0001	0,0003	0,0006	-0,0017
External crash impact	0,0012	0,0011	0,0001	0,0001	-0,0002	-0,0001	0,0001	0,0001	-0,0000	-0,0003	0,0008	0,0007	0,0001	0,0001	0,0064	0,0070	0,0042
External delay impact	0,0307	0,0279	0,0027	0,0032	-0,0160	0,0131	0,0125	0,0102	-0,0010	0,0014	0,0073	0,0150	0,0181	0,0175	0,0183	0,0227	0,0080
Emissions, NO_x & PM_{10}	0,0089	0,0086	0,0007	0,0010	-0,0046	0,0022	0,0005	0,0005	0,0002	-0,0002	-0,0012	0,0009	0,0009	0,0010	0,0081	0,0086	0,0001
Emissions, CO_2	0,0859	0,0828	0,0070	0,0107	-0,0406	0,0158	0,0055	0,0069	0,0045	0,0062	-0,0097	0,0092	0,0100	0,0104	0,0905	0,0986	0,0102
Policy implementation	-0,0001	-0,0001	-0,0001	-0,0001	-0,0001	-0,0000	-0,0001	-0,0001	-0,0001	-0,0001	-0,0001	-0,0001	-0,0001	-0,0001	0,0000	-0,0010	-0,0002
NPV Total Value	-0,04	-0,06	0,00	-0,00	0,00	-0,00	0,04	0,03	0,01	0,15	0,02	0,05	0,04	0,04	0,23	0,23	0,08

Regarding the travel time and internal delay impact, the hypothetical CBA shows positive NPV/vkm for AUSS and freight transport scenarios; while there are negative NPV/vkm for most passenger car scenarios, except parking space regulation and parking behaviour. That is, for parking behaviour, “return to origin” fares relatively better than “balanced” and vice versa for “drive around”, which obtained negative NPV/vkm; negative NPV/vkm was also the result for replacing parking space with driving lanes. The average voc will be higher under road-use pricing (city tolls) and partly also the parking scenarios. Parking space demand is reduced in automated ride sharing, GLOSA, parking behaviour, and point-to-point automated shuttle scenarios, as well as automated delivery and consolidation scenarios. The crash risk impact is negative in various passenger car scenarios, but these changes are relatively minor. There is an external delay NPV loss under parking behaviour; to a lesser extent also under automated ride sharing scenarios. Regarding emissions, most scenarios show NPV gains; the gains are relatively large under road-pricing and automated delivery and consolidation scenarios. Particularly due to the uncertainty in costs of policy implementation, one should restrain from assessments of the overall NPV (Table 4.4).

Hartveit & Veisten (2022) show the impact NPV results for all 54 deployment scenarios; they also show distributional CBA results for the “agents”. Passenger car users gain from AUSS scenarios and, to a lesser extent, from freight transport scenarios; they also gain from the parking behaviour scenarios (which are not policy scenarios as such, but behavioural scenarios), while the NPV is close to zero or negative for most passenger car scenarios (in particular for high city toll levels). Public transport users gain from most deployment scenarios, except parking replacement into road traffic lanes. Freight transport providers can be expected to gain heavily from the implementation of freight transport scenarios. Changes in external effects will be beneficial under most scenarios, except parking behaviour and some ride-sharing scenarios. For the policy entity, the result in terms of NPV/vkm (all transport) will mostly follow that of the parking space, with additional gains under road-use pricing.

We stress that the CBA results are estimated for a hypothetical area with an incomplete set of inputs (lacking in particular a well-founded estimate of the cost of implementation). Still, the relative sizes of monetised impacts may provide some guidance. The PST user will be able to alter and correct inputs in the CBA module, such that more precise estimates can be derived for the selected policy area (Hartveit & Veisten, 2022).

➢ Outlook on Costs and Benefits for Policy considerations

- In terms of net present value (NPV) estimates from the cost-benefit analysis (CBA) performed within LEVITATE, particularly the point-to-point AUSS in large scale network and the off-peak connection of two hubs show positive NPV for all included impacts in the CBA (applying a hypothetical case area with PST default values).

- In terms of net present value (NPV), there is a large variation across deployment scenarios. Road-use pricing yields large gains in terms of environment and also gains in road safety and external congestion, but substantial losses for car occupants in terms of travel time, VOC, and fees. GLOSA yields relatively less gains in external impacts, but without losses for car users. Removing 50% of parking space is the deployment scenario that show positive NPV for all included impacts in the CBA (applying a hypothetical case area with PST default values).

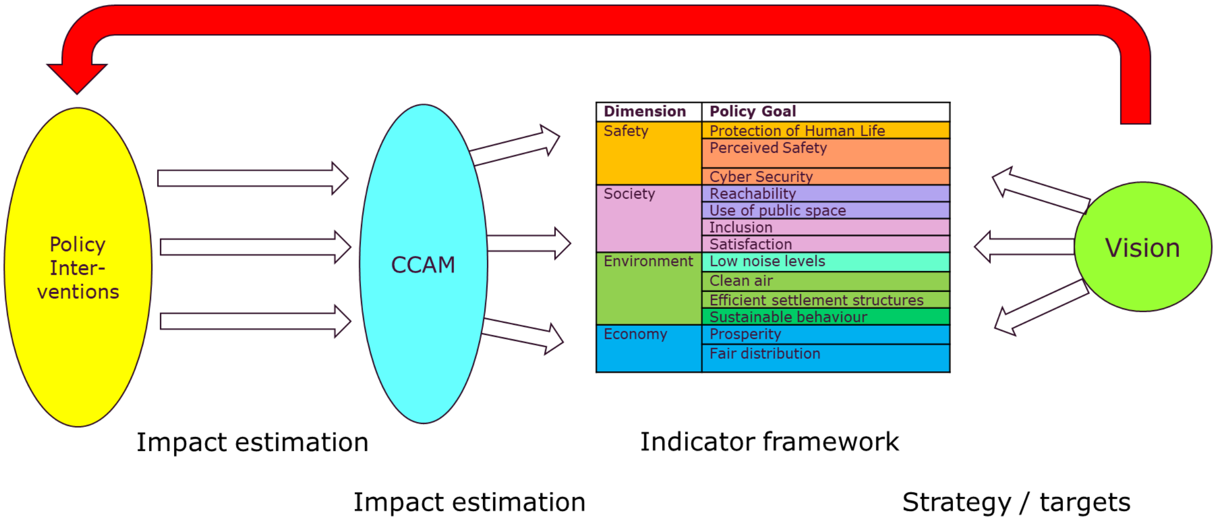
- In terms of net present value (NPV), semi- and fully automated delivery as well as automated consolidation show positive NPV for all included impacts in the CBA (applying a hypothetical case area with PST default values).

4.3 Backcasting

One of the methodological pillars of LEVITATE is the backcasting framework that has been described in detail in the Deliverables of WP4 (Zach et al., 2019). In the context of this Deliverable, the main ideas are summarized in brief, and an outline of using the LEVITATE results for a backcasting perspective is given.

As illustrated in Figure 4.1, the backcasting approach can be considered as assembly of the following basic steps:

1. Our starting point is to estimate the impacts of CCAM for various impact dimensions.
2. Coming from the opposite direction, a strategic "vision" of a city / region can also be broken down into quantified targets belonging to various dimensions (as has been discussed in section 2.1).
3. The intersection between such strategic vision and the possible CCAM impacts defines the policy goals where CCAM is expected to contribute and has been represented in the LEVITATE indicator framework – which is the base for the quantified impacts shown in the PST.
4. A second level of impact estimation is added now to steer the CCAM deployment by policy Interventions – on the left side in Figure Figure 4.1: various sub-use cases and policy interventions that have been considered for LEVITATE impact assessment.
5. Given that all these relationships and impacts (white arrows) have been quantitatively assessed, a conclusion from a defined vision (set of policy goals) to the most promising policy interventions gets possible (indicated by the red arrow) – this is the essence of the backcasting process.



Dimension	Policy Goal
Safety	Protection of Human Life
	Perceived Safety
	Cyber Security
Society	Reachability
	Use of public space
	Inclusion
	Satisfaction
Environment	Low noise levels
	Clean air
	Efficient settlement structures
	Sustainable behaviour
Economy	Prosperity
	Fair distribution

Figure 4.1: The big picture how backcasting is applied in LEVITIATE

One of the most important steps in LEVITATE was the selection and precise definition of the sub-use cases and policy interventions to be further investigated. One of the inputs for this process was the result of three backcasting city dialogues, performed with representatives from Vienna, Greater Manchester and Amsterdam (LEVITATE D4.3, Zach et al., 2019), where areas of most promising policy interventions have been identified in a qualitative way, based on the detailed description of policy goals.

Most of the results and key messages presented in this Deliverable can be interpreted through a backcasting perspective: *Which policy interventions would support the capabilities of CCAM to contribute to specified goals, which policy interventions might be required to mitigate certain CCAM impacts that are conflicting to these goals?*

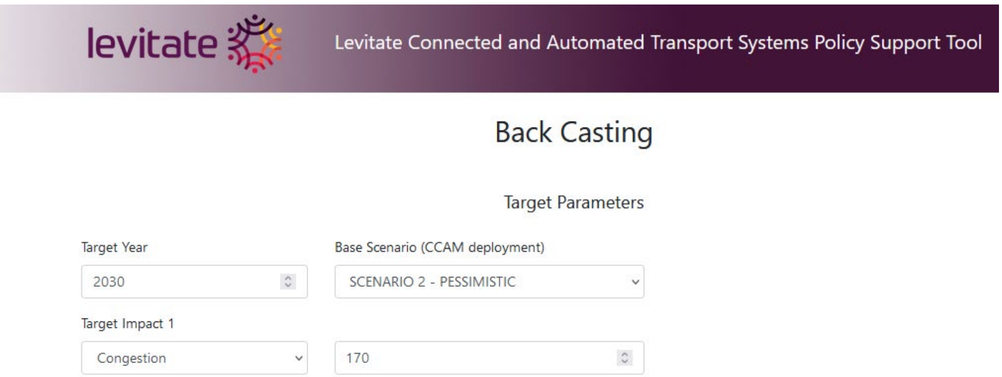
Finally, it should also be noted that an automated backcasting is supported by the online version of the PST based on all the quantitative results achieved in LEVITATE, albeit within a more strictly defined framework due to the limitations of the online platform and the back-end mechanics.

Specifically, the process in the online version is as the following:

1. The user defines their desired vision as a target for 1 to 5 impacts, along with a desired year of implementation and automation scenario.
2. The user may browse and change starting values for the Parameters and Impacts of the overall transport system, or use the ones pre-defined by the Levitate project.
3. The user presses ‘submit’ and the PST undergoes through the back-end calculations of the entire Levitate SUC database.
4. The PST presents the user with Policy Interventions based on their performance compared to the set target (for each impact). The PST also flags the Policy Interventions as ‘**true**’ or ‘**false**’ depending on whether they reach the target or not.
5. The user can sort by each column of the results to change their presentation.

Users can consult the starting impact values in order to be informed for a more realistic range of targets to set.

As an example, consider that a PST user (policy maker) may want to decrease congestion, defined as ‘Average delays to traffic (seconds per vehicle-kilometer) as a result of high traffic volume’. The user can browse and see that a starting value of 197.37 seconds per vehicle-kilometer is set for congestion. Therefore, they can consider 170 seconds per vehicle-kilometer as their vision. They would want to achieve this reduction by 2030, and consider that the Pessimistic Scenario fits their situation better. Therefore, they can make the initial selection as follows:



Back Casting

Target Parameters

Target Year: 2030

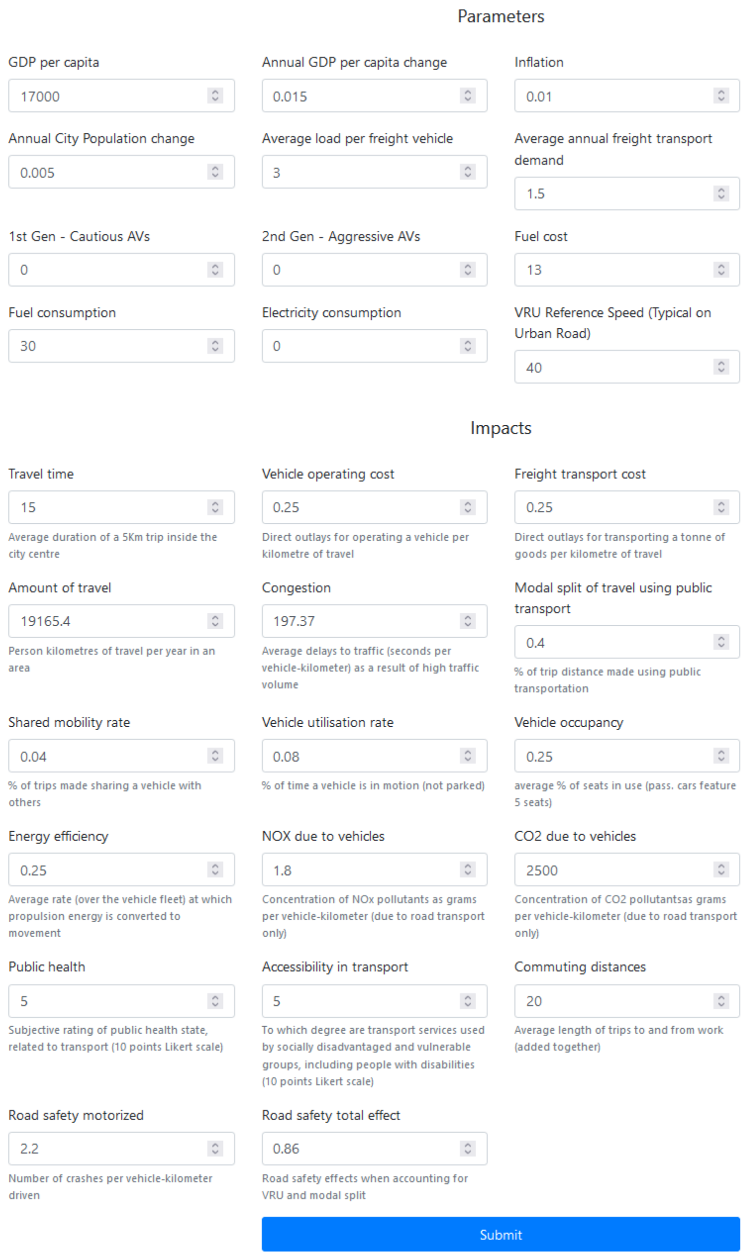
Base Scenario (CCAM deployment): SCENARIO 2 - PESSIMISTIC

Target Impact 1: Congestion

170

Figure 4.2: Backcasting vision definition in the online PST

They can browse and change initial values afterwards, and click the ‘Submit’ button whenever they are satisfied with their selection.



Parameters

GDP per capita: 17000

Annual GDP per capita change: 0.015

Inflation: 0.01

City Population: 3

Annual City Population change: 0.005

Average load per freight vehicle: 3

Average annual freight transport demand: 1.5

Human-driven Vehicles: 1

1st Gen - Cautious AVs: 0

2nd Gen - Aggressive AVs: 0

Fuel cost: 13

Electricity cost: 40

Fuel consumption: 30

Electricity consumption: 0

VRU Reference Speed (Typical on Urban Road): 40

VRU at-Fault accident share: 30

Impacts

Travel time: 15
Average duration of a 5Km trip inside the city centre

Vehicle operating cost: 0.25
Direct outlays for operating a vehicle per kilometre of travel

Freight transport cost: 0.25
Direct outlays for transporting a tonne of goods per kilometre of travel

Access to travel: 5
The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)

Amount of travel: 19165.4
Person kilometres of travel per year in an area

Congestion: 197.37
Average delays to traffic (seconds per vehicle-kilometer) as a result of high traffic volume

Modal split of travel using public transport: 0.4
% of trip distance made using public transportation

Modal split of travel using active travel: 0.03
% of trip distance made using active transportation (walking, cycling)

Shared mobility rate: 0.04
% of trips made sharing a vehicle with others

Vehicle utilisation rate: 0.08
% of time a vehicle is in motion (not parked)

Vehicle occupancy: 0.25
average % of seats in use (pass. cars feature 5 seats)

Parking space: 0.9
Required parking space in the city centre per person

Energy efficiency: 0.25
Average rate (over the vehicle fleet) at which propulsion energy is converted to movement

NOX due to vehicles: 1.8
Concentration of NOx pollutants as grams per vehicle-kilometer (due to road transport only)

CO2 due to vehicles: 2500
Concentration of CO2 pollutantsas grams per vehicle-kilometer (due to road transport only)

PM10 due to vehicles: 0.2
Concentration of PM10 pollutantsas grams per vehicle-kilometer (due to road transport only)

Public health: 5
Subjective rating of public health state, related to transport (10 points Likert scale)

Accessibility in transport: 5
To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)

Commuting distances: 20
Average length of trips to and from work (added together)

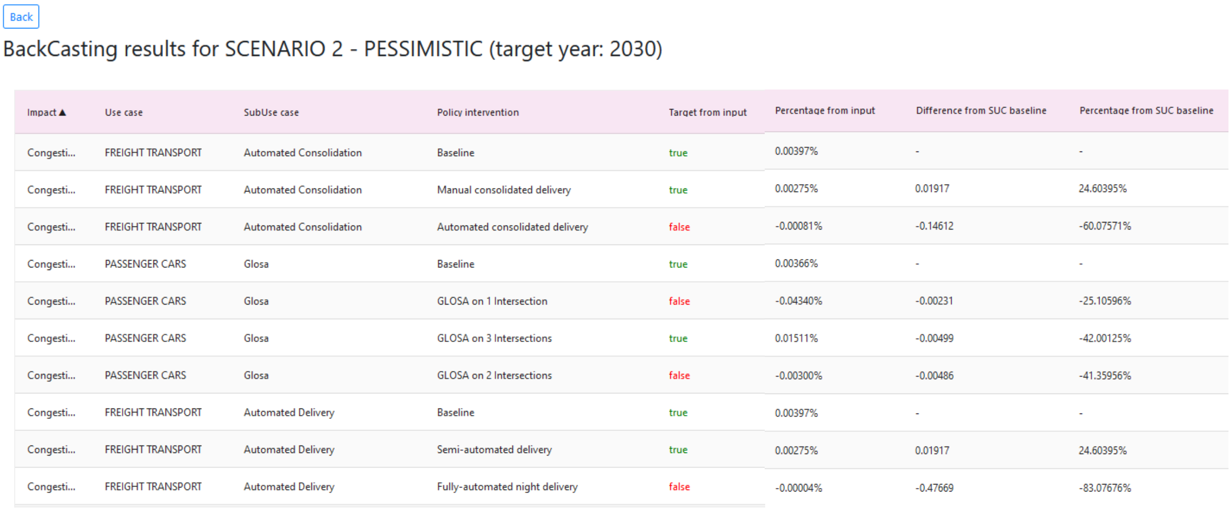
Unmotorized VRU crash rates: 1.4
Injury crashes with unmotorized VRUs per vehicle-kilometer driven

Road safety motorized: 2.2
Number of crashes per vehicle-kilometer driven

Road safety total effect: 0.86
Road safety effects when accounting for VRU and modal split

Figure 4.3: Selection of initial values and 'Submit button' in the online PST

The PST then responds with a calculation for each policy intervention for the impact of congestion, which the user can sort/browse.



BackCasting results for SCENARIO 2 - PESSIMISTIC (target year: 2030)

Impact ▲	Use case	SubUse case	Policy intervention	Target from input	Percentage from input	Difference from SUC baseline	Percentage from SUC baseline
Congesti...	FREIGHT TRANSPORT	Automated Consolidation	Baseline	true	0.00397%	-	-
Congesti...	FREIGHT TRANSPORT	Automated Consolidation	Manual consolidated delivery	true	0.00275%	0.01917	24.60395%
Congesti...	FREIGHT TRANSPORT	Automated Consolidation	Automated consolidated delivery	false	-0.00081%	-0.14612	-60.07571%
Congesti...	PASSENGER CARS	Glosa	Baseline	true	0.00366%	-	-
Congesti...	PASSENGER CARS	Glosa	GLOSA on 1 Intersection	false	-0.04340%	-0.00231	-25.10596%
Congesti...	PASSENGER CARS	Glosa	GLOSA on 3 Intersections	true	0.01511%	-0.00499	-42.00125%
Congesti...	PASSENGER CARS	Glosa	GLOSA on 2 Intersections	false	-0.00300%	-0.00486	-41.35956%
Congesti...	FREIGHT TRANSPORT	Automated Delivery	Baseline	true	0.00397%	-	-
Congesti...	FREIGHT TRANSPORT	Automated Delivery	Semi-automated delivery	true	0.00275%	0.01917	24.60395%
Congesti...	FREIGHT TRANSPORT	Automated Delivery	Fully-automated night delivery	false	-0.00004%	-0.47669	-83.07676%

Figure 4.4: Backcasting results as provided in the online PST

4.4 Final Remarks

Urban transport and mobility is experiencing a series of transformational changes resulting from a background of increasing automation in transport and connectivity. The pace with which automated vehicles will enter the fleet is uncertain due to many regulatory concerns over safety and also the challenge of finding the most appropriate business case. Nevertheless, there is now a clear pathway to increased vehicle automation. Connectivity between vehicles and infrastructure is already available and in use by many mobility services, the capabilities will be enhanced by the widespread introduction of 5G services.

CCAM services and technologies have the potential to result in major impacts to cities which will need to introduce measures to maximise the positive benefits and to mitigate the negative outcomes. Cities will need to consider these impacts when developing their long-term urban mobility plans which commonly have a 20-year horizon. Although cities will have only a small influence over increasing automation, they will have a much larger influence over the nature and implementation of services enabled by improved connectivity. They are therefore generally in a good position to ensure that CCAM services make a strong positive contribution to wider city policy goals. To achieve this a strong quantitative evidence base is essential but there is currently very little data on automated vehicles and the manner in which they will drive in traffic. It is therefore challenging for cities to develop a suitable knowledge base to inform future policymaking.

The LEVITATE project has addressed this challenge and has developed a series of simulation and analytic tools to be used to forecast the impacts of a wide range of CCAM services and technologies. These impacts have been derived controlling for the influence of an increasingly automated vehicle fleet and they cover a very wide range of societal dimensions. Access to the evidence base is managed through a new Policy Support Tool that enables cities to customise the results according to their own scenarios. Through the PST the impacts of CCAM services or technologies can be forecast individually or in combinations. The PST also enables cities to specify a desired goal and to then work backwards to identify suitable combination of CCAM services that, together, can achieve the goal. The PST also incorporates a knowledge base that provides detailed descriptions of all the supporting analysis.

The broad analytic results of the impact forecasts of a wide variety of CCAM technologies and services broadly indicate that when advanced CAVs become widespread we can expect impacts across most dimensions to be positive. Many traffic, safety and environment impacts are all reduced with the interventions and with high levels of advanced automation. Until then we will have a mixed fleet including human driven vehicles and early generation automated vehicles and the Levitate forecasts indicate a more variable set of impacts, changing with CAV prevalence and some impact types being positive and others negative.

The availability of the LEVITATE results and the Policy Support Tool is expected to strongly support cities as they develop new strategies and policy goals. The methods underpinning the results will also have wider application to future real-world trials of automated and connected vehicles and mobility services where it will be necessary to evaluate wider societal impacts.

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