levitate

Detailed list of sub-use cases, applicable forecasting methodologies and necessary output variables

Deliverable D4.4 – WP4 – PU

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Work package 4, Deliverable D4.4

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Executive summary

Work package 4 (WP4) within LEVITATE is concerned with gathering city visions and developing feasible paths of automated vehicles related interventions to achieve policy goals. City visions contributed to the project in assessing the impact indicators that are needed to be addressed for a useful policy support tool (PST). Previous deliverables of WP4 (deliverable 4.2 and 4.3) used backcasting methods to develop feasible pathways to reach these goals by using policy interventions related to connected and automated transport systems (CATS). These were carried out for the city of Vienna, Amsterdam and Greater Manchester.

This deliverable summarises the work that has been conducted in the frame of WP4 and sets the scene for the core LEVITATE work packages (WPs 5, 6 and 7), which address the three main use cases of the project: Urban transport, Passenger cars and Freight transport. Further, the goal of this deliverable is to summarise a timewise implementation of different sub-use cases, and the forecasting methodologies that need to be employed to assess the direct, wider and systemic impacts of CATS. Discussion on the specific ways to study the impacts of the interventions using micro-simulation technique is conducted and the necessary outcome variables of the forecasting models are specified.

The main contribution of deliverable 4.4 is a consolidated list of sub-use cases and output variables, and an indicative timewise implementation of the interventions. The list of sub-use cases and interventions was evaluated against the available methods by performing a decision-making exercise among the project partners. From this evaluation, downselection was carried out during a plenary project meeting at the Hague in October 2019, to select the most appropriate and feasible sub-use cases and interventions. Later, these items were arranged on a timeline from present (2020) to 2040 to indicate possible arrival of the services, technologies or interventions due to the anticipated arrival of CATS. This gives an insight into what changes are to be expected in a future city.

A small extract from Deliverable 3.2 (methods that could be applied to measure societal level impacts from CATS) is included in the current deliverable to provide a short summary of the methods available for forecasting societal level impacts. Since the systemic and wider impacts are somewhat dependent on the direct impact, traffic micro-simulation method is the first choice to initially get direct impact. Therefore, this method is described in more detail. Further research is being undertaken in WPs 5, 6 and 7 to assess the impacts from specified sub-use cases in the most efficient way. To determine these impacts quantitatively, a list of impact indicators is presented as output variables for the various methods that will be employed.

1 Introduction

1.1 LEVITATE

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

Specifically, LEVITATE has four key objectives:

1. To incorporate the methods within a **new web-based policy support tool** to enable city and other authorities to forecast impacts of connected and automated transport systems (CATS) 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 CATS measures that will result in their desired policy objectives.
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 establish **a multi-disciplinary methodology** to assess the short, medium and long-term impacts of CATS on mobility, safety, environment, society and other impact areas. Several quantitative indicators will be identified for each impact type.
4. To apply the methods and **forecast the impact of CATS** 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.

1.2 Work package 4 and Deliverable 4.4 within LEVITATE

The objective of work package 4 (WP4) is to develop target scenarios and feasible paths to reach them with interventions concerning automated vehicles, contributing mainly to the second LEVITATE objective. The main steps are:

- Research of national/European policy goals in the impact dimensions
- Definition and description of goals and visions[1] of cities and other stakeholders for short, medium and long-term.

[1] The term "visions" is used here instead of the term "scenarios" that has been used in the project proposal. Refer also to relevant part of terminology agreed in the project, given in the Appendix A (Used Terminology).

- Applying the resulting impacts from WP3 and data available from the cities to define targets.
- Using backcasting methodologies to define feasible paths to reach the stakeholders' goals with special consideration to automated vehicles
- Definition of forecasting scenarios and desired outputs for the consolidation of the different use-cases.

The main goal of Deliverable 4.4 is to provide a consolidated list of sub-use cases and output variables that will be used for the impact assessment of CATS. Moreover, within this deliverable, the available modelling and simulation techniques that can be best applied to predict the outcome of the interventions defined in the feasible paths in T4.3 are discussed, and the time sequence of the CATS related interventions is detailed.

1.3 Organization of the Deliverable

This deliverable is organised as follows:

Chapter 2 sets the background for this deliverable and refers to related work, both general and within the LEVITATE project. Then, Chapter 3 provides an overview of the methods that will be implemented for the forecasting of the outcomes of sub-use cases (interventions) and a more detailed description of the traffic micro-simulation approach. Chapter 4 includes the list of the sub-use cases that will be investigated in the frame of LEVITATE and the description of the process followed for the consolidation of them. Furthermore, in Chapter 4 the sub-use cases are arranged according to the expected timing of their implementation in an indicative diagram. Finally, Chapter 5 constitutes the epilogue with the overall conclusions and the outlook of this deliverable.

2 Background and related work

This chapter summarises the basic results of previous work in WP4 and establishes the connection to other activities in LEVITATE. An overview of the indicator framework defined in LEVITATE is presented, which has been used to identify and describe feasible visions (related to CATS aspects) for cities. Through an interactive backcasting approach, a first attempt to describe possible paths of interventions has been performed.

2.1 The LEVITATE Indicator framework

The first step performed in WP4 of LEVITATE was the investigation of quantified policy goals (Zach, Millonig, & Rudloff, 2019). These policy goals are then used for the identification of desirable visions and for the proposed backcasting approach. Along with the goals, indicators have been defined that allow precise measurement and monitoring of the progress over time.

Analysing and comparing existing approaches, initiatives and strategies, principle agreement on high-level goals and their organisation into "dimensions" (like Safety, Economic, Society and Environment) was found. The analysis considered various organisational and geographical levels, viz., (a) looking at the sustainable development goals (United Nations), (b) the Sustainable Urban Mobility Indicators (SUMI) developed as part of an EU project with the same name, the smart city index from the Smart Cities Council (which is a global initiative), and finally (c) the smart city strategies and urban development plans for the two cities Vienna and Greater Manchester. On the detailed level, the analysis also revealed that indicators are not always well defined, and they allow some variance in their measurement.

It has been proposed to classify the goals to be further considered in LEVITATE according to four dimensions: Safety, Society, Environment and Economy. From that highest level, more specific goals, objectives and targets (based on corresponding indicators) can be defined.

Goals have to be specific to the scope of the LEVITATE project which means that connected and automated transport systems (CATS) have some potential to contribute towards them. This defined the relationship to deliverable D3.1 (Elvik, 2019) that identifies the main impact areas of CATS. Further criteria like measurability and comparability, as well as completeness and interdependency have also been discussed – guiding the further goal selection process.

The final proposed set of policy goals and indicators was achieved in a multi-step process; based on existing approaches and applying the above-mentioned selection criteria, an exemplary preliminary list was generated together with experts from the City of Vienna. Strong focus in this phase was on keeping the set compact yet reflecting the long-term vision of the city, and preferring indicators where measurement data are already available today. This preliminary list served as input for an online survey, where members of the Stakeholders Reference Group (experts from different sectors and organisation types of different European cities and regions) were invited to prioritise the goals and indicators and propose additional ones.The main expert validation took place at the LEVITATE Stakeholder Reference Group Workshop in Gothenburg on 28th May 2019, where dependencies and possible conflicts across the four dimensions were also discussed. After final consultations with experts from the City of Vienna, considering the additional proposals from the workshop, the following policy goals and indicators were proposed (see Table 2.1). The list is organised along the four chosen dimensions, which provide a high-level structure (even if certain goals might be assigned to more than one dimension).

Table 2.1: Consolidated proposed goals and indicators for LEVITATE

Dimension	Policy Goal	Indicator
Safety	Protection of Human Life	Number of injured per million inhabitants (per year)
		Number of fatalities per million inhabitants (per year)
	Perceived Safety	Standardised survey: subjective rating of (overall) safety
	Cyber Security	Number of successful attacks per million trips completed
		Number of vulnerabilities found (fixed) (per year)
Society	Reachability	Average travel time per day (dispersion; goal: equal distribution)
		Number of opportunities per 30 minutes per mode of transport
	Use of Public Space	Lane space per person
		Pedestrian/cycling space per person
	Inclusion	Distance to nearest publicly accessible transport stop (including MaaS)
		Affordability/discounts
		Barrier free accessibility
		Quality of access restrictions/scoring
	Satisfaction	Satisfaction with active transport infrastructure in neighbourhood (walking and/or cycling)
		Satisfaction with public transport in neighbourhood
Environment	Low Noise Levels	Standardised survey: subjective rating of main sources of disturbing noise
	Clean Air	Emissions directly measurable: SO2, PM2,5, PM10, NO2, NO, NOx, CO, O3
	Efficient Settlement Structures	Building volume per square kilometre (total and per built-up area)
		Population density (Eurostat)
	Sustainable Behaviour	Rate of energy consumption per person (total)
		Rate of energy consumption per person (transport related)
Economy	Prosperity	Taxable income in relation to purchasing power
	Fair Distribution	GINI index

2.2 Defining desirable visions

The next step was to use this indicator framework to perform a detailed statistical analysis of available data, in particular considering European countries and cities, and based on that propose a quantitative approach to define desirable visions as regions in indicator space.

Challenging questions in this process were:

- How to prioritise different goals across the four dimensions considered in LEVITATE (Safety, Society, Environment and Economy)
- Which relationships between different goals can be identified? (Are they supporting each other or are they conflicting?)

The analyses performed within deliverable D4.2 (Zach, Rudloff, & Sawas, 2019) on available data helped to get a better understanding on how to define a vision related to CATS for a city or region in a quantitative way and to describe feasible transformation paths to reach such a vision.

A focussed survey of literature regarding relationships and correlations among the policy goals and indicators considered in LEVITATE showed that even on high level, quite complex relationships are revealed, forming a "network" of interactions. A good amount of the correlations between goals is positive (this means goals are supporting each other). For some relationships such simple statements are not possible (because there might be several contradicting causal relations). And finally, some goals are obviously conflicting to a certain extent – mainly prosperity (and related economic indicators) opposed to environmental indicators.

Defining desirable visions is the starting point for the backcasting approach proposed for LEVITATE. Even though only a few examples can be found within the transport domain, the available literature gives support regarding the methodologies that can be applied for (semi-)quantitative backcasting and specification of visions. From statistical perspective, the challenges for the analysis of available data lie primarily in high dimensionality (of indicators considered) and high sparsity in the data set (out of all combinations of indicators, city (geo-entity) and year (time), only a small percentage is available). This situation led to the selection of two approaches to be applied: principal component analysis (PCA) with data imputation and collaborative filtering.

During the collection of open data for the indicators defined in LEVITATE, several data sources have been analysed in detail, and the inputs from the Stakeholder Reference Group have been considered. For the final evaluation, data from two open data sources have been considered: European Statistical Office (Eurostat) and World Development Indicators (WDI). These data were organized along dimensions & goals (the indicator framework developed in deliverable D4.1), geographic levels (country / region / city) and time.

Based on these data, a closer analysis of example visions – with focus on CATS and the LEVITATE indicator framework – has been performed: for the two Cities (regions) of Vienna and Greater Manchester, and for "Vision Zero" (putting extreme emphasis on the Safety dimension).

The goals of these statistical evaluations were the following: analysing how "close" several indicators are to each other (similarity of indicators), analysing the similarity for geo-entities (which cities show similar behaviour), investigating the development (evolution) over time, and finally exploring ways to identify a vision that has been specified by means of the LEVITATE indicator framework.

The main results were the following:

- Similarities (i.e. correlations) between indicators are investigated in a systematic way, showing – by and large – consistency between the two selected approaches and with previous results found in the literature. Nevertheless, also a few surprising results have been found: For example, hardly any correlation between road deaths and injuries, and if any it even tends to be negative.
- Clustering of geo-entities is quite strong – cities in the same (European) region (in the same decade) show very similar behaviour.
- Development over time (how geo-entities move in indicator space over the decades) is also clearly visible.
- There are several ways how to map and illustrate a concrete vision (based on specific target values for a city or region) with slightly different but consistent results.

In this abstract indicator space, movements of geographic entities over time can be illustrated. An example for Vienna has been given in deliverable D4.2, where the average values for each decade, from the 1960s to 2010s, have been used as data points. The 2D space selected for illustration was defined by the first two components after a principal component analysis (PCA) in the abstract embedding space. The obtained results showed sufficient statistical significance to identify a straightforward movement over the decades, which also allows a linear projection over the next 10 – 20 years (assuming that the direction of movement in the abstract space remains the same).

Furthermore, as has been explained, vision points based on specific targets for some indicators (e.g., Vienna 2030, Vienna 2050) can also be mapped to this space; illustrating not only the gap between current state and these visions, but also the gap between linear projection (e.g., for 2030) and the corresponding vision for that point in time. The (multi-dimensional) difference vector of these two points can be considered as an indicator of "what has to be changed" in order to reach the defined targets of the vision. (In the physical analogue of a moving body which should be diverted in order to reach a target point, this vector would correspond to the external force that has to be applied.) A schematic illustration of this gap between projected future and vision is shown in Figure 2.1, where the evaluation of historical data and key targets for the example of Vienna in deliverable D4.2 has revealed a very similar behaviour.

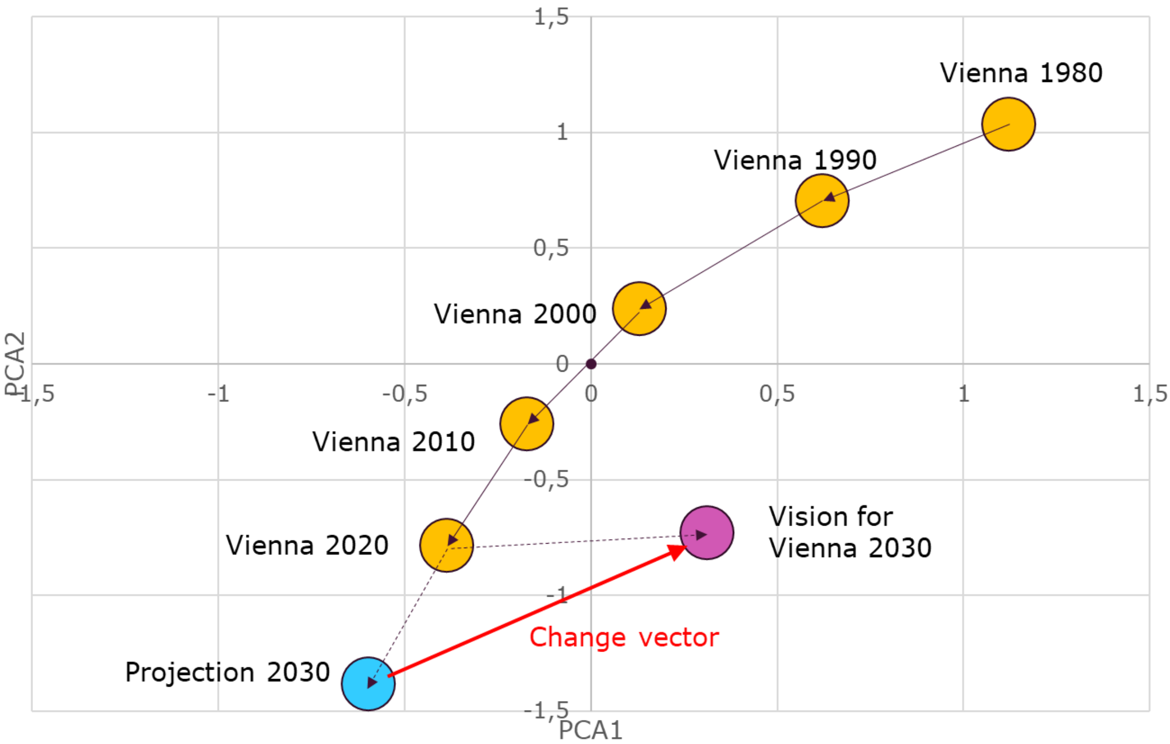

Figure 2.1: Gap between projected future and vision for a city, and resulting change vector (schematic, based on evaluated data for Vienna, the axes are the first and second principal components in embedding space)

On the other hand, both discussed approaches – principal component analysis with data imputation and collaborative filtering – were found to have clear limitations and to suffer from the high sparsity in the available data set, despite the methods that have been applied. It should also be noted that visualising the results in a two-dimensional plot can easily be misleading since it is based on further dimensional reduction.

Nevertheless, these results can be considered as a base for further tasks in WP4 – the closer analysis of "feasible paths" towards a desired vision. The investigated "structure" of the indicator space, the observed timely development of a city at present and the "direction" towards the desired vision are the main inputs that can be derived from our analyses. Combined with the preliminary results from other WPs (WP3 – CATS impacts and methods for forecasting them, WP5-7 – (sub) use cases and applications, policy interventions to be considered) and with additional inputs from the stakeholder reference group in the actual backcasting process, feasible paths of intervention can be outlined.

2.3 Backcasting approach: possible paths of interventions

An interactive backcasting approach has been described in deliverable D4.3 (Zach, Sawas, Boghani, & de Zwart, 2019). The flow chart in Figure 2.2 gives an overview on the proposed steps in the process, the used inputs and the expected outputs.

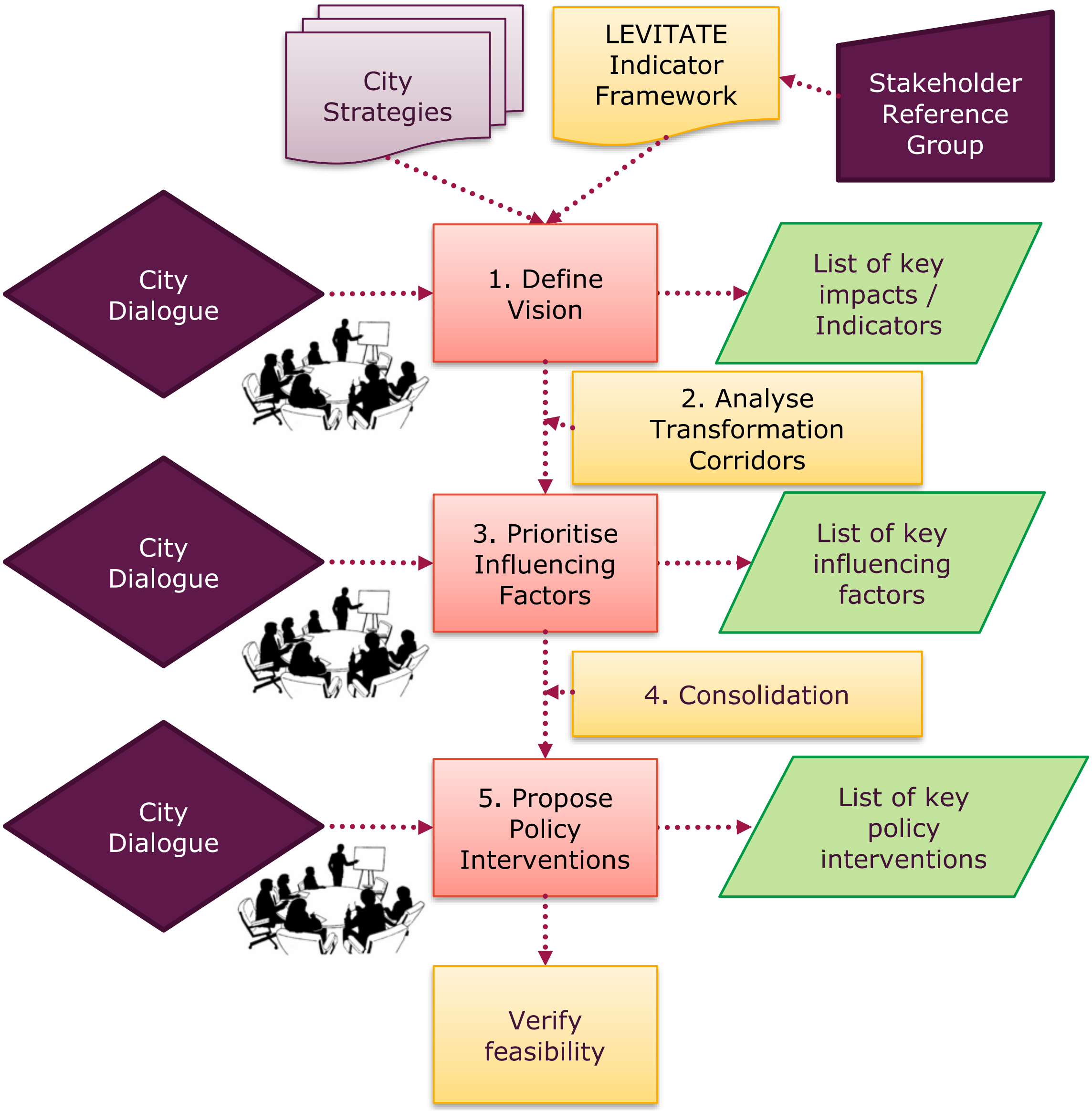

Figure 2.2: Flow chart for the steps of backcasting process in LEVITATE

In step 1, the strategies from cities are studied and relevant visions are extracted according to the impact indicators identified in LEVITATE. This is carried out through a dialogue with representatives from city authorities. Transformation corridors are analysed using the past data available and projecting them to the future. In the next step, influencing factors are identified that will have positive or negative impact on impact indicators (visions). Moreover, this step of the process is supported by dialogues with city authority representatives. Once consolidated, with the help of city authority representatives, possible interventions are identified and listed. The final step of verification cannot be performed within the scope of deliverable D4.3 (or more general, of WP4), as this is ongoing work within the project and will be carried out through work in WPs 5, 6 and 7.

The general procedure as outlined in Figure 2.2 envisages a city dialogue that is based on existing documentation of city strategies and the LEVITATE indicator framework. This has been performed in following three steps:

1. Define Vision
2. Prioritise Influencing Factors
3. Propose Policy Interventions

For Vienna and Greater Manchester, where the main contacts for the dialogue are also partners in the LEVITATE project, discussions on above mentioned building blocks have already been started before the actual backcasting process that is described here. The City of Vienna has also been closely involved already in task 4.1(as decribed in section 2.1), the definition of the LEVITATE indicator framework, according to the four impact dimensions safety, society, environment and economy.

In addition, as part of the first LEVITATE Stakeholder Reference Group Workshop, which was held in Gothenburg, Sweden, on May 28, 2019[2], experts from different sectors, including stakeholders from municipal authorities, were involved to discuss and adopt the list of goals and indicators and to disclose potential synergies and conflicts regarding efforts to achieve specific goals in the four selected dimensions.

The actual backcasting dialogue with the cities (as reported in this deliverable) has been carried out within a timeframe of close to two months (November - December 2019) and was performed as a combination of workshops / face-to-face meetings, offline reviews and phone conferences.

The results of the city dialogues for Vienna, Amsterdam and Greater Manchester as presented in Deliverable D4.3 show a high degree of congruence (for example regarding environmental goals), but also exhibit different priorisation of key targets and influencing factors. Table 2.2 attempts to summarise the key findings, showing overlaps and common goals, influencing factors and policy interventions. These results will also be discussed in the context of output variables in section 4.5 of this deliverable.

2 For details refer to https://levitate-project.eu/2019/06/11/what-do-policy-makers-want-to-know-about-the-impact-of-connected-automated-vehicles/

Table 2.2: Comparison of the cities Vienna, Amsterdam and Greater Manchester by LEVITATE backcasting steps – city goals, influencing factors and policy interventions

<table>
<tr><th></th><th>Vienna</th><th>Amsterdam</th><th>Greater Manchester</th></tr>
<tr><td rowspan="7">City goals</td><td colspan="3">reduction of CO_2 emissions by transport</td></tr>
<tr><td>decrease final energy consumption transport</td><td>decrease freight road kilometres</td><td>increase the number of dwellings</td></tr>
<tr><td colspan="2">increase public space for bicycle/pedestrians</td><td>increase employment</td></tr>
<tr><td colspan="3">increase modal split/eco-friendly ('right mix')</td></tr>
<tr><td colspan="3">decrease accidents, fatalities and injuries</td></tr>
<tr><td colspan="2">decrease private MV ownership (level of motorization)</td><td></td></tr>
<tr><td>decrease traffic crossing the municipal boundaries</td><td></td><td></td></tr>
<tr><td rowspan="6">Influencing factors</td><td colspan="2">modal split of all journeys</td><td>mobility as a service (MaaS)</td></tr>
<tr><td colspan="3">shared mobility/ travel demand management</td></tr>
<tr><td colspan="2">AV penetration rate</td><td>improved road safety at hazardous locations</td></tr>
<tr><td></td><td>freight modal split</td><td>reduction of heavy goods vehicles (HGVs) at peak times</td></tr>
<tr><td colspan="2">public parking space</td><td>car clubs</td></tr>
<tr><td>shuttles</td><td></td><td>improving buses</td></tr>
<tr><td rowspan="6">Policy interventions</td><td colspan="2">road use pricing -all vehicles (dynamic)</td><td>clean air plan</td></tr>
<tr><td colspan="2">restrictions on vehicle parking & road use</td><td>street design</td></tr>
<tr><td colspan="2">public space reorganization & provision of safe walking and bicycling facilities</td><td>improvement/provision of pedestrian and cycling routes (incl. connectivity to buses)</td></tr>
<tr><td rowspan="2">last-mile shuttle/ Micro public transport/ multimodal public transportation packages</td><td rowspan="2"></td><td>last mile shuttle</td></tr>
<tr><td>real-time information (journey, ticketing, wayfinding)</td></tr>
<tr><td></td><td colspan="2">new housing with less private parking/ reduction of informal car parks</td></tr>
</table>

One striking difference that has been observed is the significance of economic goals, like the increase in employment, in city strategies – and the relevance of related factors, e.g. the housing and road capacities between cities. This is quite important for the Greater Manchester area, but is not seen as high-priority topic for Vienna and Amsterdam.

As discussed, the backcasting process so far has delivered mainly qualitative results. The “feasible paths” of intervention as understood within the scope of deliverable D4.3 are defined by the connections between the targets of the vision, the influencing factors and areas of promising policy interventions.

What remains to be analysed in more detail is the (timely) development of influencing factors and the dependencies between these factors, as well as the sequence, timing and combination of policy interventions. Only after quantitative investigations of the relationships documented in deliverable D4.3, more concrete pathways – determined by development of influencing factors as well as indicators as a function of time – may be described.

When analysing the timing and sequence of CATS related applications, influencing factors and related policy interventions, a good starting point might be the roadmap produced by Zenzic (Zenzic UK Ltd., 2019). The UK Connected and Automated Mobility Roadmap to 2030 provides direction for decision makers, investors and policy makers for the mobile future. This roadmap is a tool, created by and intended for multiple sectors, forging new relationships and achieving collaboration across industries. With a single vision of interdependencies, the roadmap addresses developments needed to achieve connected and automated mobility (CAM) by 2030.

Overall, Zenzic takes a quite optimistic view, emphasising the opportunities related to CATS / CAM: "This tool is designed to be a neutral, independent, collaboratively-built and jointly owned vision of the future we all want to see. This vision is reinforced by industry experts' articulation of the path to 2030, cohesively structured to account for the interdependencies that will bring together the future of CAM."

The roadmap is structured along various streams belonging to four high-level themes: Society and People, Vehicles, Infrastructure, Services. Furthermore, six "Golden Threads" are identified, as "sequence of cross theme-related Milestones, which allow cross topic narratives to be found".

3 Methods for forecasting the outcomes of sub-use cases (interventions) implementation

This chapter surveys the applicability of different forecasting methods with respect to prediction of the impacts of implementing policy interventions in the use cases of WPs 5, 6 and 7 of Levitate. It thereby seeks to establish links between the menu of forecasting methods decribed in WP3 of Levitate and the needs for evaluating policy interventions that are specified in WP4 of Levitate.

3.1 Two different perspectives

The main objectives of WP3 of Levitate are:

1. To develop a taxonomy of potential impacts of connected and automated vehicles
2. To provide a menu of methods that can be used to predict the impacts of connected and automated vehicles
3. To assess the feasibility of converting impacts of connected and automated vehicles to monetary terms
4. To perform cost-benefit analysis of the introduction of connected and automated vehicles.

Deliverable D3.1 (Elvik et al. 2019) refers to the first objective and provides a list of potential impacts of connected and automated vehicles. These have been classified as direct, systemic and wider impacts. Direct impacts are noted by each road user on each trip. Systemic impacts are system-wide impacts within the transport system, such as changes in road capacity, traffic volume or travel time. Wider impacts are general societal impacts which may occur outside the transport system, like changes in employment or land use. A total of 33 potential impacts were identified, of which 7 were classified as direct, 12 as systemic and 14 as wider impacts.

Deliverable D3.2 (Elvik et al. 2020) describes methods that can be used to assess, preferably quantify, the impacts identified in deliverable D3.1. The following methods for predicting impacts were identified in deliverable D3.2:

1. Historical or retrospective methods
    a. Longitudinal studies; time-series models
    b. Before-and-after studies (several versions exist)
    c. Epidemiological studies; comparative or retrospective risk analyses
    d. In-depth studies of accidents
    e. Meta-analysis
    f. Household travel surveys (to reconstruct actual travel)
    g. Travel demand modelling
    h. Naturalistic driving studies

2. Future oriented methods
    a. Scenario analyses
    b. Delphi surveys
    c. Biomechanical modelling (of impacts involving future vehicles)
    d. Field operational trials
    e. Driving simulation; driving simulator studies
    f. Traffic simulation; mathematical modelling of traffic
    g. Mesoscopic simulation; activity-based-modelling
    h. System dynamics
    i. Reliability engineering; prospective risk analyses
    j. Surveys (can be used for many topics)
    k. Willingness to pay studies (often surveys, but listed separately here)

Examples of these methods were given, though with a main focus on summarising studies by means of (simplified) meta-analysis (1e), identifying potential impacts by means of scenario analysis (2a), discussing the potential contribution of traffic simulation (2e), showing an example of the application of system dynamics (2h) and summarising surveys and studies of willingness to pay (2j, 2k). The focus was on the extent to which impacts can be predicted in numerical terms. The reason for choosing to focus on numerical prediction, is that quantified estimates of impacts are needed in order to convert the impacts to monetary terms and include them in cost-benefit analysis.

It was found that prediction of impacts is currently possible for a number of systemic impacts but is more difficult for wider impacts. It should be noted that the systemic impacts can be viewed as direct impacts at the aggregate level, i.e. the systemic impacts are the sum for all road users of the impacts each road user experiences on each trip. Based on a review of the literature, it was found that the most widely applicable approach for predicting impacts was to model impacts as a function of the market penetration rate of connected and automated vehicles. These functions were referred to as dose-response curves and included the following potential impacts of connected and automated vehicles:

1. Impacts on capacity and mobility
    a. Lane capacity
    b. Junction capacity
    c. Delays on motorways
    d. Delays in roundabouts
    e. Delays in signalised junctions
    f. Travel time on motorways
    g. Delays in junctions (average of roundabouts and signalised)
    h. Travel time in cities (derived from changes in capacity and delays)
2. Impacts on safety
    a. Rear-end and lane change collisions (motorways)
    b. Accidents in signalised junctions
    c. Accidents in roundabouts
    d. Accidents in priority controlled junctions
    e. Cyclist and pedestrian accidents
    f. Accidents in urban junctions (average of signals, roundabouts, priority)
3. Impacts on fuel consumption (and emissions)
    a. Fuel consumption (and emissions, if these are assumed to be proportional to fuel consumption)

4. Other impacts and feedback impacts
    a. Diffusion curves for market penetration of automated vehicles
    b. (Induced) travel demand on motorways
    c. (Induced) travel demand in cities
    d. Behavioural adaptation to platoons by manually driven vehicles

These impacts are generated by automation technology and vehicle connectivity. All the dose-response functions are obviously highly uncertain and an attempt to quantify uncertainty was made. In addition to the dose-response functions, the following parameters were quantified:

1. Willingness-to-pay for automation technology
2. Demand function for automated vehicles
3. Valuation of travel time in automated vehicles

A system dynamics model was illustrated for land use and moves between parts of a city, inducing longer commutes.

By and large, the dose-response curves and other studies reviewed in deliverable D3.2 predict that vehicle automation will reduce the generalised costs of travel and thereby induce increased travel demand. Confident predictions about shared mobility are impossible to make. Opinions are divided. While some researchers think that shared mobility will become attractive, others maintain that individual vehicle ownership and individual travel will remain the most attractive.

The perspective taken in WP4 of Levitate is presented in Chapter 2 of this deliverable as well as in D4.3 (Zach, Sawas, Boghani, & de Zwart, 2019). It starts by asking what the visions for the future are in the cities of Vienna, Manchester and Amsterdam. The visions represent long term goals for city development and the transport system. Thus, both Vienna and Manchester have a goal of reducing traffic injury and greenhouse gas emissions. Both cities want a larger share of trips to be made on foot or by bike. The visions endorsed by the city of Amsterdam are the same. A set of impacts and indicators, which is highly similar in Vienna, Manchester and Amsterdam, was proposed to help assess the realisation of the visions.

Having defined long term policy objectives (visions), the next stage of analysis establishes a link to influencing factors that may influence the realisation of the visions. The link between visions and influencing factors is qualitative only. Some of the influencing factors are related to vehicle automation, such as the market penetration rate of automated vehicles, use of urban shuttles and shared mobility. Thus, if shared mobility becomes widespread, that may reduce the need for parking space and allow it to be converted to other uses, such as space for walking or cycling. Shared mobility may also contribute to less global warming. The influencing factors are not necessarily expected to lead to realisation of the visions or policy objectives automatically but may need to be supplemented by the use of targeted policy interventions that provide the optimum fine-tuning of the influencing factors. Proposing and prioritising these policy interventions represents the third stage of analysis. Thus, Amsterdam, for example, mentions dynamic road pricing for all vehicles. Other policy interventions mentioned are entry restrictions for motor vehicles, conversion of driving lanes to shared space, reducing speed limits, introducing car-free zones and plan for fewer parking spaces when building new houses. The next stage of analysis is to estimate the impacts of the policy interventions – or, more precisely – to develop a set of policy interventions which is likely to produce impacts that will realise the visions to the maximum possible extent.

Thus, the problem posed in WP4 is how to estimate the impacts of policy interventions and how to select packages of policy interventions that will realise the long-term objectives of cities.

While the source of the impacts described in WP3 is automation technology and the market penetration of automated vehicles, the sources of impacts in WP4 are the influencing factors (more precisely: changes in these factors) and a set of policy interventions. To apply the dose-response functions developed in WP3, the relationship between these functions and the influencing factors and policy interventions defined in WP4 must be established. How to establish this relationship is discussed below. Some key questions in WP4, as applied to WP5, 6 and 7 are:

1. How will road pricing influence traffic volume, in particular that related to AVs? How should dynamic road pricing be designed in order to maximise its effects?
2. How can public space be reorganised in order provide more space for walking and cycling, considering aspects like less need for parking space due to CATS?
3. How can (automated) last mile shuttles be introduced in order to reduce last-mile commuting by car to train stations and make public transport more attractive?
4. How can cities ensure that shared mobility is promoted in a way that reduces traffic volume?

These questions are of a different nature than those asked in WP3, which were intended to identify and quantify potential impacts of vehicle connectivity and automation.

The questions listed above cannot be answered by applying the results of WP3. One should rather, for example, study literature on the impacts of road pricing and apply the results from that literature, although transferability to a system with automated vehicles must be assessed carefully.

In deliverable D4.3, a distinction is made between applications, interventions, technology and scenarios with reference to the cases and sub-cases studied in WPs 5-7. Applications include:

1. Geo-fencing based powertrain use, e.g. only allowing electric vehicles in a city centre
2. Green light optimised speed advice, to reduce stops at red traffic signals
3. C-ITS day 1 or day 1.5 services, i.e. dynamic traffic information
4. Point to point shuttle
5. Anywhere to anywhere shuttle
6. Last mile shuttle
7. Multi modal integrated payments
8. E-hailing, i.e. booking rides by a mobile phone app
9. Automated ride sharing
10. Highway platooning
11. Urban platooning
12. Automated urban delivery
13. Hub-to-hub automated transport
14. Automated intermodal transport

15. Local freight consolidation
16. Multi-purpose vehicles

Interventions include:

1. Road use pricing
2. Centralised traffic management
3. Separate lanes or roads for automated vehicles
4. Redesigning streets
5. Reducing long term parking

Technology includes:

1. SAE level 2,3 or 4 automation
2. SAE level 5 automation
3. Highway pilot
4. Autopark
5. Cooperative adaptive cruise control
6. Traffic jam pilot

The impacts of these technologies are dealt with in WP3.

The perspectives taken in WPs 3 and 4 in Levitate are therefore different, complementing each other. The different perspectives should not be viewed as a problem. There are always many perspectives to be taken and usually they enrich each other. In the present context, one valuable insight from the different perspectives of WPs 3 and 4 is that cities need to develop policies to ensure that the introduction of connected and automated vehicles takes place in a way that promotes, rather than counteracts, their policy objectives.

A key issue of interest in WPs 4, 5, 6 and 7 is how to get the advantages of automated transport while avoiding unwanted secondary impacts, such as increased travel demand. Aside from the increase in road capacity, which is likely to generate more travel, the main anticipated advantages of connected and automated transport are less accidents and less energy consumption. These advantages may be reduced if travel demand increases. This suggests that an approach as outlined in the next section may be the best way of exploiting the insights gained in both WPs 3 and 4.

3.2 A synthesis of the perspectives

To integrate the perspectives of WPs 3 and 4 and make maximum use of their insights, the following approach for estimating impacts of policy interventions is proposed:

1. Use the ceteris paribus versions of the dose-response curves developed in WP3 to estimate impacts on accidents, fuel consumption and emissions.
2. The ceteris paribus versions are those that apply to current traffic volume and do not include any rebound effects from increased traffic volume.
3. Estimate how vehicle automation changes the generalised costs of travel. This should be done by vehicle class: passenger car, van, small bus, large bus.
4. Apply demand elasticities with respect to the generalised costs of travel in order to determine how much the cost of transport must be increased in order to

neutralise the expected reduction of the generalised costs of travel associated with vehicle automation.
5. Design a system of road pricing that will neutralise the reduction in the generalised costs of travel due to vehicle automation.

For details about the dose-response curves developed in WP3, please see deliverable D3.2. With respect to the first point, the relevant dose/response curves from WP3 are those that apply to urban areas, more specifically:

1. Accidents in urban junctions
2. Pedestrian and cyclist accidents
3. Fuel consumption

These functions are defined for market penetration of automated vehicles from 0 to 100 %, and one may apply any point on a curve to represent a situation with less than full market penetration of automated vehicles.

Estimating the changes in the generalised costs of travel associated with vehicle automation is more complex. At least four elements must be considered:

1. The capital cost of vehicles. These include the cost of purchasing the vehicles and keeping them. It can be converted to a cost per kilometre by assuming a depreciation rate, i.e. a rate for the fall in the value of a vehicle as it gets older. Automated vehicles are, in general, assumed to be more expensive to buy than current vehicles.
2. The operating cost of vehicles. These include expenses incurred when driving a vehicle. Operating costs are generally expected to become lower with vehicle automation. Vehicles will be operated more optimally, which reduces energy consumption.
3. Changes in travel time. Unless there is a perfect rebound effect, the increase in road capacity brought about by vehicle automation will reduce travel time between given endpoints.
4. Changes in the valuation of travel time. The studies made so far, reviewed in deliverable D3.2, suggest that the value of travel time savings will be reduced.

The first item points to an increase in the generalised costs of travel, the other three point to a reduction. It should be regarded as highly likely that automated vehicles will reduce the generalised costs of travel, as every technological transport innovation has done so far.

It would probably be a misallocation of the time available for Levitate to devote a lot of research time to estimating changes in generalised costs of travel very precisely. Developing such estimates is not a core activity of the project. It is better to make simple assumptions that can easily be varied between different scenarios to see how results vary depending on the assumptions made. For sure, it is at this stage impossible to know how large the changes in the generalised costs of travel as a result of vehicle automation will be.

3.3 Overview of forecasting methods

In this section the main forecasting methods that are used within Levitate are briefly described. For a more detailed description, the reader is referred to Deliverable D3.2 (Elvik et al., 2020).

3.3.1 Traffic micro-simulation

This is essentially agent-based modelling where vehicles follow certain rules and are placed on a geographical map (road network). They carry certain goals to go from A to B and the trips are determined by demand. When such model is simulated, a system level behaviour emerges and some traffic parameters can be calculated, such as average trip time, average network delay, etc. An example is shown in Figure 3.3Figure 3.4.

Traffic micro-simulation is the most developed method among the list, at this point of the project. Section 3.2 describes this method in detail, showcasing the depth of other methods in the list.

3.3.2 Traffic Macrosimulation

In contrast to micro-simulation, this method focuses on collective vehicle dynamics. Multiple lanes are generalised to one with a probability function to include vehicle takeover situations. Therefore, this method simulates traffic flow at a bigger scale (region scale, such as overall big city, intercity or country level) without losing generality.

3.3.3 Mesoscopic simulation

This is a supplemental method within the group of simulation approaches that emphasises the modelling of behaviours and choices of mobility populations. Such an activity-based-modelling (ABM) framework is realised by the mesoscopic traffic simulation tools of MATSim. "Mesoscopic" in this context underlines the method being less focussed on immediate interactions of road users, therefore reducing the level and complexity of these details, but on the choices the simulated agents do have to re-arrange their daily routes and schedules of activities instead. Each of the activities within a complete daily chain or "plan" are preferably reached in time by means of transportation available to each agent within the simulated area under investigation. The major conclusions that can be extracted from such models refer to changes in modal splits and shares of the studied mobility population, as well as differences in road network loads and vehicle utilization. MATSim has been applied to a wide range of scenarios and locations and in consequence provides a rich set of results for comparison and transferability.

3.3.4 System Dynamics

This method is the modelling of a whole system by breaking it down to sub-system components. These sub-system components are defined by simple algebraic relationships and sometimes differential equations. These can be linear or non-linear in nature. The relationships can be continuous or discrete time events. Any feedback loops within the system are captured through the sub-system equations that are defined. The behaviour of the whole system emerges from simulating the entire system level model that contains sub-systems. An example is shown in Figure 3.1.

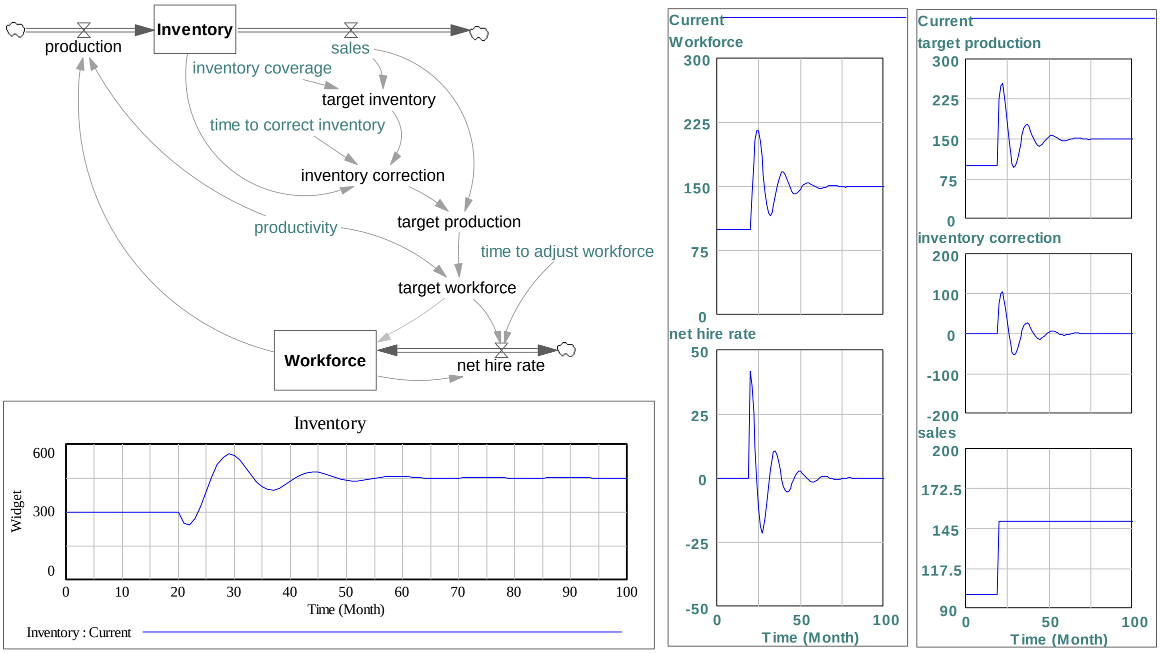

Figure 3.1: Example of a system and corresponding relationships, from Vensim® documentation (Ventana Systems, Inc.).

The model can be interrogated to look at the effect of some parameters on the overall response from the system. In the example above, a step change in demand of sales (bottom right graph) causes oscillatory behaviour in production and required workforce. The system settles to a new level after month 60.

3.3.5 Operations research

Operations research offers a complementary methodology toolset to simulation. It contains analytical methods for solving optimisation problems in the field of organisations management – in this project particularly transport management. Among the methodologies, there are two classes. The first class consists of exact approaches which aim to solve problems to proven optimality – provided that they are given enough run-time and memory. Well known representatives are mixed integer programming or branch-and-bound. The second class are (meta-)heuristics which compute approximate solutions but usually require significantly less runtime. For LEVITATE project and in practice, the latter is more suitable since real-world problems are too complex for exact approaches. Moreover, there are also the so-called hybrid methods that combines these two classes, trying to benefit from advantages of both sides.

3.3.6 Meta-analysis

This method is used to synthesise the findings of several studies dealing with the same topic. There are many techniques of meta-analysis, some of which may be relevant for summarising studies of potential impacts of connected and automated vehicles. There have been, for example, several studies of how truck platooning influences fuel consumption (Sharpe & Slowik, 2018). It is of interest to summarise the results of these studies in terms of a mean estimate of effect and the uncertainty that is surrounding this estimate. An example for congestion is presented in Figure 3.2.

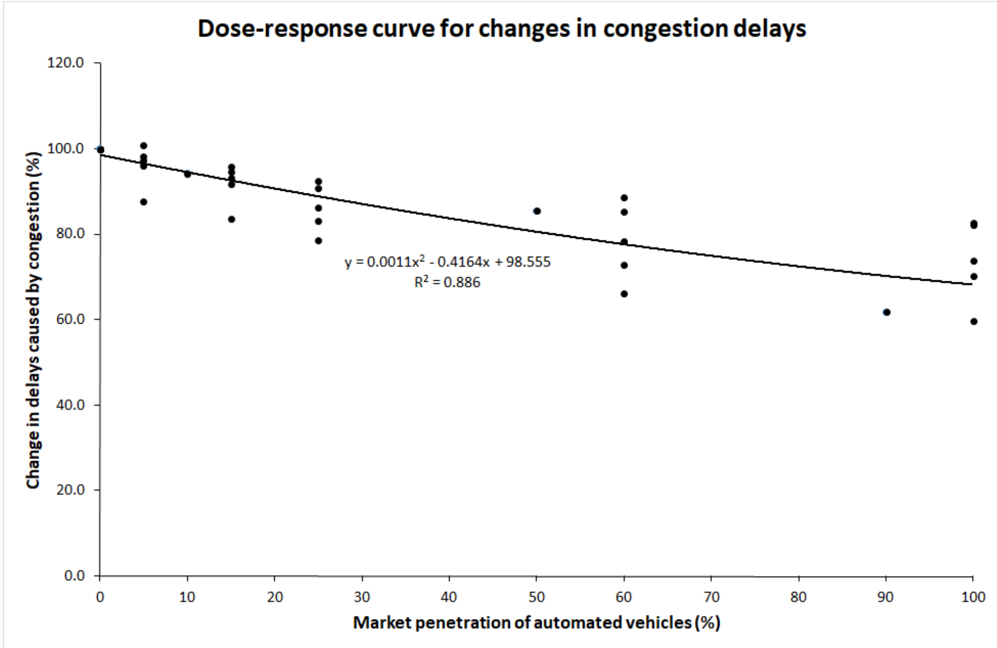

Figure 3.2: Example of a dose-response curve.

3.3.7 Delphi panels and experts' estimation

For relationships that cannot be predicted using quantitative methods, an expert guess will be provided. This can be realised through Delphi method where a structured discussion takes place amongst a group of experts and a collective opinion is recorded.

3.3.8 Driving simulator

This method entails mainly a simulated environment where a car is externally controlled (outside of the simulation environment). Generally, the scenario is created first and the behaviour of the surrounding vehicles within the simulator is provided. This method will be used to validate parts of the traffic simulation within this project.

3.4 Impact assessment of sub-use cases using traffic micro-simulation method

Traffic simulation techniques can be applied to predict the outcomes of the interventions that directly affect the vehicular traffic in the city. Aimsun Next software is used here as a mean to assess the impacts of AVs in each of the different sub-use cases.

3.4.1 Simulation framework

The simulation framework, as shown in Figure 3.3, has as objective to support the generation of metamodels for determining the impacts of CAT systems which have two main requirements:

- Scalability
- Transferability

Considering both requirements, the suggested framework is the following:

- Microsimulation layer: Perform a set of sensibility analysis applying microsimulation to the most "common" subnetworks elements (roundabouts, signalised intersections, merging's, diverging's, etc.). The result should be a characterization of the impacts in terms of macroscopic variables, such as capacity, travel time, etc. This characterization allows to investigate the scalability requirement.
- Macroscopic layer: Perform a set of sensibility analysis applying a macroscopic simulation using the macroscopic variables estimated in the lower layer and evaluate their effect considering each city infrastructure. This layer allows to investigate the transferability to other cities, and hence the integration of the outputs into the PST.

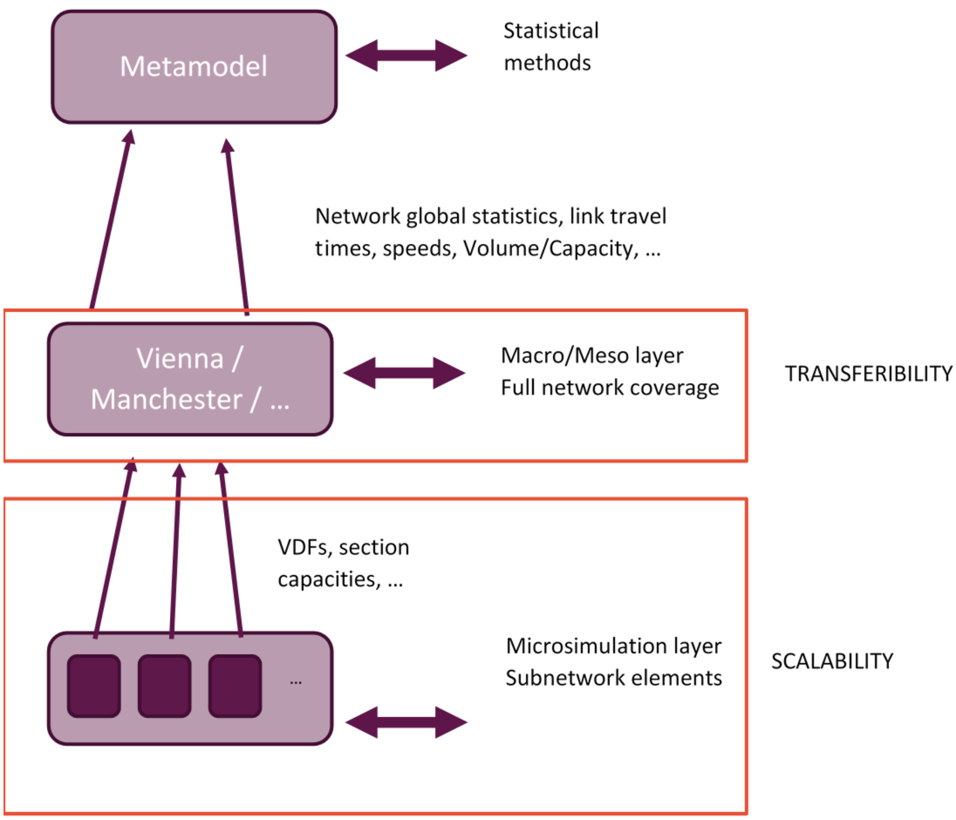

Figure 3.3 Simulation framework

Simulation of AVs

The simulation of Autonomous cars in Aimsun is performed using two different (and could be concurrent) approaches:

1. Defining an Autonomous car as a different Vehicle Type with a new set of parameter values that represents an average autonomous car behaviour. The potential set of parameters to define an autonomous car behaviour are related to the:

- Car-following behaviour
- Lane changing behaviour
- Gap acceptance behaviour

2. Replace the behaviour of a vehicle using the External Agent Interface. Through this interface, Aimsun Next sends every simulation step the state of the surrounding vehicles and traffic lights to an external AV control, and then it receives the new speed and position of the ego vehicle.

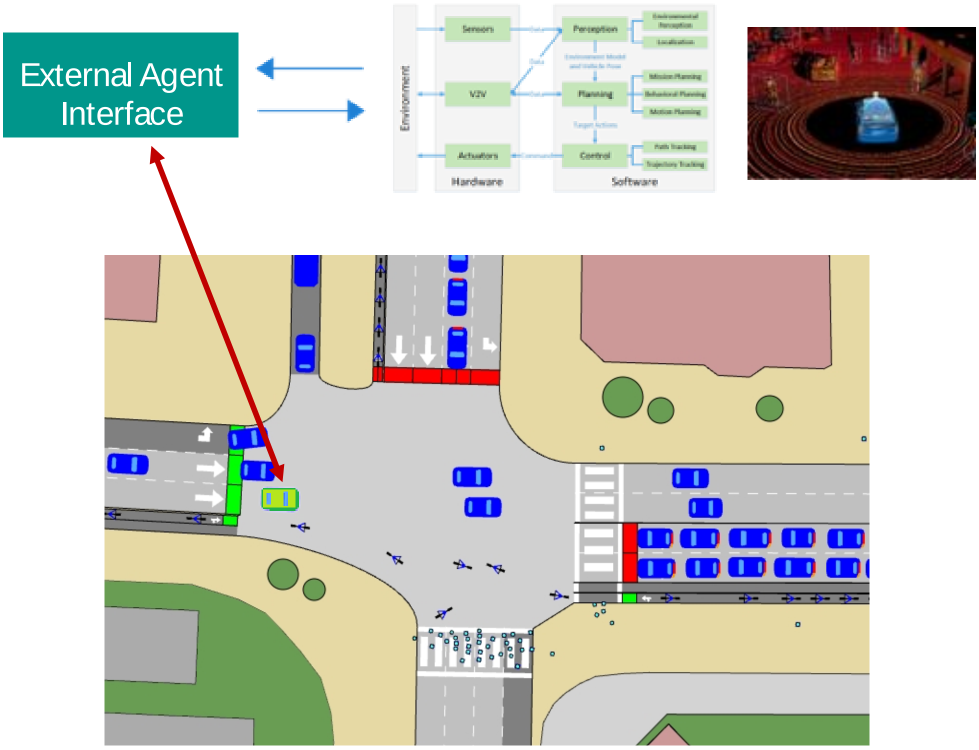

Figure 3.4 Aimsun Next External Agent Interface

Simulation of Connected Vehicles

Autonomous vehicles are controlled differently and have different decision-making behaviour from normal vehicles in the traffic network. In Aimsun Next, the physical and dynamic properties of a vehicle in a microsimulation have been specified by vehicle type: the size of a vehicle and its speed and acceleration have been determined by parameters set by type. Now, the decision-making parameters are also varied by vehicle type to enable a modeller tasked with investigating the effect of different vehicle behaviour on the traffic network and on the other vehicles in the network.
Where the decision-making is more complex than can be represented by parameter changes (such as simulating autonomous control software as it makes complex decisions about its path through the network and its reactions to vehicles in proximity to it), the controller can now include themselves in the simulation using a "Hardware-in-the-Loop"

method to present the controller with data about adjacent vehicles and to implement the actions of the controlled vehicle in the simulation.
Connected vehicles transmit and receive more information about their activity than conventional vehicles, and this information is also available to traffic control centres though ITS infrastructure. This enables new forms of vehicle behaviour through V2V communications - i.e., by platooning or by collaborative manoeuvres. It also enables new levels of traffic network control facilitated by the more detailed data available from connected vehicles through V2VI communications.

Simulation of Demand-responsive Transport

Demand-responsive transport applications can be also simulated with Aimsun Next. In the DRT simulation concept, the user(s) send a request, the DRT framework sends it to the operator(s) application and receives back the route and price. Once the users receive different trip options, combined with other transport modes, such as Public Transport, the DRT framework, applying a discrete choice models, determines the selected option.

3.4.2 Modelling of behavioural aspects

In general, during their journey through the network, vehicles are updated according to vehicle behaviour models: "Car-Following" and "Lane-Changing". Drivers tend to travel at their desired speed in each section but the environment (i.e. the preceding vehicle, adjacent vehicles, traffic signals, signs, blockages, etc.) will condition their behaviour. The simulation time is split into small time intervals called simulation cycles or simulation steps (t). This value can be set within the range ($0.1 \leq t \leq 1.5$ seconds). At each simulation cycle, the position and speed of every vehicle in the network is updated according to the following algorithm:

```
if (necessary to change lanes) then
    Apply Lane-Changing Model
endif
Apply Car-Following Model
```

Another behavioural model is the Gap-Acceptance model is used to model give way behaviour. This model determines whether a vehicle approaching an intersection can or cannot cross depending on the nearby vehicles with higher priority at the junction. This model considers the distance of vehicles to the hypothetical collision point, their speeds and their acceleration rates. It then determines the time needed by the vehicles to clear the intersection and produces a decision that also includes the level of risk of each driver. The modelling of the behavioural aspects of AVs is based on the driving logic that they use. The driving logics differ in their principles and capabilities. In Aimsun Next, three main driving behaviours are implemented and used for the simulations: aggressive, normal, cautious.

Aggressive: AVs with advanced perception and prediction technology. This behaviour leads to shorter clearance in car-following, short anticipation in lane changing and shorter gaps at intersections.

Cautious: these AVs present always a safe behaviour, which is translated to longer headways in the car-following model and longer gaps for intersections. Longer anticipation distance and clearance is adopted during lane changing. Nevertheless, cautious AV driving is still more aggressive than human driving.

Normal: human driver behaviour.

Table 3.1 presents the main assumptions on modelling the behavioural aspects of AVs for three driving logics that are implemented in Aimsun Next in relation to the microscopic behaviour models (car-following, lane changing, gap acceptance, overtaking, cooperation).

Table 3.1 AV assumptions on modelling behaviour aspects

	Car-Following	Lane Selection	Gap-Acceptance in Lane changing	Overtaking	Cooperation	Gap-Acceptance in Giveway
Aggressive	Short Clearance	Short anticipation distance	Small Clearance	Limited	NO	Small gaps
Cautious	Longer Clearance	Longer anticipation distance	Longer Clearance	Limited	NO	Longer Gaps

The modelling of AV's should consider a matrix of behaviours and degree of aggressiveness and its expected effect. For safety reasons, most AV's behaviours are expected to be more conservative than human ones, especially the ones requiring collaboration between drivers (e.g. Cooperation). Exceptions might arise for those behaviours in which AV's detection technology is superior to the partial or bias human perspective (e.g. Gap Acceptance) in which case similar behaviour is expected. With respect to the connectivity features of the AVs, the vehicles are assumed to be connected to traffic lights (as one example of V2I connectivity). Appropriate reaction times are used to simulate these behaviours.

Each of the behavioural models have a set of parameters that need to be defined. A short description of the parameters that are modified to model the different AV behaviours is presented below.

- Car-following:
    - *Sensitivity Factor*: In the deceleration component of the car-following model, the follower makes an estimation of the deceleration of the leader using the sensitivity factor.
- Lane Changing:
    - *Distance Zones*: The Distance Zones that control where decisions are made about which lane is required can be modified by vehicle type.
    - *Cooperation* and *Aggressiveness*: The Gap Acceptance Model for Lane Changing parameters that control the size of gap that a vehicle requires to make a lane change can be modified by vehicle type.
    - *Imprudent Lane Changes*: The Probability of using an unsafe gap can be set by vehicle type. This option allows a vehicle to accept a gap that requires it, or its follower, to brake up to twice their maximum

deceleration. Defines whether a vehicle of this type will still change lane after assessing an unsafe gap.

- Overtaking in Lane:
    - *Overtake Speed Threshold* and *Lane Recovery Speed Threshold*: These parameters control a vehicle's desire to overtake by making a lane change on a multi-lane carriageway.
- Gap Acceptance:
    - *Safety Margin*: In the Junction Give Way Model, this parameter controls how close vehicles may pass when assessing safe gaps to move into.
- Reaction Times:
    - *Reaction time in car following*: This is the time it takes a driver to react to speed changes in the preceding vehicle.
    - *Reaction time at stop*: This is the time it takes for a stopped vehicle to react to the acceleration of the vehicle in front.
    - *Reaction time at traffic light*: This is the time it takes for the first vehicle stopped after a traffic light to react to the traffic light changing to green.

The selection of the parameters´ values depends on the type of AV that is simulated. The relevant parameters and the recommended values are presented later in the section on Table 3.3.

3.4.3 Microscopic simulation outputs

Aimsun Next provides a wide range of simulation outputs that can be used to assess the system performance (traffic measures), safety, and environmental impacts. The traffic and environmental measures can be aggregated at different levels: network, section, turn movement, sub-path, as well as public transport lines. Traffic demand and individual vehicle (trajectories) statistics can also be collected. In particular, the traffic demand outputs provide statistics by OD Pair, by origin centroid and by destination centroid.

System performance

The system performance can be assessed using the following traffic measures obtained from the microscopic simulation:

- Speed
- Travel Times
- Delay Time
- Flow
- Queue
- Number of Lane Changes per vehicle
- Number of Stops per vehicle
- Stop time
- Total Distance Travelled
- Total Number Lane Changes
- Total Number of Stops
- Total Travel Time

Environmental assessment

Aimsun Next Microsimulation provides four Environmental Models, the Fuel Consumption Model, QUARTET Pollution Emission Model, Panis et al Pollution Emission Model and the London Emissions Model. When environmental models are used, some specific statistics are gathered by Aimsun Next at network, section, node, turn, sub-path, demand level as well as for public transport. Depending on which of the three available emission models is enabled in Aimsun Next, the following measures can be obtained:

- **Fuel Consumption**: total litres of fuel consumed inside the section by all the vehicles
- **Instant Emission**: for each pollutant, the total grams of pollution emission emitted by all the vehicles.
- **Pollutant Emission**: for each pollutant, total kilograms of pollution emitted by all the vehicles.

Road safety assessment

In order to assess the road safety, the Surrogate Safety Assessment Model (SSAM) inside Aimsun Next can be enabled. The SSAM is a software application developed by the Federal Highway Administration (FHWA) of the United States Department of Transportation (Gettman, Pu, Sayed, & Shelby, 2008) to automatically identify, classify, and evaluate traffic conflicts in the vehicle trajectory data output collected from microscopic traffic simulation models.

The results from microscopic simulations need to be scaled in terms of macroscopic variables for the integration of the various impact assessments into the PST.

3.5 Description of use-cases and simulation analysis

The use cases that are considered in the frame of Levitate are listed on Table 3.2. They are categorised as urban transport, passenger cars and freight transport cases. A short description of the sub-use cases that are investigated through simulation is also presented. For the different sub-use cases Aimsun Next Application Programming Interfaces (APIs) are implemented.

Table 3.2 Description of the use cases, the generic simulation approach and corresponding APIs

Use-Case	Description	Simulation approach	Aimsun API implementations
Passenger cars	Impacts of automated passenger cars on: • Road use pricing • Automated ride sharing • Reduction of parking space	• Path assignment modified based on changes in road and parking pricing	• Behaviour choice algorithm based on parking price

Use-Case	Description	Simulation approach	Aimsun API implementations
Urban transport	Impacts of cooperative, connected and autonomous vehicles on urban transport operations: • Point to point shuttles • Anywhere to anywhere shuttles • Last mile shuttles	• Autonomous Vehicle Type • Public transport lines definition • Dynamic Destination changes • Dedicated sections/lanes with Reserved sections/lanes	
Freight transport	Impacts of logistic concepts enabled by CATS: • Automated urban delivery • Local freight consolidation • Hub to hub automated transfer • Highway platooning	• Autonomous Vehicle Type • Dynamic Destination changes	• Demand of urban delivery vehicles • Rerouting algorithm • Short-term parking algorithm

The purpose of the API is to communicate between vehicle-based simulators and External applications. The approach taken in Aimsun Next is to consider an Advanced Telematic Application to be tested using the model as an external application that can communicate with the simulation.

Using the Aimsun Next API functions, data from the simulated network is transferred to the external application; the application applies its own algorithms to evaluate the situation in the simulation and responds with appropriate dynamic actions to be implemented in the simulation. The process of information exchange between the simulation and the external application is shown in Figure 3.5 below.

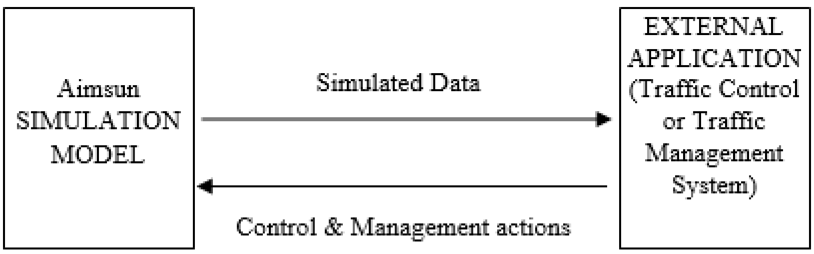

Figure 3.5 Process of information exchange between the simulation and the external application

The model of the road network emulates the detection process. Then, through a set of functions it provides the external application with the required "Simulation Detection Data" (e.g. flow, occupancy, etc.). The external application uses this data to evaluate its control policies and decides which control and/or management actions have to be applied on the road network. Finally, the external application sends, the corresponding actuations (e.g. change the traffic signal state, the phase duration, display a message in a VMS, etc.) to the simulation model, which then emulates their operation through the corresponding model components such as traffic signals, VMSs and ramp metering signs. Another use of the Aimsun Next API is to access to detailed vehicle simulated data and relay it to a user developed model (e.g. fuel consumption and pollution emissions), to keep track of a guided vehicle throughout the network by an external vehicle guidance system, or to simulate the activities of vehicles such as floating cars.

3.6 Simulation scenarios for the sub-use cases

The experimental design for the simulation scenarios for the sub-use cases are listed in Section 3.2 on Table 3.2.

3.6.1 Behavioural parameters used during the simulation

In relation to the microscopic behavioural models, adequate values need to be defined to simulate the different sub use-cases. Table 3.3 presents the recommended values for the parameters of two different types of AVs that are used in the different sub-use cases.

Table 3.3 Recommended values for the AV-related parameters. Adapted from (Mesionis & Brackstone, 2019)

	Vehicle Type								
	Cautious AV			**Aggressive AV**			**Human driver**		
Safety Margin factor:	1.25 - 1.75			0.75 - 1.25			1.00		
Car Following Model									
Sensitivity factor (Normally distributed):	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
	0.70	0.3	0.90	0.50	0.10	0.90	1.00	1.00	1.00
Vehicles Equipped with CACC:	0%			0%			0%		
Lane Changing Model									
Overtake Speed Threshold:	85%			85%			90%		
Lane Recovery Speed Threshold	95%			95%			95%		
Imprudent Lane Changing	No			No			Varies		
Aggressiveness Level	0			0.0 - 0.25			0.0 - 1.0		
Cooperate in Creating a Gap:	No			No			Yes		

	Vehicle Type								
	Cautious AV			Aggressive AV			Human driver		
	Lane changing Model								
Distance Zone factor:	Min		Max	Min		Max	Min		Max
	1.10		1.30	1.00		1.25	0.80		1.20
Reaction Times									
Reaction time in car following	0.1 sec			0.1 sec			0.8 sec		
Reaction time at stop	0.1 sec			0.1 sec			1.2 sec		
Reaction time at traffic light	0.1 sec			0.1 sec			1.6 sec		

4 Selection process and consolidated list of sub-use cases for CATS impact analysis

In this section the process of the finalisation of the sub-use cases that will be used in Levitate and the reasoning behind this is described.

In early stages of the project several sub-use cases in the form of applications or interventions have been discussed and added in a finally lengthy list. Project feasibility reasons demanded a selection and eventually a consolidation of the most appropriate ones within LEVITATE.

4.1 The decision-making exercise

The project coordinator team proposed and implemented the idea of a decision-making exercise that would facilitate that process. More specifically, an excel sheet (containing the list of sub-use cases) was created and sent to WP leaders to choose the sub-use cases that are most interested in or even add others. Moreover, a second excel sheet (with a table to fill) was sent to methods experts (experts in the proposed impact assessment methods) in order to evaluate the difficulty of applying the corresponding method to investigate the impact of the relevant sub-use case.

Category	Sub use cases	Remove (0) or Keep (1)
General		
Application	Geo-fencing based powertrain use	
Application	Green light optimized speed advisory	
Application	C-ITS day 1 services	
Application	C-ITS day 1.5 services	
Intervention	Road use pricing	
Intervention	Centralized traffic management	
Application	Urban platooning	
Intervention	Segregated pathway operations	
Application	Option to select route by motivation	
Application	Cluster-wise cooperative eco-approach and departure	
	New general 1	
	New general 2	
	New general 3	

Figure 4.1 Table of sub-use cases list

The table included the list of sub-use cases against the four impact dimensions in LEVITATE, safety, environment, society and economy and they were asked to score with 2, 1 or 0 the cases that were easy, hard or not possible to assess respectively. Figure 4.1 and Figure 4.2 are indicative screenshots of characteristic parts of these excel sheets while the full tables are placed in Appendix B. This decision-making exercise conducted before the third LEVITATE plenary meeting in The Hague where the results were thoroughly presented and discussed in order for all the partners to conclude in the final list of sub-use cases.

Category	Sub use cases	Impacts			
		Safety	Environment	Society	Economy
		Road safety	Propulsion energy, Energy efficiency, Vehicle emissions, Air pollution, Noise pollution,	Travel time, Travel comfort, Value of travel time, Access to travel, Route choice, Amount of travel, Road capacity, Congestion,Modal split of travel, Infrastructure wear, Infrastructure design, Optimisation of route choice, Vehicle ownership cost, Vehicle operating cost, Vehicle ownership rate, Shared mobility rate, Vehicle utilisation rate, Parking space, Traffic data availability, Trust in Technology, Public health, Geographic accessibility, Inequality in transport, Commuting distances	Public finances, Employment, Land use
Intervention	Introduction of a dynamic city toll for non-automated passenger cars	1	1	2	0
Intervention	Introduction of a dynamic city toll for all passenger cars	1	1	2	0
Intervention	Introduction of annual tax on non AV vehicle ownership	1	1	2	0
Intervention	Banning of parking inside city center - parking space for public use	1	1	2	0
Intervention	Banning of parking inside city center - parking space transformed to driving lanes	1	1	2	0
Intervention	Responsibility for accidents in AVs	0	0	0	0
Intervention	Introduction of centralized traffic management for Connected AVs	1	1	2	0
Intervention	Cybersecurity framework implementation	0	0	0	0

Figure 4.2 Table of sub-use cases against impact dimensions

4.2 Processing the feedback

The process described above was designed to aid the partners in considering the selection of sub-use cases in a more thoughtful way. Therefore, it was important to handle the feedback provided in the frame of this exercise with the corresponding attention.

Firstly, the information from the WP leaders was combined in a single file to aggregate the data by keeping the average from the 3 methods (Meta-analysis, Agent-based modelling and Dynamical Systems) experts tables. The aggregated table with the methods experts feedback (relevant screenshot in Figure 4.3) and the combined information from the WP leaders were finally added in a "master" file. The final document that created, facilitated the discussion among partners and sufficiently informed the decision regarding the sub-use cases which should be kept for further investigation in the frame of LEVITATE. Figure 4.4 depicts a screenshot of the aforementioned file.

Category	Sub use cases	Safety	Environme	Society	Economy
Application	Geo-fencing based powertrain use	1.0	1.3	1.7	0.3
Application	Green light optimized speed advisory	1.0	1.3	1.3	0.0
Application	C-ITS day 1 services	2.0	2.0	2.0	0.0
Application	C-ITS day 1.5 services	1.0	1.0	1.0	0.0
Intervention	Road use pricing	1.0	1.3	2.0	0.7
Intervention	Centralized traffic management	0.7	0.7	1.3	0.3
Application	Urban platooning	1.0	1.5	2.0	0.0
Intervention	Segregated pathway operations	1.0	1.5	2.0	0.0

Figure 4.3 Screenshot of aggregated methods feasibility table[3]

Category	Sub use cases	Bin	Hitesh	Julia	Safety	Environme	Society	Economy
		Remove (0) or Kee	ove (0) or Kee	ove (0) or Kee				
Intervention	Cybersecurity framework implementation		✖ 0	✖ 0	0.0	0.0	0.0	0.0

Figure 4.4 Screenshot of the combined feedback table

Table 4.1 indicates the values with which the methods experts have scored the sub-use cases regarding their feasibility (i.e. the level of difficulty for impact assessment with the corresponding method) in order to result in the aggregated table numbers while Figure 4.5 visualises the decision-making process.

[3] Full table is provided in Appendix B.

Table 4.1 Aggregated table metrics

	Agent-based modelling	Meta-Analysis	Dynamical Systems
0.3	1 (Hard)	0 (Not possible)	0 (Not possible)
0.5	1 (Hard)	0 (Not possible)	Not known
0.7	1 (Hard)	1 (Hard)	0 (Not possible)
	2 (Easy)	0 (Not possible)	0 (Not possible)
1	1 (Hard)	1 (Hard)	1 (Hard)
1.3	2 (Easy)	1 (Hard)	1 (Hard)
	2 (Easy)	2 (Easy)	0 (Not possible)
1.5	2 (Easy)	1 (Hard)	Not known
1.7	2 (Easy)	2 (Easy)	1 (Hard)
2.0	2 (Easy)	2 (Easy)	2 (Easy)

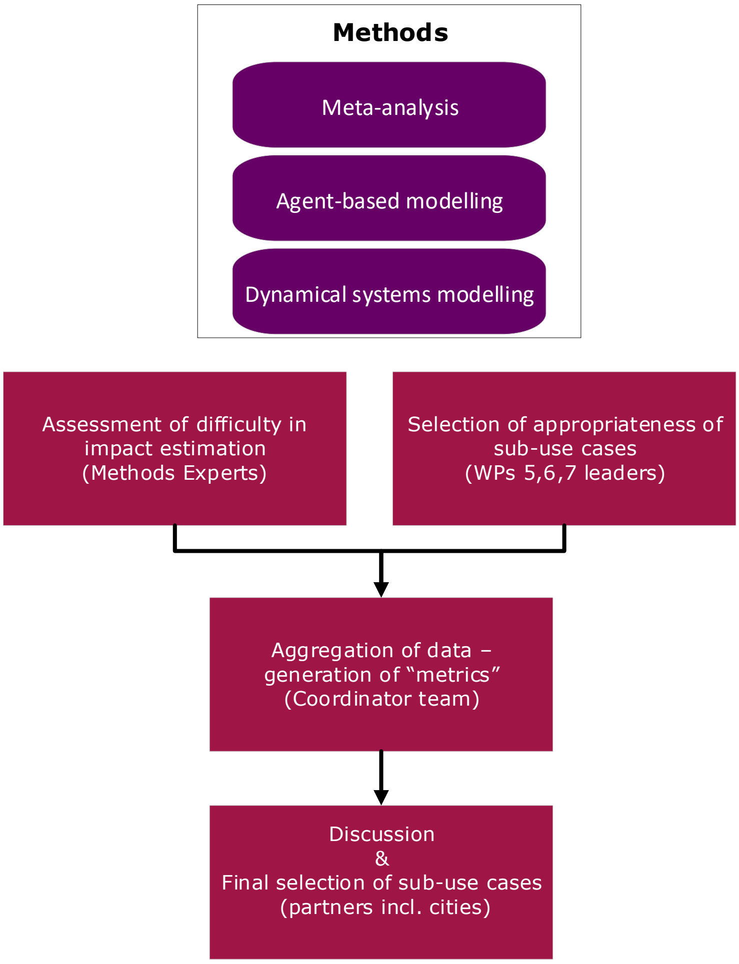

Figure 4.5 Decision-making process

4.3 Results – downselection of sub-use cases

Combining the feedback of the two actions revealed which sub-use cases should be kept or respectively dropped. There were cases where more discussion was needed though. More specifically, there were sub-use cases where:

(1) The methods could work easily, and WP leaders are interested (priority cases)

(2) All WP leaders are interested but they are not feasible by any method

(3) None of the methods can work and WP leaders are not interested (easily "dropped" cases).

In terms of the rest of them, one by one was discussed thoroughly among partners and cities regarding their usefulness and feasibility. Finally, the sub-use cases that was decided to be considered in the frame of Levitate are listed (per use-case) below in Table 4.2. It should be noted that this list includes the consolidated sub-use cases at the current stage of the project and could be possible to extend within the project progression.

Table 4.2 List of sub-use cases

Sub-use cases
Passenger cars
Road use pricing: • Empty km pricing • Static toll on non-automated vehicles • Static toll on all vehicles • Dynamic toll on non-automated vehicles • Dynamic toll on all vehicles
Automated ride sharing
Parking space regulation: • Parking price • Replace long-term parking with public space • Replace long-term parking with driving lanes • Replace long-term parking with short-term parking
Provision of dedicated lanes for AVs on urban highways

Sub-use cases
Urban transport
E-hailing (on-demand last mile shuttles)
Automated shuttles: • Point to point shuttles • Anywhere to anywhere shuttles • Last mile shuttles
Freight Transport
Automated urban delivery • Semi-automated delivery by CAV and staff • Fully-automated night delivery by CAV and robots
Local freight consolidation • Automated delivery via city-hubs • Automated re-stocking of city-hubs
Hub to hub automated transfer
Highway platooning • Platooning on city highways • Access control for bridges on city highways

4.4 Timewise implementation of sub-use cases

In this section, arrangements of sub-use cases (includes interventions) are presented on timeline. This is to see possible feasible combinations of those sub-use cases due to dependencies or due to availability of technologies. These sub-use cases are taken from the selection process within the project and were arranged by using information available from past and present research and development projects within Europe and beyond. The combinations presented are not assessed quantitatively but only qualitatively to foresee some dependencies.

Figure 4.6 shows interventions and sub-use cases that are arranged from year 2020 to 2040. The placement of text for each sub-use case is an approximation of the timepoint they might appear or could be implemented at their earliest. The length of text is not indicative of the sub-use case endpoint, but as the shape of the frame implies, it continues forever. It is understood that some implementation might happen at certain rate (ramp input) and others might happen with sudden change (step input). Also, some interventions could be lowered in their intensity after certain period. These considerations can be taken when modelling these interventions and sub-use cases. However, for simplicity, these details are not considered here at this stage.

Currently, there is huge amount of R&D activities in automating transport systems. This is mainly on the basis of economical gains it may bring due to increase in efficiencies and also increase of the safety. According to roadmap produced by Zenzic (Zenzic UK Ltd., 2019), it will be at least 2030 until necessary infrastructure, regulations and development will be in place to realise the AVs on road. For this reasons, most AV dependent sub-use cases are placed after 2030.

At present, the vision for autonomous shuttles is that they can optimise the service levels as well as routes where there is demand. Whilst this is a desire, the required efforts towards achieving that must be incremental steps. Currently, there are public trials being operated at selected routes only for point to point shuttles in the cities of Gothenberg, Vienna, Greater Manchester and, London, just to name a few. However, it is most likely that it will take another 5 years for the full testing of AV shuttles to be complete in a way that they can enter into public services. Also, point to point shuttles are the easiest form to implement as the route does not change and path planning and navigation algorithms can be optimised for a particular route. Changing destination (last mile shuttles) and also routes (anywhere to anywhere) will require substantial amount of R&D to reach the technological advancements needed. For this reasons, they are placed much later than point to point shuttles.

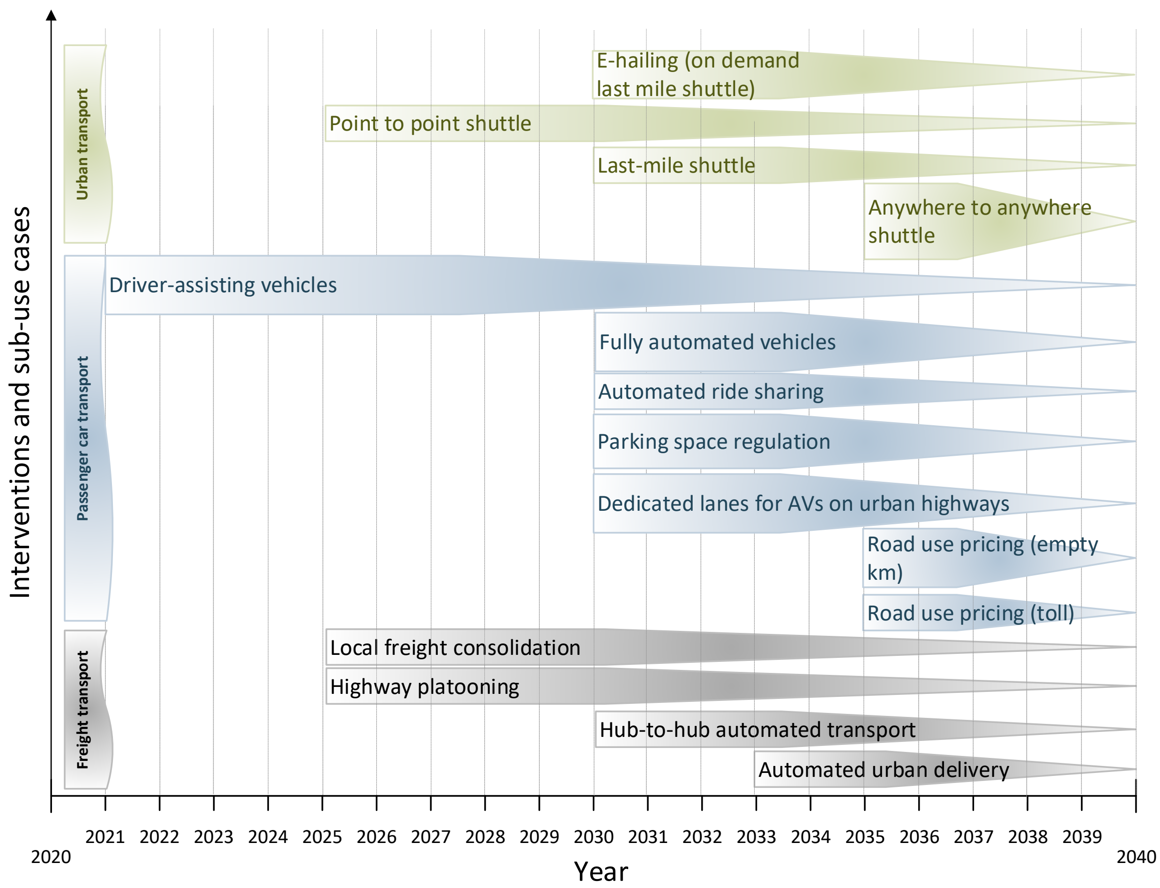

Figure 4.6 Combination of sub-use cases

Automated passenger cars are widely accepted to be categorised into 5 levels defined by SAE (SAE International, 2018). These are evolutionary steps of incremental autonomy and are aimed at technology developers. It is unclear how and when exactly these levels will be deployed and in practice, there is no clear distinction between levels when it comes to marketing of autonomous cars. However, there are fundamental differences in these levels at a higher level. This is the involvement of human driver. It is clear that human driver must be available for driving task up to certain level of car autonomy and therefore, it is expected that in terms of societal impacts, there will be a marginal difference due to involvement of humans. It may be reasonable to assume that the big impacts are anticipated when human is not required for the driving task, at all and this is the point when human travel behaviour and linked behaviours will significantly change compared to present days. Based on this thinking process, it is assumed that there will be driver assisted autonomous cars coming into the market in incremental steps and it will be around 10 years from now when the technology will mature enough to start deployment of fully automated vehicles.

Ride sharing is already happening with many firms like BlablaCar, Liftshare and UberPool app allows to share a vehicle/taxi (in case of Uber) between travellers who are heading towards the same direction. This is possible to continue in the context of CATS as well, and so this is considered to be available when CATS are available, around the year 2030. E-hailing for on demand last mile shuttles is considered the same way.

It is widely being debated that the autonomous vehicles will require less parking and therefore, this space could be changed into driving lanes to increase the road capacity or changed to leisure centres, parks, etc. for public use. However, this could negatively affect car user behaviours that may drive around for their short trips or cars that drive longer distances because they cannot find parking nearby for longer stops. To avoid such negative effects, road use pricing will need to be considered.

Local freight consolidation will alleviate city congestion due to fewer vehicles travelling at the same time and also improve environment due to less emission contribution. Thi concept is being studied worldwide (Duin, Quak, & Muñuzuri, 2010; Future City Logistics & Lambeth Council, 2019; Rooijen & Quak, 2010) for their feasibility and this will continue to be effective when automated transport will be a reality. This change in logistics will streamline the delivery of goods from hub to hub and further, to depots and homes. Hub to hub automated transport would be necessary to maximise the efficiencies in freight transportation and also harness potential safety and environmental benefits from automated transport. Furthermore, automated urban delivery could alleviate congestion arising from daytime economy greatly since they can be operated during the night time. This relies heavily on fully autonomous vehicles and therefore this application of use case may be possible much further, after the arrival of fully automated vehicles.

Highway platooning is a viable option because it delivers fuel efficiency. ZENZIC roadmap (Zenzic UK Ltd., 2019) suggests that the trials for platooning will be complete by 2025 and so it may be implemented after 2025. However, urban platooning does not seem to have substantial benefit in terms of fuel efficiency and also it complicates the signal timing requirements. So, for this reason it may not happen in foreseeable future and so it is not included for now.

Green Light Optimised Speed Advisory (GLOSA) is considered to be one of the use cases of connected vehicles. It advises the vehicle driver to either : 1) continue through the junction and avoid unneccessary braking or 2) apply brakes in advance to avoid harsh decceleration based on whether that vehicle will be or not be able to pass through the junction before the signal turning to red. Several projects have been run in the Europe who demonstrated this technological capability (C-Roads Germany, n.d.; JLR Newsroom, n.d.). It is not well understood what form of GLOSA will take place in the future and whether this will be implemented at all. So, this is left out of Figure 4.6 for now but not completely excluded from the assessment within the project.

Centralised traffic management has been researched widely. Currently, it is not yet well understood whether centralised or decentralised traffic management approach will provide the optimum control on traffic to reduce congestion (LD Baskar, 2006; Mitrovic, 2016; Monteil, 2012; de Souza, 2017). This may influence other sub-use cases such as segragated pathways, platooning, etc. However, this application is not considered at this stage.

4.5 Output variables

4.5.1 Feasible paths of interventions towards visions

Dialogues with cities aid to the identification of visions that are relevant to LEVITATE. Discussions included the city goals and the influencing factors for a specific point in the future while policy interventions are also proposed towards the goals' accomplishment.

City dialogues were utilised to align and refine the backcasting with recent developments. Discussions with stakeholders contributed to the definition of feasible paths of interventions towards the visions. The overall backcasting results for Vienna, Greater Manchester and Amsterdam are shown respectively in Figure 4.7, Figure 4.8 and Figure 4.9. For furher details, the reader should refer to Deliverable 4.3 of LEVITATE, (Zach et al., 2019).

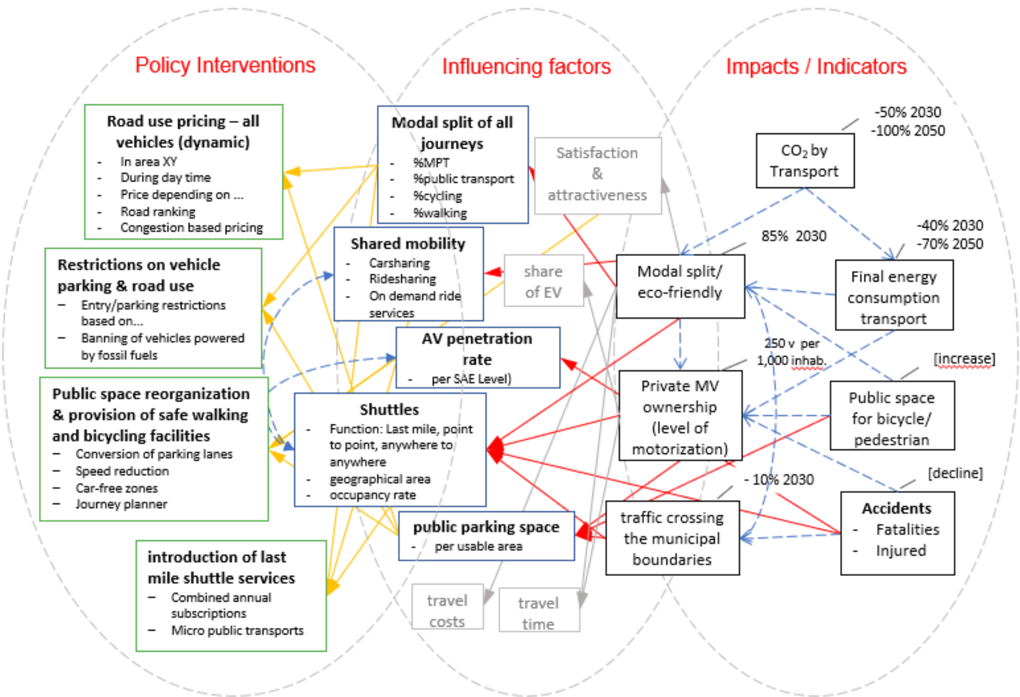

Figure 4.7 Backcasting for Vienna – Overview

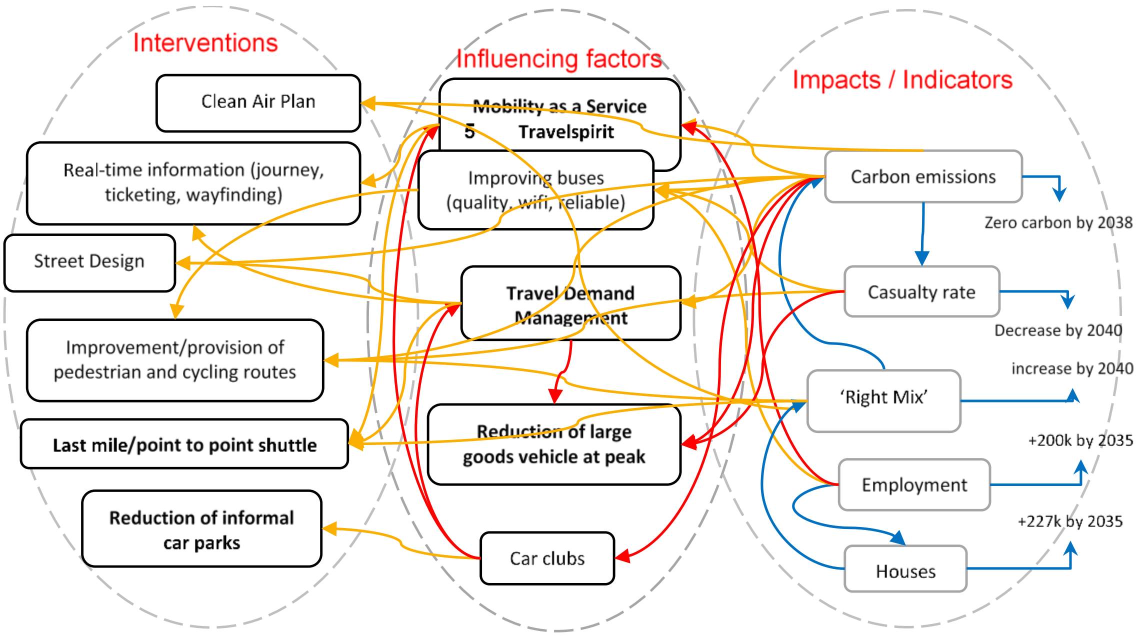

Figure 4.8 Backcasting for Greater Manchester

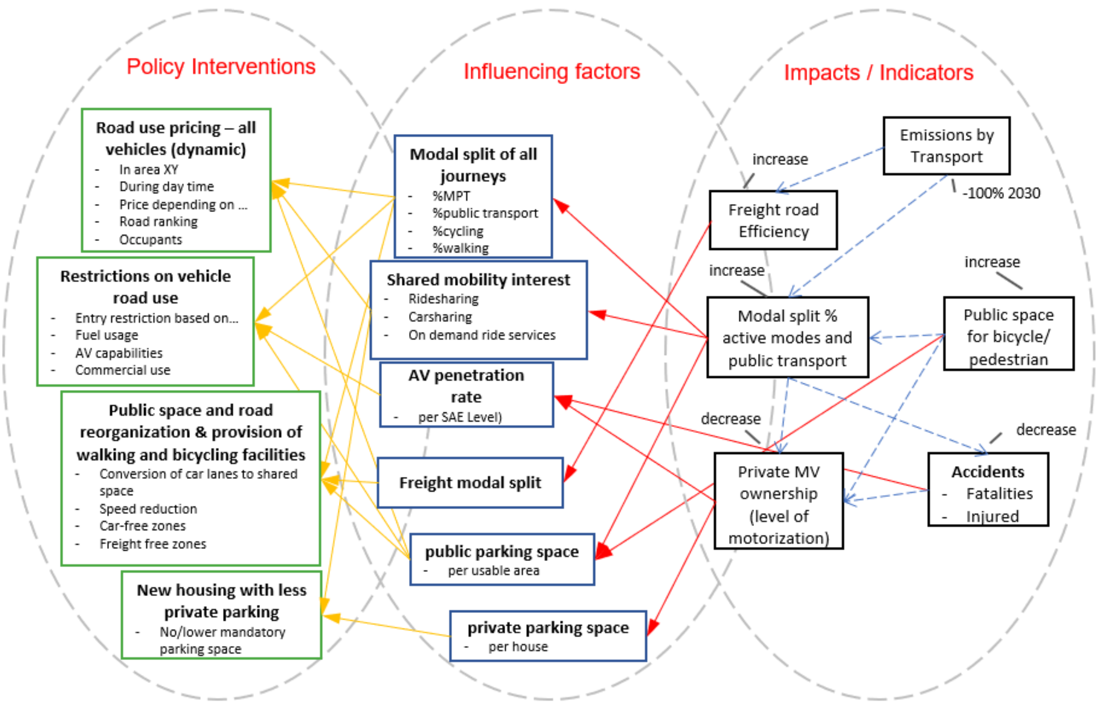

Figure 4.9: Backcasting for Amsterdam – Overview

As already mentioned in section 2.3, the results of these dialogues are mostly harmonised (e.g., regarding environmental goals), but different prioritisation of key targets and influencing factors can also be observed (e.g., regarding the significance of economic goals for cities' strategies).

4.5.2 Output variables for impact assessment

The main outcome of LEVITATE is a Policy Support Tool that will be able to inform policy makers and other stakeholders about necessary interventions or about the impact these will have in the future. Therefore, the discussions with cities played a very important role in the course of the project as it is essential to know the cities goals and priorities to plan accordingly for the development of a useful PST.

The LEVITATE consortium has considered the city dialogues and the nature of the consolidated sub-use cases and decided on the following output variables (Table 4.3) in order to assess CATS direct, systemic and wider impacts within four directions: safety, environment, society and economy.

Table 4.3 Output variables

Impact	Description / measurement	Unit of Measurement
	Direct impacts	
Travel time	Average duration of a 5Km trip inside the city centre	min
Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel	€/Km
Freight transport cost	Direct outlays for transporting a tonne of goods per kilometre of travel	€/(tonne·km)
Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)	-
	Systemic impacts	
Amount of travel	Person kilometres of travel per year in an area	Km
Congestion	Average delays to traffic (per vehicle · trip) as a result of high traffic volume	min
Modal split of travel using public transport	% of trip distance made using public transportation	%
Modal split of travel using active travel	% of trip distance made using active transportation (walking, cycling)	%
Shared mobility rate	% of trips made sharing a vehicle with others	%

Impact	Description / measurement	Unit of Measurement
Vehicle utilisation rate	% of time a vehicle is in motion (not parked)	%
Vehicle occupancy	average % of seats in use	%
Wider impacts		
Parking space	Required parking space in the city centre per person	m2/person
Road safety	Number of injury accidents in an area	accidents/year
Energy efficiency	Average rate (over the vehicle fleet) at which propulsion energy is converted to movement	%
NOX due to vehicles	Concentration of NOx pollutants per cubic metre of air (due to road transport only)	µg/m3
CO2 due to vehicles	Concentration of CO2 pollutants per cubic metre of air (due to road transport only)	µg/m3
PM10 due to vehicles	Concentration of PM10 pollutants per cubic metre of air (due to road transport only)	µg/m3
Public health	Subjective rating of public health state, related to transport (10 points Likert scale)	-
Inequality in transport	To which degree are transport services 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)	Km

5 Conclusions and outlook

A large part of this deliverable constitutes an overview of WP4 of LEVITATE and its implications for the further work in the project, while it also refers to a part of WP3 regarding the methodologies that will be implemented within the project to assess the impacts of CATS. The selection process along with the consolidated list of sub-use cases/interventions are detailed and an informed attempt to present the interventions in a sequence has been performed, according to the timing they may be implemented. Finally, the output variables from forecasts of interventions have been listed to fullfill the scope of WP4 and set the scene for the next steps in WPs 5, 6, 7.

The feasible paths of intervention, as defined in deliverable 4.3, are characterised by the areas of policy interventions, the influencing factors and their connections to the targets of the vision. The focus of this deliverable has been on the sequence and timing of the policy interventions, and a well-informed diagram with their timewise implementation has been developed. By determining the sequence of different interventions and the forecasting methods that will be employed to test the direct, systemic and wider impacts of CATS, the paths of scenarios that should be tested in WP5,6 and 7 could be refined. In the frame of WP5, 6 and 7, it will be further investigated whether some sub-use cases could be combined, providing bundles of interventions. Certainly, the employed methodologies, e.g. historical or retrospective methods, Delphi surveys, micro- and mesoscopic simulations, system dynamics, etc. played a crucial role in the final selection of the interventions /sub-use cases that are listed in this deliverable.

The discussions with the cities constituted a very important part of WP4 as the knowledge of what cities consider significant regarding their future visions is critical for the course of the LEVITATE project and especially for the development of the PST. All the steps taken in the frame of WP4 contributed towards the decision making for the sub-use cases that should be investigated later in WP5, 6 and 7. The paths of the interventions, the interventions per se and the methods to assess the relative impacts of CATS have been identified, and this paves the way for the selection and implementation of the most suitable scenarios to test. This procedure will take place during the realisation of the next WPs (WPs 5, 6, 7) where the results will be presented including details concerning the number and the specifications of the scenarios.

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Appendix A

Used Terminology

Following definitions that have been discussed in LEVITATE across the work packages are relevant for this deliverable; these are the terms that are proposed to be used throughout the project:

Table A.1 Terminogy within LEVITATE

Term	***Description***	***Examples***
Impact categorisation	In order to simplify the categorisation of CATS impacts, two main categories are identified: (1) Direct impacts: impacts that are produced directly from the introduction of CATS on the transport system such as vehicle design and driving behaviour. (2) Indirect impacts: impacts that are a by-product of the direct impacts of CATS. For example, driving behaviour will affect road user interaction and therefore road safety which is an indirect impact.	
Policy	Definition: A set of ideas or a plan of what to do in the future in particular situations that has been agreed to officially by a group of people, a business organisation, a government or a political party.	Environmentally friendly, social equity, increase in health, liveability
Policy goals / Policy objectives	Definition: A single target within the whole policy (should be SMART) Should be third order impacts, which are wider impacts e.g. societal and are usually not directly transport related.	One of the European 20-20-20 Targets: The 2020 energy goals are to have a 20% (or even 30%) reduction in CO2 emissions compared to 1990 levels.
Policy interventions / measures	Definition: An intervention is an action undertaken by a policy-maker to achieve a desired objective. Interventions may include educational programs, new or stronger regulations, technology and infrastructure improvements, a promotion campaign.	Introduction of a city toll, conversion of driver license training, dedicated lanes for automated vehicles
Vision	Definition: Description of a future situation defined by a bundle of vision characteristics and dedicated at a specific point in time. Note that this term is used instead of the term "desired future scenario" that was used in the project proposal, in order to avoid any confusions with simulation scenarios in LEVITATE context	The case of Vienna (modal share, mobility demand, penetration rate of automated vehicles of level x, …)
Vision characteristic	Definition: An indicator representing a policy goal that has to be achieved at a certain time. A single target within the vision in the level of first and second order	Number of accidental deaths, particulate

	impacts (which occur in the transport system, on a trip-by-trip basis / which involve system-wide changes in the transport system).	pollution, noise, public green space.
Transformation Path	Definition: A postulated sequence or development of policy interventions / measures (and external events/measures/conditions) driving from a vision 'A' at time 'X' (which can be the current situation) to a vision 'B' at time 'Y'.	Situation now in Vienna (modal share, mobility demand, penetration rate of automated vehicles of level x, …), measures: campaign in 2020, funding for dedicated research in 2025, restricted access to freight in 2025, city toll in 2028; situation in 2030: (specified modal shift, expected mobility demand, penetration rate of automated vehicles of level x, …)

Appendix B

Table B.1 Aggregated average from scores given by method experts.

Use Case	Category	Sub use cases	Safety	Environment	Society	Economy
Freight	Intervention	Road use pricing	1.0	1.3	2.0	0.7
Freight	Application	Point to point shuttle	1.0	1.3	1.3	0.7
Freight	Application	Anywhere to anywhere shuttle	1.0	1.3	1.3	0.7
Freight	Application	Last-mile shuttle	1.0	1.3	1.3	0.7
Freight	Application	e-hailing (on demand last mile shuttle)	0.5	1.0	1.0	0.3
Freight	Application	Automated ride sharing	0.5	1.0	1.0	0.3
Freight	Intervention	Introduction of a static city toll for non-automated passenger cars	1.0	1.7	2.0	0.7
Freight	Intervention	Introduction of a static city toll for all passenger cars	1.0	1.7	2.0	0.7
Freight	Intervention	Introduction of a dynamic city toll for non-automated passenger cars	1.0	1.7	2.0	0.7
Freight	Intervention	Introduction of a dynamic city toll for all passenger cars	1.0	1.7	2.0	0.7
Freight	Intervention	reduction of parking space by X% - parking space for public use	0.7	1.3	1.7	0.7
Freight	Intervention	reduction of parking space by X% - parking space transformed to driving lanes	1.0	1.7	2.0	0.7
Freight	Intervention	Autopark -> Pricing on empty vehicles	1.0	1.7	2.0	0.7
Freight	Application	Automated urban delivery	1.0	1.5	1.5	0.3
Freight	Application	Local freight consolidation	0.0	1.0	1.0	0.5

Use Case	Category	Sub use cases	Safety	Environment	Society	Economy
Freight	Application	Green light optimised speed advisory	1.0	1.3	1.3	0.0
General	Intervention	Centralised traffic management	0.7	0.7	1.3	0.3
General	Application	Urban platooning	1.0	1.5	2.0	0.0
General	Intervention	Segregated pathway operations	1.0	1.5	2.0	0.0
General	Application	Hub to hub automated transfer	1.0	2.0	2.0	0.0
General	Intervention	Introduction of annual tax on non AV vehicle ownership	0.3	1.0	1.3	0.7
General	Application	Highway platooning	1.0	1.0	1.3	0.0
General	Application	Geo-fencing based powertrain use	1.0	1.3	1.7	0.3
General	Application	C-ITS day 1 services	2.0	2.0	2.0	0.0
General	Application	C-ITS day 1.5 services	1.0	1.0	1.0	0.0
General	Application	Option to select route by motivation	0.0	1.0	1.0	0.7
General	Application	Cluster-wise cooperative eco-approach and departure	0.0	0.0	0.0	0.0
General	Intervention	de-centralised traffic management				
Passenger	Scenario	On road operations	0.5	1.0	1.0	0.0
Passenger	Intervention	Street design implications	0.5	0.5	0.5	0.0
Passenger	Application	Multi-modal integrated payments	0.0	1.0	1.0	0.7
Passenger	Application	Campus shuttle	1.0	2.0	1.5	0.3
Passenger	Intervention	Responsibility for accidents in AVs	0.0	0.7	0.7	0.7
Passenger	Intervention	Introduction of centralised traffic management for Connected AVs	0.7	1.0	1.5	0.0
Passenger	Intervention	Cybersecurity framework implementation	0.0	0.0	0.0	0.0

Use Case	Category	Sub use cases	Safety	Environment	Society	Economy
Passenger	Intervention	Introduction of Automated Multi Purpose Vehicles for Freight and Passengers Transport	0.0	0.5	0.5	0.3
Passenger	Technology	SAE L2/3/4 automation	0.7	1.0	1.3	0.3
Passenger	Technology	SAE L5 automation	0.7	1.0	1.3	0.3
Passenger	Technology	Highway pilot	0.7	1.0	1.5	0.0
Passenger	Technology	(Cooperative) Adaptive Cruise Control	1.0	1.3	1.5	0.0
Passenger	Application	Traffic jam pilot	1.0	1.0	1.3	0.0
Passenger	Technology	In-vehicle signage	0.3	0.5	1.0	0.0
Passenger	Intervention	Introduction of a static city toll for non-automated passenger cars	1.0	1.3	1.7	0.3
Passenger	Intervention	Introduction of a static city toll for all passenger cars	1.0	1.3	1.7	0.3
Passenger	Intervention	Introduction of a dynamic city toll for non-automated passenger cars	1.0	1.3	1.7	0.3
Passenger	Intervention	Introduction of a dynamic city toll for all passenger cars	1.0	1.3	1.7	0.3
Passenger	Intervention	Provision of economic incentive for purchase of AV - passenger car	0.3	1.0	1.3	0.3
Passenger	Intervention	Provision of economic incentive for purchase of electric AVs	0.3	1.0	1.3	0.3
Passenger	Intervention	Introduction of annual tax on non AV vehicle ownership	0.3	1.0	1.3	0.3
Passenger	Intervention	Banning of parking inside city center - parking space for public use	0.7	1.3	1.7	0.7
Passenger	Intervention	Banning of parking inside city center - parking space transformed to driving lanes	1.0	1.7	2.0	0.7
Passenger	Intervention	Reduce minimum allowed headway between automated passenger cars	1.0	1.0	1.3	0.0
Urban	Intervention	Responsibility for accidents in AVs	0.0	0.3	0.3	0.3

Use Case	Category	Sub use cases	Safety	Environment	Society	Economy
Urban	Intervention	Introduction of centralised traffic management for Connected AVs	0.5	0.5	0.5	0.0
Urban	Intervention	Cybersecurity framework implementation	0.0	0.0	0.0	0.0
Urban	Intervention	Introduction of point to point shared mobility as a service (MaaS)	1.0	1.5	1.5	0.3
Urban	Intervention	Introduction of point to point non-shared mobility as a service (MaaS)	1.0	1.5	1.5	0.7
Urban	Intervention	Cross-border interoperability of CATS	0.0	0.5	0.5	0.7
Urban	Intervention	Provision of dedicated lanes for AVs	1.0	1.0	1.7	0.3
Urban	Intervention	Street design optimised for urban AV shuttles	1.0	2.0	2.0	0.0
Urban	Intervention	Intelligent access control for infrastructure/bridge	1.0	1.0	1.3	0.0
Urban	Application	Automated intermodal transport	1.0	1.5	1.5	0.3
Urban	Application	Multi purpose vehicles	0.0	1.0	1.0	0.5
Urban	Intervention	Provision of economic incentive for purchase of AV - freight transport	0.0	0.5	0.5	0.3
Urban	Intervention	Responsibility for accidents in AVs	0.0	0.0	0.3	0.0
Urban	Intervention	Introduction of centralised traffic management for Connected AVs	0.5	0.5	0.5	0.0
Urban	Intervention	Cybersecurity framework implementation	0.0	0.0	0.0	0.0
Urban	Intervention	Dynamic trucks platooning	0.5	0.5	0.5	0.0
Urban	Intervention	Provision of dedicated lanes for AVs	1.0	1.0	1.3	0.3

Table B.2 Assessment of appropriateness of sub-use cases by WP leaders. 1 = keep, 0 = remove.

Use Case	Category	Sub use cases	WP7 leader	WP6 leader	WP5 leader
Freight	Intervention	Road use pricing	1	1	1
Freight	Application	Point to point shuttle	1	1	1
Freight	Application	Anywhere to anywhere shuttle	1	1	1
Freight	Application	Last-mile shuttle	1	1	1
Freight	Application	e-hailing (on demand last mile shuttle)	0	1	0
Freight	Application	Automated ride sharing	1	1	1
Freight	Intervention	Introduction of a static city toll for non-automated passenger cars	1	1	1
Freight	Intervention	Introduction of a static city toll for all passenger cars	1	1	1
Freight	Intervention	Introduction of a dynamic city toll for non-automated passenger cars	1	0	1
Freight	Intervention	Introduction of a dynamic city toll for all passenger cars	1	1	1
Freight	Intervention	reduction of parking space by X% - parking space for public use	1	1	1
Freight	Intervention	reduction of parking space by X% - parking space transformed to driving lanes	1	1	1
Freight	Intervention	Autopark -> Pricing on empty vehicles	1	1	1
Freight	Application	Automated urban delivery	1	1	1
Freight	Application	Local freight consolidation	1	1	1
Freight	Application	Green light optimised speed advisory	1	1	1

Use Case	Category	Sub use cases	WP7 leader	WP6 leader	WP5 leader
General	Intervention	Centralised traffic management	1	1	1
General	Application	Urban platooning	1	1	1
General	Intervention	Segregated pathway operations	1	1	1
General	Application	Hub to hub automated transfer	1	1	1
General	Intervention	Introduction of annual tax on non AV vehicle ownership	1	0	1
General	Application	Highway platooning	1	1	1
General	Application	Geo-fencing based powertrain use	1	1	0
General	Application	C-ITS day 1 services	0	1	1
General	Application	C-ITS day 1.5 services	0	1	1
General	Application	Option to select route by motivation	0	1	0
General	Application	Cluster-wise cooperative eco-approach and departure	0	1	0
General	Intervention	de-centralised traffic management		1	
Passenger	Scenario	On road operations	1	0	0
Passenger	Intervention	Street design implications	0	0	1
Passenger	Application	Multi-modal integrated payments	0	1	1
Passenger	Application	Campus shuttle	0	0	0
Passenger	Intervention	Responsibility for accidents in AVs	0	1	0

Use Case	Category	Sub use cases	WP7 leader	WP6 leader	WP5 leader
Passenger	Intervention	Introduction of centralised traffic management for Connected AVs	1	0	1
Passenger	Intervention	Cybersecurity framework implementation	0	0	0
Passenger	Intervention	Introduction of Automated Multi Purpose Vehicles for Freight and Passengers Transport	1	1	0
Passenger	Technology	SAE L2/3/4 automation	0	1	0
Passenger	Technology	SAE L5 automation	0	1	0
Passenger	Technology	Highway pilot	1	1	0
Passenger	Technology	(Cooperative) Adaptive Cruise Control	1	1	0
Passenger	Application	Traffic jam pilot	1	1	0
Passenger	Technology	In-vehicle signage	1	1	0
Passenger	Intervention	Introduction of a static city toll for non-automated passenger cars		0	0
Passenger	Intervention	Introduction of a static city toll for all passenger cars		0	0
Passenger	Intervention	Introduction of a dynamic city toll for non-automated passenger cars		0	0
Passenger	Intervention	Introduction of a dynamic city toll for all passenger cars		0	0
Passenger	Intervention	Provision of economic incentive for purchase of AV - passenger car		1	0
Passenger	Intervention	Provision of economic incentive for purchase of electric AVs		1	0

Use Case	Category	Sub use cases	WP7 leader	WP6 leader	WP5 leader
Passenger	Intervention	Introduction of annual tax on non AV vehicle ownership		0	0
Passenger	Intervention	Banning of parking inside city center - parking space for public use		1	0
Passenger	Intervention	Banning of parking inside city center - parking space transformed to driving lanes		1	0
Passenger	Intervention	Reduce minimum allowed headway between automated passenger cars		0	0
Urban	Intervention	Responsibility for accidents in AVs		1	0
Urban	Intervention	Introduction of centralised traffic management for Connected AVs		1	1
Urban	Intervention	Cybersecurity framework implementation		0	0
Urban	Intervention	Introduction of point to point shared mobility as a service (MaaS)		1	1
Urban	Intervention	Introduction of point to point non-shared mobility as a service (MaaS)		1	1
Urban	Intervention	Cross-border interoperability of CATS		0	0
Urban	Intervention	Provision of dedicated lanes for AVs		1	1
Urban	Intervention	Street design oprimised for urban AV shuttles		0	0
Urban	Intervention	Intelligent access control for infrastructure/bridge	1	1	0
Urban	Application	Automated intermodal transport	0	0	1
Urban	Application	Multi purpose vehicles	1	1	0

Use Case	Category	Sub use cases	WP7 leader	WP6 leader	WP5 leader
Urban	Intervention	Provision of economic incentive for purchase of AV - freight transport	1	1	0
Urban	Intervention	Responsibility for accidents in AVs		0	0
Urban	Intervention	Introduction of centralized traffic management for Connected AVs		0	0
Urban	Intervention	Cybersecurity framework implementation		0	0
Urban	Intervention	Dynamic trucks platooning		1	0
Urban	Intervention	Provision of dedicated lanes for AVs		0	0