D8.1 Integration of outputs of WP4-7

WP8 – Deliverable D8.1 – NTUA

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

D8.1 Integration of outputs of WP4-7

Work package 8, Deliverable D8.1

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Legal Disclaimer

List of abbreviations

AUSS	Automated Urban Shuttle Service
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CAV	Connected and automated vehicle
CAFE	Corporate Average Fuel Economy
CBA	Cost-benefit analysis
CBR	Cost-Benefit Ratios
CCAM	Cooperative, Connected and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
CMF	Crash Modification Factor
CV	Connected Vehicle
DisA	Distraction Alert
DrowA	Drowsiness Alert
ERTRAC	European Road Transport Research Advisory Council
EU	European Union
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FORS	Fleet Operation Recognition Scheme
GDPR	General Data Protection Regulation
GLOSA	Green Light Optimal Speed Advisory
HSM	Highway Safety Manual
IMA	Intersection Movement Assist
IMF	Impact Modification Factors
ISA	Intelligent Speed Assist
IVS	In-vehicle Signage
LCA	Lane Change Assist
LDW	Lane Departure Warning
LKA	Lane Keeping Assist
MPR	Market Penetration Rate
mUoM	marginal Utility of Money
NHTSA	National Highway Traffic Safety Administration
NRC	National Research Council
PI	Policy Implementation
PST	Policy Support Tool
SAE	Society of Automotive Engineers
SRG	Stakeholder Reference Group
SUC	Sub-Use Case
TA	Turn Assist
TTC	Time to Collision
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to everything
VKT	Vehicle Kilometers Travelled
VOC	Vehicle Operating Cost

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Executive summary

The aim of the LEVITATE project is to prepare a new impact assessment framework to enable policymakers to manage the introduction of cooperative, connected, and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives. As part of this work, the LEVITATE project seeks to forecast societal level impacts of cooperative, connected, and automated mobility (CCAM), by developing an open access web-based Policy Support Tool (PST).

This report specifically focuses on the integration of outputs from Work Packages (WPs) 4 to 7, in order to create the LEVITATE PST. More precisely, in WP4 an analysis of the cities desirable future (D4.2 – Zach et al., 2019) took place in order to identify the feasible paths of interventions (D4.3 – Zach et al., 2019) and thus define the policy interventions (sub-use cases), the forecasting methodologies and the necessary outputs to be included in the PST. The list of proposed sub-use cases developed in D4.4 (Papazikou et al., 2020) was studied in WPs 5, 6 and 7, which represent the three use cases studied in LEVITATE: automated urban transport, automated passenger cars and automated freight transport, respectively. The impacts to be studied were defined in D3.1 (Elvik et al., 2019), which provided a preliminary taxonomy of the potential impacts of CCAM, and each of these WPs proceeded to the impact assessment of the proposed interventions using the methodologies described in D4.4.

The Policy Support Tool will integrate the methodologies and findings of WPs 4 to 7, in order to develop an overall framework for the assessment of impacts, benefits and costs of CCAM for different automation and penetration levels and on different time horizons, as well as a public toolkit and a decision support system allowing the testing of various policy scenarios on the basis of the needs of relevant stakeholders. The PST will be an open access, web-based system that will provide future users with access to LEVITATE methodologies and results. The PST comprises two main modules: the Knowledge module (static component) and the Estimator module (dynamic component). The knowledge module aims to provide a searchable static repository through fully detailed and flexible concise reports. The concise reports aim to inform the user in the most essential and summarizing way, offering the necessary information on CCAM impacts. More specifically, the user is able to search by any parameter, to adjust and customize the search according to preliminary results and to access all background information about any stage of the project. The estimator module will provide estimates for different types of impacts and allow comparative analyses. It includes four pillars of analysis: (i) forecasting, serving as the basis of predicting the quantitative and qualitative estimated impacts for different horizons, (ii) backcasting, serving as the basis of acquiring relevant policy targets for each impact area, (iii) cost-benefit analysis, serving as the basis of monetizing costs and benefits of CCAM interventions and (iv) case study examples, serving as a basis for documented applied paradigms of CCAM interventions within real-world environments at a city level.

1 Introduction

1.1 LEVITATE

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

Specifically LEVITATE has four key objectives:

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

1.2 Work package 8 and Deliverable 8.1 within LEVITATE

Within LEVITATE, WP8 is the Work Package responsible for creating and designing the LEVITATE Policy Support Tool, establishing its modules, standardizing the inputs of the different methodologies used within the project in WPs 4-7, and populating the PST with results, case study analyses and impact assessments, and documentation of the methodologies. The objectives of WP8 include:

- Consolidation of the outputs of WPs 4-7 into an overall framework for the assessment of impacts, benefits and costs of CCAM;
- Analysis of user needs for a decision support tool to assist in the analysis of urban policy scenarios and targets;

- Development and implementation of a toolkit and a decision support tool to demonstrate the added value by means of a set of analyzed scenarios for selected cities and use cases;
- Policy recommendations.

The purpose of Deliverable 8.1 is to perform the decomposition of estimated impacts per different scenario, use case and time horizon along with the integration of the impacts within combined use cases. This allows the development of an enhanced repository of impacts, costs and benefits, forming the basis of the knowledge module of the PST, as well as models, algorithms and other estimation tools bringing together the results of individual case studies in a combined way and enabling their feeding into the estimator module.

1.3 Earlier work and involvement of other work packages

In the early phases of the project, in D3.1 (Elvik et al., 2019), a taxonomy of potential impacts of connected and automated vehicles at different levels of implementation was presented. From there, methods for predicting and quantifying impacts were surveyed in D3.2 (Elvik et al., 2019). This included a distinction of variables that are direct, systemic and wider impacts. The final list of studied variables in LEVITATE was then determined in various meetings within the consortium. Based on that taxonomy and on feasible paths of interventions defined by D4.3 (Zach et al., 2020), the estimation, delevopment of techniques and specifications was then done in use-case work packages (urban transport (WP5), passenger cars (WP6) and freight transport (WP7)), in parallel to the development of the general methodology for conducting a CBA for measures handling the new autonomous vehicles.

1.4 Overview of the LEVITATE Policy Support Tool

The LEVITATE Policy Support Tool (PST) is envisioned to be the go-to, one-stop-shop to support decisions on CCAM-related interventions. It is expected to be used by city authorities, transport planners and engineers, transport researchers and interested citizens and NGOs.

It is designed as an open access, web-based system that will provide interested users with access to LEVITATE methodologies and results. The detailed design will take into account the specific needs of the key stakeholders and it will provide access to related bibliography, project results, documentation of tools and methods, excerpts from CCAM guidelines, as well as a Policy Support Tool with forecasting and backcasting capabilities.

The LEVITATE PST is designed as a user-friendly, dynamic and interactive policy support tool, which can be used to support decision making related to the introduction of CCAM in the urban environment. For the purposes of this project, short-, medium- and long-term impacts would be those defined by D3.1 (Elvik et al., 2019) as direct, systemic and wider impacts, respectively. Based on that taxonomy and on feasible paths of interventions defined by D4.3 (Zach et al., 2019) the impact assessment took place for the introduction of CCAM in urban transport (WP5), passenger cars (WP6) and freight transport (WP7). The outcomes of the impact assessment are integrated in the LEVITATE

PST. The impacts have been estimated and forecasted using appropriate assessment methods suggested by D3.2 (Elvik et al., 2019) . The methods used are the microscopic simulation, mesoscopic simulation, system dynamics, operations research and the Delphi method.

Based on the above concept, the LEVITATE PST comprises two main modules: the Knowledge module (static component) and the Estimator module (dynamic component). A graphical representation of the Tool, the two modules and the various sub-systems within each module is presented in Figure 1.1. This concept figure was utilized during development to provide direction towards a comprehensive PST; it is not a representation of the final visual interface of the system.

The **Knowledge module** provides access to the knowledge base, repository and guidelines of LEVITATE project, namely:

- the bibliography,
- the project results, including the case studies on the participating cities (scenarios and baseline conditions, results) and the predefined impact assessments,
- the documentation of LEVITATE Tools and methods, to enable cities to explore the expected impacts of CCAM,
- excerpts from CCAM suggested Guidelines and Policy Recommendations.

The **Estimator module** provides estimates for different types of impacts (including cost-benefit ratios) and allows comparative analyses. It will include two sub-systems:

- the **Forecasting sub-system** provides quantified output on the expected impacts of CCAM related policies, using both pre-defined key scenarios and customised scenarios;
- the **Backcasting sub-system** enables users to identify the sequences of CCAM measures that are expected to result in their desired policy objectives.

Both sub-systems will include Cost-Benefit Analysis estimators, which will quantify the efficiency of the selected policy interventions, in terms of changes in infrastructure user surplus, external costs, and the income change minus implementation costs (plus tax financing cost) for policy-making entities which implement each considered policy scenario.

For the development of the LEVITATE PST, knowledge and expertise from past online decision-support systems was exploited, such as the SafetyCube DSS (www.roadsafety-dss.eu), the PRACT repository (www.pract-repository.eu) and the SafeFITS tool (https://unecetrans.shinyapps.io/safefits/).

A series of steps had to be undertaken to combine and integrate the inputs of the individual contributing methodologies and activities, undertaken in WPs 4 to 7 within LEVITATE, in order to create this interactive tool. Specifically:

1. A common input Excel-based template was devised
2. Common scenarios were established, governed by different MPR progression of CCAM

3. Different methods provided input for each impact across different key MPR mixtures
4. The intermediate points were calculated with linear interpolation, formulating the full PST datasets
5. Capabilities describing the temporal lag of policy intervention introduction were introduced
6. Measure effectiveness and intensity capabilities were introduced
7. Forecasting and backcasting processes could be then conducted
8. CBA modules were created and operated based on the underlying datasets, and on user specification made during the forecasting and backcasting processes as well

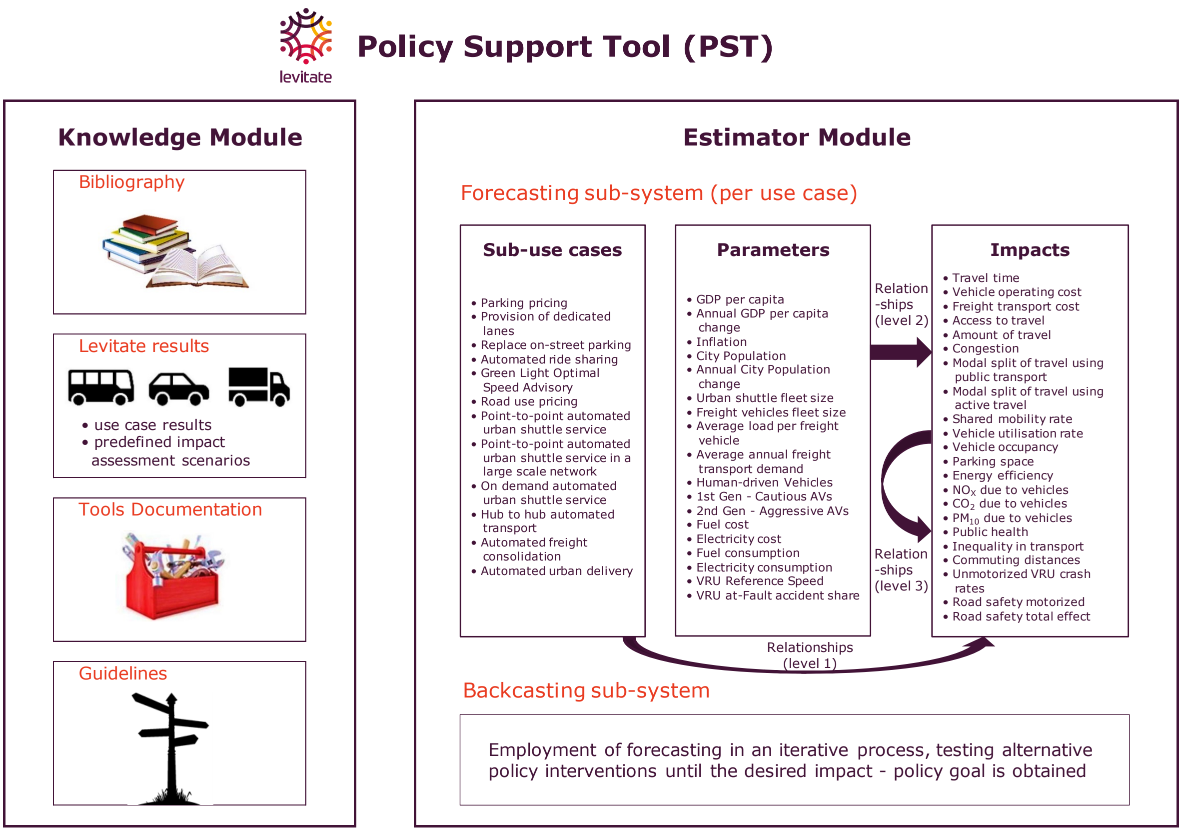

Figure 1.1 Structure of the LEVITATE Policy Support Tool

The present Deliverable 8.1 is organized as follows: in the next section the PST use cases, sub-use cases and scenarios formulation are described. Afterwards, the overview of the PST Estimator module is presented, in which the input parameters, the examined impacts and the PST inputs of each methodology as well as their integration are described. In the next three sections the Forecasting, Backasting and Cost Benefit Analysis sub systems are discussed. In addition, the capabilities that the PST offers for estimating the combined impacts of two measures are then presented. The overview of the PST Knowledge module is included in the following section while the conclusions and future work of WP8 are presented in the last section of the deliverable.

2 PST Use case, Sub-use case and scenario formulation

2.1 Objectives

This Section describes broadly the formulation of use cases and sub-use cases within the LEVITATE PST. These paradigms were selected within the LEVITATE project in order to capture, through detailed analysis, the projected effects of several different policies in the form of fluctuations of direct, wider and systemic impacts (D3.1 – Elvik et al., 2019) on the examined networks. Direct impacts refer to changes noticed by each road user on each trip and can be measured directly after the introduction of intervention or technology, these are travel time, vehicle operating cost and access to travel. Systemic impacts are impacts wide enough to be observed across the entirety of the transport system, they are measured indirectly from direct impacts and are considered as medium-term. Wider impacts are even broader changes occurring outside the transport system, i.e. road safety, emissions, energy efficiency, parking space, public health and accessibility in transport. These are inferred impacts measured at a larger scale and are the result of direct and system wide impacts.

2.2 Automation use cases and sub-use cases

Following the terminology established in the LEVITATE project, a use case is defined as any high-level area of application of CCAM. The **use cases** that are considered in the frame of LEVITATE are listed on Table 2.1. They are categorized as passenger cars, urban transport and freight transport cases.

Table 2.1 Description of the use cases

Use-Case	Description
Passenger cars	Impacts of automated passenger cars on: • Road use pricing • Automated ride sharing • Reduction of parking space
Urban transport	Impacts of cooperative, connected and autonomous vehicles on urban transport operations: • Point to point shuttles • Anywhere to anywhere shuttles • Last mile shuttles
Freight transport	Impacts of logistic concepts enabled by CCAM: • Automated urban delivery • Local freight consolidation • Hub to hub automated transfer • Highway platooning

Accordingly, a more in-depth examination follows and within LEVITATE, specific **sub-use cases** are created for each use case domain. This second layer is necessary, as within each use case there may be many specific technologies that are deployed individually or in combination and within certain operational design domains; these are considered sub-use cases.

As described in D4.1 (Zach et al., 2019) a preliminary list of policy goals, indicators and policy interventions was created based on an extensive literature review regarding the future of CCAM. After consultation with experts from the City of Vienna and the City of Manchester, this list was prioritised and the most important policy goals and policy interventions (sub-use cases) to achieve them were selected following a Stakeholders Reference Group workshop. The detailed description of the LEVITATE sub-use cases is included in D5.2 (Roussou et al., 2021) for the automated urban transport use case, in D6.2 (Haouari et al., 2021) for automated passenger cars and in D7.2 (Hu et al., 2021) for the automated freight transport use case.

The list of the **sub-use cases** that are investigated are also presented in Table 2.2. In addition, specific network management strategies, policies, deployments or other measures are considered policy interventions. In that context, several policy intervention scenarios for each of the above sub-use cases were also investigated. The list of the **policy interventions** are presented in Table 2.2 as well.

Table 2.2 List of sub-use cases and policy interventions

Use-case	Sub-use case	Policy intervention
Passenger cars	• Parking pricing	• Baseline (no policy intervention) • Drive Around • Balanced • Heavy Return to Origin and Park Outside
	• Provision of dedicated lanes	• Baseline (no policy intervention) • CAV dedicated lane on the Motorway and A road • CAV dedicated lane on the right most lane • CAV dedicated lane on the left most lane • CAV dedicated lane on the Motorway only
	• Replace on-street parking	• Baseline (no policy intervention) • Removing half of the on-street parking spaces • Replacing on-street parking spaces with driving lanes • Replacing on-street parking spaces with pick-up and/or drop-off points • Replacing on-street parking spaces with public spaces • Replacing on-street parking spaces with cycling lanes

	• Automated ride sharing	• Baseline (no policy intervention) • 5% of the traffic demand to be served - 20% passenger’s willingness to share rides • 5% of the traffic demand to be served - 50% passenger’s willingness to share rides • 5% of the traffic demand to be served - 80% passenger’s willingness to share rides • 5% of the traffic demand to be served - 100% passenger’s willingness to share rides • 10% of the traffic demand to be served - 20% passenger’s willingness to share rides • 10% of the traffic demand to be served - 50% passenger’s willingness to share rides • 10% of the traffic demand to be served - 80% passenger’s willingness to share rides • 10% of the traffic demand to be served - 100% passenger’s willingness to share rides • 20% of the traffic demand to be served - 20% passenger’s willingness to share rides • 20% of the traffic demand to be served - 50% passenger’s willingness to share rides • 20% of the traffic demand to be served - 80% passenger’s willingness to share rides • 20% of the traffic demand to be served - 100% passenger’s willingness to share rides
	• Green Light Optimal Speed Advisory (GLOSA)	• Baseline (no policy intervention) • GLOSA on 1 Intersection • GLOSA on 2 Intersections • GLOSA on 3 Intersections
	• Road use pricing	• Baseline (no policy intervention) • Dynamic city toll • Static city toll • Empty km pricing
Urban transport	• Point-to-point Automated Urban Shuttle Service (AUSS)	• Baseline (no policy intervention) • Peak hour - Mixed traffic conditions • Peak hour - Dedicated lane for the AUSS • Peak hour – Incident occurrence • Off Peak hour - Mixed traffic conditions • Off Peak hour - Dedicated lane for the AUSS
	• Point-to-point automated urban shuttle service in a large scale network	• Baseline (no policy intervention) • Peak hour - Mixed traffic conditions • Peak hour - Dedicated lane for the AUSS • Off Peak hour - Mixed traffic conditions

	• On demand automated urban shuttle service	• Baseline (no policy intervention) • 8 passengers capacity - 5% of the traffic demand to be served • 15 passengers capacity - 5% of the traffic demand to be served • 8 passengers capacity - 10% of the traffic demand to be served • 15 passengers capacity - 10% of the traffic demand to be served
Freight transport	• Hub to hub automated transport	• Baseline (no policy intervention) • Transfer hub
	• Automated freight consolidation	• Baseline (no policy intervention) • Manual consolidated delivery • Automated consolidated delivery
	• Automated urban delivery	• Baseline (no policy intervention) • Semi-aumated delivery • Fully-automated delivery • Fully-automated night delivery
	• Platooning on bridges*	• Baseline (no policy intervention) • Structural strenghtening • Intelligent access control

**This sub-use case is included only in the PST knowledge module and is not part of the PST estimator module.*

2.3 Scenarios of automation penetration

In order to enable the impact assessments, predefined base scenarios are established as per the PST development process, concerning the temporal distribution of the market penetration rates (MPRs) of connected and autonomous vehicles throughout the study period, which is from 2020 to 2050. These scenarios are part of the assumptions that have been made within PST development and attempt to identify the conditions of the area, which the PST user wishes to examine. The **base scenarios** are the following.

1. **No automation base scenario**: All vehicles will be conventional (i.e. human-driven) vehicles up to 2050.
2. **Pessimistic base scenario**: Vehicles will be 50% conventional vehicles, 40% autonomous vehicles of first generation and 10% autonomous vehicles of second generation in 2050. The first generation of autonomous vehicles will appear in 2021 and will rise from 10% in 2028 to 40% in 2045 and will remain stable till 2050. The second generation will appear in 2046 and will rise to 10% in 2050.
3. **Neutral base scenario**: Vehicles will be 20% conventional vehicles, 40% autonomous vehicles of first generation and 40% autonomous vehicles of second generation in 2050. The first generation of autonomous vehicles will appear in 2021 and will be rise from 10% in 2024 to 40% in 2036 and will remain stable till 2050. The second generation will appear in 2037 and will rise to 40% in 2050.
4. **Optimistic base scenario**: All vehicles will be autonomous up to 2042. More specifically, vehicles will be 0% autonomous vehicles of first generation and 100% autonomous vehicles of second generation in 2050. The first generation of

autonomous vehicles will appear in 2021 and will be rise from 10% in 2023 to 40% in 2030, will remain stable till 2042 and will be drop to 0% in 2050. The second generation will appear in 2031 and will rise to 100% in 2050.

It should be noted that these scenarios refer to the advent of CAVs in the traffic of the network regardless of any policy interventions that are or are not adopted by authorities. The visualization of the different scenarios is displayed on Figures 2.1, 2.2, 2.3, 2.4.

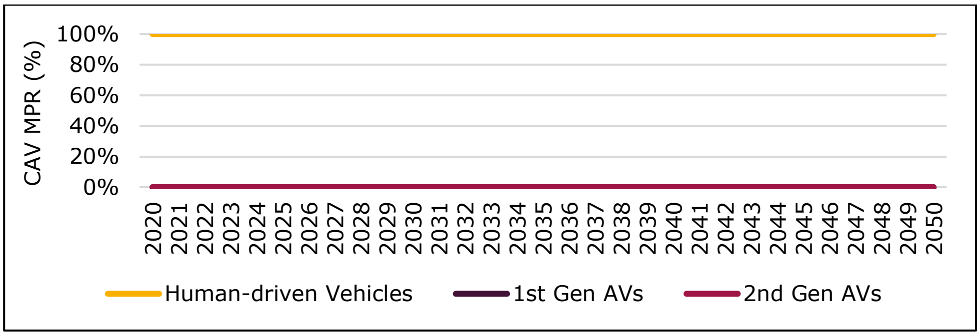

Figure 2.1 MPR development over time for the no automation base scenario

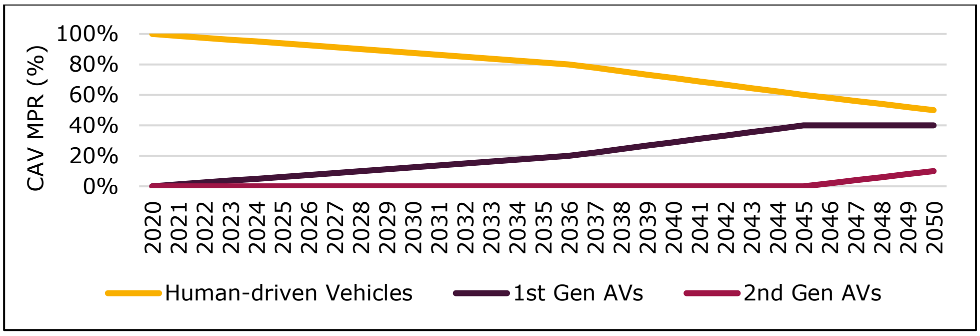

Figure 2.2 MPR development over time for the pessimistic base scenario

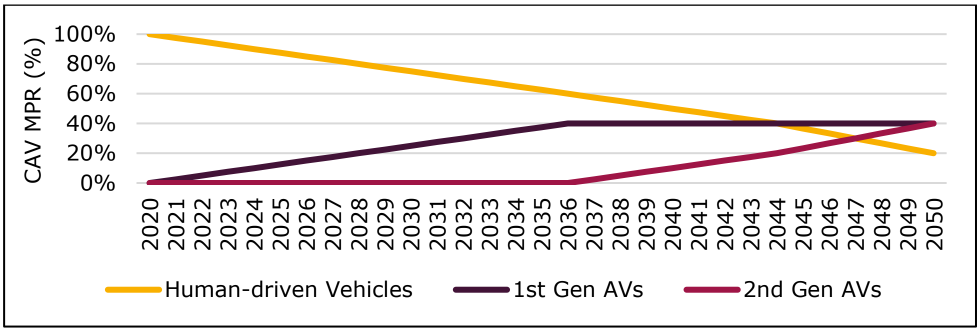

Figure 2.3 MPR development over time for the neutral base scenario

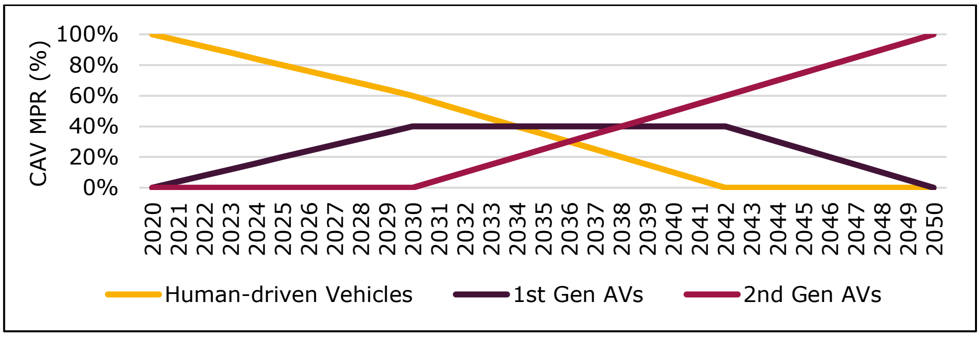

Figure 2.4 MPR development over time for the optimistic base scenario

Two types of CAVs were considered within the Levitate project: 1st Generation CAVs and 2nd Generation CAVs. Both types are assumed to be fully automated vehicles with level 5 automation as defined in the SAE CAV levels; thus, they are assumed to be completely AI-piloted and driverless human-wise. The main idea behind modelling these two types is based on the assumption that technology will advance with time. Therefore, 2nd Gen CAVs will have improved sensing and cognitive capabilities, decision making, driver characteristics, and anticipation of incidents etc. The **two driving profiles** of connected autonomous vehicles are the following:

- **1st Generation** (Cautious): limited sensing and cognitive ability, long gaps, early anticipation of lane changes and longer time in give way situations.
- **2nd Generation** (Aggressive): advanced sensing and cognitive ability, data fusion usage, confident in making decisions, small gaps, early anticipation of lane changes and less time in give way situations.

3 Estimator Module Overview

3.1 Objectives

This section provides a high-level overview of the estimator module of the LEVITATE PST, which is essentially the quantitative aspect of the PST. The core objective of the estimator module is to provide the user with scientific estimates on the projected impacts of specific policies that they can consider.

The module provides estimates for different types of impacts (including cost-benefit and monetary impacts) and allows for comparative analyses. As already mentioned, it includes two sub-systems:

- the **forecasting sub-system**, combined with the CBA estimator, provides quantified and/or monetized output (depending on the impact) on the expected impacts of CCAM related policies, using both pre-defined key scenarios and customised scenarios;
- the **backcasting sub-system** enables users to identify the sequences of CCAM measures that are expected to result in their desired policy objectives.

3.2 Approach

To create the LEVITATE PST, an approach combining the different methodologies and their results into a single integrated system was required. At the same time, the approach has to keep the resulting PST understandable, comprehensive and approachable for the wide array of users that would be potentially interested in using it. A third dimension to be considered is that the system has to be feasible from a coding and software development scope without diluting or distorting the mathematical and scientific content.

The foundation of the estimator module was required to contain the databases from which the LEVITATE PST essentially draws inputs to conduct the calculations. These databases include data provided by the activities of WP5, WP6 and WP7, as well as data obtained from the horizontal methodologies implemented within the project (microscopic simulation, mesoscopic simulation, system dynamics, operations research and the Delphi panel method).

The aforementioned methodologies are necessary to cover the wide array of impacts provided by the LEVITATE PST. However, they are quite different by inherent nature: microscopic simulation, for instance, concerns the definition of a testbed network and the application of underlying traffic simulation models through several iterations. In contrast, system dynamics considers an entire system in transition and calculates impact quantities in an iterative/incremental process.

This variety entailed that, inevitably, the integration of results from different methods was not an intuitive or straightforward task at first. As an example, the examination of temporal fluctuations was much easier in a system dynamics framework, while it would require a very large number of microscopic simulations and/or Delphi questionnaires for the other methods and provide comparable effects. The results integration is described in more detail in the 3.3.4 section of the deliverable. The solution to that problem entailed the attachment of the different methods results as functions of the different Market Penetration Rates (MPRs). Subsequently, this reflect the temporal evolution of the advent of automation in an indirect manner, namely through the different base scenarios (as described in Section 2.3). Results for intermediate stages were interpolated and ultimately the databases used by the LEVITATE PST were fully populated, as further elaborated on Section 3.3.4.

Therefore, during the project, an intermediate step of MS Excel-based templates was adopted and followed. These documents were created for each SUC, and were termed ‘PST-Demo-‘ files (followed by SUC-specific suffix), which were the documents used to receive the inputs of the different methodologies used in WP5-7 for each examined impact and policy intervention.

3.3 Contents of the PST

3.3.1 Input parameters

Within LEVITATE, a number of input parameters are considered; the exact number is different on a use case basis. These parameters provide an initial basis for the formulation of the city network and they provide important finetuning capabilities to the PST user in order to make the results relevant and transferable to the area which the PST user wishes to examine. Predefined values for each parameter not influenced by an intervention will be available and the user will be able to change these values if needed. These default initial values do not explicitly represent any specific city network, however they give a preliminary attempt to identify the related parameters and suggest a respective range of values for each parameter. The form and definition of these parameters are provided on Table 3.1.

Table 3.1 Parameters

no.	Description	CCAM related	Unit of Measurement	Default Initial Value (can be changed by user)
1	GDP per capita	no	€	17,000
2	Annual GDP per capita change	no	%	1.50%
3	Inflation	no	%	1.00%
4	City Population	no	million persons	3.000
5	Annual City Population change	no	%	0.50%
6	Urban shuttle fleet size	yes	no. of vehicles	300
7	Freight vehicles fleet size	yes	no. of vehicles	100
8	Average load per freight vehicle	yes	tones	3
9	Average annual freight transport demand	no	million tones	1.5
10	Human-driven Vehicles	yes	%	100%
11	1st Gen - Cautious AVs	yes	%	0%

no.	Description	CCAM related	Unit of Measurement	Default Initial Value (can be changed by user)
12	2nd Gen - Aggressive AVs	yes	%	0%
13	Fuel cost	no	€ / lt	13.00
14	Electricity cost	no	€ / KWh	0.000
15	Fuel consumption	yes	lt / 100Km	0.00
16	Electricity consumption	yes	KWh / 100Km	0.00
17	VRU Reference Speed (Typical on Urban Road)	km/h	40.00	17
18	VRU at-Fault accident share	%	30.00	18

By the initial values of the parameters that represent year 2020 of the no automation base scenario, the respective values for the rest of the base scenarios and years of the study period (from 2020 to 2050) are calculated.

3.3.2 Examined impacts

The LEVITATE PST incudes 22 distinct impacts, defined by D3.1 (Elvik et al., 2019), which were classified into three broad categories: (i) Direct impacts; changes that are noticed by each road user on each trip, (ii) Systemic impacts; system-wide impacts within the transport system and (iii) Wider impacts; changes occurring outside the transport system. Based on that taxonomy and on feasible paths of interventions defined by D4.3 (Zach et al., 2019) the impact assessment took place for the introduction of CCAM in urban transport (WP5), passenger cars (WP6) and freight transport (WP7). The outcomes of the impact assessment are integrated in the LEVITATE PST. The examined impacts, which are shown in Table 3.2, are calculated based on the respective default initial values as well as the outputs from the different methods (microscopic simulation, Delphi method, mesoscopic simulation and system dynamics) of WP5, WP6 and WP7. The methods used are selected based on the outcomes of D4.4 (Papazikou et al., 2020). It should be mentioned that default initial values allow users to have an informed start, and an idea of what the range of inputs is expected to be for the PST. However, there is the option to change these starting values, e.g. when data of the user preference is available, with free entry of values within reasonable margins (e.g. 0-100% for any percentages). These initial values are required as they represent the corresponding impacts of year 2020 of the no automation base scenario to be calculated. Taking into account these results as well as the percentage changes of the methods results, the respective values for the rest of the base scenarios and years of the study period (from 2020 to 2050) are estimated.

Table 3.2 Output variables

#	Impact	Description / measurement	Unit of Measurement	Default Initial Value (can be changed by user)
		Direct impacts		

#	Impact	Description / measurement	Unit of Measurement	Default Initial Value (can be changed by user)
1	Travel time	*Average duration of a 5Km trip inside the city centre*	*min*	*15*
2	Vehicle operating cost	*Direct outlays for operating a vehicle per kilometre of travel*	*€/Km*	*0.25*
3	Freight transport cost*	*Direct outlays for transporting a tonne of goods per kilometre of travel*	*€/tonne.Km*	*0.25*
4	Access to travel	*The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)*	*-*	*5*
		Systemic impacts		
5	Amount of travel	*Person kilometres of travel per year in an area*	*person-km*	*19165.40*
6	Congestion	*Average delays to traffic (seconds per vehicle-kilometer) as a result of high traffic volume*	*s/veh-km*	*197.37*
7	Modal split of travel using public transport	*% of trip distance made using public transportation*	*%*	*40.00%*
8	Modal split of travel using active travel	*% of trip distance made using active transportation (walking, cycling)*	*%*	*3.00%*
9	Shared mobility rate	*% of trips made sharing a vehicle with others*	*%*	*4.00%*
10	Vehicle utilisation rate	*% of time a vehicle is in motion (not parked)*	*%*	*8.00%*
11	Vehicle occupancy	*average % of seats in use (pass. cars feature 5 seats)*	*%*	*25.00%*
		Wider impacts		
12	Parking space	*Required parking space in the city centre per person*	*m^2/person*	*0.9*
13	Energy efficiency	*Average rate (over the vehicle fleet) at which propulsion energy is converted to movement*	*%*	*25.00%*
14	NO_x due to vehicles	*Concentration of NO_x pollutants as grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*1.80*
15	CO_2 due to vehicles	*Concentration of CO_2 pollutants as grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*2500.00*
16	PM_{10} due to vehicles	*Concentration of PM_{10} pollutants as grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*0.20*
17	Public health	*Subjective rating of public health state, related to transport (10 points Likert scale)*	*-*	*5*
18	Inequality in transport	*To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)*	*-*	*5*
19	Commuting distances	*Average length of trips to and from work (added together)*	*Km*	*20*
20	Unmotorized VRU crash rates	Injury crashes with unmotorized VRUs per vehicle-kilometer driven	injury-crashes/veh-km	2.20
21	Road safety motorized	Number of crashes per vehicle-kilometer driven	crashes/veh-km	1.40
22	Road safety total effect	Road safety effects when accounting for VRU and modal split	crashes/veh-km	-

* *Freight transport cost concerns only WP7 results*

More specifically, these impacts are calculated for the baseline (no policy implementation) and the policy intervention cases scenarios as well as for each base scenario (namely no automation, pessimistic, neutral and optimistic scenario) and from year 2020 to 2050. In addition, the respective graphs for each impact are also created, for instance the congestion graph of the baseline scenario is presented in Figure 3.1.

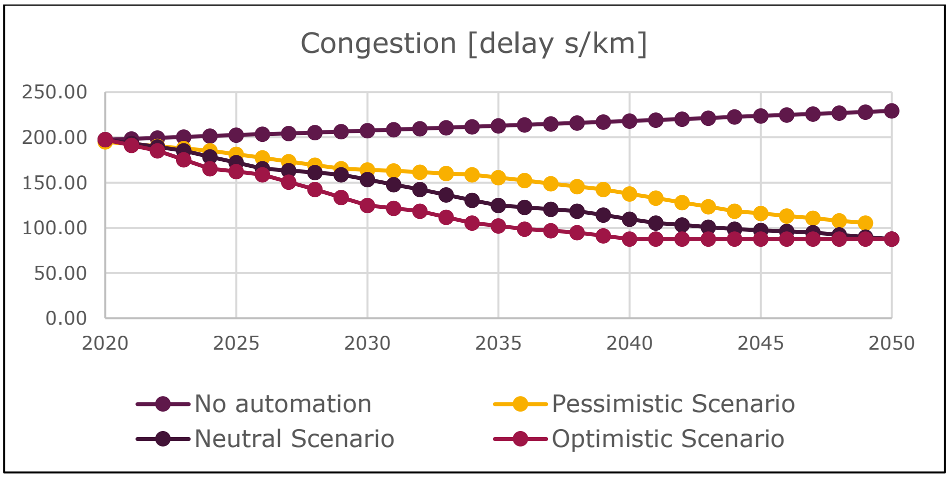

Figure 3.1 Congestion Impact graph

3.3.3 PST inputs

3.3.3.1 Inputs from Microsimulation

In the LEVITATE project, the microscopic simulation method was selected to examine several impacts of CAVs mainly on traffic, environment and energy efficiency. More specifically, the main purpose of this methodology is to identify the impacts of the adoption of CCAM on traffic, including travel times, flows, traffic emissions and road safety under several simulation scenarios and to evaluate the influence of different CAV penetration rates on a microscopic level. Microscopic simulation provides information related to individual vehicles by modelling traffic flows at a high level of detail (Ehlert & Rothkrantz, 2001). The simulation inputs concern various data such as the network geometry, traffic volume and modal split. The data exported by the microsimulation can provide an initial, descriptive estimation of several impacts. Each vehicle is tracked as it interacts with surrounding traffic as well as with the environment.

Moreover, microscopic simulation is widely used to evaluate new traffic control and management technologies as well as performing analysis of existing traffic operations (Owen et al., 2000). Modelling traffic flows allows to simulate the driving of every vehicle inside the considered transport network and provide many traffic-related impacts, while the traffic characteristics are taking into account, which also leads to traffic emissions estimation with high accuracy (Zhu et al., 2017; Lopez et al., 2018). In addition, many studies have used the microsimulation method in order to analyze traffic conflicts and present the sequence of events with the causal factors of conflicts (Young et al., 2014). In many researches through simulation approaches, the effects of CAVs introduction and their different implementations were identified (Talebpour et al., 2017; Kouvelas et al., 2017; Chen et al., 2017; Ard et al., 2020; Lu et a., 2020). In addition, several simulation models have been developed and applied for designing and testing autonomous urban transport services (Marczuk et al., 2015; Azevedo et al., 2016; Lam, 2016; Zellner et al., 2016; Scheltes & Correia, 2017; Shen et al., 2018; Gasper et al., 2018).

It should be noted that, within LEVITATE, traffic conflicts are translated and quantified to various road safety impacts using the Surrogate Safety Assessment Model (SSAM) ouptuts in a process thoroughly described in the respective working paper (Weijermars et al., 2021).

3.3.3.2 Delphi method

The Delphi method is a process used to arrive at a collective, aggregate group opinion or decision by surveying a panel of experts. This concept was developed by the RAND Corporation for the military in order to forecast the effects of new military technology on the future of warfare, and then continued to make multiple practical applications of this method (Dalkey & Helmer, 1963). The Delphi methodology is based on a repetitive interview process in which the respondent can review his or her initial answers and thus change the overall information on each topic (Hsu & Sandford, 2007). This method has three different dimensions: the exploratory Delphi aiming at the forecast of future events, the normative Delphi, in order to achieve policy consensus on goals and objectives within organisations or groups and the focus Delphi in order to gain feedback from stakeholders in some policy outcome (Garson, 2012). The Delphi method guarantees the anonymity of experts which assures free expression of opinions provided by the experts. At any point, experts can change their opinions or judgments without fear of being exposed to public criticism, providing controlled feedback as experts are informed about views of other experts who participate in the study (Profilidis & Botzoris, 2018).

Within LEVITATE, the Delphi method is used to determine all impacts that cannot be defined by the other quantitative methods (traffic microsimulation/ system dynamics). The Delphi process consists of two rounds of e-mails. During the first round experts received a questionnaire (30-45min duration) regarding a few (2-4) automation interventions related to automated urban transport, automated passenger cars or automated freight transport, as per their specific expertise. They were asked to evaluate the percentage influence of the proposed interventions on the different impact areas for various AVs market penetration rates. Their answers were then analyzed in order to create anonymized summaries for the different CCAM related interventions, which were sent during the second round of the Delphi, giving the experts the opportunity to change their answer or retain the original. The outcome of the Delphi that will be introduced in the PST is a coefficient representing the percentage of change that each sub-use case will have on each impact.

3.3.3.3 Mesoscopic simulation

Within the LEVITATE project, the mesoscopic simulation method was selected in order to complement the aforementioned methods by identifying additional impacts of CAVs regarding modal split of travel using public transport or active travel as well as the amount of travel. Through this methodology, the impacts of the adoption of CCAM were investigated under several simulation scenarios and for different CAV penetration rates.

Mesoscopic simulation method combines the elements from both microscopic and macroscopic simulations. Through mesoscopic simulation models, individual vehicles are simulated, while their interactions are based on aggregate and macroscopic relationships. The simulated traffic flows are based on estimation of the macroscopic indices on a microscopic level. In addition, mesoscopic models present traffic entities at a high level of detail while provide significant reductions in simulation time and modeling efforts, in case of a large area network analysis, without compromising the accuracy of their results (Burghout et al., 2005). Therefore, mesoscopic models are considered ideal for forecasting cases that require detailed modelling of route choice and other driver choices, while the driver interaction with the road network and other drivers is not needed. Due to these advantages, mesoscopic models were widely developed and several transportation agencies and researchers have used them (Florian et al., 2001; Chiu et al., 2008; Toledo et al., 2010; Ben-Akiva et al., 2012; Hou et al., 2013; Kristoffersson, 2013; Xu et al., 2014; Vu and Tan, 2017). Within the Levitate project, the impacts estimated through the mesoscopic simulation method and included in the PST were the amount of travel and the modal split of travel using public transport and using active travel, as well.

3.3.3.4 System Dynamics

As Boghani & Zach (2020) note, system dynamics is a modelling technique where a system is modelled at an abstract level by modelling the sub-systems at component level and aggregating the combined output. This breaking down and individual examination of components enables the use of feed-back/feed-forward mechanisms from one component to another within the system, which unfolds when the output is viewed against time.

Within LEVITATE, transportation systems that are undergoing transformation (in terms of introduction of connected and automated transport systems) are considered. These systems have a complex impact on the users who can be described by factors such as income, age, education level, etc. Consequently, complex dynamics emerge when all these sub-systems comprising of population dynamics, employment dynamics, housing dynamics, etc., interact with each other. The system dynamics framework provides a basis to understand them, as well as interact with the model by playing 'what if' scenarios to look at (i) external disturbances and (ii) the effects of policy measures. Furthermore, it is very much a 'white box' modelling approach which allows for the examination of which part of the system causes a component of observed behaviour and how it affects the overall system.

In the context of LEVITATE, system dynamics is mainly used to evaluate the impact of policy interventions (for example, road use pricing or the introduction of last-mile shuttles) during a transition period of increasing CAV percentage. The impact indicators will be typically commuting distances, modal split and others as a function of time so that the evolution of impacts over the long-term duration can be compared against various scenarios.

3.3.3.5 Operations research

In LEVITATE we apply operations research (OR) to assess several impacts for freight delivery. OR is widely used in freight logistics (Lagorio et al., 2016) and calculates results for transport costs, fleet operation costs, and vehicle mileage. They mainly consist of optimisation algorithms for route planning, also commonly known as the vehicle routing problem (VRP), where the goal is to calculate the optimal route or set of routes at the lowest possible cost (and often also the shortest possible time) from a given depot to a number of customers (Toth and Vigo, 2014).

The underlying algorithm for calculating the delivery scenarios is based on optimising the routing of the delivery vehicles. In all delivery variants considered, the delivery points are assigned to a depot from which the parcels are delivered. Depending on the delivery scenario, this depot can be a logistics center or a city-hub (in case of consolidated delivery). Subsequently, a problem instance of the Capacitated Vehicle Routing Problem (CVRP) (Toth and Vigo, 2014) is generated for each depot, with the delivery addresses acting as so-called customers. Finally, these instances are solved using the Savings algorithm (Clarke and Wright, 1964). This algorithm is able to handle large size problems which is the case here when the full city is considered.

3.3.4 Result integration

The results provided as input in the LEVITATE PST originate from the four aforementioned methods, which are inherently very different and depend on different parameters for their respective internal calculations or questionnaire formulation, in the case of the Delphi method. The details of the methods and the impact assessment results for each sub-use case are presented in the deliverables of WPs 5,6 and 7. The short, medium and long-term impacts of CCAM on urban transport are presented in D5.2 – Roussou et al., 2020, D5.3 (Roussou et al., 2021) and D5.4 (Roussou et al., 2021) respectively. The detailed results of impact assessment in the sub-use cases of the automated passenger cars are presented in D6.2 (Haouari et al., 2021), D6.3 (Sha et al., 2021) and D6.4 (Chaudhry et al., 2021). Finaly, the short, medium and long-term impacts of CCAM on freight transport are in detail presented in D7.2 (Hu et al., 2021), D7.3 (Hu et al., 2021) and D7.4 (Hu et al., 2021) respectively. To include the results of the aforementioned methods, a common ground had to be established. The selected approach in the LEVITATE PST involves attaching all results to specific MPR percentages as shown on Table 3.2. In a sense, these percentages can be considered milestones of CAV maturity within a network. The temporal compression or expansion of the distribution of the MPR percentages lead to one of the four scenarios presented on Figure 2.1, 2.2, 2.3, 2.4. Therefore initial results are spread differently across the timespan examined by the project.

Regarding the "No automation" base scenario, each impact calculation was not originated from the four aforementioned methods, while essentially was based only on the “City Population” and “Annual City Population change” parameters’ default initial values that can be changed by the PST user (as shown in Table 3.1).

For that purpose first of all, the city population was estimated for each year (2021-2050) as follows:

$$\text{City Population}_{t} = \text{City Population}_{2020} * (1 + \text{Annual City Population change}_{2020})^{t-2020} \quad (3.1)$$

When t is the year (2021-2050), City Population $_{2020}$ is the default initial value of the City Population parameter and Annual City Population change $_{2020}$ is the default initial value of the Annual City Population parameter.

Then, the "Amount of travel" impact (**# 5** as shown in Table 3.2) was calculated according to the below equation:

$$\text{Amount of travel}_{t} = \text{Amount of travel}_{t-1} * \frac{\text{City Population}_{t}}{\text{City Population}_{t-1}} \quad (3.2)$$

Where t is the year (2021-2050).

Afterwards, the impacts **# 6, 7, 8, 9, 10, 11, 12, 13, 17, 18, 21** (that are presented in Table 3.2) were estimated according to the amount of travel impact as follows:

$$x_{t} = x_{t-1} * \frac{\text{Amount of travel}_{t-1}}{\text{Amount of travel}_{t}} \quad (3.3)$$

Where x is the examined impact and t is the year (2021-2050).

For instance, using the impact of Public health, if the initial value of City Population is 3.000 million persons and the initial value of Annual City Population change is 0.50 % then the City Population for year 2021 and for the no automation base scenario is 3,000 $* (1 + 0.005)^{2021-2020}$ = 3,015 million persons (according to equation 3.1). Therefore, if the initial value of the Amount of travel impact is 19,165.40 person-km then the Amount of travel of the year 2021 and for the no automation base scenario is 19,165.40 $* \frac{3,015}{3,000}$ = 19,261.23 person-km (according to equation 3.2). Thus, if a user input of 5 as a starting Public health value would lead to a value of 5 $* \frac{19,165.40}{19,261.23}$ = 4.98 for 2021 and for the no automation base scenario (according to equation 3.3).

Additionally, there is a particularity for the "Travel time" impact (**# 1** as shown in Table 3.2) that is based on Congestion impact (**# 6** according to Table 3.2) and was estimated as follows:

$$\text{Travel time}_{t} = \text{Travel time}_{t-1} + \frac{\text{Congestion}_{t} - \text{Congestion}_{t-1}}{60} \quad (3.4)$$

Where t is the year (2021-2050).

The rest of the impacts, namely **# 2, 3, 4, 14, 15, 16, 19** (that are presented in Table 3.2) were estimated according to the amount of travel and travel time impact as follows:

$$x_{t} = \frac{\frac{x_{t-1} * \text{Amount of travel}_{t}}{\text{Amount of travel}_{t-1}} * \text{Travel time}_{t}}{\text{Travel time}_{t-1}} \quad (3.5)$$

Where x is the examined impact and t is the year (2021-2050).

Regarding the Pessimistic, Neutral and optimistic base scenarios for the intermediate years, simple linear interpolation is conducted to obtain the respective values for all methods and impacts as shown in Table 3.3.

Table 3.3 CAV Deployment microsimulation scenarios

Year	Pessimistic base scenario	Neutral base scenario	Optimistic base scenario

	MPR-1st Generation	MPR-2nd Generation	MPR-1st Generation	MPR-2nd Generation	MPR-1st Generation	MPR-2nd Generation
2020	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
2021	linear interpolation		linear interpolation		linear interpolation	
2022	linear interpolation		linear interpolation		linear interpolation	
2023	linear interpolation		linear interpolation		linear interpolation	
2024	linear interpolation		linear interpolation		linear interpolation	
2025	linear interpolation		linear interpolation		**20%**	**0%**
2026	linear interpolation		linear interpolation		linear interpolation	
2027	linear interpolation		linear interpolation		linear interpolation	
2028	linear interpolation		**20%**	**0%**	linear interpolation	
2029	linear interpolation		linear interpolation		linear interpolation	
2030	linear interpolation		linear interpolation		**40%**	**0%**
2031	linear interpolation		linear interpolation		linear interpolation	
2032	linear interpolation		linear interpolation		linear interpolation	
2033	linear interpolation		linear interpolation		linear interpolation	
2034	linear interpolation		linear interpolation		**40%**	**20%**
2035	linear interpolation		linear interpolation		linear interpolation	
2036	**20%**	**0%**	**40%**	**0%**	linear interpolation	
2037	linear interpolation		linear interpolation		linear interpolation	
2038	linear interpolation		linear interpolation		**40%**	**40%**
2039	linear interpolation		linear interpolation		linear interpolation	
2040	linear interpolation		linear interpolation		linear interpolation	
2041	linear interpolation		linear interpolation		linear interpolation	
2042	linear interpolation		linear interpolation		**40%**	**60%**
2043	linear interpolation		linear interpolation		linear interpolation	
2044	linear interpolation		**40%**	**20%**	linear interpolation	
2045	**40%**	**0%**	linear interpolation		linear interpolation	
2046	linear interpolation		linear interpolation		**20%**	**80%**
2047	linear interpolation		linear interpolation		linear interpolation	
2048	linear interpolation		linear interpolation		linear interpolation	
2049	linear interpolation		linear interpolation		linear interpolation	
2050	linear interpolation		**40%**	**40%**	**0%**	**100%**

Linear interpolation was applied, as follows:

Let x_1, x_2 be the examined impact values at two different years t_1, t_2 with milestone MPRs, for which results are available from the three methods. The impact at intermediate year t_i, x_i is calculated as:

$$x_i = x_1 + (x_2 - x_1) * \frac{t_i - t_1}{t_2 - t_1} \quad (3.6)$$

The PST handles different starting values internally by creating fluctuation coefficients from the methodological inputs, with which the baseline scenario is calculated. For instance, using the impact of CO2, if a value of 1250.00 CO2 g/veh-km is calculated from microsimulation as a baseline value (i.e. year 2020, no policy or automation present), and a value of 930.00 CO2 g/veh-km is calculated for year 2025, for a specific policy intervention, then the coefficient of 930.00/1250.00=0.744 [-] is obtained. A user input of 2500.00 as a starting CO2 g/veh-km value would lead to a value of 2500.00 * 0.744=1860.00 g/veh-km for 2025 and for the same policy intervention.

In addition, for each impact the methodology with which it is calculated is defined and presented in the following sections.

3.3.4.1 Microsimulation results

The microsimulation results concern the different scenarios of each sub-use case, namely the baseline and policy intervention cases scenarios for different market penetration rates of autonomous vehicles (0%-100%) with 20% increments as shown in Table 3.4.

Table 3.4 CAV Deployment microsimulation scenarios

Type of Vehicle	CAV Deployment scenarios							
Human-Driven passenger vehicle	100%	80%	60%	40%	20%	0%	0%	0%
1st Generation (Cautious) CAV	0%	20%	40%	40%	40%	40%	20%	0%
2nd Generation (ambitious) CAV	0%	0%	0%	20%	40%	60%	80%	100%
Human-Driven HGV	100%	80%	40%	0%	0%	0%	0%	0%
HGV-AV	0%	20%	60%	100%	100%	100%	100%	100%

The microsimulation measurements are the following and an example is shown in Figure 3.2:

- Delay (sec/km)
- Total Distance travelled (km)
- Human crashes (-)
- Human total distance travelled (-)
- 1st generation AV crashes (-)
- 1st generation AV total distance travelled (-)
- 2nd generation AV crashes (-)
- 2nd generation AV total distance travelled (-)
- NOx (g)
- CO2 (g)
- PM10 (g)

At the next stage, these results are converted to standardized values per km, which were also extracted from microsimulation method, compared to the Baseline with 0% market penetration rate of autonomous vehicle in order for respective impacts to be calculated.

Description	CASE	MPR-1st Generation	MPR-2nd Generation	Delay (sec/km)	Total crashes adjusted for user input	Total distance travelled (km)	Human Crashes (number of)	Human Total distance travelled (km)	AV 1 crashes (number of)	AV 1 Total distance travelled (km)	AV 2 crashes (number of)	AV 2 Total distance travelled (km)	NOX (g)	CO2 (g)	PM (g)
Baseline	Baseline	0%	0%	243.05	121179.20	90541.82	513.26	86556.57	0.00	0.00	0.00	0.00	258401.84	72367218.34	12115.29
Baseline	Baseline	20%	0%	215.34	137390.72	113469.28	473.86	86863.92	108.06	21400.00	0.00	0.00	210984.88	60312181.34	10952.32
Baseline	Baseline	40%	0%	214.43	136353.75	113750.50	359.21	65643.92	218.32	42774.91	0.00	0.00	139244.23	43301380.22	8051.87
Baseline	Baseline	40%	20%	214.84	104782.68	97757.88	220.17	37786.72	188.89	36740.94	34.75	18986.94	67810.80	25854850.82	4640.78
Baseline	Baseline	40%	40%	218.98	69313.51	80939.00	84.82	16079.74	152.64	31187.19	56.12	30354.96	47362.99	13573941.22	2365.83
Baseline	Baseline	40%	60%	234.30	45744.39	68180.22	0.00	0.00	129.15	27135.90	64.61	38332.01	27410.59	2024833.97	589.65
Baseline	Baseline	20%	80%	141.22	76754.28	138732.63	0.00	0.00	126.57	26210.33	198.53	105660.20	31537.45	3249532.98	989.27
Baseline	Baseline	0%	100%	133.49	61192.71	144847.82	0.00	0.00	0.00	0.00	259.18	137665.20	32200.49	3395964.04	1037.20
8 pax - 5% demand served	Case 1	0%	0%	196.37	127634.73	100349.52	540.60	95776.96	0.00	0.00	0.00	0.00	233895.71	67534904.01	12098.55
8 pax - 5% demand served	Case 1	20%	0%	188.89	136091.68	111854.37	470.41	85682.96	106.01	20988.97	0.00	0.00	211123.21	60098453.02	10838.92
8 pax - 5% demand served	Case 1	40%	0%	185.07	140837.73	113035.11	378.88	65123.32	217.64	42557.65	0.00	0.00	138308.17	42950069.94	7936.30
8 pax - 5% demand served	Case 1	40%	20%	189.79	106190.40	98753.10	219.21	38046.02	194.58	37102.53	35.98	19266.46	67465.51	25770045.65	4642.44
8 pax - 5% demand served	Case 1	40%	40%	189.82	67627.98	81711.53	82.12	16066.38	151.90	31417.77	52.42	30816.72	47383.90	13543530.66	2389.41
8 pax - 5% demand served	Case 1	40%	60%	194.73	46049.54	69228.57	0.00	0.00	129.89	27459.69	65.15	38988.90	27422.12	2023595.50	589.29
8 pax - 5% demand served	Case 1	20%	80%	146.81	78515.81	142265.84	0.00	0.00	131.71	26689.68	200.85	108467.40	31478.48	3285661.69	999.43
8 pax - 5% demand served	Case 1	0%	100%	143.61	60072.27	145510.40	0.00	0.00	0.00	0.00	254.44	138248.20	32085.50	3387197.79	1033.29
15 pax - 5% demand served	Case 2	0%	0%	190.82	127551.51	111868.21	540.25	106733.40	0.00	0.00	0.00	0.00	259155.28	75057358.23	13472.87

Figure 3.2 Example of microscopic simulation measurements

The above microscopic simulation results converted to standardized values per km are used in order the following impacts of Table 3.2 to be estimated:

- Congestion (sec/veh-km) **#6**
- NOX due to vehicles (g/veh-km) **#14**
- CO2 due to vehicles (g/veh-km) **#15**
- PM10 due to vehicles (g/veh-km) **#16**
- Road safety motorized (crashes/veh-km) **#21**

3.3.4.2 Road safety results

The road safety impact **#21**: Road safety motorized is described in section 3.3.3.1 as its calculation based on the microsimulation results. More specifically, traffic conflicts obtained through microscopic simulation are translated to crashes using the Surrogate Safety Assessment Model (SSAM) ouptuts in a process thoroughly described in the respective working paper (Weijermars et al., 2021). The impacts **#20**: Unmotorized VRU crash rates and **#22**: Road safety total effect (previously presented in Table 3.2) differed both in the no automation and in the rest of the base scenario approaches. Their calculation is based solely on parameters regarding the characteristics of the base scenarios (which can be changed by the user) and the impacts derived from the other various methods, and not a stand-alone methodology.

The main steps for obtaining the impacts **#20** and **#22** can be outlined as follows:

For impact **#20**, an estimate of accident causes to be eliminated via automation, based on available accident data, was combined with a relation between driven speeds and accident numbers. The latter relation is known as the "power model" of accident numbers, based on speeds driven (Cameron & Elvik, 2010).

Studying the available estimates of accident causes which automated vehicles would prevent, an average 70% of car-pedestrian and car-cyclist accidents, that caused by human-driven vehicles, was estimated that might be avoided when interacting with an automated vehicle. Additionally, a formula was derived that expressed the assumed superior reaction time of an automated vehicle in terms of an "equivalent speed" i.e. formalizing the notion that an automated vehicle, driving at a given physical speed (v_{old}), should be able to react at least as well a human driven vehicle driving at a lower "equivalent" or "new" speed (v_{new} or v_{1stGen} and v_{2ndGen}) that a human would have to drive in order to have the same braking distance as the CAV.

The discussion in Cameron and Elvik (2010), suggests an exponent to be used for the effect of speed on the number of injury crashes would be 2.0, giving us (for the remaining share of injury crashes) a final estimation formula (3.7), which also produces an estimate for impact **#20** via a reduction in the proportion of accidents remaining, based on the market penetration with 1st and 2nd generation automated vehicles.

$$prop_{new} = 0.7prop_{human} + 0.3\left(prop_{human} + prop_{1stGen}\left(\frac{v_{1stGen}}{v_{Human}}\right)^2 + prop_{2ndGen}\left(\frac{v_{2ndGen}}{v_{Human}}\right)^2\right) \qquad (3.7)$$

In this formula, $prop_{new}$ denotes the remaining share of crashes, while $prop_{human}$ denotes the share of human driven vehicles, $prop_{1stGen}$ denotes the current penetration rate (between 0 and 1) of 1st generation AVs and $prop_{2ndGen}$ denotes the penetration rate (between 0 and 1) of 2nd generation AVs. Naturally, the sum of these three rates equals 100% at all times.

An estimate of resulting crash numbers N_{est} can then be obtained by multiplying this formula with a starting number of crashes $N_{initial}$, resulting in

$$N_{est} = prop_{new} * N_{initial}. \tag{3.8}$$

For impact **#22**, the estimated impacts on unmotorized VRU crash rates, motorized crash rates and the changes in modal split are combined assuming a linear effect of changes in traffic volume for each mode of transport using the following formula:

$$N_{est\ mode} = V_{mode} * R_{mode} \tag{3.9}$$

Where R_{mode} is defined as the number of crashes per million kilometers travel as determined in the microsimulation and V_{mode} is the share of travel multiplied by the total amount of travel.

A total estimate $N_{est\ total}$ can then be made by summing all different modes together, resulting in

$$N_{est\ total} = V_h * R_h + V_{a1} * R_{a1} + V_{a2} * R_{a2} + V_O * R_O + N_{est\ VRU} \tag{3.10}$$

Note that halving the traffic volume of human driven vehicles V_h will half the component $V_h * R_h$, so it will not result in halving the number of crashes.

To conclude, the above framework aims to estimate the two of the three road safety impacts namely **#20** and **#22** by combining the following approaches:

- Estimating the impact of improved driving behaviour on crash rates between motorized vehicles and vulnerable road users by using crash data and assumptions concerning types of crashes that can be prevented by CAVs.
- Combining the estimated impacts on crash rates with the estimated impacts on distance travelled, which are determined via microsimulation, in order to estimate the overall impact on the number of crashes.

A full literature review of the background, reasoning and description of this process is provided in Weijermars et al. (2021) as well as in Deliverables 5.4 (Roussou et al, 2021), 6.4 (Chaudhry et al., 2021) and 7.4 (Hu et al., 2021) which focus on the road safety impacts for the corresponding sub-use cases. As per the aforementioned process, there were specific 'node' calculations for which microsimulation results were obtained for certain years, differing by automation penetration scenario. For the intermediate values of road safety impacts, linear interpolation was applied similar to the other impacts when creating the PST.

3.3.4.3 Delphi method results

The Delphi method results concern different scenarios for each sub-use case, namely the baseline and policy intervention cases scenarios for different market penetration rates of autonomous vehicles (0%-100%) with 20% increments. The Delphi method measurements are the following and concern the following highlighted impacts of Table 3.2:

- Travel time (min) **#1**
- Vehicle operating cost (€/Km) **#2**
- Freight transport cost (€/tonne.Km) **#3**
- Access to travel (-) **#4**
- Amount of travel (person-km) **#5**
- Modal split of travel using public transport (%) **#7**
- Modal split of travel using active travel (%) **#8**
- Shared mobility rate (%) **#9**
- Vehicle utilisation rate (%) **#10**
- Vehicle occupancy (%) **#11**
- Parking space (m^2/person) **#12**
- Energy efficiency (%) **#13**
- Public health (-) **#17**
- Inequality in transport (-) **#18**

In addition, an example of the Delphi method measurements is shown in Figure 3.3.

Description	CASE	MPR-1st Generation	MPR-2nd Generation	Travel time	Vehicle operating cost	Freight transport cost	Access to travel	Amount of travel	Modal split of travel using public transport	Modal split of travel using active travel	Shared mobility rate	Vehicle utilisation rate	Vehicle occupancy	Parking space	Energy efficiency	Public health	Inequality in transport
Baseline	Baseline	0%	0%	1.000	1.000	-	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Baseline	Baseline	20%	0%	1.087	0.973	-	1.026	1.096	0.962	0.966	1.007	1.043	1.016	0.975	1.030	1.010	1.044
Baseline	Baseline	40%	0%	1.179	1.011	-	0.986	1.166	0.894	0.953	1.050	1.143	1.058	0.945	1.071	1.010	1.097
Baseline	Baseline	40%	20%	1.191	0.982	-	1.188	1.270	0.851	0.851	1.180	1.260	1.092	0.858	1.084	1.036	1.139
Baseline	Baseline	40%	40%	1.116	0.917	-	1.312	1.349	0.745	0.838	1.193	1.380	1.161	0.823	1.157	1.022	1.192
Baseline	Baseline	40%	60%	0.939	0.897	-	1.339	1.390	0.690	0.824	1.216	1.417	1.198	0.789	1.141	1.041	1.225
Baseline	Baseline	20%	80%	0.939	0.897	-	1.339	1.390	0.690	0.824	1.216	1.417	1.198	0.789	1.141	1.041	1.225
Baseline	Baseline	0%	100%	0.939	0.897	-	1.339	1.390	0.690	0.824	1.216	1.417	1.198	0.789	1.141	1.041	1.225
8 pax - 5% demand served	Case 1	0%	0%	1.000	1.000	-	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
8 pax - 5% demand served	Case 1	20%	0%	0.998	1.004	-	1.084	1.092	1.054	0.961	1.029	1.055	1.007	0.987	1.040	1.019	0.998
8 pax - 5% demand served	Case 1	40%	0%	0.998	0.991	-	1.156	1.149	1.034	0.919	1.040	1.087	1.017	0.960	1.059	1.045	0.998
8 pax - 5% demand served	Case 1	40%	20%	0.980	0.971	-	1.229	1.206	1.025	0.903	1.089	1.148	1.021	0.901	1.095	1.048	0.980
8 pax - 5% demand served	Case 1	40%	40%	0.991	0.951	-	1.306	1.274	1.018	0.871	1.109	1.177	1.027	0.861	1.138	1.044	0.991

Figure 3.3 Example of Delphi method measurements

The last three scenarios values of every case were considered to be the same, in order to achieve a correspondence between Delphi and microscopic simulation CAV deployment scenarios. The reason behind this is that the last two scenarios results of the Delphi method (red colored in Figure 3.3) were missing, as Delphi results concered six MPR scenarios (0% - 100% with 20% increments), while microsimulation concerned eight MPR scenarios (as shown in Table 3.4).

3.3.4.4 Mesoscopic simulation results

The mesoscopic simulation results concern different scenarios of the on-demand shuttle bus service and road use pricing sub-use cases, namely the baseline and policy intervention cases scenarios for different market penetration rates of autonomous vehicles (0%-100%) with 20% increments as shown in Table 3.3. The mesoscopic simulation measurements, when available, replace the corresponding Delphi results and are presented in 3.3.4.3 with the corresponding impacts of Table 3.2:

- Amount of travel (person-km) **#5**

- Modal split of travel using public transport (%) **#7**
- Modal split of travel using active travel (%) **#8**

In addition, an example of the mesoscopic simulation measurements is shown in Figure 3.4.

Description	CASE	MPR-1st Generation	MPR-2nd Generation	Price (€)	Marginal utility of money	Modal split of travel using active travel	Modal split of travel using public transport	Amount of travel
Baseline	Baseline	0%	0%	-	0.95	0.082725525	0.51310259	60.57707792
Baseline	Baseline	20%	0%	-	0.95	0.082407068	0.507538293	60.47031177
Baseline	Baseline	40%	0%	-	0.95	0.080833388	0.501263161	60.37675776
Baseline	Baseline	40%	20%	-	0.95	0.08021458	0.495341183	60.28664369
Baseline	Baseline	40%	40%	-	0.95	0.079787759	0.488487947	60.22685183
Baseline	Baseline	40%	60%	-	0.95	0.079171023	0.481401179	60.06312032
Baseline	Baseline	20%	80%	-	0.95	0.079069252	0.48025678	60.08385083
Baseline	Baseline	0%	100%	-	0.95	0.079191296	0.479752386	60.0889009
Baseline	Baseline	0%	0%	-	1	0.081499303	0.521321395	60.57998878
Baseline	Baseline	20%	0%	-	1	0.082367114	0.515532726	60.67823566
Baseline	Baseline	40%	0%	-	1	0.083072949	0.511143657	60.55194264
Baseline	Baseline	40%	20%	-	1	0.081234278	0.506124819	60.51633556
Baseline	Baseline	40%	40%	-	1	0.082297692	0.498148238	60.40946714
Baseline	Baseline	40%	60%	-	1	0.081661699	0.493185499	60.24798182
Baseline	Baseline	20%	80%	-	1	0.080419335	0.491047966	60.30926765
Baseline	Baseline	0%	100%	-	1	0.079932705	0.490071371	60.25076124
Baseline	Baseline	0%	0%	-	1.05	0.084506453	0.529218637	60.86268452
Baseline	Baseline	20%	0%	-	1.05	0.083160454	0.523620271	60.80694539
Baseline	Baseline	40%	0%	-	1.05	0.082715712	0.519293076	60.75552968
Baseline	Baseline	40%	20%	-	1.05	0.082256153	0.513368533	60.68226656
Baseline	Baseline	40%	40%	-	1.05	0.081674986	0.507580058	60.6353406
Baseline	Baseline	40%	60%	-	1.05	0.08126938	0.50103549	60.52559877
Baseline	Baseline	20%	80%	-	1.05	0.082425748	0.500874866	60.46605631
Baseline	Baseline	0%	100%	-	1.05	0.081282907	0.499124625	60.4483248
8 pax - 5% demand served	Case 1	0%	0%	-	0.95	0.080195576	0.496401098	57.83935366
8 pax - 5% demand served	Case 1	20%	0%	-	0.95	0.098113013	0.493461332	56.76715708

Figure 3.4 Example of mesoscopic simulation measurements

3.3.4.5 System dynamics results

The outputs from system dynamics method of the WP5, WP6 and WP7 are considered as an input in the PST. The system dynamics results concern the different scenarios of each sub-use case, namely the baseline and policy intervention cases scenarios for different market penetration rates of autonomous vehicles (0%-100%) with 10% increments. The system dynamics measurements are the following and concern the following highlighted impacts of Table 3.2:

- Modal split of travel using public transport (%) **#7**
- Modal split of travel using active travel (%) **#8**
- Parking space (m^2/person) **#12**
- Commuting distances (km) **#19**

In addition, an example of the system dynamics measurements is shown in Figure 3.5.

Description	CASE	MPR-1st Generation	MPR-2nd Generation	Commuting	Modal split of travel using public transport	Modal split of travel using active travel	Parking space
Baseline	Baseline	0%	0%	15.58	1.000	1.000	1.000
Baseline	Baseline	20%	0%	15.5	1.024	1.029	1.002
Baseline	Baseline	40%	0%	15.41	1.030	1.048	1.003
Baseline	Baseline	40%	20%	15.35	1.029	1.059	1.004
Baseline	Baseline	40%	40%	15.28	1.024	1.070	1.005
Baseline	Baseline	40%	60%	15.1	1.000	1.097	1.009
Baseline	Baseline	20%	80%	15.1	1.000	1.097	1.009
Baseline	Baseline	0%	100%	15.1	1.000	1.097	1.009
20% willingness to share - 5% demand served	Case 1	0%	0%	15.59	1.000	1.000	1.000
20% willingness to share - 5% demand served	Case 1	20%	0%	15.51	0.993	0.966	1.027
20% willingness to share - 5% demand served	Case 1	40%	0%	15.44	0.961	0.900	1.078

Figure 3.5 Example of system dynamics measurements

The last three scenarios values of every case were considered to be the same, in order for a correspondence between system dynamics and microscopic simulation CAV deployment scenarios to be succeed. The reason behind this is that the last two scenarios results of the system dynamics method (red colored in Figure 3.3) were missing, as system dynamics results concered six MPR scenarios (0% - 100% with 20% increments), while microsimulation concerned eight MPR scenarios (as shown in Table 3.4).

Regarding the impacts numbered **#7** and **#8**, when system dynamics measurements are available, they replace the corresponding Delphi results. Similarly, when estimation of impact **#12** through mesoscopic simulation is availiable, it replace the corresponding Delphi result.

In addition, the calculation of the remaining two following impacts of Table 3.2 is based on the parameters regarding the characteristics of the base scenarios (that can be changed by the user) as well as the rest of the impacts derived from the above methods:

- Unmotorized VRU crash rates (injury-crashes/veh-km) **#20**
  Is implemented from the relations (3.7) and (3.8) outlined above.
- Road safety total effect (crashes/veh-km) **#22**
  Is implemented from the relations (3.9) and (3.10) outlined above.

According to the above, the methods impacts correspondence for each sub-use case is presented in Table 3.5. The method impacts correspondence concerns the baseline as well as the policy interventions scenarios.

Table 3.5 Method impacts correspondence

#	Impact	WP5			WP6						WP7		
		Point-to-point shuttle bus service	Point-to-point shuttle bus service in a large-scale network	On-demand shuttle bus service	Replacing On-street parking	Provision of dedicated lanes for AVs	Automated ride sharing	GLOSA	Parking Price	Road use pricing	Automated delivery	Automated consolidation	Hub to hub
1	Travel time	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi
2	Vehicle operating cost	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Operations research	Operations research	Operations research
3	Freight transport cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Operations research	Operations research	Operations research
4	Access to travel	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	N/A	N/A	N/A
5	Amount of travel	Delphi	Delphi	Mesoscopic simulation	Delphi	Delphi	Delphi	Delphi	Delphi	Mesoscopic simulation	N/A	N/A	N/A
6	Congestion	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	N/A	Micro-simulation	Micro-simulation	Micro-simulation
7	Modal split of travel using public transport	Delphi	Delphi	Mesoscopic simulation	System dynamics	Delphi	System dynamics	Delphi	System dynamics	Mesoscopic simulation	N/A	N/A	N/A
8	Modal split of travel using active travel	Delphi	Delphi	Mesoscopic simulation	System dynamics	Delphi	System dynamics	Delphi	System dynamics	Mesoscopic simulation	N/A	N/A	N/A
9	Shared mobility rate	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	N/A	N/A	N/A
10	Vehicle utilisation rate	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	N/A	N/A	N/A
11	Vehicle occupancy	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	N/A	N/A	N/A
12	Parking space	Delphi	Delphi	System dynamics	System dynamics	Delphi	System dynamics	Delphi	System dynamics	System dynamics	Delphi	Delphi	Delphi
13	Energy efficiency	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi
14	NOX due to vehicles	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	N/A	Micro-simulation	Micro-simulation	Micro-simulation
15	CO2 due to vehicles	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	N/A	Micro-simulation	Micro-simulation	Micro-simulation
16	PM10 due to vehicles	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	N/A	Micro-simulation	Micro-simulation	Micro-simulation
17	Public health	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi
18	Inequality in transport	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	Delphi	N/A	N/A	N/A
19	Commuting distances	N/A	N/A	System dynamics	System dynamics	N/A	System dynamics	N/A	System dynamics	System dynamics	N/A	N/A	N/A
20	Unmotorized VRU crash rates	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*
21	Road safety motorized	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	Micro-simulation	N/A	Micro-simulation	Micro-simulation	Micro-simulation
22	Road safety total effect	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	*Compu-tational*	N/A	*Compu-tational*	*Compu-tational*	*Compu-tational*

3.3.5 Policy interventions correspondence

The integration of the above results involves considerable harmonization and alignment in order each sub-use case to be described in one result table handled by the online PST system. All included results must refer to the same scale of areas, for the same period and same policy interventions. Therefore, a correspondence between the policy interventions of the methods is required based on the microscopic simulation policy interventions since this method provides a large number of impacts. The microscopic simulation policy interventions correspondence with the Delphi, system dynamics and mesoscopic simulation cases is presented in Table 3.6.

Table 3.6 Policy interventions correspondence

Use case	Sub-use case	Policy interventions (Microsimulation Case)	Delphi Case correspondence	System Dynamics Case correspondence	Mesoscopic simulation Case correspondence
Urban transport	Point-to-point shuttle service	Baseline	Baseline	N/A	N/A
		Peak hour - Mixed traffic	Point-to-Point	N/A	N/A
		Peak hour - Dedicated lane	Equal to the above cell	N/A	N/A
		Peak hour - Incident	Equal to the above cell	N/A	N/A
		Off Peak hour - Mixed traffic	Equal to the above cell	N/A	N/A
		Off Peak hour - Dedicated lane	Equal to the above cell	N/A	N/A
	Point-to-point shuttle service in a large scale network	Baseline	Baseline	N/A	N/A
		Peak hour - Mixed traffic	Point-to-Point	N/A	N/A
		Peak hour - Dedicated lane	Equal to the above cell	N/A	N/A
		Off Peak hour - Mixed traffic	Equal to the above cell	N/A	N/A
	On demand shuttle bus service	Baseline	Baseline	Baseline	Baseline
		8 passenger - 5% demand served	Average of the Anywhere to anywhere, Last-mile and e-hailing	Last-mile shuttle bus service	On demand – 250 veh – 4 passenger
		15 passenger - 5% demand served	Equal to the above cell	Equal to the above cell	Equal to the above cell
		8 passenger - 10% demand served	Equal to the above cell	Equal to the above cell	On demand – 500 veh – 4 passenger
		15 passenger - 10% demand served	Equal to the above cell	Equal to the above cell	Equal to the above cell
Passenger cars	Replacing On-street parking	Baseline	Baseline	Baseline	N/A
		Removing half of the on-street parking spaces	Replace on-street parking space with pick up/drop off parking space	Replacing On-street parking - restrict 50% of parking space	N/A
		Replacing on-street parking spaces with driving lanes	Replace on-street parking space with driving lanes	Replacing On-street parking - converting to driving / cycling lanes	N/A
		Replacing on-street parking spaces with pick-up and/or drop-off points	Replace on-street parking space with pick up/drop off parking space	Replacing On-street parking - restrict 50% of parking space	N/A
		Replacing on-street parking spaces with public spaces	Replace on-street parking space with space for public use	Replacing On-street parking - converting to driving / cycling lanes	N/A
		Replacing on-street parking spaces with cycling lanes	Equal to the above cell	Equal to the above cell	N/A
	Provision of dedicated lanes for AVs	Baseline	Baseline	N/A	N/A
		Motorway and A road	AV dedicated lane on the outermost motorway lane and A-road	N/A	N/A
		A road right most lane	AV dedicated lane on the outermost motorway lane	N/A	N/A
		A road left most lane	AV dedicated lane on the innermost motorway lane	N/A	N/A
		Motorway only	Equal to the above cell	N/A	N/A

Use case	Sub-use case	Policy interventions (Microsimulation Case)	Delphi Case correspondence	System Dynamics Case correspondence	Mesoscopic simulation Case correspondence
	Automated ride sharing	Baseline	Baseline	Baseline	N/A
		5% demand served - 20% willingness to share	Automated ride sharing	20% demand served - 100% willingness to share	N/A
		5% demand served - 50% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		5% demand served - 80% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		5% demand served - 100% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		10% demand served - 20% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		10% demand served - 50% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		10% demand served - 80% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		10% demand served - 100% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		20% demand served - 20% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		20% demand served - 50% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		20% demand served - 80% willingness to share	Equal to the above cell	Equal to the above cell	N/A
		20% demand served - 100% willingness to share	Equal to the above cell	Equal to the above cell	N/A
	GLOSA	Baseline	Baseline	N/A	N/A
		GLOSA on 1 Intersection	GLOSA	N/A	N/A
		GLOSA on 2 Intersections	Equal to the above cell	N/A	N/A
		GLOSA on 3 Intersections	Equal to the above cell	N/A	N/A
	Parking Price	Baseline	Park inside	Baseline	N/A
		Drive Around	Parking ban - drive around	Parking ban - drive around	N/A
		Balanced	Average of the Parking ban - drive around, - return to origin and - park outside	Balanced behaviour	N/A
		Heavy Return to Origin and Park Outside	Average of the Parking ban - return to origin and - park outside	Park Outside and return home	N/A
	Road use pricing	Baseline	Baseline	Baseline	Baseline
		Dynamic city toll	Dynamic city toll	Road use pricing	Dynamic city toll
		Static city toll	Static city toll	Equal to the above cell	Static city toll
		Empty km pricing	Empty km pricing	N/A	N/A
Freight transport	Automated delivery	Baseline	Baseline	N/A	N/A
		Semi-aumated delivery	Fully automated urban freight delivery	N/A	N/A
		Fully-automated delivery	Equal to the above cell	N/A	N/A
		Fully-automated night delivery	Fully automated urban freight delivery with night shifts only	N/A	N/A
	Automated consolidation	Baseline	Baseline	N/A	N/A
		Manual consolidated delivery	Automated freight consolidation	N/A	N/A
		Automated consolidated delivery	Equal to the above cell	N/A	N/A
	Hub to hub	Baseline	Baseline	N/A	N/A
		Transfer hub	Hub to hub automated transfer	N/A	N/A

3.3.6 Temporal introduction of policy interventions

The PST user has the option to select the time within the study period (i.e. 2020 – 2050) at which a policy intervention is introduced in the considered network. The PST framework considers the previous year as the last baseline year, which is the foundation upon which new impact values are calculated. In other words, the impacts diverge starting from the year when the policy is set to be implemented. This can be observed on Figure 3.6 and 3.7 depicting the energy efficiency of a policy intervention (in the pessimistic scenario) with implementation in 2025 (Figure 3.6) and 2035 (Figure 3.7); the horizontal offset of the curve is observable.

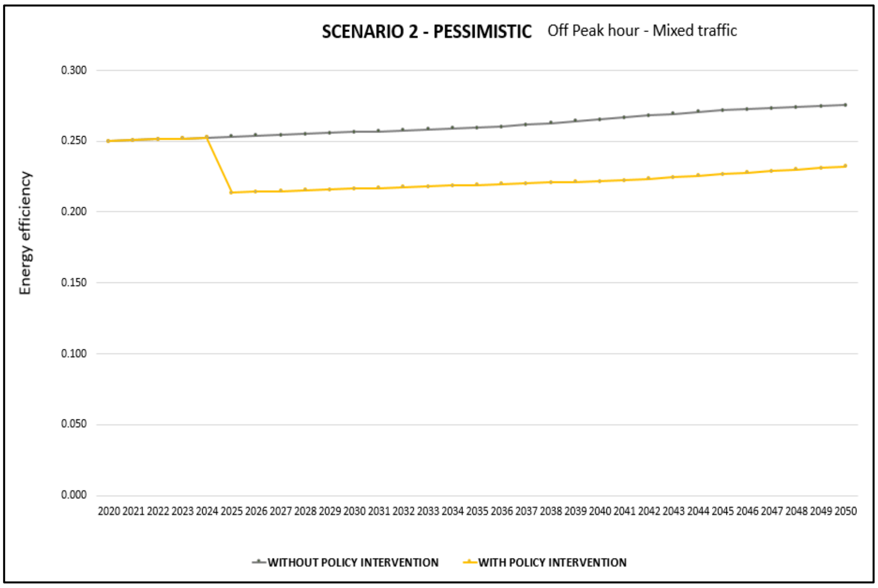

Figure 3.6 Energy efficiency example with implementation in 2025

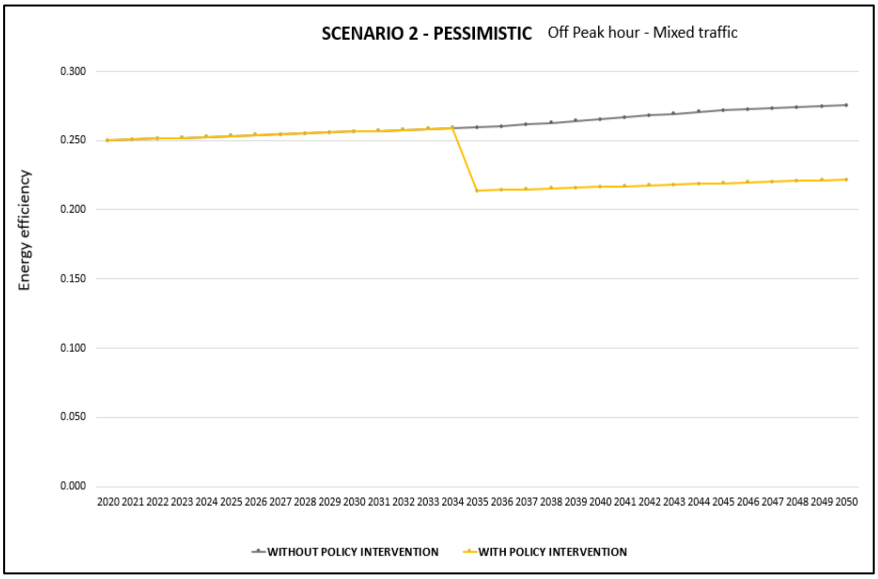

Figure 3.7 Energy efficiency example with implementation in 2035

3.3.7 Policy intensity & policy effectiveness

Two additional inputs are required before results are presented to the user: (i) policy intensity (or magnitude), which refers to what lies within the control of the authorities, such as route frequency for shuttle buses and (ii) policy effectiveness, which refers to what the authorities can measure, observe or expect but cannot directly control, such as public acceptance, regulation obedience or similar aspects of the network and, most importantly, the behavior of the network users. These percentages are implemented at a high level and provide the PST user with additional flexibility to anticipate the influence that these aspects may have on the examined impacts. It is intended that the default values of these percentages are 100%, and users will change it if they have a reason to suspect different circumstances for their networks. In essence, both of these percentages act as coefficients that influence the degree to which a policy intervention diverges from the baseline. It should be noted that this is not a direct interference in results, ergo the user is not allowed to 'draw their own impact curve'. Rather, these percentages are part of the inputs describing how rapidly a policy intervention curve diverges from the baseline curve.

3.4 PST Sub-systems

In the **forecasting** sub-system, the user is able to select a policy intervention (or group of interventions), define the required CCAM factors (or accept pre-defined values) and the module provides quantified and/or monetized output (depending on the impact) on the expected impacts. The impact assessment results also include:

- an assessment of uncertainty in the estimates (e.g. confidence intervals or qualitative assessment);

- references on the methodology applied for the impact assessment (i.e. how were the respective links and interrelations estimated: literature review, questionnaire survey, simulation study, etc.).

Predefined values for each factor (variable) not influenced by the intervention will be available; however the user will be able to change these values if needed.

In addition, indications on the evolution of the estimated impacts over time - short (5 years), medium (10 years) and long term (25+ years) impacts - will be included.

In the **backcasting** sub-system, the user will be able to select a policy objective, i.e. a targeted impact (Table 3.2), and the PST will provide "sequences" of the CCAM measures that will result in this impact. Similarly to the forecasting sub-system, predefined values for parameters (Table 3.1) will be available, with the option to be modified by the user.

The operation of the backcasting sub-system will be based on the forecasting models: by application of a suitable iterative process ("goal seek" procedure) alternative policy interventions will be tested by the system until the desired outcome is achieved.

Both forecasting and backcasting sub-systems will include **CBA add-on functionalities**. These additional sub-modules will draw inputs both from the base impact calculation but also on dedicated CBA-related inputs. Their outline is provided in a dedicated section, section 6: "Cost-Benefit Analysis sub-system".

The PST Estimator, developed in **Javascript code, with the React framework,** will comprise a highly ergonomic interface, simple and easy to use. It will include a graphical environment (interactive infographics) for both the input of user defined data (where possible) and the presentation of results.

Especially regarding the impacts, the graphical presentation of results (e.g. in a suitably designed chart) allows for the visualisation of the time dimension of the impact (in the x-axis of the chart).

In the following sections, the forecasting and backcasting sub-systems are described in detail, to provide a thorough examination of the inner workings of the PST estimator module.

4 Forecasting sub-system

4.1 Objectives and approach

The main purpose and function of the forecasting sub-system is to provide quantitative estimates to users about the future impacts of policy interventions. The databases previously established are utilised in an intuitive and straightforward manner by the system (provide CCAM-related and systemic policy inputs, acquire results).

The user:

1) Makes several drop-down selections, which serve to define which parts of the data the system will look at to provide the respective results (e.g. automation scenario definition, use-case selection, sub-use case selection, policy intervention selection).
2) Adjusts the initial PST values if desired to values more representative of their case in order to increase the predictive accuracy of the PST (e.g. increased population, reduced GDP, increased NO_x emissions).
3) Provides input in terms of temporal implementation of the measures, their effectiveness and their intensity, for the system to take into account by adjusting the response curves of the impacts
4) Receives the results for the wide array of impacts examined within LEVITATE, which may vary depending on sub-use case selection.

4.2 Forecasting process: from Inputs to Results

To successfully conduct impact forecasting with the LEVITATE PST, the user has to follow the sequence of steps outlined below. This entails a process of several inputs, in the form of drop-down or free entry menus, and a 'Submit' execution order, in order to prompt the system to provide the desired forecasting output. The input and output process were initially created in the Excel Demo phase and depicted in a pseudo-interface shown in Figure 4.1. This preparatory phase facilitated the subsequent development of the PST in the fully functional online Javascript version considerably.

Step 1: Selection of use case

(i) Passenger cars, (ii) Urban transport, (iii) Freight transport

Step 2: Definition of initial values

The user will be prompted to review default the initial values for parameters and impact indicators, and change any initial value that are considered not appropriate for the specific urban environment under consideration.

Step 3: Definition of base scenario

The user will be prompted to choose between the four predefined scenarios regarding temporal penetration rates of CCAM:

(i) No automation, (ii) Pessimistic, (iii) Neutral, (iv) Optimistic

Step 4: Selection of sub-use case and policy intervention

The user will be prompted to choose one or two between the predefined sub-use cases and the corresponding policy interventions of the selected use case (step 1):

Passenger cars

- Parking pricing
  - Baseline (no policy intervention)
  - Drive Around
  - Balanced
  - Heavy Return to Origin and Park Outside
- Provision of dedicated lanes
  - Baseline (no policy intervention)
  - Motorway and A road
  - A road right most lane
  - A road left most lane
  - Motorway only
- Replace on street parking
  - Baseline (no policy intervention)
  - Removing half of the on-street parking spaces
  - Replacing on-street parking spaces with driving lanes
  - Replacing on-street parking spaces with pick-up and/or drop-off points
  - Replacing on-street parking spaces with public spaces
  - Replacing on-street parking spaces with cycling lanes
- Automated ride sharing
  - Baseline (no policy intervention)
  - 5% demand served - 20% willingness to share
  - 5% demand served - 50% willingness to share
  - 5% demand served - 80% willingness to share
  - 5% demand served - 100% willingness to share
  - 10% demand served - 20% willingness to share
  - 10% demand served - 50% willingness to share
  - 10% demand served - 80% willingness to share
  - 10% demand served - 100% willingness to share
  - 20% demand served - 20% willingness to share
  - 20% demand served - 50% willingness to share
  - 20% demand served - 80% willingness to share
  - 20% demand served - 100% willingness to share
- Green Light Optimal Speed Advisory (GLOSA)
  - Baseline (no policy intervention)
  - GLOSA on 1 Intersection
  - GLOSA on 2 Intersections
  - GLOSA on 3 Intersections
- Road use pricing
  - Baseline (no policy intervention)
  - Dynamic city toll
  - Static city toll
  - Empty km pricing

Urban transport

- Point-to-point automated urban shuttle service

        - Baseline (no policy intervention)
        - Peak hour - Mixed traffic
        - Peak hour - Dedicated lane
        - Peak hour - Incident
        - Off Peak hour - Mixed traffic
        - Off Peak hour - Dedicated lane
    - Point-to-point automated urban shuttle service in a large scale network
        - Baseline (no policy intervention)
        - Peak hour - Mixed traffic
        - Peak hour - Dedicated lane
        - Off Peak hour - Mixed traffic
    - On demand automated urban shuttle service
        - Baseline (no policy intervention)
        - 8 passengers - 5% demand served
        - 15 passengers - 5% demand served
        - 8 passengers - 10% demand served
        - 15 passengers - 10% demand served

Freight transport

- Hub to hub automated transport
    - Baseline (no policy intervention)
    - Transfer hub
- Automated freight consolidation
    - Baseline (no policy intervention)
    - Manual consolidated delivery
    - Automated consolidated delivery
- Automated urban delivery
    - Baseline (no policy intervention)
    - Semi-aumated delivery
    - Fully-automated delivery
    - Fully-automated night delivery

Step 5: Details of sub use-case implementation

The user will be prompted to enter:

- The implementation year **(Step 5a)**
- Selection of policy intensity/magnitude for each year (controlled by authorities) **(Step 5b)**
- Selection of policy effectiveness (not controlled by authorities) **(Step 5c)**

Step 6: Details of economic situation of agents

The user will be prompted to enter some additional details that were required for some of the use-cases:

For the Road use pricing sub-use case

- Selection of the pricing level (€) **(Step 6a)**

For the Road use pricing and on demand urban shuttle service sub-use cases

- Selection of Marginal utility of money **(Step 6b)**

SUC impact estimation – presentation of results

The difference between the reference estimations of step 5 and the intervention estimations of step 6 is the estimated impact of the examined SUC. Results in terms of forecast of the expected future in the reference scenario, the scenario with intervention(s) and the impact of the intervention(s) will be presented both quantitatively and graphically.

Step 1: Selection of use case — **PASSENGER CARS**

Step 2: Definition of initial values

	no.	Description	Unit of Measurement	Default Initial Value (can be changed by user)
PARAMETERS	1	GDP per capita	€	17,000
	2	Annual GDP per capita change	%	1.50%
	3	Inflation	%	1.00%
	4	City Population	million persons	3.000
	5	Annual City Population change	%	0.50%
	6	Urban shuttle fleet size	no. of vehicles	~~300~~
	7	Freight vehicles fleet size	no. of vehicles	~~100~~
	8	Average load per freight vehicle	tones	~~3~~
	9	Average annual freight transport demand	million tones	~~1.5~~
	10	Human-driven Vehicles	%	100%
	11	1st Gen - Cautious AVs	%	0%
	12	2nd Gen - Aggressive AVs	%	0%
	13	Fuel cost	€ / lt	1.50
	14	Electricity cost	€ / KWh	0.10
	15	Fuel consumption	lt / 100Km	8.00
	16	Electricity consumption	KWh / 100Km	13.00
	17	VRU Reference Speed (Typical on Urban Road)	km/h	40.00
	18	VRU at-Fault accident share	%	30.00

	no.	Impact	Description / measurement	Unit of Measurement	Initial Value
Direct impacts	1	Travel time	*Average duration of a 5Km trip inside the city centre*	*min*	*15.0*
	2	Vehicle operating cost	*Direct outlays for operating a vehicle per kilometre of travel*	*€/Km*	*0.3*
	3	Freight transport cost	*Direct outlays for transporting a tonne of goods per kilometre of travel*	*€/tonne.Km*	*0.3*
	4	Access to travel	*The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)*	-	*5*
Systemic impacts	5	Amount of travel	*Person kilometres of travel per year in an area*	*person-km*	*19165.40*
	6	Congestion	*Average delays to traffic (seconds per vehicle-kilometer) as a result of high traffic volume*	*s/veh-km*	*197.4*
	7	Modal split of travel using public transport	*% of trip distance made using public transportation*	*%*	*0.4*
	8	Modal split of travel using active travel	*% of trip distance made using active transportation (walking, cycling)*	*%*	*3%*
	9	Shared mobility rate	*% of trips made sharing a vehicle with others*	*%*	*4%*
	10	Vehicle utilisation rate	*% of time a vehicle is in motion (not parked)*	*%*	*8%*
	11	Vehicle occupancy	*average % of seats in use (pass. cars feature 5 seats)*	*%*	*25%*
Wider impacts	12	Parking space	*Required parking space in the city centre per person*	*m2/person*	0.9
	13	Energy efficiency	*Average rate (over the vehicle fleet) at which propulsion energy is converted to movement*	*%*	*0.25*
	14	NO_X due to vehicles	*Concentration of NO_x pollutants as grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*1.80*
	15	CO_2 due to vehicles	*Concentration of CO_2 pollutantsas grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*2500.00*
	16	PM_{10} due to vehicles	*Concentration of PM_{10} pollutantsas grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*0.20*
	17	Public health	*Subjective rating of public health state, related to transport (10 points Likert scale)*	-	*5*
	18	Inequality in transport	*To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)*	-	*5*
	19	Commuting distances	*Average length of trips to and from work (added together)*	*Km*	*20.00*
	20	Unmotorized VRU crash rates	*Injury crashes with unmotorized VRUs per vehicle-kilometer driven*	*injury-crashes/veh-km*	*2.20*
	21	Road safety motorized	*Number of crashes per vehicle-kilometer driven*	*crashes/veh-km*	*1.40*
	22	Road safety total effect	*Road safety effects when accounting for VRU and modal split*	*crashes/veh-km*	~~0.86~~

Step 3: Definition of base scenario — **SCENARIO 2 - PESSIMISTIC**

Step 4: Selection of sub-use case — **Dynamic city toll**

Step 5a: Enter the policy implementation year — **2021**

Introduction lag: 1

Step 5b: Selection of policy intensity/magnitude for each year (controlled by authorities) (start at column R) ------->

Step 5c: Selection of policy effectiveness (not controlled by authorities) (start at column R) ------->

Policy intensity/magnitude	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Policy effectiveness	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%

Step 6a: Selection of the pricing level (€) — **1.42857142**

Step 6b: Selection of Marginal utility of money — **0.95**

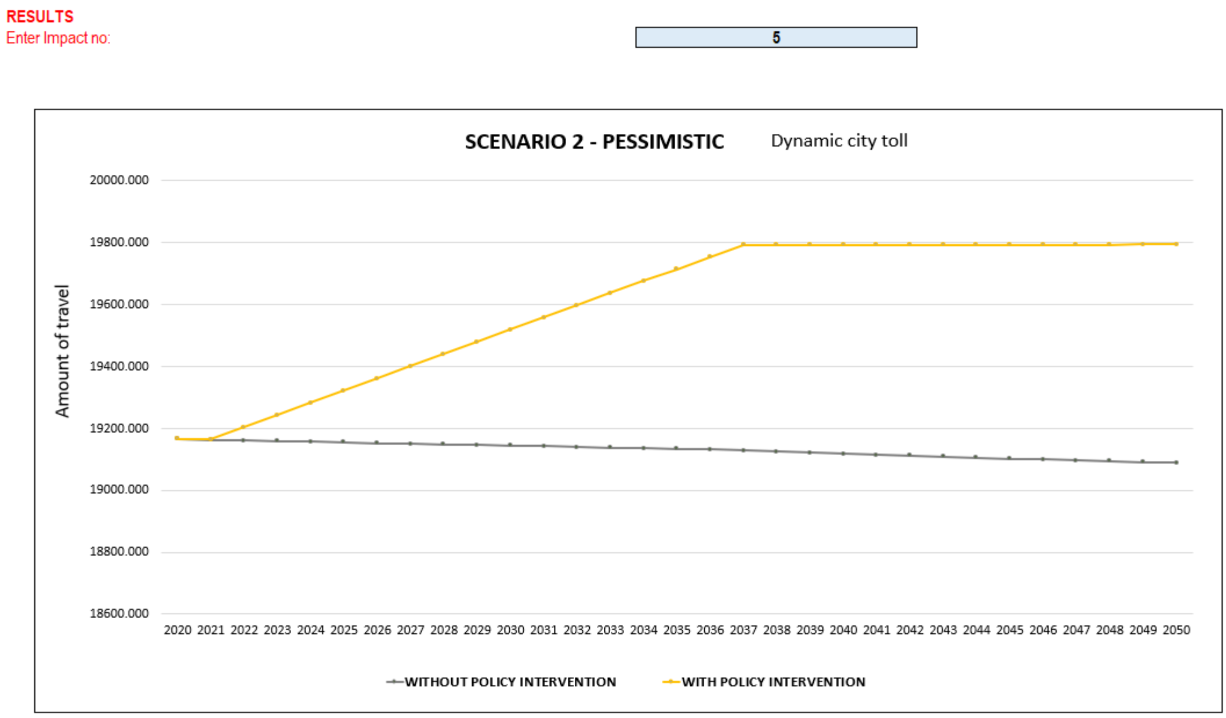

Figure 4.1 Working versions of the forecasting user interface in the Excel Demos

Furthermore, the capability of an intervention combination will be made as well, based on a methodological basis drawn from the Crash Modification Factor (CMF) approach highlighted in the Highway Safety Manual (HSM) and the respective CMF clearinghouse repository of the US Federal Highway Administration (FHWA). More detailed description of the PST capabilities in regards to the combination of two measures can be found in Section 7 ("Measure Combination within the PST").

5 Backcasting sub-system

5.1 Objectives

The term “Backcasting” was coined by (Robinson, 1990) and is a method to define future scenarios and to investigate their effects. Backcasting means defining future goals without current restrictions in order to be able to answer the following questions: “What shall we do today to get there, and what measures may lead into blind alleys and should be avoided?” (Bibri, 2018). The key assumptions of Robinson’s backcasting approach are oriented to the goal, policy, design and system. The backasting steps that are followed in the LEVITATE PST, are those described in D4.3 (Zach et al., 2019):

1. Set long-term targets (by the decision maker)
2. Evaluation of the target against the current situation, prevailing trends and expected developments for different policy interventions (done inside the backcasting sub-system)
3. Generation of policy recommendations that fulfill the targets (outcome of backcasting sub-system)
4. Analysis of recommended policy interventions in terms of feasibility, potential and path toward the expected future (done by the decision maker using the backcasting results and the knowledge module information).

The detailed Backcasting process used in the LEVITATE PST is presented in the following section.

5.2 Backcasting process: from Inputs to Results

To successfully conduct impact backcasting with the LEVITATE PST, firstly, the user has to follow the sequence of **Steps 1-6** of the forecasting estimator (described in Section 4.2) calculating all impacts by running the forecasting estimator. The PST user then will define the desired policy vision described in terms of desired changes in 1 (minimum) to 5 (maximum) impacts. Therefore the user has to select impacts of interest (**Step 7a**) as well as the desired percentage change for each of the selected impacts (**Step 7b**). Afterwards, the selection of the target year for achieving the desired policy vision examination follows (**Step 8**). If the impact lies within the targeted percentage changes, towards the desirable policy vision, the solution is retained. Otherwise, a solution is given to the PST user. For example in Figure 5.1, a solution is given to the PST user as there is a prercentage change that is not approved. Hence, the verdict is that the impacts will lie within the targeted percentage changes in 2050. If the desirable policy vision is impossible, then a new set of baseline data and interventions can be selected and the analysis runs again (**Step 1-8**). The input and output process were initially created in the Excel Demo phase and depicted in a pseudo-interface shown in Figure 5.1. This preparatory phase facilitated the subsequent development of the PST in the fully functional online Javascript version considerably.

Step 1: Selection of use case — **URBAN TRANSPORT**

Step 2: Definition of initial values

	no.	Description	Unit of Measurement	Default Initial Value (can be changed by user)
PARAMETERS	1	GDP per capita	€	17,000
	2	Annual GDP per capita change	%	1.50%
	3	Inflation	%	1.00%
	4	City Population	million persons	3.000
	5	Annual City Population change	%	0.50%
	6	Urban shuttle fleet size	no. of vehicles	~~300~~
	7	Freight vehicles fleet size	no. of vehicles	~~100~~
	8	Average load per freight vehicle	tones	~~3~~
	9	Average annual freight transport demand	million tones	~~1.5~~
	10	Human-driven Vehicles	%	100%
	11	1st Gen - Cautious AVs	%	0%
	12	2nd Gen - Aggressive AVs	%	0%
	13	Fuel cost	€ / lt	1.50
	14	Electricity cost	€ / KWh	0.10
	15	Fuel consumption	lt / 100Km	8.00
	16	Electricity consumption	KWh / 100Km	13.00
	17	VRU Reference Speed (Typical on Urban Road)	km/h	40.00
	18	VRU at-Fault accident share	%	30.00

	no.	Impact	Description / measurement	Unit of Measurement	Initial Value
Direct impacts	1	Travel time	*Average duration of a 5Km trip inside the city centre*	*min*	*15.0*
	2	Vehicle operating cost	*Direct outlays for operating a vehicle per kilometre of travel*	*€/Km*	*0.3*
	3	Freight transport cost	*Direct outlays for transporting a tonne of goods per kilometre of travel*	*€/tonne.Km*	*0.3*
	4	Access to travel	*The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)*	-	*5*
Systemic impacts	5	Amount of travel	*Person kilometres of travel per year in an area*	*person-km*	*19165.40*
	6	Congestion	*Average delays to traffic (seconds per vehicle-kilometer) as a result of high traffic volume*	*s/veh-km*	*197.4*
	7	Modal split of travel using public transport	*% of trip distance made using public transportation*	*%*	*0.4*
	8	Modal split of travel using active travel	*% of trip distance made using active transportation (walking, cycling)*	*%*	*3%*
	9	Shared mobility rate	*% of trips made sharing a vehicle with others*	*%*	*4%*
	10	Vehicle utilisation rate	*% of time a vehicle is in motion (not parked)*	*%*	*8%*
	11	Vehicle occupancy	*average % of seats in use (pass. cars feature 5 seats)*	*%*	*25%*
Wider impacts	12	Parking space	*Required parking space in the city centre per person*	*m2/person*	0.9
	13	Energy efficiency	*Average rate (over the vehicle fleet) at which propulsion energy is converted to movement*	*%*	*0.25*
	14	NO_x due to vehicles	*Concentration of NO_x pollutants as grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*1.80*
	15	CO_2 due to vehicles	*Concentration of CO_2 pollutantsas grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*2500.00*
	16	PM_{10} due to vehicles	*Concentration of PM_{10} pollutantsas grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*0.20*
	17	Public health	*Subjective rating of public health state, related to transport (10 points Likert scale)*	-	*5*
	18	Inequality in transport	*To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)*	-	*5*
	19	Commuting distances	*Average length of trips to and from work (added together)*	*Km*	*20.00*
	20	Unmotorized VRU crash rates	*Injury crashes with unmotorized VRUs per vehicle-kilometer driven*	*injury-crashes/veh-km*	*2.20*
	21	Road safety motorized	*Number of crashes per vehicle-kilometer driven*	*crashes/veh-km*	*1.40*
	22	Road safety total effect	*Road safety effects when accounting for VRU and modal split*	*crashes/veh-km*	~~*0.86*~~

Step 3: Definition of base scenario — **SCENARIO 4 - OPTIMISTIC**

Step 4: Selection of sub-use case — **Baseline**

Step 5a: Selection of policy implementation year — **2022**

Introduction lag: 2

Step 5b: Selection of policy intensity/magnitude for each year (controlled by authorities) — (start at column R) ------->

Step 5c: Selection of policy effectiveness (not controlled by authorities) — (start at column R) ------->

Policy intensity/magnitude	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Policy effectiveness	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%

~~**Step 6a:** Selection of the pricing level (€)~~

Step 6b: Selection of Marginal utility of money — **1.05**

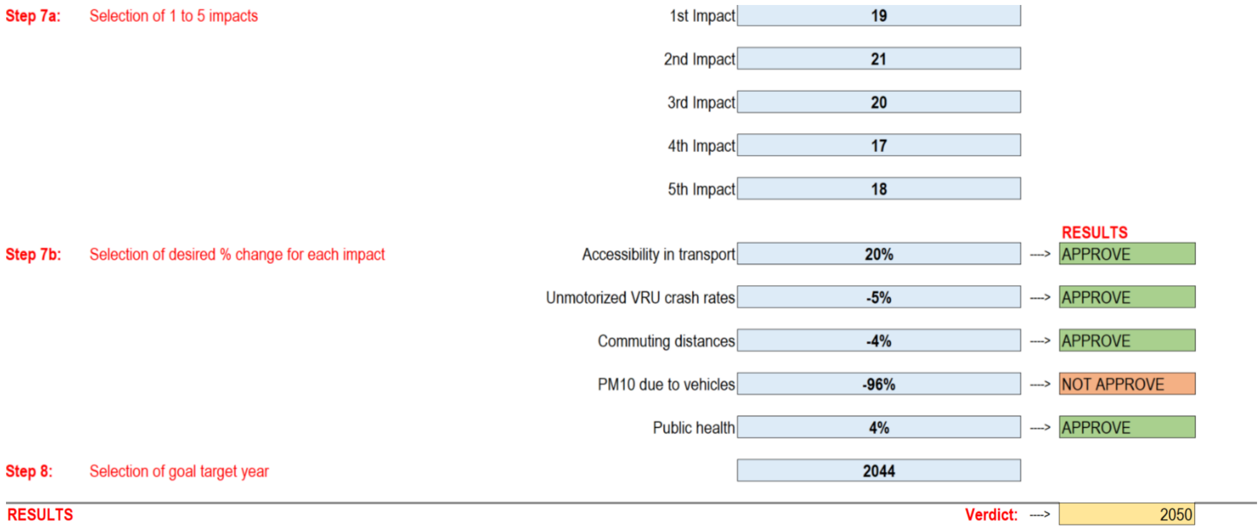

Figure 5.1 Working versions of the backcasting user interface in the Excel Demos

Furthermore, the capability of an intervention combination will be made as well, as in the forecasting estimator, based on a methodological basis drawn from the Crash Modification Factor (CMF) approach highlighted in the Highway Safety Manual (HSM) and the respective CMF clearinghouse repository of the US Federal Highway Administration (FHWA). More detailed description of the PST capabilities in regards to the combination of two measures can be found in Section 7 (“Measure Combination within the PST”).

6 Cost-Benefit Analysis sub-system

6.1 Objectives

In the PST one can select a policy measure, select the level of optimism in terms of how fast the introduction of CAVs will be in the market, add data describing the area/city where the measure will be introduced. The PST then provides impacts of the measure across a range of variables. Major expected impacts comprise congestion and travel time changes, and for some measures also changes in emissions, road safety, land use (i.e., replacing parking space), and more.

The Cost-Benefit Analysis sub-system (CBA module) is set up as an extra module in the PST (Hartveit & Veisten 2021). After selecting scenarios and sub-use cases in the PST, with subsequent results presented, the PST user can choose to continue with the CBA. In the CBA, some additional default values will have to be considered by the PST user, e.g. the costs related to the selected policy scenario (policy implementation costs).

The objective of the CBA module is to convert the "physical" effects (travelling time, emissions, etc.) simulated and estimated in the PST to monetary terms and provide socio-economic results. One key contribution from the CBA module is hence a set of valuations and guidelines for monetizing physical effects. This embeds a framework with methodologies and calculations for conducting a CBA.

Most importantly, the CBA provides an overall assessment of all the changes from a reference ("no policy intervention") to a selected policy scenario. The monetized impacts and results from the CBA will be presented on various levels: a net benefit estimate and a cost-benefit-ratio in total, results for each infrastructure user group (transport modes), the policy entity (which carries out the policy scenario) and the surrounding community, as well as sensitivity analyses and a break-even analysis.

6.2 Approach

The CBA module consists of various formulas for doing a CBA and it draws relevant information from various sources (Figure 6.1).

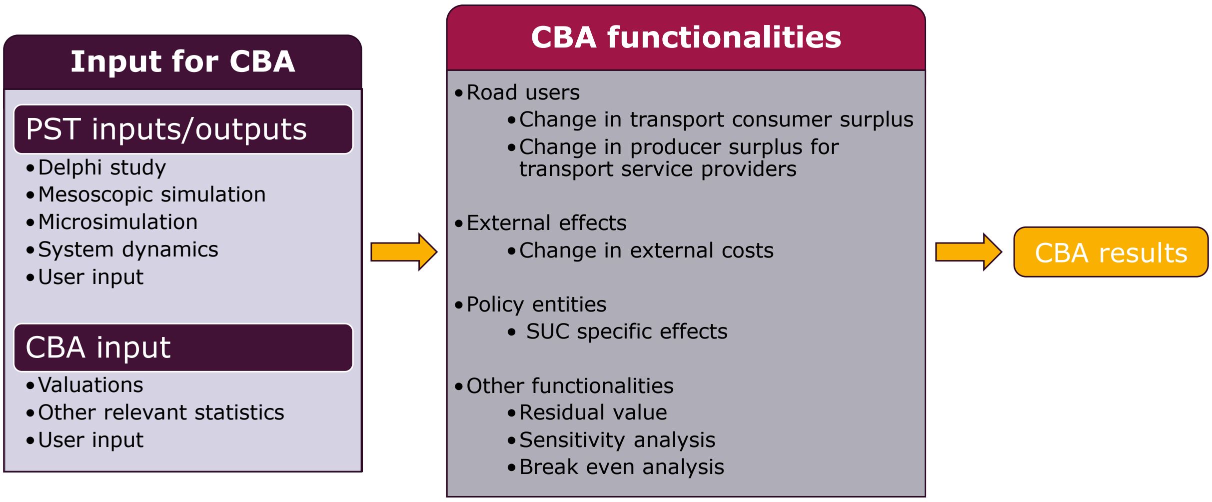

Figure 6.1 Structure of the CBA module

The CBA module relies primarily on inputs that are either inserted into the PST (inputs) or produced within the PST (outputs). This comprises the specific case area and its gross domestic product (GDP) that sets the level for all default valuations of impacts in the CBA. Annual passenger kilometres or vehicle kilometres, average travel time, average delays, emissions of air pollutants and CO_2, as well as number of crashes, are also brought over from the PST to the CBA, for the baseline scenario(s) as well as the sub-use-case (policy) scenario(s). The sub-use cases will affect some of these variables, yielding differences between the policy scenario and the baseline scenario.

Thus, the primary input additions to the CBA tool comprise the values fof the monetization of the impacts. Another basic input to the CBA is the (social) discount rate for calculating the net present value of the measure, where we apply 3% as default (Sartori et al. 2014). The discount rate will enable comparison of benefits and costs (cash flow) in the different years of the project period, irrespective of the length of the project period.[1] The underlying default project period in the PST is 2020-2050, i.e., 30 years. For a later start year set in the PST, say 2025, the CBA updates the project period to 2050-2025 = 25 years. Moreover, in the CBA module, the user can specify an end year different to 2050, implying a residual value after the original period of analysis. This mandates a calculation of residual value.

6.2.1 Basic handling of valuations and transferability

In the CBA module, default valuations are provided, but the user will have the opportunity to change them. Some of the default valuations can also be overruled by specific PST input, e.g. cost figures for automated vehicles. The default valuations that we propose are based on various sources, including D3.3 (Elvik 2020), the European Handbook of External Costs (van Essen et al. 2019) and a meta-analysis of European travel-time valuations (Wardman et al. 2016).

[1] The project period (T) and the discount rate (r) will, i.a., enter the formula for assessing total benefits and costs (the total cash flow) in annual terms, the present value annuity factor: $(1-(1+r)^{-T})/r$.

In D3.4 (Hartveit & Veisten 2021), most of the valuations were firstly assessed as representing EU-28 average values, stated in 2020-Euro prices (EUR_{2020}). The underlying GDP/capita for valuations in EUR_{2020} in EU-28 is approximately 30,500.[2] However, the initial GDP/capita in the PST, and subsequently the CBA module, is 17,000 EUR_{2020}. Thus, D3.4 presented double set of the main valuations, in EUR_{2020} for GDP/capita equal to 30,500 and in EUR_{2020} for GDP/capita equal to 17,000 (downscaled to 57% of the EU-28 average values). Thus, the default valuations in the CBA module will be downscaled to 57% of the values that were presented.

General methodology

The methodology follows CBA standards as per the EU guide to CBA of investment projects (Sartori et al., 2014), with some added input from national guides (e.g., Hagen et al., 2012). Monetary valuations are based primarily on Elvik (2020), van Essen et al. (2019), and Wardman et al. (2016), with some few additional input sources.

The estimation of the impact of the policy measures is divided into infrastructure users (incl. transport service providers), external effects (changes in emissions, safety, congestion levels, and land use) and policy enitites. There are also some additional functionalities for handling uncertainty and project lifetime, as well as a break-even analysis for showing when (if) the measure has a net positive effect.

The estimation of the impacts for the infrastructure users has a categorization into transport consumer surplus and producer surplus for transport service providers. With regards to the user surplus, we estimate the *change* in consumer surplus. This is done by use of the "rule-of-half" formula, applied to a change in generalized costs of travel, primarily travel time and operation costs. For a change in travel quantity, the rule-of-a-half depicts that half the product of the generalized cost change times travel quantity change represents the change in consumer surplus (Boardman et al., 2018; Mishan & Quah, 2020; de Rus & Johansson 2019). This change in transport consumer surplus is, in principle, estimated in the same way for the transport consumer groups (those using cars, active modes, and shuttle buses and other public transport).

The change in producer surplus for transport service providers is calculated in a somewhat simpler way. The difference between the price for transport services (P) and the cost of providing the transport (C), is multiplied by the amount of transport (T): $(P - C) * T$, under the policy scenario and the baseline scenario.

Changes in monetized external effects are, in an aggregate approach, calculated by multiplying some impact measure (kg of emissions, or no. of crashes) by some Euro unit value. However, all impacts related to emissions, road safety, as well as congestion, are allocated to each of the transport modes. For road safety and congestion, this disaggregated approach is also needed for the distribution of external versus internal

[2] The EU-27 GDP/capita was 29,660 EUR_{2020}, according to Eurostat (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_pc&lang=de, retrieved 11th of May 2021). The EU-28 GDP/capita is not stated for 2020, only for EU-27 (omitting the UK). However, based on differences between EU-27 and EU-28 in the foregoing years, an estimate of GDP/capita for EU-28 that is about 8-900 euro higher than for EU-27 seems reasonable.

congestion and road safety costs; the internal part enters the generalized cost of travel. The impact for the policy entities will comprise changes in income or assets brought about by the policy implementation; these changes may be due to fees, e.g., road tolls, or altered use of space in the city centre due to change in parking space, etc. Thus, formulas that retain such payments or transfers, for the relevant policy scenarios were included.

6.3 Contents of the CBA module

In section 6.2 a general introduction to the approach and inputs for the CBA was provided. The present section provides a more detailed and specific overview over the contents of the CBA module. The module is developed in MS Excel and uses mainly simple functions and formulas to ensure a smoother transition into the online PST version.

6.3.1 Inputs

The CBA module draws information from three broad categories; PST inputs, PST outputs and CBA specific inputs, as illustrated in Figure 6.1. Table 6.1 is a modified version of Table 3.1, and it shows the input parameters from PST being used in the CBA.

Table 6.1 PST input parameters being used in the CBA

no.	Description	CCAM related	Unit of Measurement	Default Initial Value (can be changed by user)
1	GDP per capita	no	€	17,000
2	Annual GDP per capita change	no	%	1.50%
3	Inflation	no	%	1.00%
4	City Population	no	million persons	3.000
5	Annual City Population change	no	%	0.50%
6	Urban shuttle fleet size	yes	no. of vehicles	300
7	Freight vehicles fleet size	yes	no. of vehicles	100
8	Average load per freight vehicle	yes	tones	3
9	Average annual freight transport demand	no	million tonnes	1.5
11	1st Gen - Cautious AVs	yes	%	0%
12	2nd Gen - Aggressive AVs	yes	%	0%

Table 6.2 is a modified version of Table 3.2, and it shows the input parameters from PST being used in the CBA.

Table 6.2 PST Output parameters being used in the CBA

#	Impact	Description / measurement	Unit of Measurement	Default Initial Value (can be changed by user)
		Direct impacts		
1	Travel time	*Average duration of a 5Km trip inside the city centre*	*min*	*15*
2	Vehicle operating cost	*Direct outlays for operating a vehicle per kilometre of travel*	*€/Km*	*0.25*
3	Freight transport cost	*Direct outlays for transporting a tonne of goods per kilometre of travel*	*€/tonne.Km*	*0.25*
		Systemic impacts		
5	Amount of travel	*Person kilometres of travel per year in an area*	*person-km*	*19165.40*
6	Congestion	*Average delays to traffic (seconds per vehicle-kilometer) as a result of high traffic volume*	*s/veh-km*	*197.37*
7	Modal split of travel using public transport	*% of trip distance made using public transportation*	*%*	*40.00%*
8	Modal split of travel using active travel	*% of trip distance made using active transportation (walking, cycling)*	*%*	*3.00%*
11	Vehicle occupancy	*average % of seats in use (pass. cars feature 5 seats)*	*%*	*25.00%*
		Wider impacts		
12	Parking space	*Required parking space in the city centre per person*	*m^2/person*	*0.9*
14	NO_X due to vehicles	*Concentration of NO_x pollutants as grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*1.80*
15	CO_2 due to vehicles	*Concentration of CO_2 pollutants as grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*2500.00*
16	PM_{10} due to vehicles	*Concentration of PM_{10} pollutants as grams per vehicle-kilometer (due to road transport only)*	*g/veh-km*	*0.20*
19	Commuting distances	*Average length of trips to and from work (added together)*	*Km*	*20*
22	Road safety total effect	Road safety effects when accounting for VRU and modal split	crashes/veh-km	-

The parameters presented in Table 6.1 and Table 6.2 are presented as growth rates in the final PST sheet. The growth rates are based on the PST results and specify the yearly changes for the various impacts. They were estimated for a certain city or area (Zach et al. 2019a, 2019b, 2019c), and the PST, and hence the CBA, assumes that the effects are valid for all other cities or areas. Through parameters as those presented in Table 3.1 and Table 6.3 (for the CBA), an initial basis for the formulation of the city network is provided. Moreover, they describe important aspects in order to make the results relevant and transferable to the area which the PST user wishes to examine. In addition, the predefined values for each parameter not influenced by an intervention, will be available and the user will be able to change these values if needed. This indicates the type of adaptability of the PST and the CBA module to location-specific user input. Table 6.3 shows the CBA-specific variables.

Table 6.3 Variables specifically being used in the CBA

Description	Unit of Measurement	Default Initial Value (can be changed by user)
User input		
Policy implementation cost	€	
Discount rate	%	3%
Project lifetime	*Years*	30
Project start	*Year*	2020
Income elasticity	*Numeric*	0.5
Occupancy number	*Numeric*	Various
Value of parking space	*€/m²*	300
Tax financing cost (on the cost of implementation)	%	20%
SUC specific variables		
Average length of distance travelled by new modes	*km/trip*	
Share of trips entering the city centre	%	
Share of trips inside the city centre	%	
Share of trips inside the city centre with empty cars	%	
Toll charge (static toll, dynamic toll, empty km pricing)	€	
Converted parking space to public space	%	
Valuations		
Value of travel time savings	*€/km*	Various
Emission costs (CO_2, NO_X, PM_{10})	*€/kg*	Various
Weighted average cost of a crash	*€/crash*	14,800 €

6.3.2 The technical structure of the CBA module in MS Excel

Due to the CBA module drawing most of the information from the PST, the CBA module in MS Excel is being built as an extension of the PST demos. This sheet provides both the PST input and PST output relevant for the CBA (see Table 6.1 and Table 6.2 for the relevant variables).

After being presented with the forecasting and backcasting Excel Demo sheets (a pseudo-interface), the next sheet for the user is the first CBA sheet where CBA specific input is listed (see the "User input" section in Table 6.3 for the variables). This sheet allows the user to align some of the CBA specific variables with e.g. national guidelines for the discount rate or tax financing cost. This also applies if the user has the knowledge of local or national values of travel time savings, cost of a crash or other variables presented in Table 6.3 and this does not correspond with the provided default GDP-adjusted values. The remaining CBA specific inputs are in another sheet (inputs based on Hartveit & Veisten 2021). These inputs comprise e.g. the various valuations of travel time savings (VTTS) for the modes, occupancy numbers, etc.

The last CBA sheet is where all the relevant data is collected, the physical impacts are monetized, and the calculations are carried out. For a more comprehensive description of the calculation and monetizing of the variables, we refer to D3.4 (Hartveit & Veisten 2021). The steps are presented in chronological order in the following.

The module first collects **MPR** for the relevant sub-use case and MPR-scenario. For passenger transport, the MPR consists of the sum of the two PST variables "*1st Gen - Cautious AVs*" and "*2nd Gen - Aggressive AVs*". For freight transport, the MPR consists of automated freight vehicles (not differentiating between HGV and LCV). Dependent on the base scenario ("no automation", "pessimistic", "neutral" and "optimistic") the MPR is distributed across the project period years (2020-2050).

Whether the scenario is a (i) passenger transport scenario or a (ii) freight transport scenario will have a bearing on the handling of the subsequent steps. If (i), the aggregated travel in the case area (*amount of travel*) is the sum of passenger kilometres (pkm). If (ii), the aggregated travel in the case area (*amount of travel*) is the sum of freight vehicle kilometres. In the latter case, the CBA by default applies 10% freight vkm in the total of freight+passenger transport vkm; and the share of heavy versus light freight vehicle (HGV and LCV) vkm is 10%-90% (Rødseth et al., 2019).

Then, it proceeds to collecting the **direct impacts**. These comprise *vehicle operating costs* and *travel time*, for weighted averages of manual and automated passenger cars, or for weighted averages of manual and automated freight vehicles. In this step, also the PST variable *congestion* (systemic impact) is applied. *Travel time* and *congestion* (average delay, in congested traffic) is applied to calculate the travel time for the various modes, on average, as well as in free-flow vs. congestion.

The rest of the **systemic impacts** (*amount of travel, vehicle occupancy rate and modal split)* is then retrieved from the PST output. In case of a passenger transport scenario, the *amount of travel* in pkm is applied with the *vehicle occupancy rate*, for passenger cars, plus the additional occupancy defaults proposed by Hartveit & Veisten (2021), and the *modal split* of passenger transport modes, to estimate the vkm per passenger transport mode. (The amount of freight could then be calculated as the ninth of total passenger transport vkm.) In case of a freight transport scenario, only amount of travel is provided, including the total freight vkm. (The amount of passenger transport, in vkm, can then be calculated as nine times the freight vkm; and by use of the default modal split and occupancies, also derive the pkm per passenger transport mode.)

Having established the physical variables affecting the **internal costs** of the transport consumers and providers, the module calculates the internal costs (generalized cost of travel) for the transport consumers (passenger cars, autonomous and manual, public transport users, active transport users, and, given a shuttle-bus sub-use case, shuttle bus users). The various internal cost elements for the various agents are given in Table 6.4.

The value of travel time savings (VTTS) is an important component in the analysis. While we assume in general that the relative price levels remain fixed, Sartori et al. (2014) propose to model VTTS as increasing over time in proportion to real GDP increase per capita. We propose using 0.5 as the common elasticity for all VTTS (based on nominal *annual GDP per capita change* of 1.5% minus the *inflation* of 1%). If VTTS grows by an elasticity of 0.5 with respect to GDP per capita, the VTTS growth factor will be 0.25% *per annum* (Hartveit & Veisten 2021).

Table 6.4: Relevant internal cost components for the various transport mode users/passengers

Transport mode users/passengers	Value of travel time savings (in free-flow and in congestion)	Vehicle operating (and ownership) costs	Internal cost of traffic injury (person injury and material damage)	Ticket cost	Toll costs	Parking price cost
Passenger cars	X	X	X		X*	X*
Active transport	X	X	X			
Public transport	X		X	X		
Shuttle bus	X		X	X		

* Applicable in some specific sub-use cases.

Similarly, for the transport service providers, the cost of providing the transport service consists of various cost elements, illustrated in Table 6.5.

Table 6.5: Relevant cost components for the various transport service providers

Transport mode	Vehicle operating (and ownership) costs	Internal cost of traffic injury (primarily material damage)	Ticket income	Freight transport cost
Freight transport	X	X		X
Public transport	X	X	X	
Shuttle bus	X	X	X	

Next, the **external cost** is calculated. The external cost is the cost a transport user or provider induces on other agents. These are listed in Table 6.6.

Table 6.6: Relevant external cost elements for the various agents

Elements	Passenger cars (manual)	Passenger cars (autonomous)	Public transport	Shuttle bus	Freight transport
CO_2	X		X		X
NO_X	X	X	X	X	X
PM_{10}	X	X	X	X	X
Congestion	X	X	X	X	X
Traffic injury	X	X	X	X	X

Note: Active travel produces external traffic injury costs.

Another impact that might consist of an external effect is the change in *parking space*. Reducing parking space or replacing parking by public areas, provides a positive external effect. In that case a fixed square metre value is applied and the added space of public area is handled as an income to the public entity.

The **sub-use case-specific effects** for the public entiry include income from road-use pricing, parking fees, and seized space from replacing or removing on-street parking space.

After estimating all the relevant physical sizes and monetized impacts, the **change in user surplus** and **total external costs** can be estimated according to the procedure described in 6.2.3.

Furthermore, the policy implementation (implementing a sub-use case), will have a cost that can be compared to the sum of monetized impacts ("benefits"). The entity assuming these implementation costs is the so-called "policy entity". The CBA also allows for adding a tax financing cost to the cost of implementation, a fixed percentage addendum.

Lastly, the **final results** are calculated. The total is simply the sum of the change in infrastructure user surplus, external costs, and the income change minus implementation costs (plus tax financing cost) for the policy entity. The final calculation will comprise corrections for relevant alterations in implementation year and end year; then the net present value can be derived.

The results are shown as a total and by agent type. Furthermore, a break-even analysis is done to see when (if) the policy has a net positive effect on society (based on the variables included in the Levitate project). If the project lifetime is longer than the analysis period, a residual value is calculated if the cash flow after the analysis period is over is positive. Sensitivity analyses are also conducted to illustrate how the results change if some of the physical effects, like amount of travel, is higher or lower.

6.3.3 Backcasting

The PST has a backcasting functionality, as described in chapter 5. This backcasting is set up for the "physical" CCAM impacts in the PST (discussed in chapters 3, 4 and 5) and is not set up for achieving various monetary goals directly. Thus, the users select one or more (up to 5) physical impacts they want to focus on, and after this, the impacts are calculated. Lastly, they can get the CBA result from the particular strategy. The CBA module is hence compatible with the backcasting process and provides results from the strategy chosen in the PST backcasting. It is important to note, however, that the CBA module is not set up for doing backcasting on monetary variables.

7 Measures Combination within the PST

7.1 Objectives

The aim of this section is to showcase the capabilities that the PST offers for estimating the combined impacts of two measures when their application on study areas has temporal and objective overlap.

7.2 Approach

7.2.1 Methodological background

The proposed methodology draws from the Crash Modification Factor (CMF) approach highlighted in the Highway Safety Manual (HSM) and the respective CMF clearinghouse repository of the US Federal Highway Administration (FHWA).

CMFs are coefficients which influence crash numbers when a road safety countermeasure or treatment (or any other change in road infrastructure) is applied. A CMF value less than one ($CMF < 1$) denotes a beneficial intervention leading to crash reductions, while a CMF value greater than one ($CMF > 1$) denotes a detrimental intervention leading to crash increases. More detailed introduction to CMFs can be found online (CMF Clearinghouse, 2013).

Apart from the previous, the HSM provides guidance on estimating the impact on crashes when multiple treatments are applied to a single location. In other words, a single CMF that represents the combined treatments can be calculated and applied to represent the cumulative crash change.

Therefore, in a parallel reasoning with the HSM, Impact Modification Factors (IMFs) are calculated within the LEVITATE project. IMFs are coefficients with which baseline impacts are multiplied, in order to reach a forecasting or backcasting estimate.

The combination of measures requires the calculation of individual IMFs (IMF1, IMF2) as a first step, which are derived from the difference of the baseline with the current value for each impact:

$$IMF_{1,2} = 1 - \frac{Impact_{examined\ value} - Impact_{baseline\ value}}{Impact_{baseline\ value}} \quad (7.1)$$

Within LEVITATE, the impacts of 17 SUCs are examined. Multiple impacts, as many as 22, can be examined per SUC. When examining the problem on an impact level, it was determined that 22*17*16 = 5984 combined IMFs would be required. Therefore, due to reasons of dimensionality reduction, it was decided to work on a SUC level, regardless of case, and derive 17*16 = 272 combined IMFs in total.

7.2.2 Practical Examples

The following examples consider the case of two SUCs being implemented from the results that are available for the PST, namely:

1. SUC1 : Parking pricing
2. SUC2 : Provision of dedicated lanes for AVs on urban highways

For illustration purposes, the impact of the concentration of **CO2** pollutants as grams per vehicle-kilometer due to road transport only (or CO2 for short) is considered, as forecasted from microsimulation. The CO2 impact is considered for both policies to be implemented on the year 2025 for the pessimistic automation penetration scenario (impact number: **#15**). Furthermore, for SUC1, the case of Parking toll - balanced behavior is considered and for SUC2, the case of Motorway (outermost) is considered.

For the PST, there are typically three important years to consider:

1. The baseline year, fixed across LEVITATE PST, which is **2020**.
2. The year of policy implementation, which is **2025** for this example.
3. The year when impacts are examined, which is **2035** for this example.

Within the PST, all values are calculated as coefficients - percentages of the baseline 2020 values, which are set to **2500** g/veh-km for **CO2** pollutants.

However, a critical point is to try to isolate the effects of the implementation of each measure from the baseline. These effects fluctuate with time. This can be seen from the fluctuating difference of the two curves of the impact graph: gray (baseline) – yellow (policy implementation) in Figure 7.1.

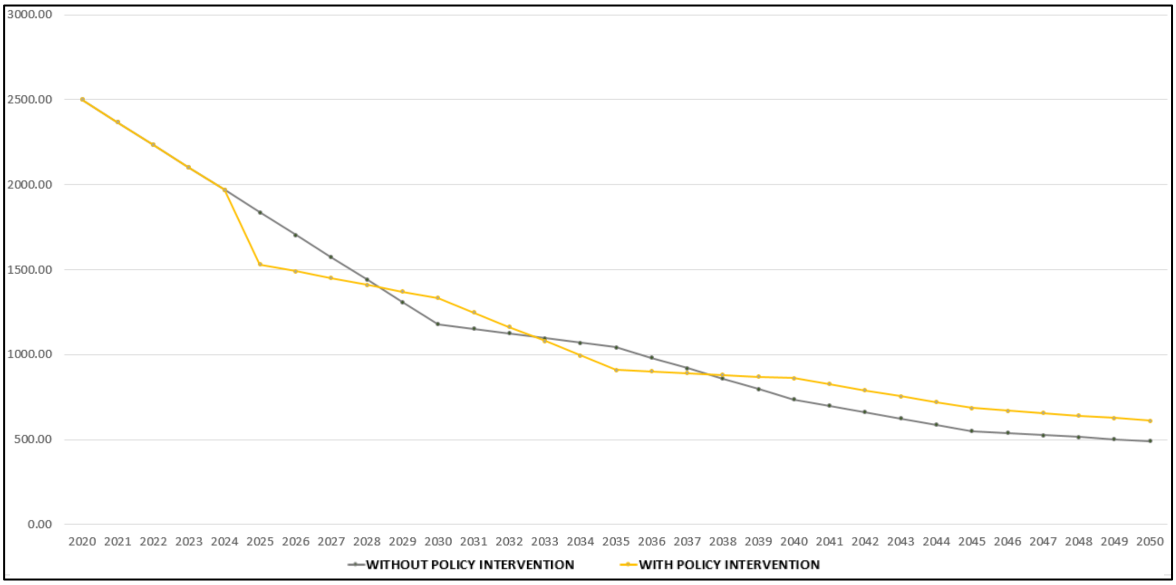

Figure 7.1 CO_2 Impact graph

Therefore, to take into account the baseline fluctuations of MPR and its consequences, IMFs (and combined IMFs) need to be calculated from the baseline projection **each year**. In other words, each year the IMF will have **different values**.

As an example, if impacts on the year 2035 are examined, then the baseline value is obtained from the PST Demo if no policy intervention is considered (again, for the pessimistic automation penetration scenario):

CO2, Base, 2035, 1 = 1043.49 g/veh-km

If the Parking toll – balanced behavior measure is introduced (SUC1) then the projected CO2 values are calculated from the microsimulation results by the PST (for 2035 - 10 years after the policy is introduced):

CO2, SUC1, 2035 = 910.02 g/veh-km

The percentage change of CO2 value only from the measure implementation is:
(910.02 - 1043.49)/1043.49 = **- 12.79%**

Therefore according to formula 7.1, IMF1 = 1 – 0.1279 = **0.8721**
The same calculations are done to calculate the effect of SUC2. Baseline values need to be calculated again because this SUC was calibrated in a different network than the previous one. At this point it needs to be clarified that, the different sub-use cases of each use case did not concern the same calibrated network necessarily. There were several challenges in the choice of the optimal network due to practicalities, including availability and suitability. Given that the most appropriate network is not always

available, the network requirements were considered in order to best satisfy the needs of every sub-use case, e.g. the need of different network scale.

$\mathbf{CO2}_{\mathbf{Base,\ 2035,\ 2}}$ = 1857.58 g/veh-km

The introduction of the Motorway (outermost) case of the Dedicated lane measure gives the following values:

$\mathbf{CO2}_{\mathbf{SUC2,\ 2035}}$ = 1841.98 g/veh-km

The percentage change only from the measure implementation is:
(1841.98 - 1857.58)/1857.58 = **- 0.84%**

Therefore according to formula 7.1, IMF2 = 1 – 0.084 = **0.9916**

Suppose that the combined impact of SUC1 and SUC2 is needed to be determined, therefore a combined IMF (or IMFc) is required. To combine the impacts of these SUCs, the following mathematical alternatives are available (based on the existing combined CMF methods (AASHTO, 2010; US FHWA, 2019).

The IMFc will be multiplied with whatever baseline the user selects for their own network – assuming linear interpolation.

The following examples consider a baseline of 2000 g/veh-km as user input.
If only SUC1 was considered, the 2035 **CO2** values would be:
$\mathbf{CO2}_{\mathbf{SUC1,\ 2035,\ new}}$ = 2000 g/veh-km * 0.8721 = **1744.19** g/veh-km

Respectively, if only SUC2 was considered, the 2035 **CO2** values would be:
$\mathbf{CO2}_{\mathbf{SUC2,\ 2035,\ new}}$ = 2000 g/veh-km * 0.9916 = **1983.20** g/veh-km

7.2.2.1 Additive combined IMF

In the additive method, the combined IMF is:

$$IMF_{c,\ add} = 1 - [(1 - IMF_1) + (1 - IMF_2)] \text{ if } > 0; \text{ otherwise } 0 \qquad (7.2)$$

For the considered example:
IMFc, add = 1 – [(1 – **0.8721**) + (1 – **0.9916**)] = **0.8637**

Therefore, with this method, the 2035 CO2 values for the user's network would be:
$\mathbf{CO2}_{\mathbf{comb,\ 2035}}$ = 2000 g/veh-km * 0.8637 = **1727.39** g/veh-km

It appears that the additive method leads to the maximum reduction with the values of the current example.

Originally, the additive method was recommended by FHWA for cases where there was no overlap expected among the intervention effects or where there is an expected enhancing effect among the countermeasures. For instance there is no overlap between the urban transport "Anywhere to anywhere shuttles" SUC and passenger cars "GLOSA" SUC as GLOSA is mostly on major roads.

7.2.2.2 Multiplicative combined IMF

In the multiplicative method, the combined IMF is the product of the two individual IMFs:

$IMF_{c,\ mult} = IMF_1 * IMF_2$

For the considered example:
$IMF_{c,\ mult} = 0.8721 * 0.9916 = 0.8648$

Therefore, with this method, the 2035 **CO2** values would be:
$\mathbf{CO2}_{\mathbf{comb,\ 2035}}$ = 2000 g/veh-km * 0.8648 = **1729.54** g/veh-km

It should be noted that, originally, the multiplicative method was recommended by FHWA for cases where one or both CMFs are larger than 1. For instance, for the case of the passenger cars "Dynamic toll on all vehicles" SUC and "Automated ride sharing" SUC the multiplicative method is recommended since both affect the way how people travel.

7.2.2.3 Dominant effect combined IMF

In the dominant effect method, the combined IMF is defined as equal to the smallest individual IMF only, while ignoring the other effect:

$$IMF_{c,\ dom\ eff} = \min(IMF_1, IMF_2) \qquad (7.3)$$

For the considered example:
$IMF_{c,\ dom\ eff} = \min(0.8721, 0.9916) = 0.8721$

Therefore, with this method, the 2035 **CO2** values would be:
$\mathbf{CO2}_{\mathbf{comb,\ 2035}}$ = 2000 g/veh-km * 0.8721= **1744.19** g/veh-km

The dominant effect method was recommended by FHWA for cases where there is complete overlap expected among the countermeasure effects, effectively nullifying the weakest countermeasure. For instance, for the case of the passenger cars "Empty km pricing" SUC and "Replace on-street parking with driving lanes" SUC the dominant effect method is recommended since driving lanes will generate more traffic that will be partially reduced by the empty km pricing.

7.2.2.4 Dominant common residuals combined IMF

In the dominant common residuals method, the effect of both countermeasures is considered, but the effectiveness of the second countermeasure is reduced. The combined IMF is defined as the product of the two individual IMFs raised to the power of the smallest IMF in the equation.

$$IMF_{c,\ dom\ com\ res} = (IMF_1 * IMF_2)^{\min(IMF1,\ IMF2)} \qquad (7.4)$$

For the considered example:

$IMF_{c,\ dom\ com\ res} = (0.8721 * 0.9916)^{min(0.8721,\ 0.9916)} = (0.8721 * 0.9916)^{0.8721} = 0.8810$

Therefore, with this method, the 2035 **CO2** values would be:
$CO2_{,\ comb,\ 2035}$ = 2000 g/veh-km * 0.8810 = **1761.98** g/veh-km

Originally, the dominant common residuals method was recommended by FHWA for cases where there is some overlap expected among the countermeasure effects. It provides a more conservative estimate of the combined effect compared to the multiplicative method.

If there is some overlap (but not complete) expected among the countermeasure effects, the FHWA recommends comparing the results of the dominant effect and dominant common residuals methods, and applying the largest reduction. For instance, for the case of the urban transport "Last mile AV shuttles" SUC and passenger cars "Replace on-street parking with driving lanes" SUC the dominant common residuals method is recommended.

7.2.2.5 Amplificatory IMF

Models have been developed for estimating the combined impacts of a set of measures or actions. These models normally assume that impacts combine multiplicatively and that the combined impacts of a set of measures or actions are thus smaller than the sum of their individual impacts.

Thus, if three measures A, B, and C reduce a problem by, respectively, 30 %, 20 % and 10 %, combined impacts can be estimated according to the following models:

Additive impacts = 30 + 20 + 10 = 60 = 60 % reduction

Independent impacts (common residuals) = $1 - (0.9 \cdot 0.8 \cdot 0.7) = 1 - 0.504 = 0.496$ (49.6 % reduction)

Dominant impacts (dominant common residuals) = $1 - [0.9 \cdot 0.8 \cdot 0.7]^{0.7} = 1 - 0.619 = 0.381$ (38.1 % reduction)

The functional form of a fourth type of model is explored below, amplifying impacts, in which the measures or actions that are combined have a larger combined impact than the sum of their individual impacts. In principle, such a model can be multiplicative, but with an exponent greater than one. Thus:

Amplifying impacts = $1 - [0.9 \cdot 0.8 \cdot 0.7]^2 = 1 - 0.254 = 0.746$ (74.6 % reduction)

To assess plausible values for the exponent in a model of amplifying impacts, studies of the combined impacts of risk factors will be used. There is, logically speaking, no difference between measures intended to reduce a problem and risk factors. While the measures will have impact factors with values lower than 1, the risk factors will have values greater than 1, i.e. they increase risk.

Studies of the combined effects on risk of use of multiple drugs have been reviewed in order to estimate amplifying models for the combined impacts of factors.

Figure 7.2 presents estimates of risk from selected studies (Gjerde et al. 2011, Bogstrand et al. 2012, Hels et al. 2011) that were mainly conducted as part of the EU-funded DRUID-project. The blue staples are estimates of the risk associated with a single drug, the red are estimates of the risk associated with the use of two or more drugs.

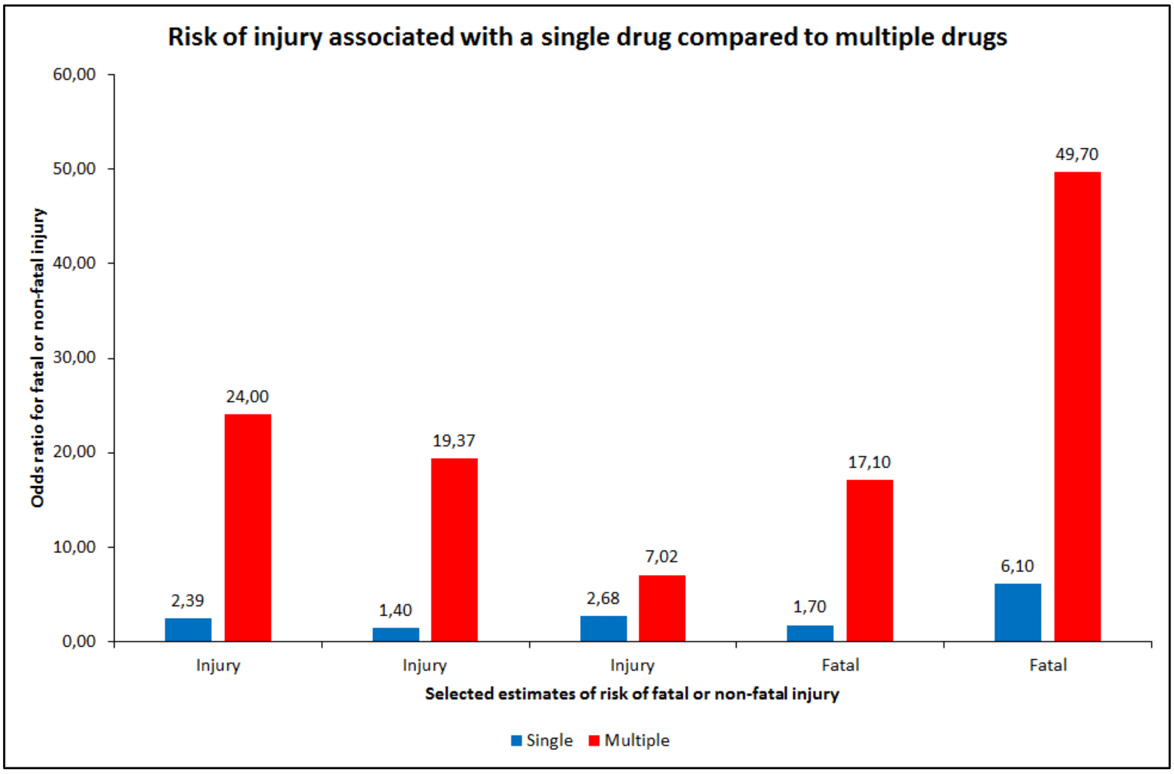

Figure 7.2 Risks (odds ratios) associated with the use of a single or multiple drugs

Unfortunately, the studies do not state the number of drugs that were used when more than one drug was used. It will be assumed that two drugs were used and that their effects on risk were identical.

For the first case listed in Figure 7.2, a simple estimate of the combined effect on risk thus becomes:

Combined effect on risk = $2.39 \cdot 2.39 = 5.69$.

As can be seen from Figure 7.2, the estimate of risk for combined use of drugs was 24, rather than 5.69. This implies the following model:

Combined effect on risk = $(2.39 \cdot 2.39)^{1.828} = 24.00$

Treating the other pairs of risk estimates the same way, we get:

Combined effect on risk = $(1.40 \cdot 1.40)^{4.405} = 19.37$

Combined effect on risk = $(2.68 \cdot 2.68)^{0.989} = 7.02$

Combined effect on risk = $(1.70 \cdot 1.70)^{2.675} = 17.10$

Combined effect on risk = $(6.10 \cdot 6.10)^{1.080} = 49.70$

The values of the exponent vary between 0.989 and 4.405. Only values greater than 1 are consistent with an amplifying effect. The mean value of the exponents is 2.195. The median value is 1.828. This suggests that using a multiplicative model with an exponent of 2 can be a reasonable way of estimating amplifying impacts.

Thus, if the residual terms for two factors are 0.7 and 0.5, the model becomes:

Combined impact (amplifying) = $1 - (0.7 \cdot 0.5)^2 = 0.123$ = 87.3 % impact

If no amplification is assumed, the combined impact is:

Combined impact = $1 - (0.7 \cdot 0.5) = 1 - 0.35$ = 65 % impact

Care should be taken to avoid estimating a combined impact of more than 100 %, which is impossible.

Therefore, While this is not covered by the FHWA HSM, as measures are always aimed to reduce crash numbers, it becomes useful for LEVITATE as the examine impacts can be expected to both increase and decrease. This method fills a gap where the measures have a larger combined impact than the sum of their individual impacts:

The amplificatory formulation is based on the multiplicative model, with an exponential >1 – an exponential value of 2 is reasonable for providing amplificatory estimations (Elvik, 2020).

$$IMF_{c,\ amplify} = (IMF1 * IMF2)^2 \qquad (7.5)$$

All these combined IMFs are simple to calculate given the individual IMFs, and allow for a flexible approximation of real conditions of combined measures.

As an example, the amplificatory method is recommented for the case of the passenger cars “Automated ride sharing” SUC and “Parking pricing” SUC since the prohibitive parking price could amplify the effect of automated ride sharing as people might choose to prefer that for cost saving.

7.2.3 Application restrictions

The US FHWA provides some general guidelines as per Figure 7.3 for selecting a method, however it is underlined that each case must be examined separately, thoroughly and under the lens of engineering knowledge and insight.

An important point to mention is that the FHWA CMF combinations are meaningful when the target population is common. In other words, CMF combinations are meaningful only when they target crashes of the same types and severities. In cases where the interventions target different crash types, the individual changes need to be calculated separately, and the results aggregated afterwards, rather than combining the individual CMFs for each change/ treatment.

Similar parallels must be ensured for the impacts considered within the LEVITATE PST. Needless to say, any combined IMF is still an IMF, namely cannot have a negative value. At the present stage, no additional hard limits will be enforced to the combined IMF results.

Magnitude	Overlap	Method
One or more CMFs > 1.0	Not Applicable	Multiplicative
Both CMFs < 1.0	Zero Overlap or Enhancing Effects	Additive
	Complete Overlap	Dominant effect
	Some Overlap	Dominant effect OR Dominant common residuals; whichever produces the greatest reduction (i.e., smallest combined CMF)

Figure 7.3 Overall guidelines for combining CMFs (US FHWA, 2019)

7.2.4 PST integration

After taking the previous into account, the following IMF tables are populated to reflect the reasoning of each assignment for combined IMF calculations within the LEVITATE PST. The tables showcase the selection of combined IMF methods for each calculation. As a note, the IMF tables refer to symmetric matrices; in other words, the relation of SUC #17 with SUC #3 is equal to that of SUC #3 with SUC #17 and will not be repeated. The overall process involved initial consideration of the measures within the backcasting group, and a proposition of the degree of overlap between two measures based on the definitions of said measures and of the group members' apriori understanding of their application. The combination table was initially reviewed by the entire backcasting group, and a first draft was compiled. Afterwards, it was reviewed by the entire LEVITATE consortium and, after minor modifications, the final version was obtained.

Regarding the reasoning followed by the group, as a rule of thumb:

- No-overlap between measures would lead them to being assigned to an additive method
- Moderate overlap between measures would lead them to being assigned to the multiplicative method

- Complete overlap between measures would lead them to being assigned to a dominant method

An overarching reasoning within backcasting is that there can be some form of rules when considering the combination of one SUC from freight with one non-freight SUC. In such cases, it can be considered that no overlap exists between the freight and non-freight SUCs as a general rule. Therefore, the additive method is preferred as discussed in Section 7.2.2.1 when dealing with WP5-WP7 & WP6-WP7 combinations. The combined IMF tables are presented in the Appendix A.

Mathematically, all alternative methods are easy to calculate. The final choice depends on which combination is more reasonable based on the physical interaction of the two SUC measures.

In cases where it becomes too unclear and too difficult to predict a reasonable future estimation, there will be an option in the PST to declare the impacts of the SUC combination as "Unknown" rather than provide uncertain guesses.

In summary of the specifics included in the LEVITATE PST, the case of estimating impacts from the combination of two (and only two) SUCs and the related case-by-case implications are considered. The impacts are combined with a methodological basis drawn from the Crash Modification Factor (CMF) approach highlighted in the Highway Safety Manual (HSM) and the respective CMF clearinghouse repository of the US Federal Highway Administration (FHWA). CMFs are coefficients which influence crash numbers when a road safety countermeasure or treatment is applied. However the HSM predicts CMFs when multiple treatments are applied to a single location. In other words, a single CMF that represents the combined treatments is calculated and applied to represent the cumulative crash change. Therefore, in a parallel reasoning with the HSM, Impact Modification Factors (IMFs) are calculated within the LEVITATE project. IMFs are coefficients with which baseline impacts are multiplied, in order to reach a forecasting or backcasting estimate. Within LEVITATE, due to reasons of dimensionality reduction, it was decided to work on a SUC level, regardless of case, and therefore 17*16 = 272 combined IMFs were derived in total.

8 Knowledge Module

8.1 Objectives

The **Knowledge module** is one of the main modules of the LEVITATE Policy Support Tool. This module lists the synthetized knowledge that was acquired during the LEVITATE project. The PST Knowledge Module is envisioned to be static and searchable. Its components provide access to the knowledge base, repository and recommendations of the LEVITATE project. The contents of the module are the following:

- **Bibliography**: the bibliography of all relevant literature concerning impact assessments of CCAM,
- **Project results**: the project results, including the case studies on the participating cities (scenarios and baseline conditions, results) and the predefined impact assessments,
- **Documentation of tools**: the documentation about the toolbox of methods developed in LEVITATE, to enable cities to explore the expected impacts of CCAM in the users circumstances (including underlying models, data and impact assessment methods),
- **Guideline excerpts**: Guidelines and policy recommendations regarding CCAM.

As the topics addressed by LEVITATE and the PST are multidimensional and interdisciplinary, a basic understanding of the transport systems to be examined would be beneficial to the user. Within the PST documentation, definitions and similar informative texts will be provided to facilitate this understanding.

8.2 Approach

The knowledge module aims to provide a **searchable static repository** through fully detailed and flexible concise reports. The concise reports aim to inform the user in the most essential and summarizing way, offering the necessary information. More specifically, the user is able to search by any parameter, to adjust and customize the search according to preliminary results and to access all background information about any stage of the project. The reports differ in the documentation categories that essentially are the contents of the module as well as in different levels namely the cross project and use-case or sub-use case level. The explanation of the different categories are the following.

8.2.1 Bibliography

Bibliography section contains the results of a **systematic literature review** that has been conducted within the project. More specifically, the bibliography includes a section across the project and one per use case. On a sub-use case level, the bibliography consists of (i) documentation providing additional scientific reference material and

(ii) a short synopsis. The synopsis provides the title, other reference information, scope and some information about the study methodology with the necessary data and the results of the study.

Resulting lists of potentially relevant studies are assessed regarding their eligibility for further analysis and inclusion in the bibliography section. The lists record the characteristics and results of each study including document title, issue date, author/publisher, topic, category, user type, geographic area covered, area and DOI links as it is presented in the Figure 8.1.

No	Title	Issue Date	Author/ Publisher	Topic	Category	User Types	Geographic Area Covered	Area	DOI
1	Analyzing effects of transport policies on travelers' rational behaviour for modal shift in Denmark	2019	Ahanchian et al.	Development of an innovative agent-based model simulating emergent patterns arising from individual actions to analyze opportunities for modal shift in Denmark	Modal shift	All	Denmark	Urban, Suburban and Rural	https://doi.org/10.1016/j.cstp.2019.07.010

Figure 8.1 Literature list display

8.2.2 Project results

Regarding the project results, an **introductory material** of the case studies is provided on project level, describing their objectives, common reasoning, issues and limitations. Similarly on sub-use case level, the platform provides information about their scenarios and baseline conditions relating to specific deployments of CCAM. Additionally, the results of each use-case are publicly accessible with the respective assumptions and limitations relevant to each case study and their explanation as well.

8.2.3 Documentation of tools

The knowledge base also includes the documentation about the **tools used and developed** during the project. This category includes a summary of the used methodologies on project level, describing their aim, common reasoning, issues and limitations. For each methodology namely microsimulation, Delphi, mesoscopic simulation, System Dynamics and operations research, information regarding their background, assumptions and limitations are explained in detail as well.

8.2.4 Guideline excerpts

Regarding the use of the PST, introduction of its material as well as explanations and tutorials for its modules are provided. One of the aims of this project is to provide **guidelines and policy recommendation** to stakeholders, regarding the increasing prevalence of connected and automated systems. To this purpose the LEVITATE PST includes a specific section for guidelines. These guidelines consists of overall recommendations for the cities from project results for each use case and also additional recommendations from the literature.

8.3 Description of documentation

According to the knowledge module approach that is described above, all the exported reports of the project were categorized in order for the module to be understandable and searchable for the PST user. In this **categorization**, different levels are obtained as well. The levels offer to the user the ability to find concisely the information of the category that is requested on a general view or a more specific one. The PST knowledge module structure is presented in Figure 8.2.

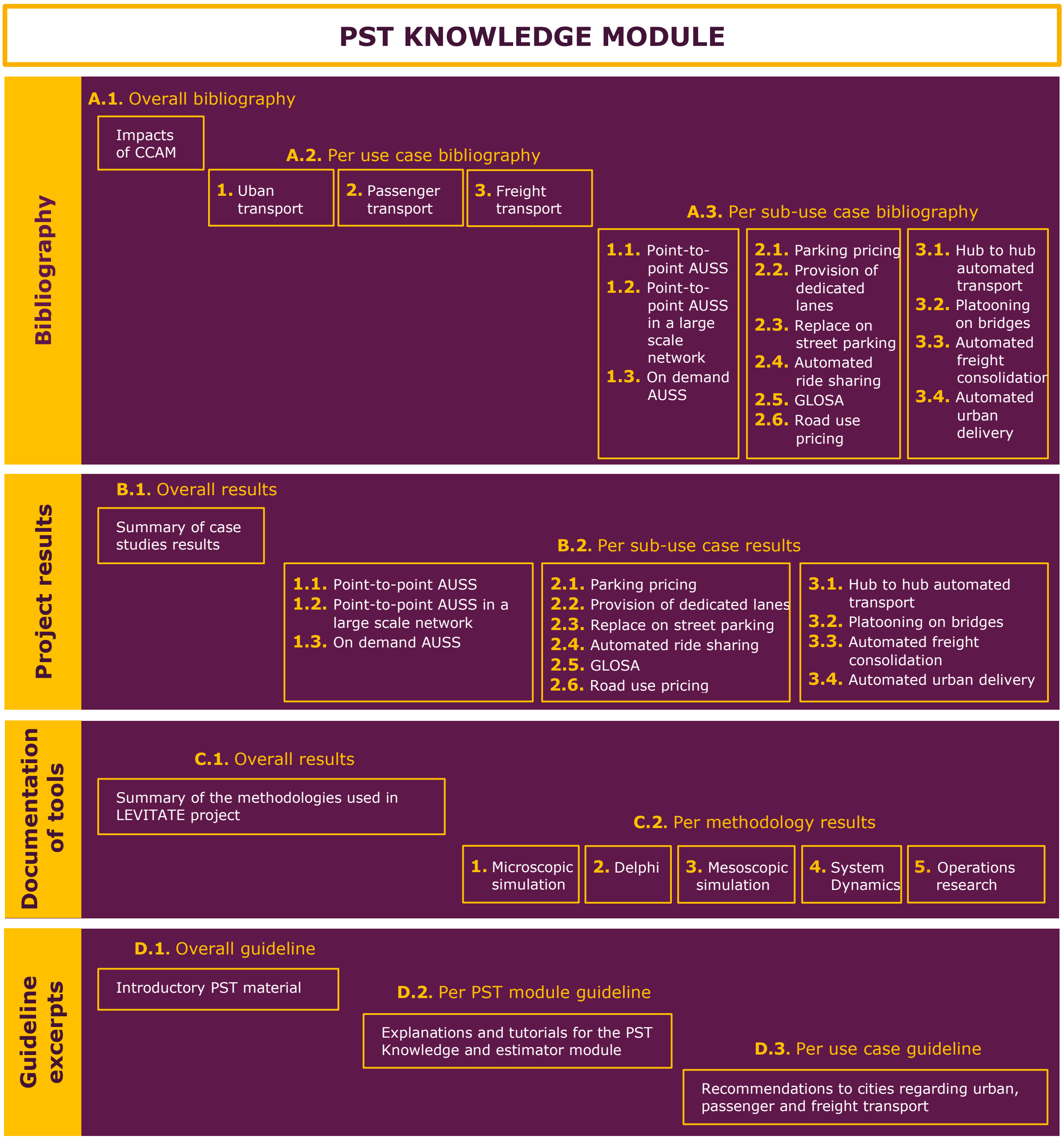

Figure 8.2 PST Knowledge module structure

The categorization of the reports including their levels and components are described in more detail in Appendix B.

The user will be able to access each report according to their desires, and to download and read each file individually. This taxonomy and the respective separation enhances the comprehension of each different aspect of the LEVITATE PST, and provides a way to break down the work undertaken within the project into more manageable pieces of information.

9 Conclusions and future work

9.1 Conclusions

The advent of automation is expected to considerably transform the transport market. For transport researchers, practitioners and stakeholders alike, it is prudent to anticipate and plan for the impacts that the introduction of automation will introduce. The LEVITATE PST is designed as a user-friendly, dynamic and interactive policy support tool, which can be used to support decision making related to the introduction of CCAM in the urban environment. The PST comprises two main modules: the Knowledge module (static component) and the Estimator module (dynamic component). The knowledge module aims to provide a searchable static repository through a fully detailed and flexible concise reports. The concise reports aim to inform the user in the most essential and summarizing way, offering the necessary information. More specifically, the user is able to search by any parameter, to adjust and customize the search according to preliminary results and to access all background information about any stage of the project. The reports differ in the documentation categories that essentially are the contents of the module as well as in different levels namely the cross project and use-case or sub-use case level. The estimator module will provide estimates for different types of impacts and allow comparative analyses. It includes four pillars of analysis: (i) forecasting, serving as the basis of predicting the quantitative and qualitative estimated impacts for different horizons, (ii) backcasting, serving as the basis of acquiring relevant policy targets for each impact area, (iii) cost-benefit analysis, serving as the basis of monetizing costs and benefits of CCAM interventions and (iv) case study examples, serving as a basis for documented applied paradigms of CCAM interventions within real-world environments at a city level.

9.2 Future work

Further work to be carried out in WP8 includes the following tasks:

a. Design the online dynamic LEVITATE PST which will have an attractive and ergonomic user interface and will be complemented with the full project knowledge and documentation (developed in deliverable D8.2 as part of task 8.3).
b. Conduct the project case studies using the methodologies developed by the harmonization of results within the LEVITATE PST. The application of the LEVITATE PST on these selected cases studies will be the content of deliverable D8.3 in terms of task 8.4.
c. Promote and exploit the LEVITATE PST with road authorities, interested stakeholders and the scientific community, as part of the task 8.2 as well as the ongoing works of WP2, which focusses on the exploitation and dissemination of the project outcomes throughout the whole duration of LEVITATE.
d. Develop the synthesis of the key messages and outputs of the project, in order to provide the most important policy recommendations which will derive from the outputs of the LEVITATE PST for different types of stakeholders, and for optimal use of the methodologies. These policy recommendations will be in detail

developed in deliverable D8.4, as part of the task 8.5 and will be included in the knowledge module of the LEVITATE PST.

As of the finalization of the present Deliverable, the time-frame for the PST is for the data import process from the completed PST Demos and the related dataframe creation process in the online platform to be completed by January 2022. This will allow the launching of the online version of the LEVITATE PST with its main forecasting functions. Backcasting and CBA capabilities are expected to be added by February 2022. Finally, quality control, feedback by the city partners and corrections by the consortium are expected to be completed by March 2022.

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Appendix A Combined IMFs

SUC 1 Belongs to WP5 – urban transport

SUC1	SUC2	Selected Method	Reasoning
UT: E-hailing (on-demand last mile shuttles)	**UT: Station to station AV shuttles**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**UT: Anywhere to anywhere shuttles**	Dominant effect	Complete overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**UT: Last mile AV shuttles**	Dominant effect	Complete overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: Empty km pricing**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: Static toll on all vehicles**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: Dynamic toll on all vehicles**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: Automated ride sharing**	Dominant common residuals	Some overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: Parking pricing**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: Replace on-street parking with public space**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: Replace on-street parking with driving lanes**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: Replace on-street parking with pick-up/drop-off parking**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**PC: GLOSA**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**FT: Automated urban freight delivery**	Additive	No overlap between measures
UT: E-hailing (on-demand last mile shuttles)	**FT: Automated freight consolidation**	Additive	No overlap between measures

SUC1	SUC2	Selected Method	Reasoning
UT: E-hailing (on-demand last mile shuttles)	**FT: Hub to hub automated transfer**	Additive	No overlap between measures
UT: Station to station AV shuttles	**UT: Anywhere to anywhere shuttles**	Dominant effect	Complete overlap between measures
UT: Station to station AV shuttles	**UT: Last mile AV shuttles**	Dominant common residuals	Some overlap between measures
UT: Station to station AV shuttles	**PC: Empty km pricing**	Additive	No overlap between measures
UT: Station to station AV shuttles	**PC: Static toll on all vehicles**	Additive	No overlap between measures
UT: Station to station AV shuttles	**PC: Dynamic toll on all vehicles**	Additive	No overlap between measures
UT: Station to station AV shuttles	**PC: Automated ride sharing**	Dominant effect/dominant common residuals	Some overlap between measures
UT: Station to station AV shuttles	**PC: Parking pricing**	Additive	No overlap between measures
UT: Station to station AV shuttles	**PC: Replace on-street parking with public space**	Additive	No overlap between measures
UT: Station to station AV shuttles	**PC: Replace on-street parking with driving lanes**	Dominant common residuals	Some overlap between measures
UT: Station to station AV shuttles	**PC: Replace on-street parking with pick-up/drop-off parking**	Additive	No overlap between measures
UT: Station to station AV shuttles	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	No overlap between measures
UT: Station to station AV shuttles	**PC: GLOSA**	Additive	No overlap between measures
UT: Station to station AV shuttles	**FT: Automated urban freight delivery**	Additive	No overlap between measures
UT: Station to station AV shuttles	**FT: Automated freight consolidation**	Additive	No overlap between measures
UT: Station to station AV shuttles	**FT: Hub to hub automated transfer**	Additive	No overlap between measures
UT: Anywhere to anywhere shuttles	**UT: Last mile AV shuttles**	Dominant effect	Complete overlap between measures
UT: Anywhere to anywhere shuttles	**PC: Empty km pricing**	Additive	No overlap between measures
UT: Anywhere to anywhere shuttles	**PC: Static toll on all vehicles**	Additive	No overlap between measures
UT: Anywhere to anywhere shuttles	**PC: Dynamic toll on all vehicles**	Additive	No overlap between measures
UT: Anywhere to anywhere shuttles	**PC: Automated ride sharing**	Dominant common residuals	Some overlap between measures (some competition for users)
UT: Anywhere to anywhere shuttles	**PC: Parking pricing**	Additive	No overlap between measures
UT: Anywhere to anywhere shuttles	**PC: Replace on-street parking with public space**	Additive	No overlap between measures

SUC1	SUC2	Selected Method	Reasoning
UT: Anywhere to anywhere shuttles	**PC: Replace on-street parking with driving lanes**	Dominant common residuals	Some overlap between measures
UT: Anywhere to anywhere shuttles	**PC: Replace on-street parking with pick-up/drop-off parking**	Additive	No overlap between measures
UT: Anywhere to anywhere shuttles	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	No overlap between measures
UT: Anywhere to anywhere shuttles	**PC: GLOSA**	Additive	No overlap between measures (GLOSA will be mostly on major roads)
UT: Anywhere to anywhere shuttles	**FT: Automated urban freight delivery**	Additive	No overlap between measures
UT: Anywhere to anywhere shuttles	**FT: Automated freight consolidation**	Additive	No overlap between measures
UT: Anywhere to anywhere shuttles	**FT: Hub to hub automated transfer**	Additive	No overlap between measures
UT: Last mile AV shuttles	**PC: Empty km pricing**	Additive	No overlap between measures
UT: Last mile AV shuttles	**PC: Static toll on all vehicles**	Additive	No overlap between measures
UT: Last mile AV shuttles	**PC: Dynamic toll on all vehicles**	Additive	No overlap between measures
UT: Last mile AV shuttles	**PC: Automated ride sharing**	Dominant common residuals	Some overlap between measures
UT: Last mile AV shuttles	**PC: Parking pricing**	Additive	No overlap between measures
UT: Last mile AV shuttles	**PC: Replace on-street parking with public space**	Additive	No overlap between measures
UT: Last mile AV shuttles	**PC: Replace on-street parking with driving lanes**	Dominant common residuals	Some overlap between measures
UT: Last mile AV shuttles	**PC: Replace on-street parking with pick-up/drop-off parking**	Additive	No overlap between measures
UT: Last mile AV shuttles	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	No overlap between measures because last mile shuttles won't use highways
UT: Last mile AV shuttles	**PC: GLOSA**	Additive	No overlap between measures (GLOSA will be mostly on highways)
UT: Last mile AV shuttles	**FT: Automated urban freight delivery**	Additive	No overlap between shuttle buses and freight vehicles during the night
UT: Last mile AV shuttles	**FT: Automated freight consolidation**	Additive	No overlap between shuttle buses and freight vehicles during the night
UT: Last mile AV shuttles	**FT: Hub to hub automated transfer**	Additive	No overlap between shuttle buses and urban highway traffic

SUC 1 Belongs to WP6 – passenger cars

SUC1	SUC2	Selected Method	Reasoning
PC: Empty km pricing	**PC: Static toll on all vehicles**	Dominant effect	Complete overlap between road pricing measures – the most expensive measure for the user will lead the impacts.
PC: Empty km pricing	**PC: Dynamic toll on all vehicles**	Dominant effect	Complete overlap between road pricing measures – the most expensive measure for the user will lead the impacts.
PC: Empty km pricing	**PC: Automated ride sharing**	Multiplicative	Moderate overlap since both measures affect the way how people travel.
PC: Empty km pricing	**PC: Parking pricing**	Additive	The effect is larger when both SUCs are applied simultaneously
PC: Empty km pricing	**PC: Replace on-street parking with public space**	Additive	Similar thinking to the above row
PC: Empty km pricing	**PC: Replace on-street parking with driving lanes**	Dominant effect	Driving lanes will generate more traffic that will be partially reduced by empty km pricing
PC: Empty km pricing	**PC: Replace on-street parking with pick-up/drop-off parking**	Additive	Similar thinking to the above row
PC: Empty km pricing	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	Dedicated AVs will be on urban highways whereas empty km pricing is to tackle cars going around a few blocks. There could also be an argument for empty km pricing to tackle 'empty cars return to home' journeys but then again, they can be considered independent.
PC: Empty km pricing	**PC: GLOSA**	Additive	These are considered independent.
PC: Empty km pricing	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Empty km pricing	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Empty km pricing	**FT: Hub to hub automated transfer**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Static toll on all vehicles	**PC: Dynamic toll on all vehicles**	Dominant effect	Overlap between road pricing measures – the most expensive measure for the user will lead the impacts.
PC: Static toll on all vehicles	**PC: Automated ride sharing**	Multiplicative	Moderate overlap since both measures affect the way how people travel.
PC: Static toll on all vehicles	**PC: Parking pricing**	Additive	This combination is dependent on the prices, but

SUC1	SUC2	Selected Method	Reasoning
			additive covers all the cases (high toll, high parking cost, both equally high)
PC: Static toll on all vehicles	**PC: Replace on-street parking with public space**	Additive	Similar thinking to the above row
PC: Static toll on all vehicles	**PC: Replace on-street parking with driving lanes**	Additive	Similar thinking to the above row
PC: Static toll on all vehicles	**PC: Replace on-street parking with pick-up/drop-off parking**	Additive	Similar thinking to the above row
PC: Static toll on all vehicles	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	No overlap in the effects of measures
PC: Static toll on all vehicles	**PC: GLOSA**	Additive	These are considered independent.
PC: Static toll on all vehicles	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Static toll on all vehicles	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Static toll on all vehicles	**FT: Hub to hub automated transfer**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Dynamic toll on all vehicles	**PC: Automated ride sharing**	Multiplicative	Moderate overlap since both measures affect the way how people travel.
PC: Dynamic toll on all vehicles	**PC: Parking pricing**	Additive	This combination is dependent on the prices, but additive covers all the cases (high toll, high parking cost, both equally high)
PC: Dynamic toll on all vehicles	**PC: Replace on-street parking with public space**	Additive	Similar thinking to the above row
PC: Dynamic toll on all vehicles	**PC: Replace on-street parking with driving lanes**	Dominant effect	Similar thinking to the above row
PC: Dynamic toll on all vehicles	**PC: Replace on-street parking with pick-up/drop-off parking**	Additive	Similar thinking to the above row
PC: Dynamic toll on all vehicles	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	No overlap between measures
PC: Dynamic toll on all vehicles	**PC: GLOSA**	Additive	Independent
PC: Dynamic toll on all vehicles	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Dynamic toll on all vehicles	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night

SUC1	SUC2	Selected Method	Reasoning
PC: Dynamic toll on all vehicles	**FT: Hub to hub automated transfer**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Automated ride sharing	**PC: Parking pricing**	Amplificatory (if not additive)	Prohibitive parking price could amplify the effect of automated ride sharing as people might choose to prefer that for cost saving
PC: Automated ride sharing	**PC: Replace on-street parking with public space**	Amplificatory (if not additive)	Similar thinking to the above row
PC: Automated ride sharing	**PC: Replace on-street parking with driving lanes**	Amplificatory (if not additive)	Similar thinking to the above row. No parking means people can't use their private vehicles.
PC: Automated ride sharing	**PC: Replace on-street parking with pick-up/drop-off parking**	Amplificatory (if not additive)	Similar thinking to the above row. Pick-up/drop-off would work in favour of automated ride sharing.
PC: Automated ride sharing	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	Considered independent. Dedicated lanes will affect private AV users and automated ride sharing users the same way. It could be different under the circumstances that automated ride sharing cars are only connected but not AVs. But even in this case, additive could be applied.
PC: Automated ride sharing	**PC: GLOSA**	Additive	Independent
PC: Automated ride sharing	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Automated ride sharing	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Automated ride sharing	**FT: Hub to hub automated transfer**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Parking pricing	**PC: Replace on-street parking with public space**	Additive	They are similar as they both affect journey decisions based on parking.
PC: Parking pricing	**PC: Replace on-street parking with driving lanes**	Additive	Similar thinking to the above row
PC: Parking pricing	**PC: Replace on-street parking with pick-up/drop-off parking**	Additive	Similar thinking to the above row
PC: Parking pricing	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	Independent
PC: Parking pricing	**PC: GLOSA**	Additive	Independent
PC: Parking pricing	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night

SUC1	SUC2	Selected Method	Reasoning
PC: Parking pricing	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Parking pricing	**FT: Hub to hub automated transfer**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Replace on-street parking with public space	**PC: Replace on-street parking with driving lanes**	Display 'N/A'	They both involve replacing the same thing.
PC: Replace on-street parking with public space	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	Independent
PC: Replace on-street parking with public space	**PC: GLOSA**	Additive	Independent
PC: Replace on-street parking with public space	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Replace on-street parking with public space	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Replace on-street parking with public space	**FT: Hub to hub automated transfer**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Replace on-street parking with driving lanes	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	Independent
PC: Replace on-street parking with driving lanes	**PC: GLOSA**	Additive	Independent
PC: Replace on-street parking with driving lanes	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Replace on-street parking with driving lanes	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Replace on-street parking with driving lanes	**FT: Hub to hub automated transfer**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Replace on-street parking with pick-up/drop-off parking	**PC: Provision of dedicated lanes for AVs on urban highways**	Additive	Independent
PC: Replace on-street parking with pick-up/drop-off parking	**PC: GLOSA**	Additive	No overlap between on-street parking (city central area)
PC: Replace on-street parking with pick-up/drop-off parking	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Replace on-street parking with pick-up/drop-off parking	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Replace on-street parking with pick-up/drop-off parking	**FT: Hub to hub automated transfer**	Additive	No overlap between day traffic and freight vehicles during the night

SUC1	SUC2	Selected Method	Reasoning
PC: Provision of dedicated lanes for AVs on urban highways	**PC: GLOSA**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Provision of dedicated lanes for AVs on urban highways	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Provision of dedicated lanes for AVs on urban highways	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night
PC: Provision of dedicated lanes for AVs on urban highways	**FT: Hub to hub automated transfer**	Additive	No overlap between traffic in the city and urban highway traffic
PC: GLOSA	**FT: Automated urban freight delivery**	Additive	No overlap between day traffic and freight vehicles during the night
PC: GLOSA	**FT: Automated freight consolidation**	Additive	No overlap between day traffic and freight vehicles during the night
PC: GLOSA	**FT: Hub to hub automated transfer**	Additive	No overlap between traffic in the city and urban highway traffic

SUC 1 Belongs to WP7 – freight transport

SUC1	SUC2	Selected Method	Reasoning
FT: Automated urban freight delivery	**FT: Automated freight consolidation**	Dominant effect	Automated freight consolidation further extends the effects of automated urban freight delivery, therefore there is a complete overlap on the operational business
FT: Automated urban freight delivery	**FT: Hub to hub automated transfer**	Additive	Almost no overlap between freight transport in the city and urban highway traffic
FT: Automated freight consolidation	**FT: Hub to hub automated transfer**	Additive	Almost no overlap between freight transport in the city and urban highway traffic

Appendix B Categorization of PST Knowledge Module reports

A. Bibliography

A.1. Overall bibliography regarding impacts of CCAM based on Deliverables 3.1, 3.2 and 3.3 of WP3

A.2. Per use case bibliography

A.2.1. Urban transport bibliography based on Deliverable 5.1 of WP5

A.2.2. Passenger transport bibliography based on Deliverable 6.1 of WP6

A.2.3. Freight transport bibliography based on Deliverable 7.1 of WP7

A.3. Per sub-use case bibliography

A.3.1. Urban transport

A.3.1.1. Point-to-point AUSS bibliography based on respective documentation report of WP5
A.3.1.2. Point-to-point AUSS in a large scale network bibliography based on respective documentation report of WP5
A.3.1.3. On demand AUSS bibliography based on respective documentation report of WP5

A.3.2. Passenger transport

A.3.2.1. Parking pricing bibliography based on respective documentation report of WP6
A.3.2.2. Provision of dedicated lanes bibliography based on respective documentation report of WP6
A.3.2.3. Replace on street parking bibliography based on respective documentation report of WP6
A.3.2.4. Automated ride sharing bibliography based on respective documentation report of WP6
A.3.2.5. GLOSA bibliography based on respective documentation report of WP6
A.3.2.6. Road use pricing bibliography based on respective documentation report of WP6

A.3.3. Freight transport

A.3.3.1. Hub to hub automated transport bibliography based on respective documentation report of WP7
A.3.3.2. Platooning on bridges bibliography based on respective documentation report of WP7
A.3.3.3. Automated freight consolidation bibliography based on respective documentation report of WP7
A.3.3.4. Automated urban delivery bibliography based on respective documentation report of WP7

B. Project results

B.1. An introductory material summarizing information, common reasoning, issues, limitations and results of the case studies on a project level

B.2. Per sub-use case results

B.2.1. Urban transport

B.2.1.1. Point-to-point AUSS results based on respective documentation report of WP5
B.2.1.2. Point-to-point AUSS in a large scale network results based on respective documentation report of WP5
B.2.1.3. On demand AUSS results based on respective documentation report of WP5

B.2.2. Passenger transport

B.2.2.1. Parking pricing results based on respective documentation report of WP6
B.2.2.2. Provision of dedicated lanes results based on respective documentation report of WP6
B.2.2.3. Replace on street parking results based on respective documentation report of WP6
B.2.2.4. Automated ride sharing results based on respective documentation report of WP6
B.2.2.5. GLOSA results based on respective documentation report of WP6
B.2.2.6. Road use pricing results based on respective documentation report of WP6

B.2.3. Freight transport

B.2.3.1. Hub to hub automated transport results based on respective documentation report of WP7
B.2.3.2. Platooning on bridges results based on respective documentation report of WP7
B.2.3.3. Automated freight consolidation results based on respective documentation report of WP7
B.2.3.4. Automated urban delivery results based on respective documentation report of WP7

C. Documentation of tools

C.1. An introductory material summarizing the used methodologies as well as their common reasoning, issues and limitations a project level based on documentation reports of WP5, 6, 7

C.2. Per each methodology

C.2.1. Information about microsimulation including the methodological background, assumptions and limitations based on documentation reports of WP5, 6, 7

C.2.2. Information about Delphi methodology including the methodological background, assumptions and limitations based on documentation reports of WP5, 6, 7

C.2.3. Information about mesoscopic simulation methodology including the methodological background, assumptions and limitations based on documentation reports of WP5, 6, 7

C.2.4. Information about system dynamics including the methodological background, assumptions and limitations based on documentation reports of WP5, 6, 7

C.2.5. Information about operations research including the methodological background, assumptions and limitations based on documentation reports of 7

D. Guideline excerpts

D.1. Introductory PST material

D.2. Explanations and tutorials on the use of the PST Knowledge and Estimator module

D.3. Overall recommendations to cities from project results regarding urban, passenger and freight transport