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The LEVITATE Policy Support Tool of Connected and Automated Transport Systems

Apostolos Ziakopoulos[a]* , Julia Roussou[a], Amna Chaudhry[b], Bin Hu[c], Martin Zach[c], Maria Oikonomou[a], Knut Veisten[d], Knut Johannes Liland Hartveit[d], Mark Brackstone[e], Eleni Vlahogianni[a], Pete Thomas[b], George Yannis[a]

[a]Department of Transportation Planning and Engineering, National Technical University of Athens, 5 Heroon Polytechniou St., GR-15773, Athens, Greece
[b]Loughborough University, Loughborough, LE11 3TU, United Kingdom
[c]AIT Austrian Institute of Technology, Center for Mobility Systems, Giefinggasse 2, 1210 Vienna, Austria
[d]Departement of Safety and Security – Institute of Transport Economics Norwegian Centre for Transport Research, Gaustadalléen 21, 0349 Oslo, Norway
[e]Aimsun Ltd,Waterhouse Square, 138 Holborn, London EC1N 2ST, United Kingdom

Abstract

Rapid technological advances leave limited margins for the preparation of cities to receive Connected, Cooperative and Automated Mobility (CCAM). The LEVITATE project endeavours to develop an open access web-based Policy Support Tool (PST), that will provide decision makers at all levels with access to LEVITATE methodologies and results. The aim of the PST is to consolidate the outputs of different methods into an overall framework for the assessment of impacts, benefits and costs of CCAM, for different automation and penetration levels and on different time horizons. The PST comprises two modules: the Knowledge and the Estimator module, which includes a forecasting and a backcasting sub-system. The present research provides an insight of the PST, by presenting the studied automation use cases, parameters and impacts of CCAM, the applied methodologies and the online tool.

Keywords: Connected and Automated Transport Systems; Connected and Autonomous Vehicles; Policy Support Tool; Forecasting; Backcasting

1. Overview and Motivation

Rapid technological advances leave limited margins for the preparation of cities in order to receive Connected, Cooperative and Automated Mobility (CCAM). Automation technologies are expected to roll out in a rapid pace in all transport domains, including land transport modes such as passenger cars, urban public transport and freight transport.

* Corresponding author. Tel.: +30-210-772-1575; fax: +0-000-000-0000 .
E-mail address: apziak@central.ntua.gr

Within the coming decade of 2030s, the market penetration of connected human-driven vehicles will approximate 100% (Frost & Sullivan, 2019). Research has indicated numerous advantages and disadvantages of the applications of automation in transport (indicatively, Ambühl et al., 2016; Moreno et al., 2018; Bahamonde-Birke, 2018; Soteropoulos et al., 2019; Paddeu et al., 2019; Blas et al., 2020; Ivanov et al., 2020). The introduction of automated driving of levels 3, 4 and 5 is expected to bring significant safety benefits, especially as the level of automation increases and the human error (factor) will be gradually eliminated. According to Logan et al. (2017), the US Federal Highway Administration predicted that 50-80% of highway crashes could be eliminated with the adoption of Automated Highway Systems. Even though automation is expected to be highly beneficial, potential disbenefits may arise especially during the transition period when automated and conventional vehicles will share the urban roads. The transition phase to high automation may last decades, with a wide variation of automation and connectivity levels across the vehicle fleet and across traffic infrastructure.

Therefore, Policy Support Tools (PSTs) are introduced in order to assist in the decision-making process for challenging projects and for the implementation of difficult measures (Perimenis et al., 2011). Their goal is to link computational information to the judgement ability of the decision maker (Shim et al., 2002). The LEVITATE project endeavours to develop an open access web-based PST targeting decision makers at all levels: Municipalities, Regional Authorities & National Governments. The aim of the LEVITATE PST is to consolidate the outputs of different methods into an overall framework for the assessment of impacts, benefits and costs of CCAM, for different automation and penetration levels and on different time horizons. In addition, the PST will analyse the user needs for a decision support tool aiming to assist in the analysis of urban policy scenarios and targets. Finally, this will be achieved by developing and implementing a toolkit and a decision support tool, by allowing the testing of various policy scenarios on the basis of the needs of relevant stakeholders and incorporating both forecasting and backcasting approach, as well as providing policy recommendations.

The objective of the present paper is to provide an insight on the LEVITATE PST development, by presenting the considered automation use cases, critical parameters and impacts of CCAM as well as the applied methodologies. Specifically, in this paper, an outline of the contents of the PST will be presented starting by the impact assessment methodology developed within the LEVITATE project and followed by the structure of the PST. Subsequently, the two components of the online PST, the estimator and knowledge module, will be presented, with an emphasis on the forecasting and backcasting sub-systems included in the estimator module. The paper will conclude with a discussion of the limitations and future research possibilities.

2. Impact assessment methodology

The LEVITATE PST will provide estimates of the impacts of CCAM through a multi-disciplinary impact assessment methodology. Within the framework of LEVITATE, three automation use cases are considered: Passenger cars, Urban transport and Freight transport, as well as specific sub use-cases are investigated for each domain. In addition, twenty distinct impacts are examined, classified into three distinct categories: (i) Direct impacts, (ii) Systemic impacts and (iii) Wider impacts. In order to enable the impact assessments, four predefined base scenarios are also established, concerning the temporal distribution of the market penetration rates (MPRs) of Connected and Autonomous Vehicles (CAVs) throughout the study period (from 2020 to 2050) and are the following: No automation, Pessimistic, Neutral, Optimistic base scenario. Moreover, four different methods are used in order to provide and forecast the examined impacts, which are the microscopic simulation, mesoscopic simulation, system dynamics, operations research and the Delphi method.

2.1. 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 categorized as passenger cars, urban transport and freight transport cases. 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. Zach et al. (2019) provided a preliminary list of policy goals, indicators and policy interventions based on an extensive literature review regarding the future of CCAM. Following a Stakeholders Reference Group workshop this list was prioritised and the most important policy goals and policy interventions (sub-use cases) to achieve them were selected. The list of the sub-use cases that are investigated are presented in Table 1.

Table 1. LEVITATE use cases and sub-use cases.

LEVITATE Use Cases	Sub-Use Cases
Automated Urban Transport	Point-to-point Automated Urban Transport Services (AUSS)
	Autonomous mobility on-demand
Automated Passenger Cars	Road use pricing
	Green Light Optimised Speed Advisory
	Automated ridesharing
	Parking pricing policies
	Parking space regulations
	Dedicated lanes on urban highways
Automated Freight Transport	Automated urban delivery
	Automated freight consolidation
	Hub-to-hub automated transport
	Truck platooning on urban highway bridges

2.2. Impacts

The impacts studied in the LEVITATE project have been defined by Elvik et al. (2019) which provided a preliminary taxonomy of the potential impacts of CCAM (Fig. 2). A range of impacts were classified into three categories, direct impacts, systemic impacts and wider impacts. Direct impacts are changes that are noticed by each road user on each trip. These impacts are relatively short-term in nature and can be measured directly after the introduction of intervention or technology. Systemic impacts are system-wide impacts within the transport system. These are measured indirectly from direct impacts and are considered medium-term. Wider impacts are changes occurring outside the transport system, such as changes in land use and employment. These are inferred impacts, considered to be long-term, measured at a larger scale and are result of direct and system wide impacts.

Fig. 1. LEVITATE impacts

2.3. Scenarios of automation penetration

In order to enable the impact assessments, predefined base scenarios are established, 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. 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 base scenarios are the following:

- No automation base scenario: All vehicles will be conventional (i.e. human-driven) vehicles up to 2050.
- 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 2020 and will rise from 10% in 2033 to 40% in 2045 and will remain stable till 2050. The second generation will appear in 2045 and will rise to 10% in 2050.
- Neutral base scenario: Vehicles will be 20% conventional vehicles, 50% autonomous vehicles of first generation and 30% autonomous vehicles of second generation in 2050. The first generation of autonomous vehicles will appear in 2020 and will be rise from 10% in 2030 to 50% in 2040 and will remain stable till 2050. The second generation will appear in 2040 and will rise to 30% in 2050.
- Optimistic base scenario: All vehicles will be autonomous up to 2050. More specifically, vehicles will be 50% autonomous vehicles of first generation and 50% autonomous vehicles of second generation in 2050. The first generation of autonomous vehicles will appear in 2020 and will be rise from 10% in 2025 to 50% in 2035 and will remain stable till 2050. The second generation will appear in 2035 and will rise to 50% in 2050.

2.4. Scenarios of automation penetration

The aforementioned impacts have been estimated and forecasted using appropriate assessment methods. The methods used are the microscopic simulation, mesoscopic simulation, system dynamics, operations research and the Delphi method. For the sake of simplicity and transferability of assessment methods, it is assumed that for the appropriate level of automation, adequate infrastructure exists. It is also assumed that the pure technological obstacles for the sub-use cases in consideration are solved. The methods used are:

- Microscopic simulation: 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.
- Mesoscopic simulation: This 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. Within the LEVITATE project, the mesoscopic simulation method was selected in order to identify 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.
- System dynamics: This method 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 (Boghani, H. et Zach, M., 2020). 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.
- Operations research: This method is widely used in freight transport (Lagorio et al, 2016) and calculates results for freight transport costs, fleet operation costs, and vehicle mileage. Within the LEVITATE project operations research method was used to identify the impacts of all the freight transport related sub-use cases.

- Delphi method: is a process used to arrive at a collective, aggregate group opinion or decision by surveying a panel of experts. 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). Within LEVITATE, the Delphi method is used to determine all impacts that cannot be defined by the other quantitative methods.

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. This variety entailed that, inevitably, the integration of results from different methods was not an intuitive or straightforward task at first. 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 predefined base scenarios.

3. Online PST components

The Policy Support Tool is an open access, web-based system that will provide future users with access to Levitate methodologies and results. The LEVITATE Policy Support Tool (PST) is 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. The detailed design takes into account the specific needs of the key stakeholders and it provides 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 online PST can be found in the following link https://www.ccam-impacts.eu/. The PST comprises two main modules (fig. 2) the Knowledge module (static component) and the Estimator module (dynamic component), presented in detail in the following sections.

3.1. Knowledge module

The PST 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 different categories 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.

3.2. Estimator module

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. 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.

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 impact assessment activities that took place during the project.

3.2.1. Forecasting sub-system

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. 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.

More precisely the steps needed for the online PST forecasting analysis are:

1. Select one or two policy interventions
2. Select the CCAM deployment scenario
3. Define the policy intensity and policy effectiveness through the years 2020-2050
4. Adjust the initial PST values, for the parameters and impacts, if desired to values more representative of the user’s case in order to increase the predictive accuracy of the PST
5. Provide input in terms of temporal implementation of the measure(s) for the system to take into account by adjusting the response curves of the impacts.
6. Receive the results, in form of table with analytical results and curves presenting both results for the baseline scenario (no intervention) and for the selected policy intervention(s) as seen in fig.3.

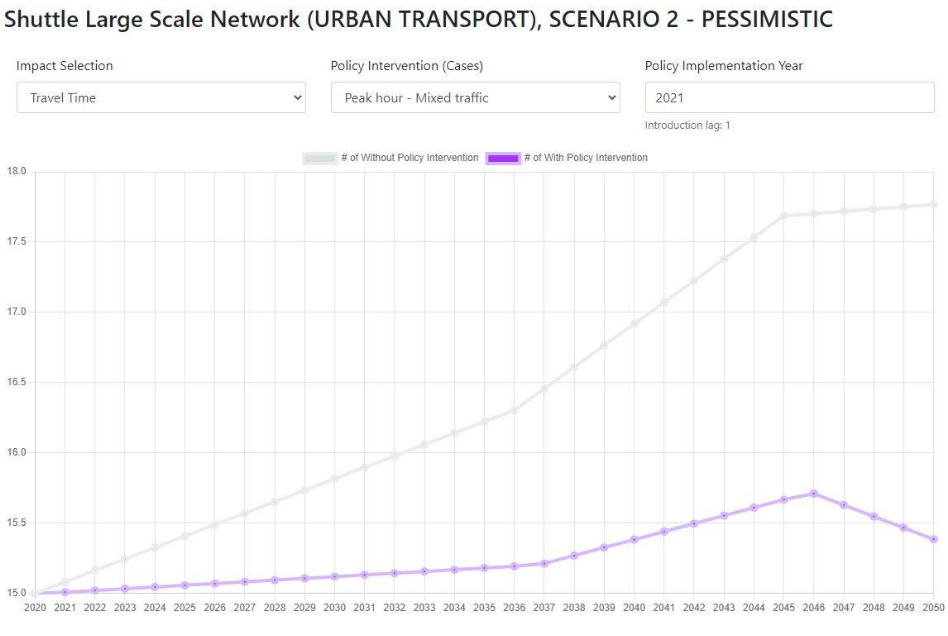

Fig. 3. Forecasting sub-system results example

The results included in the forecasting sub-system originate from the aforementioned methods. Given the fact that the selected approached involves attaching all results to specific MPR percentages as those mentioned in the predefined base scenarios, the temporal compression or expansion of the distribution of the MPR percentages lead to one of the four scenarios. Therefore, initial results are spread differently across the timespan examined by the project. For intermediate years, simple linear interpolation is conducted to obtain the respective values. Furthermore, the capability of an intervention combination is made 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).

3.2.2. Backcasting sub-system

The term "Backcasting" was coined by (Robinson, 1990) and is a method to define future scenarios and to investigate their effects. The key assumptions of Robinson's backcasting approach are oriented to the goal, policy, design and system. The backasting steps that are followed by the user in the online LEVITATE PST are:

1. Selection of target year between 2020-2050
2. Selection of CCAM deployment scenario
3. Definition of the desired policy vision described in terms of desired changes in 1 (minimum) to 5 (maximum) impacts as well as the desired percentage of change for each of the selected impacts.
4. Adjust the initial PST values, for the parameters and impacts, if desired to values more representative of the user's case in order to increase the predictive accuracy of the PST
5. Receive the results, in form of table where all policy interventions are presented with the characterisation "true" or "false", based on the potential to reach the desired policy vision as seen in Fig. 4.

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

Impact ▲	Use case	SubUse case	Policy intervention	Target from input
Congestion	FREIGHT TRANSPORT	Automated Consolidation	Baseline	true
Congestion	FREIGHT TRANSPORT	Automated Consolidation	Manual consolidated delivery	true
Congestion	FREIGHT TRANSPORT	Automated Consolidation	Automated consolidated delivery	false
Congestion	PASSENGER CARS	Glosa	Baseline	true
Congestion	PASSENGER CARS	Glosa	GLOSA on 1 Intersection	false
Congestion	PASSENGER CARS	Glosa	GLOSA on 3 Intersections	true
Congestion	PASSENGER CARS	Glosa	GLOSA on 2 Intersections	false
Congestion	FREIGHT TRANSPORT	Automated Delivery	Baseline	true
Congestion	FREIGHT TRANSPORT	Automated Delivery	Semi-automated delivery	true
Congestion	FREIGHT TRANSPORT	Automated Delivery	Fully-automated night delivery	false

Fig. 4. Backcasting sub-system results example

4. Conclusion and future works

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 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 a fully detailed and flexible concise reports. The estimator module will provide estimates for different types of impacts and allow comparative analyses.

LEVITATE is the first project to develop a tool providing such an extensive impact assessment on the impacts of CCAM on safety, mobility, environment and society. It considers a variety of scales, in terms of direct, systemic and wider impacts, with transferability control across different networks and several tailoring mechanisms like policy intensity/effectiveness. Nonetheless, it should be emphasized that the most fruitful use of the PST is the provision of trends to be examined in order to form informed decisions rather than acquiring extremely precise numbers for a network. Additionally, a mechanism for updating the PST with more results is foreseen for future expansion and examination of sub-use cases and policy interventions within the tool. It is intended that the LEVITATE PST will remain in operation long after the end of the project and it will gradually become a reference information system, in which more and more municipalities, cities, experts and organisations contribute their studies with quantitative results, using the LEVITATE protocol. The extent of the development of additional data and knowledge features depends on the size of the external funding received after the end of the project.

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