Forecasting impacts of Connected and Automated Transport Systems within the LEVITATE project

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Abstract

Automation is expected to gradually arrive in all transport domains, such as passenger cars, urban public and freight transport. Therefore, it is imperative that the Connected and Automated Transport Systems (CATS) impacts are estimated. The LEVITATE project aims to prepare an impact assessment framework enabling policymakers to manage the CATS introduction, culminating with the creation of an online Policy Support Tool (PST). The present research provides a closer examination of the forecasting capabilities of the PST. Three methodologies were utilized: microsimulation, system dynamics and Delphi method and their estimations feeds information to the PST forecasting and backcasting sub-systems. In the forecasting sub-system, the user selects policy intervention, defines CATS factors and the module provides quantified on the expected impacts. In the backcasting sub-system, the user sets impact targets and time-frames and the system provides feedback as to which measures can be used to attain them. To combine interventions, the US FHWA methodology is modified to create combined Impact Modification Factors (cIMFs). The Levitate PST aspires to become the go-to, one-stop-shop tool for the calculation of societal impacts of automation by experts, authorities, stakeholders and any other interested party.

Keywords: *Connected and Automated Transport Systems, automation impacts, Policy Support Tool, policy interventions, combination of measures.*

Περίληψη

Η αυτοματοποίηση αναμένεται να εξαπλωθεί σταδιακά σε όλα τα μέσα επίγειων μεταφορών, όπως τα επιβατικά αυτοκίνητα, οι δημόσιες συγκοινωνίες και οι εμπορευματικές μεταφορές. Επομένως, είναι επιτακτική ανάγκη να αποτιμηθούν οι επιπτώσεις των Συνδεδεμένων και Αυτοματοποιημένων Συστημάτων Μεταφορών (CATS). Το έργο LEVITATE στοχεύει στην προετοιμασία ενός πλαισίου αποτίμησης επιπτώσεων που επιτρέπει στους φορείς που είναι αρμόδιοι για τη χάραξης πολιτικής να διαχειρίζονται την εισαγωγή των CATS. Η αποτίμηση επιπτώσεων ενσωματώνεται στο Εργαλείο Υποστήριξης Πολιτικής (PST). Η παρούσα έρευνα πραγματοποιεί μια εξέταση αυτών των δυνατοτήτων. Χρησιμοποιήθηκαν τρεις μεθοδολογίες: προσομοίωση, η δυναμική συστημάτων και η μέθοδος των Δελφών και οι εκτιμήσεις τους τροφοδοτούν πληροφορίες στα υποσυστήματα πρόβλεψης του PST. Στο υποσύστημα πρόβλεψης, ο χρήστης επιλέγει την παρέμβαση πολιτικής, καθορίζει τους παράγοντες CATS και λαμβάνει ποσοτικοποιημένες αναμενόμενες επιπτώσεις. Στο υποσύστημα αντίστροφης πρόβλεψης, ο χρήστης θέτει στόχους επιπτώσεων και χρονικά περιθώρια και το σύστημα παρέχει ανατροφοδότηση σχετικά με το ποια μέτρα μπορούν να χρησιμοποιηθούν για την επίτευξή τους. Για να συνδυαστούν οι παρεμβάσεις, η μεθοδολογία FHWA των ΗΠΑ τροποποιήθηκε για τη δημιουργία συντελεστών συνδυασμένων παρεμβάσεων για τις επιπτώσεις. Το Levitate PST φιλοδοξεί να γίνει ένα ενιαίο εργαλείο υπολογισμού των κοινωνικών επιπτώσεων της αυτοματοποίησης από τις αρχές, συναφείς φορείς και οποιοδήποτε άλλο ενδιαφερόμενο.

Λέξεις-κλειδιά: *Συνδεδεμένα και αυτοματοποιημένα συστήματα μεταφορών, επιπτώσεις αυτοματισμού, Εργαλείο Υποστήριξης Πολιτικής, επεμβάσεις δικτύου, συνδυασμός μέτρων.*

1. Introduction

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. Cities, road administration authorities and practitioners, researchers and road users need to start preparing for the advent of automation.

Within the coming decade of 2030s, the market penetration of connected human-driven vehicles will approximate 100% (Frost & Sullivan, 2019). Moving forward, connected autonomous vehicles (CAVs) are expected to progressively circulate on city road networks in the coming years. CAVs could represent 15% of the vehicles fleet by 2030 and 45% by 2050 (Litman, 2015). The market penetration of level 3-5 CAVs is expected to be below 50% by 2030, though projections vary overall (Boghani et al. 2019). By 2050 level 4-5, CAVs are estimated to represent the vast majority of traffic fleets, with market penetration rates approximating 100% (Litman, 2015).

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). Researchers, engineers and automobile manufacturers are working intensively on mitigating the drawbacks and possible failures of automation and on providing comfort and safety to drivers. Given the projections of even the most conservative scenarios, it is imperative that the various impacts of Connected and Automated Transport Systems (CATS) are estimated on the city level as well.

LEVITATE (Societal Level Impacts of Connected and Automated Vehicles) is a European Commission supported Horizon 2020 project with the objective to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives. The LEVITATE impact assessment framework will culminate in the Policy Support Tool (PST) which will include forecasting and backcasting capabilities. The reader should note that the work carried out within LEVITATE is still ongoing as of the time of writing of the present research, therefore there are certain.

The aim of the present research will provide a closer examination of the aforementioned forecasting and backcasting capabilities. Specifically, in this paper, an outline of the examined automation use cases and sub-use cases is provided. The formulation of the four scenarios for the advent of automation which form the backbone of the projections conducted in the PST is outlined. Afterwards, the integration of results provided by the three methodological pillars of the LEVITATE project, namely (i) microsimulation, (ii) system dynamics and (iii) the Delphi method, is presented, and indicative results are also provided. The paper concludes with a discussion of the methodologies.

2. Scope of the PST

2.1 Automation use cases and sub-use cases

A use case is defined as any high-level area of application of CATS. The use cases that are considered within the framework of LEVITATE are listed on Table 1. They consider automation applications, or use cases, in the domains of urban transport, passenger cars and freight transport.

Table 1: *Description of the LEVITATE use cases*

LEVITATE Use-Cases	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 CATS: • Automated urban delivery • Local freight consolidation • Hub to hub automated transfer • Highway platooning

Accordingly, specific sub use-cases are created for each 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. Specific network management strategies, policies, deployments or other measures are considered policy interventions.

Table 2: *Description of the LEVITATE sub-use cases*

LEVITATE Use-Cases	Sub-use cases
Passenger cars	• Parking pricing • Provision of dedicated lanes • Replace on street parking • Automated ride sharing • GLOSA (Green Light Optimized Speed Advisory)
Urban transport	• Point-to-point automated urban shuttle service • Point-to-point automated urban shuttle service in a large scale network • On demand automated urban shuttle service
Freight transport	• Hub to hub automated transport • Platooning on bridges • Automated freight consolidation • Automated urban delivery

2.2 Description of 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 network and they describe important aspects in order to make the results relevant and transferable to the area which the road user wishes to examine. The form and definition of these parameters are provided on Table 3:

Table 3: *Description of the examined parameters within LEVITATE*

No.	Parameter description / measurement	Unit of Measurement
1	GDP per capita	€
2	Annual GDP per capita change	%
3	Inflation	%
4	City Population	million persons
5	Annual City Population change	%
6	Urban shuttle fleet size	no. of vehicles
7	Freight vehicles fleet size	no. of vehicles
8	Average load per freight vehicle	tones
9	Average annual freight transport demand	million tones
10	Human-driven Vehicles	%
11	1st Gen - Cautious AVs	%
12	2nd Gen - Aggressive AVs	%
13	Fuel cost	€ / lt
14	Electricity cost	€ / KWh
15	Fuel consumption	lt / 100Km
16	Electricity consumption	KWh / 100Km

As an example, if one considers the Point-to-point automated urban shuttle service SUC, impacts 7, 8, 9 are not a requirement as they refer to freight transport.

2.3 Description of examined impacts

In addition to the previous, 20 distinct impacts are considered, classified into three distinct categories: (i) Direct impacts, (ii) Systemic impacts and (iii) Wider impacts. For each impact the methodology with which is calculated is defined. More specifically, from microsimulation approach congestion, road safety, CO_2, NO_x and PM_{10} emissions impacts are provided. Through system dynamics the commuting distances are calculated and the rest of the impacts by the Delphi method. The impact form and definition are provided on Table 4, along with a column describing the method with which they are calculated.

It should be mentioned that the present design is for all starting parameters and impacts to have assigned starting values. This allows 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 with free entry of values within reasonable margins (e.g. 0-100% for any percentages). Examples of considered starting values are: 1.50% for annual GDP per capita change, 1.00% Inflation and City Population of 3.000 million people.

***Table 4:** Description of the examined impacts within LEVITATE*

No.	Impact categories	Impact	Description / measurement	Unit of Measure ment	Calculation Method
1	Direct impacts	Travel time	Average duration of a 5Km trip inside the city centre	min	Delphi Method
2		Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel	€/Km	Delphi Method
3		Freight transport cost	Direct outlays for transporting a tone of goods per kilometre of travel	€/tonne.Km	Delphi Method
4		Access to travel	The opportunity of taking a trip whenever and wherever wanted (10 points Likert scale)	-	Delphi Method
5	Systemic impacts	Amount of travel	Person kilometres of travel per year in an area	person-km	Delphi Method
6		Congestion	Average delays to traffic (seconds per vehicle-kilometer) as a result of high traffic volume	s/veh-km	Microsimulation
7		Modal split of travel using public transport	% of trip distance made using public transportation	%	Delphi Method
8		Modal split of travel using active travel	% of trip distance made using active transportation (walking, cycling)	%	Delphi Method
9		Shared mobility rate	% of trips made sharing a vehicle with others	%	Delphi Method
10		Vehicle utilisation rate	% of time a vehicle is in motion (not parked)	%	Delphi Method
11		Vehicle occupancy	average % of seats in use (pass. cars feature 5 seats)	%	Delphi Method
12	Wider impacts	Parking space	Required parking space in the city centre per person	m^2/person	Delphi Method
13		Road safety	Number of traffic conflicts per vehicle-kilometer driven (temporarily until crashes are derived).	Conflicts/ veh-km	Microsimulation
14		Energy efficiency	Average rate (over the vehicle fleet) at which propulsion energy is converted to movement	%	Delphi Method
15		NO_X due to vehicles	Concentration of NOx pollutants as grams per vehicle-kilometer (due to road transport only)	g/veh-km	Microsimulation
16		CO_2 due to vehicles	Concentration of CO2 pollutants as grams per vehicle-kilometer (due to road transport only)	g/veh-km	Microsimulation
17		PM_{10} due to vehicles	Concentration of PM10 pollutants as grams per vehicle-kilometer (due to road transport only)	g/veh-km	Microsimulation
18		Public health	Subjective rating of public health state, related to transport (10 points Likert scale)	-	Delphi Method
19		Inequality in transport	To which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities (10 points Likert scale)	-	Delphi Method
20		Commuting distances	Average length of trips to and from work (added together)	Km	System Dynamics

2.4 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. Within the LEVITATE project, two main driving profiles of connected autonomous vehicles are considered and are the following:

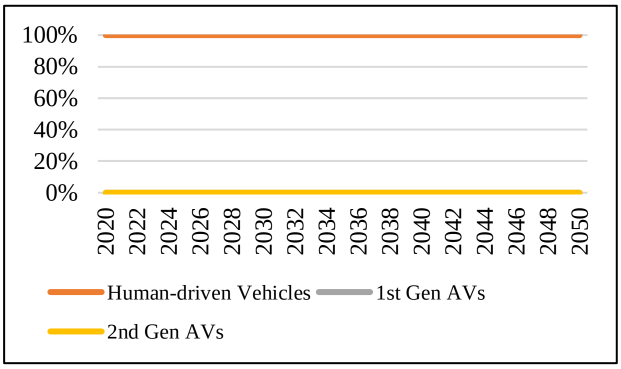
- 1st Generation (Cautious): limited sensing and cognitive ability, long gaps, early anticipation of lane changes and longer time in give way situations.

- 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.

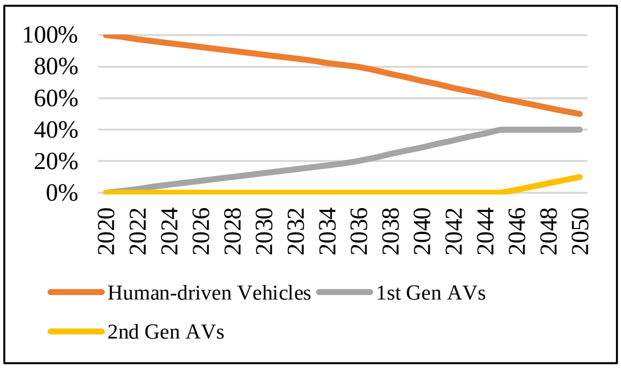
The base scenarios are the following.

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.

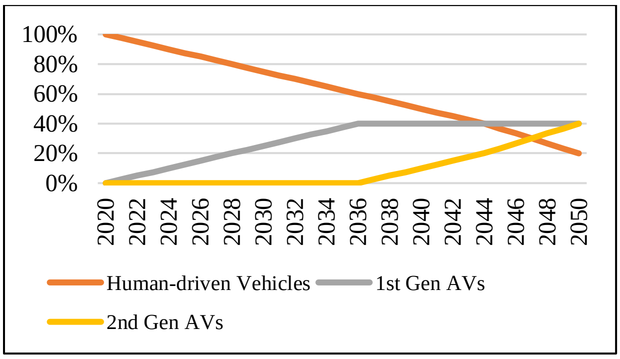
It should be noted that these scenarios refer to the advent of CAVs in the traffic of the network regardless of any policy interventions that are or are not adopted by authorities. The visualization of the different scenarios can be seen on Figure 1 (a, b, c, d):



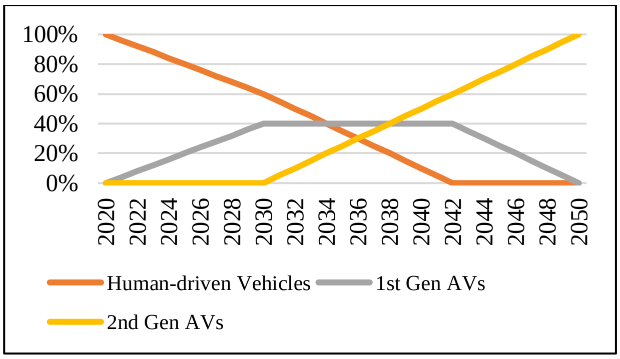
(a) No automation scenario



(b) Pessimistic scenario



(c) Neutral scenario



(d) Optimistic scenario

Figure 1: *Market Penetration Scenarios used in the PST*

3. PST inputs

This section provides a brief overview of the different methods used to provide inputs in the PST.

3.1 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 CATS 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 data from various sources 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 that leads to estimate emissions with higher accuracy, as well (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 causative 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 multiple 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).

3.2 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 feedback/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 relationship with the users who can defined 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 AV 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 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 aforementioned 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 CATS 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.

4. PST internal workings

4.1 Result integration & interpolation

The results provided as input in the LEVITATE PST originate from the three 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. 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 4. 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 1. 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, as follows:

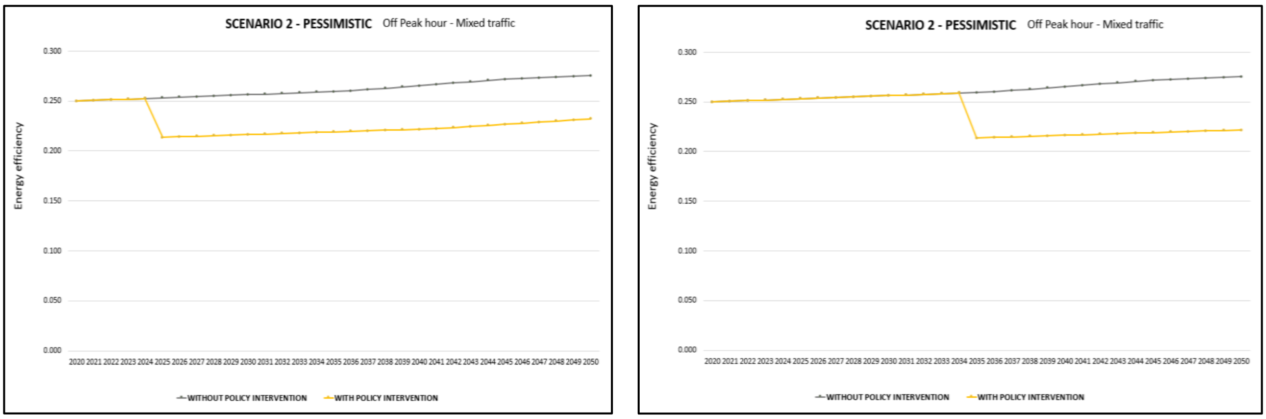
Let x_1, x_2 be the examined impact values at two different years t_1, t_2 with milestone MPRs, for which results are available from the three methods. The impact at intermediate year t_i, x_i, is calculated as:

$$x_i = x_1 + (x_2 - x_1) * \frac{t_i - t_1}{t_2 - t_1} \quad \textbf{(1)}$$

The rationale of this equation represents how simple linear interpolation can be used to obtain intermediate values for impacts. 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 CO_2, if a value of 1250.00 CO_2 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 CO_2 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 CO_2 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.

4.2 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 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 2 depicting the energy efficiency of a policy intervention (in the pessimistic scenario) with implementation in 2025 (a) and 2035 (b); the horizontal offset of the curve is observable.



(a) Energy efficiency example with implementation in 2025

(b) Energy efficiency example with implementation in 2035

Figure 2: *Temporal offset for measure implementation in the PST*

4.3 Policy intensity & policy effectiveness

Two additional percentages are introduced and considered 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, more importantly, the behavior of the network users. These percentages operate 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 is 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.

4.4 Forecasting example

Summarizing the previous, to obtain results from the PST, the steps outlined below are followed in succession:

1. Initially, the user makes a set of selections defining the use case, the sub-use case and the automation scenario that they wish to consider.
2. The user can provide their own values for the parameters and impacts (within the acceptable margins) or they can keep the provided starting values.
3. The user then has the option to add a policy intervention, along with the respective implementation year.
4. If the user adds a policy intervention, they may also determine policy intensity & effectiveness different than 100% based on their knowledge/estimates.

To showcase the forecasting capabilities of the LEVITATE PST, an example following the same steps is provided below:

1. Initially, the use case of public transport, with the SUC of Point to point Automated shuttles and the Neutral automation scenario is considered.
2. The provided starting values are retained for input parameters and examined impacts.
3. From the policy interventions available to that SUC, the policy intervention of off Peak hour Automated shuttles operating under mixed traffic conditions is selected. The policy implementation year is set to 2025.
4. Based on knowledge and experience for the anticipated situation, policy intensity/magnitude is set to 90% uniformly across all years. Policy effectiveness is set to start at 20% on 2025, as the user anticipates mistrust in the automated service. In subsequent years there are projected increases as the public accepts the service, and effectiveness is set to 30% on 2026, 45% on 2027, 65% on 2028 and 95% steadily from 2029 onwards.

The PST then provides estimates for the impacts of Table 3 for the years 2025-2050 for the aforementioned configuration. Naturally, the years before the policy implementation (2020-2024 in this case) follow the baseline trends. Indicatively, results for the years 2025-2030 are provided on

Figure 3 for the impact of Congestion. The gradual departure from the baseline, due to lower initial effectiveness, can be seen during the years 2025-2028.

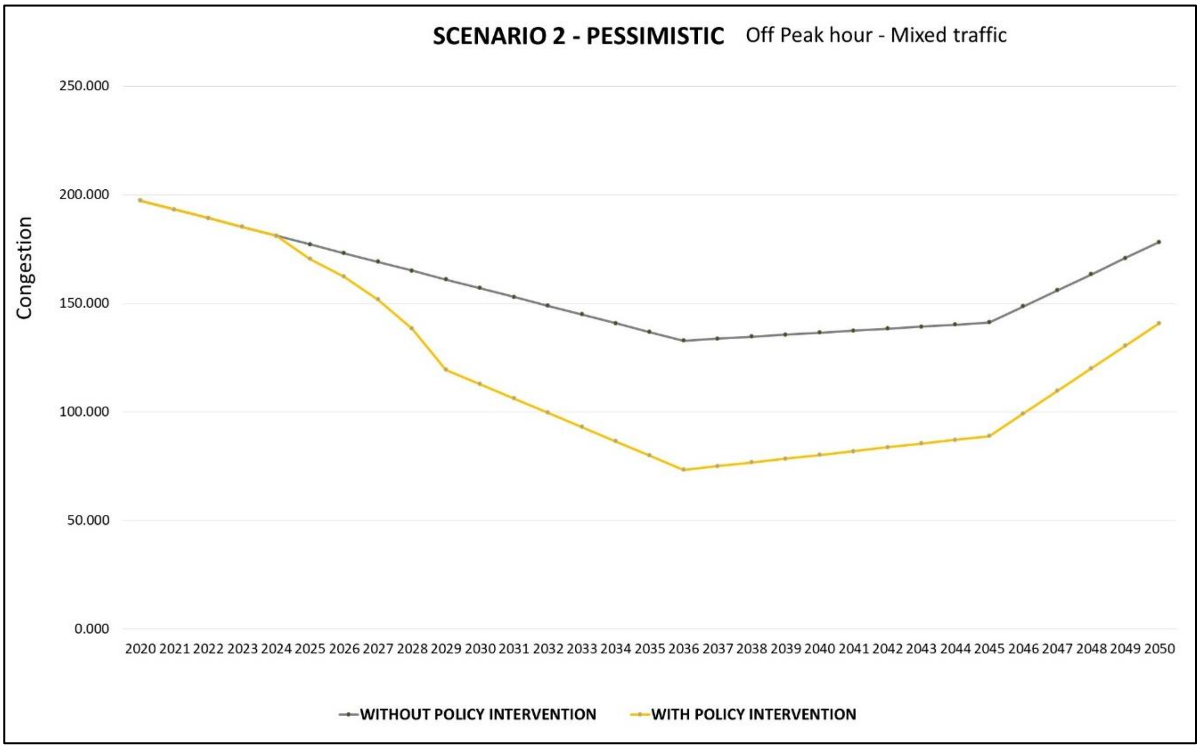


Figure 3: *Congestion forecasting for the presented example*

The backcasting module of the PST is set to follow a comparable, but reverse course of calculation with the forecasting module. The backcasting process utilizes the existing forecasting data. However, the user will set a specific year as input, and will also supply a specific goal in terms of impacts; i.e., a vision for the future that they wish to achieve. In other words, this can be expressed in the form of: "By year 2040, the aim is to have a +50% increase in the 'access to travel' impact." The PST will provide the policy intervention (or combination of policy interventions) that yields results closer to the set goal. Furthermore, a change of policy is an anticipated possibility. The user can make an intermediate substitution by adding a policy or removing one, to allow for more flexibility of the PST.

5. Combining policy interventions

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. A positive CMF denotes a beneficial intervention leading to crash reductions, while a negative CMF 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 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, the impacts of 17 SUCs are examined. Multiple impacts, as many as 20, can be examined per SUC. When examining the problem on an impact level, it was determined that 20*17*16 = 5440 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. This process has been completed for LEVITATE.

The combination of measures requires the calculation of individual IMFs (IMF_1, IMF_2) as a first step, which are derived from the difference of the baseline with the current value for each impact:

$$\text{IMF1,2} = 1 - \frac{\text{Impact}_{\text{examined value}} - \text{Impact}_{\text{baseline value}}}{\text{Impact}_{\text{baseline value}}} \quad \textbf{(2)}$$

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, an effect which can be seen from the fluctuating difference of the two curves of the impact diagram: gray (baseline) – yellow (policy implementation), shown on Figure 4.

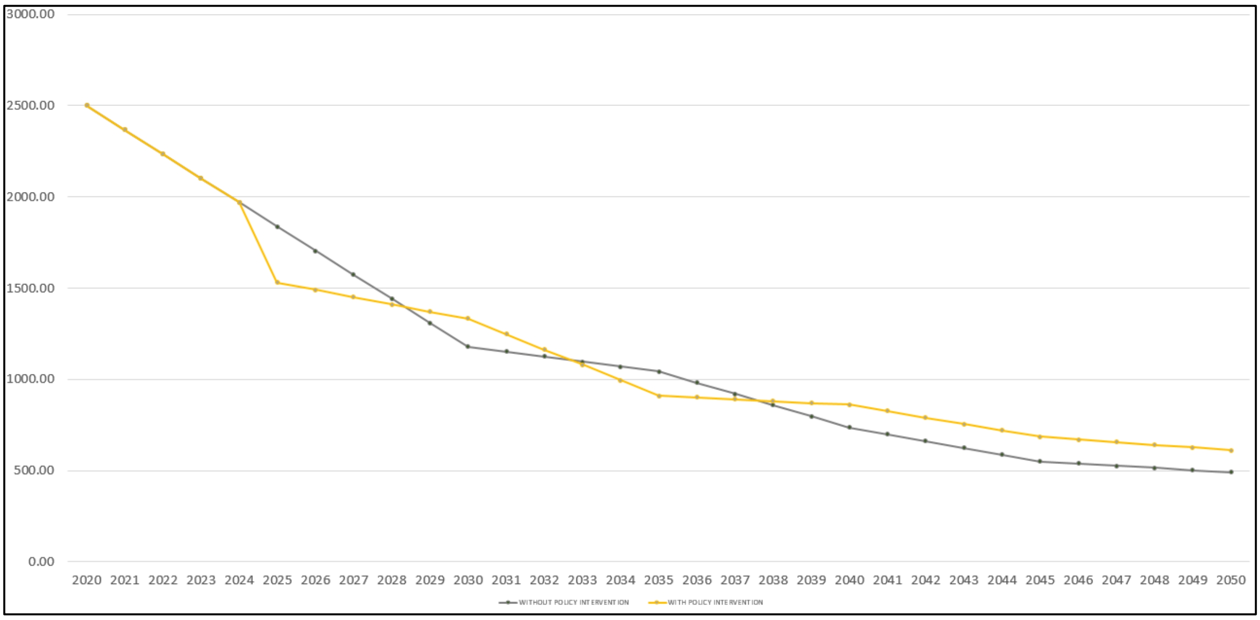


Figure 4: *IMF fluctuation example in the PST results*

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 if no policy intervention is considered (again, for the pessimistic automation penetration scenario):

$CO_{2,\text{ Base, 2035, 1}}$ = 1043.49 g/veh-km

If a certain policy intervention 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):

$CO_{2,\ SUC1,\ 2035}$ = 910.02 g/veh-km

Therefore $IMF_1 = 1 – (910.02 - 1043.49)/1043.49 = 0.8721 = 87.2\%$

Stemming from the FHWA HSM, the following four methods are defined for IMFs:

1. 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. In the additive method, the combined IMF is:

$$IMF_{c,add} = 1 – [(1 – IMF_1) + (1 – IMF_2)] \text{ if } > 0; \text{ otherwise } 0 \quad \textbf{(3)}$$

2. The multiplicative method was recommended by FHWA for cases where one or both CMFs are larger than 1. In the multiplicative method, the combined IMF is the product of the two individual IMFs:

$$IMF_{c,mult} = IMF_1 * IMF_2 \quad \textbf{(4)}$$

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

$$IMF_{c,dom\ eff} = \min(IMF_1, IMF_2) \quad \textbf{(5)}$$

4. 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. 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.

$$IMF_{c,\ dom\ com\ res} = (IMF_1 * IMF_2)^{\min(IMF1,\ IMF2)} \quad \textbf{(6)}$$

Additionally, as a novel approach developed for the purposes of LEVITATE, the case of amplificatory combined IMF is created. 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:

5. 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).

$$IMF_{c,amplify} = (IMF_1 * IMF_2)^2 \quad \textbf{(6)}$$

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

6. Discussion & future developments

Rapid technological advances leave limited margins for the preparation of cities in order to receive Connected and Automated Transport Systems (CATS). 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. The LEVITATE project endeavors to develop a new impact assessment framework to enable policymakers to manage the introduction of CATS, maximise the benefits while minimizing any unforeseen drawbacks, and achieve societal objectives through CATS integration. The collective output of LEVITATE culminates with the creation of the LEVITATE Policy Support Tool (PST).

Three methodological pillars were utilized to provide estimations of the impacts of CATS for the PST: these are (i) microsimulation, (ii) system dynamics and (iii) the Delphi method. The provided impact estimations are integrated and interpolated in the PST database and feed information to the forecasting and backcasting modules. Four automation scenarios are considered, which allow for anticipation of different temporal spreads of MPRs within the considered timespan (from 2020 to 2050), i.e.: no automation, pessimistic, neutral and optimistic scenarios.

It is important to note that a priori assessments are already conducted within the framework of LEVITATE, such as the research of Elvik (2021). That study anticipated that CAVs will lead to increased travel demand, while simultaneously reducing travel time, make it more fruitful and introduce positive reductions in road crashes and emissions.

As the LEVITATE project moves forward, and several activities come to fruition, additional results and functionalities will be available for the PST user. Several of these aspects are already undergoing considerable development, and will be populated as individual methods are finalizing their results. It should be mentioned that the Delphi method is a good means to acquire estimations for impacts where other methods lack the means to provide them. However, the expert estimates can be eschewed when more quantitative estimates are obtained from microsimulation or System Dynamics.

Furthermore, work conducted within the Road Safety Working Group of LEVITATE will allow for the substitution of the 'Conflicts' impact with three crash categories (total crashes, fatal crashes and VRU crashes). Additionally, CBA capabilities are already being examined as an extension of the forecasting module database in order to monetize costs and benefits induced from the overall transformation of the transport networks in general and from the specific policy interventions as described by the SUCs in particular. Overall, the Levitate PST aspires to become the go-to, one-stop-shop tool for the calculation of societal impacts of automation by experts, authorities, stakeholders and any other interested party.

7. Conclusions

In anticipation of rapid technological advancements, cities have to prepare and anticipate the impacts of both the automation of overall traffic, which is beyond their control, and of specific automation-related interventions. In light of this need, the Levitate PST aspires to become the go-to, one-stop-shop tool for the calculation of societal impacts of automation by experts, authorities, stakeholders and any other interested party. In this paper, an outline of the examined automation use cases and sub-use cases was provided. The formulation of the four scenarios for the advent of automation which form the backbone of the projections conducted in the PST was outlined. Afterwards, the integration of results provided by the three methodological pillars of the LEVITATE project, i.e. microsimulation, (ii) system dynamics and (iii) the Delphi method was presented, and indicative results were also provided. The paper concluded with a discussion of the methodologies.

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