LEVITATE: Delphi Method

Authors: Julia Roussou (NTUA), Apostolos Ziakopoulos (NTUA), Maria Oikonomou (NTUA), George Yannis (NTUA)

LEVITATE SCOPE & PURPOSE

The aim of the LEVITATE project is to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives. The main output of LEVITATE will be a **policy support tool** (PST) to help local authorities forecast the impacts of Connected and Automated Transport Systems (CATS) over short, medium and long-term periods. The **PST** will also contain a back-casting tool providing guidance to local authorities on which measures to implement to achieve desired outcomes against a backdrop of increasing vehicle automation. Impact assessment will focus on three primary use cases: Automated **urban transport** (WP5), Automated **passenger cars** (WP6) and Automated **freight transport** (WP7). Within each of these automation use cases there are many specific scenarios relating to the deployment of automation, connected systems or Mobility as a Service (MaaS) applications, which may be vehicle or infrastructure based.

IMPACTS

In order to provide a structure describing how CATS impacts will manifest in the short, medium and long-term, a preliminary **taxonomy** of the potential impacts of CATS was developed by Elvik et al. (2019). This process involved identifying an extensive range of potential impacts which may occur from the future expansion of CATS. A range of impacts were classified into three distinct categories:

I. **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.

II. **Systemic** impacts are system-wide impacts within the transport system. These are measured indirectly from direct impacts and are considered medium-term.

III. **Wider** impacts are changes occurring outside the transport system, such as changes in land use and employment. These are inferred impacts measured at a larger scale and are result of direct and system wide impacts. They are considered to be long-term impacts.

METHODS

The types of impacts that are presented in Deliverable 3.1: A taxonomy of potential impacts of connected and automated vehicles at different levels of implementation (Elvik et al., 2019) will be estimated and forecasted using appropriate assessment methods, such as **traffic microsimulation**, **system dynamics**, **operations research** and **Delphi** panel method. For example, traffic microsimulation can directly provide short-term impacts. Therefore, it will be used to forecast short-term impacts to be able to develop relationships that can receive input in terms of dose (in terms of introduction of sub-use case) and infer response (selected impact(s)). Traffic microsimulation also provides further input to assess medium-term impacts by processing those results appropriately to infer such impacts. System level analysis (such as by tools found within system dynamics) can provide measure of long-term impacts. For the sake of simplicity and applicability of assessment methods, it is assumed that for the appropriate level of automation, adequate infrastructure exists. It is also assumed that the pure technological obstacles for the sub-use cases in consideration are solved. All these results relating to the relationships between sub-use cases, impacts and any intermediate parameters will be provided to WP8 of LEVITATE, which concerns the development of the LEVITATE Policy Support Tool (PST). The results will be integrated within the PST modules and functionalities so that impact assessment can be carried out by the users.

Background of the 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 presupposes that the participants will be willing to not only give answers on the topics but also to repeat the interview in possibly more than two cycles. The Delphi 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, G. D., 2012). The Delphi method presents the following characteristics and features: **anonymity** of experts which assures free expression of opinions provided by the experts. This method helps to **avoid social pressure** from dominant or dogmatic individuals or even from the majority or minorities. 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).

The Delphi method within LEVITATE

Within LEVITATE, the Delphi method is used to determine all impacts that cannot be defined by the other quantitative methods (traffic microsimulation/system dynamics). Initially, a long list of experts were identified for each use case, and contacted via an introductory mail asking them to express the willingness of participation. Those who responded positively (70 expertes) participated in the main Delphi process.

The Delphi method consisted 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. Before starting the questionnaire they were asked to reply to the consent form accepting the use of the information they will add in the questionnaire. Then they were asked to evaluate the potential influence of the proposed interventions on different impact areas. 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.

List of impacts and sub-use cases

In each 1st round questionnaire, experts were asked about the influence of automation related interventions on the proposed impacts for different connected & automated vehicle (CAV) **market penetration rates**. The CAV market penetration rates used are 0% (in the baseline scenario), 20%, 40%, 60%, 80% and 100%, as defined by micro-simulation scenarios; all methods have been using the same scenarios to achieve uniformity of the different results.

The impacts included in the Delphi method are:

- **Travel time**: average duration of a 5km trip inside the city centre.
- **Vehicle operating cost**: Direct outlays for operating a vehicle per kilometer of travel (€/km).
- **Freight transport cost**: direct outlays for transporting a tonne of goods per kilometer of travel (€/tonne-km)
- **Amount of travel**: person kilometres of travel per year in an area.
- **Access to travel**: the opportunity of taking a trip whenever and wherever wanted (10 points Likert scale).
- **Modal split of travel using public transport**: % of trip distance made using public transportation.
- **Modal split of travel using active travel**: % of trip distance made using active transportation (walking, cycling).
- **Shared mobility rate**: % of trips made sharing a vehicle with others.
- **Vehicle utilization rate**: % of time a vehicle is in motion (not parked).
- **Vehicle occupancy**: average % of seats in use.
- **Parking space**: Required parking space in the city centre per person (m2/person).
- **Energy efficiency**: average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%).
- **Public health**: Subjective rating of public health state, related to transport.
- **Inequality in transport**: to which degree are transport services used by socially disadvantaged and vulnerable groups including people with disabilities (10 points Likert scale).

Participants were divided in **seven groups**. Each group had a different questionnaire related to a specific type of interventions based on their expertise. Each questionnaire concerned 2-4 automation related interventions including the baseline scenario were no policy intervention is applied except the introduction of CAVs in the urban environment. The scenarios included in the questionnaires are defined in the LEVITATE project by the WPs 5,6 & 7 partners. Furthermore, they have been finalized during a stakeholder reference group workshop that was conducted to gather views from city administrators and industry on the future of CATS and possible uses (i.e. use cases) of automated public transport, passenger cars, and freight transport termed **sub-use cases**.

The seven questionnaires were divided as follows:

1) Introduction of CAVs in urban transport:

a. Baseline scenario: Introduction of CAVs in the urban environment.

b. Point to point Automated Urban Shuttle Service (AUSS): automated urban shuttles travelling between fixed stations, complementing existing urban transport.

c. Anywhere to anywhere AUSS: automated urban shuttles travelling between not fixed locations.

d. Last-mile AUSS: automated urban shuttles providing convenient first/last mile solutions, complementing public transport.

e. E-hailing: on-demand last-mile CAV shuttles.

2) Introduction of CAVs in freight transport:

a. Baseline scenario: Introduction of CAVs in the urban environment.

b. Automated urban freight delivery: parcel delivery in urban area is fully automated by CAV vans and delivery robots. The CAV vans operate as motherships which carry parcels

and robots. At a stop, these small autonomous delivery robots replace human delivery personnel and bring the parcels to the customers. It is assumed that the necessary infrastructure on the customer side for contactless handover is given.
c. Automated urban freight delivery with night shifts only.
d. Automated freight consolidation: In addition to automated delivery, freight will be consolidated at city-hubs and terminals to reduce the redundancy in the last-mile delivery. Emphasis is put on where to install these city-hubs and how to implement the logistic process that utilizes vehicle automation in a most efficient way.
e. Hub to hub automated transfer: Introduction of transfer terminals at the city border with access to the highway. At these terminals long-range freight containers are passed to level 4 automated trucks, which operate the long-haul highway segments without drivers. At a transfer terminal of the destination city, containers are passed to manually operated trucks again to distribute them in the urban area.

3) Introduction of CAV dedicated lanes:
a. Baseline scenario: Introduction of CAVs in the urban environment.
b. CAV dedicated lane on the outermost motorway lane.
c. CAV dedicated lane on the innermost motorway lane.
d. CAV dedicated lane on the outermost motorway lane and on A-road.
e. dynamically controlled CAV dedicated lane.

4) Introduction of CAVs parking behaviors:
a. Baseline scenario: Introduction of CAVs in the urban environment.
b. CAVs parking inside the city centre after dropping the passenger.
c. CAVs returning to origin.
d. CAVs driving around.
e. CAVs parking outside the city centre.

5) Introduction of city toll:
a. Baseline scenario: Introduction of CAVs in the urban environment.
b. Empty km pricing: A dynamic fee is applied to every empty vehicle inside the city center (depending on area, traffic load and time of day). Average € per Km inside city center zone 0.25€/km - 0.85€/km
c. Static city toll: a fixed fee is applied to all vehicles entering the city center.
d. Dynamic city toll: a dynamic fee is applied to all vehicles inside the city center (depending on area, traffic load and time of day). Average € per Km inside city center zone 0.05 €/km - 0.15 €/km.

6) Introduction of parking space regulations:
a. Baseline scenario: Introduction of CAVs in the urban environment.
b. Replace on-street parking space with space for public use: on-street parking inside city center is reduced by the designated rate, and the space previously used for parking is transformed to sidewalks, planted areas, etc.
c. Replace on-street parking space with driving lanes: on-street parking inside city center is reduced by the designated rate, and the space previously used for parking is transformed to additional driving lanes.
d. Replace on-street parking space with “pick-up/drop-off” parking space: on-street parking inside city center is reduced by the designated rate, and transformed to 'pickup/drop off' parking space.

7) Introduction of automated ridesharing and GLOSA:
a. Baseline scenario: Introduction of CAVs in the urban environment.
b. Automated ride-sharing: automated passenger cars booked by multiple passengers (using a smartphone app) to travel between convenient points. Passengers' final destinations could be near each other, but not necessarily the same.
c. Green Light Optimal Speed Advisory (GLOSA): a Day 1 C-ITS signage application, enabled by the C-ITS service "Signalised Intersections". The application utilises traffic signal information and the current position of the vehicle to provide a speed recommendation in order for the drivers to pass the traffic lights during the green phase and therefore, reduce the number of stops, fuel consumption and emissions. The distance to stop, the plans for signal timing and the speed limit profile for the area are taken into account to calculate the speed recommendation displayed to the driver. GLOSA service is provided through ETSI G5 into the on-board computer of the vehicle or via mobile network into a smartphone app.

For each impact and each automation related scenario the participants were asked to indicate the **percentage of change** that the intervention would have for the mentioned CAV market penetration rates (Figure 1). The percentages varied from -100% to 100% where the minus was either an improvement or a deterioration depending on the type of impact. For example a minus effect on travel time would mean a reduction and thus an improvement, on the other hand a negative percentage of change on public health would mean a deterioration.

1. In your opinion how will the introduction of AVs affect travel time? *

Mark only one oval per row.

	-100% to -70%	-69% to -40%	-39% to -20%	-19% to 0%	0% to 20%	21% to 40%	41% to 70%	71% to 100%
for AV penetration rate 20%								
for AV penetration rate 40%								
for AV penetration rate 60%								
for AV penetration rate 80%								
for AV penetration rate 100%								

Figure 1: Example Delphi question

Result introduction into the PST

After receiving the answers of the 1st Delphi round questionnaires they were analysed. For each intervention and each impact a **table** was created: its rows represented the CAVs market penetration rates and the columns the different percentages of change (Figure 2). All experts' answers were introduced in the table and then for each row (each CAVs market penetration rate) the percentage equal with the average of all answers was extracted. This percentage is the **coefficient** that will be used in the PST (Figure 3). The conversion to percentage fluctuations ensures that the PST operates with different starting values provided either by default or by the user, to increase the flexibility and applicability of the tool.

Additionally, for each impact a **curve** was created representing the values of the percentages for the different CAV market penetration rates. The resulting curves for all interventions and impacts were presented to the experts for the 2nd round of the Delphi, who were then asked whether they agreed with the 1st round results. They were given the opportunity to propose different percentages in case they disagreed. These results which will then be incorporated in the final coefficients introduced in the LEVITATE PST through a weighted average scheme to make sure that each expert contributes equally.

Q12	In your opinion what will be the impact of the introduction of GLOSA on public health?								
	percentages	-85	-55	-30	-10	10	30	55	85
	AV penetration rates	-100% to -70%	-69% to -40%	-39 to -20%	-19 to 0%	0% to 20%	21% to 40%	41% to 70%	71% to 100%
	20%	0	0	0	3	3	0	0	0
	40%	0	0	0	3	3	0	0	0
	60%	0	0	0	3	3	0	0	0
	80%	0	0	0	3	3	0	0	0
	100%	0	0	0	3	3	0	0	0

Figure 2: Delphi answers table

Bin Centroids		-85%	-55%	-30%	-10%	10%	31%	56%	86%	Aggregate Change	PST Coefficients
AV penetration rates	20%	0,003								0,25%	1,003
	40%	0,003								0,25%	1,003
	60%	0,003								0,25%	1,003
	80%	0,003								0,25%	1,003
	100%	0,003								0,25%	1,003

Figure 3: Delphi resulted coefficients

1st Round results

The general experts' opinion extracted by the 1st round questionnaires is that all automation interventions including the baseline scenario will **improve public health and energy efficiency** especially in the long term when CAVs market penetration rates reach 100% (Figure 4).

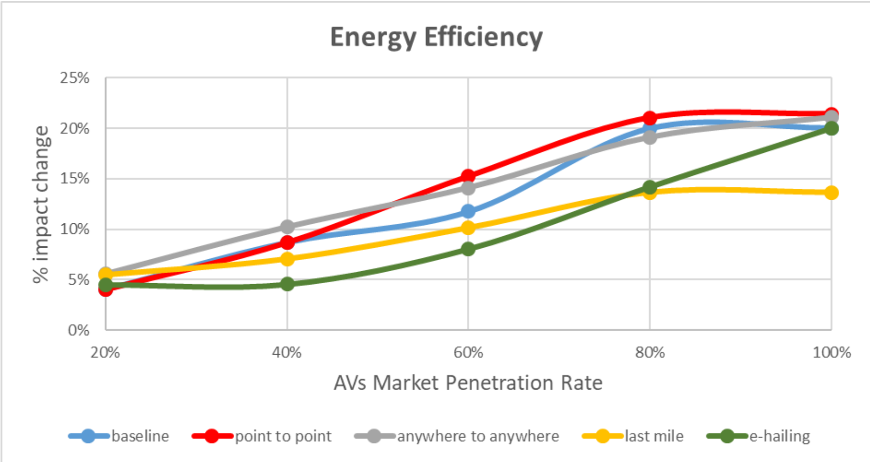

Figure 4: Impact on energy efficiency for automated urban transport scenarios

Regarding the inequality in transport and access to travel (Figure 5), experts indicated that the public transport automation interventions enables more people to travel reducing inequality. The **amount of travel** will be **increased** by the introduction of automation and by the public transport interventions, since more people will have access to travel and autonomous vehicles will reduce traffic and make travel easier and faster, reducing travel time in the long term. Additionally, **vehicle utilization rate** will increase with the introduction of autonomous vehicles, according to experts, which can also lead to an augmentation of the amount of travel.

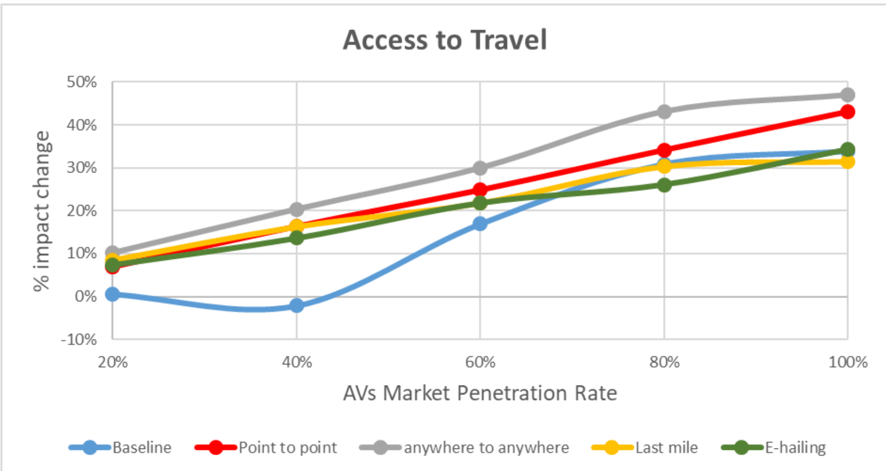

Figure 5: Impact on access to travel for automated urban transport scenarios

Modal split presents the most variations depending on the studied intervention. According the experts the baseline scenario (introduction of automation with no other intervention), as well as the CAVs dedicated lanes interventions will negatively affect modal split using public transport and modal split using active travel. The automated passenger cars interventions, concerning the introduction of city tolls, parking space regulations and CAVs parking behaviors will improve modal split using public transport and active travel. On the other hand the introduction of point to point AUSS, anywhere to anywhere AUSS and automated ridesharing will **reduce** the **modal split** using active travel (Figure 6). Finally, shared mobility rate presents an improvement for all automation scenarios affecting also negatively modal split.

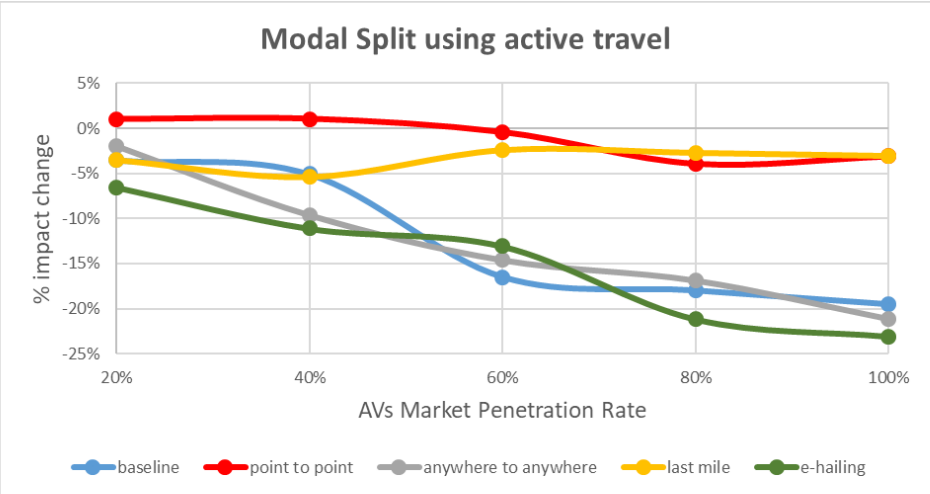

Figure 6: Impact on modal split using active travel for automated urban transport scenarios

Concluding remarks

The Delphi method has been utilized extensively to obtain a collective, aggregate **group opinion** or decision by surveying a panel of experts. Within the LEVITATE project, the Delphi method is used to quantify all impacts that cannot be defined by other methods. Experts provided important insights on 14 impacts as a function of CAV market penetration rate. These figures will be integrated into the LEVITATE PST for use by all interested stakeholders.

References:

Elvik, R. Quddus, M. Papadoulis, A. Cleij, D. Weijermars, W. A. M. Millonig, A. Vorwagner, A. Hu, and P. B & Nitsche. "LEVITATE Societal Level Impacts of Connected and Automated Vehicles. Deliverable D3. 1 of the H2020 project LEVITATE: A taxonomy of potential impacts of connected and automated vehicles at different levels of implementation." (2019).

Hsu, C. C., & Sandford, B. A. (2007). The Delphi technique: making sense of consensus. Practical Assessment, Research, and Evaluation, 12(1), 10.

Garson, G. D. (2012). Testing statistical assumptions. Asheboro, NC: Statistical Associates Publishing.

Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. Management science, 9(3), 458-467.

Profillidis, V. A., & Botzoris, G. N. (2018). Modeling of transport demand: Analyzing, calculating, and forecasting transport demand. Elsevier.