D7.2 Short-term impacts of cooperative, connected, and automated mobility on freight transport

Deliverable D7.2 – WP7 – PU

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

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Work package 7, Deliverable D7.2

Please refer to this report as follows:
Hu, B., Brandstätter, G., Ralbovsky, M., Kwapisz, M., Vorwagner, A., Zwart, R.d., Mons, C., Weijermars, W., Roussou, J., Oikonomou, M., Ziakopoulos, Chaudhry, A., Sha, S., Haouari, R., Boghani, H.C., (2021). *Short-term impacts of cooperative, connected, and automated mobility on freight transport, Deliverable D7.2 of the H2020 project LEVITATE.

Project details:	
Project start date: **Duration:** **Project name:**	01/12/2018 42 months LEVITATE – Societal Level Impacts of Connected and Automated Vehicles
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	This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824361.

Deliverable details:	
Version: **Dissemination level:** **Due date:** **Submission date:**	Final PU 31/10/2021 3/11/2021

*The original title of this deliverable was "The short-term impact, cost and benefits of cooperative and automated freight transport". The title has been revised to better reflect the current terminology used in this field of research.

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Revision history

Date	Version	Reviewer	Description
30/08/2021	Preliminary draft 1	Mark Brackstone - Aimsun	Review round 1 – Accepted wit reservations
30/08/2021	Preliminary draft 1	Govert Schermers (SWOV)	Review round 1 – Accepted wit reservations
02/11/2021	Final report	Vanessa Millar	
03/11/2021	Final deliverable	Andrew Morris – Loughborough University ➔ EC	

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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 connected and automated transport systems, maximize the benefits and utilize 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). This includes impacts on road safety, environment, economy and society.

The impacts to be studied, have been defined in Deliverable 3.1 (Elvik et al., 2019), which provided a preliminary taxonomy of the potential impacts of CCAM. Three impact levels were defined; short term or direct impacts; medium term or systemic impacts and long term or wider impacts. This report focuses on freight transport, specifically providing an analysis of the short-term (direct) impacts of the different freight transport concepts – also called "sub-use cases". The short-term impacts that are discussed in this report are fleet size and mileage of freight vehicles, their operating costs and freight transport costs.

After an extensive literature review and a LEVITATE stakeholder reference group (SRG) workshop, a preliminary list of the urban transport sub-use cases was developed and reported in Deliverable 7.1 (Hu et al., 2019). The proposed automated freight transport sub-use cases were prioritized for their consideration in further investigation. During prioritization, the feedback from SRG, the existence of widespread studies on those sub-use cases and the feasibility of impact assessment have been considered. Following prioritisation, two sub-use cases, namely automated urban delivery and automated consolidation, were selected and are discussed in this report. Both these SUC's are directed at changing the future of parcel delivery.

To assess the direct impacts of these SUC's the project team opted for an operations research methodology consisting of analytical and optimisation methods for decision support on a macroscopic level. Since freight operations are fundamentally different to public and private transport (dealt with in WP5 and WP6 of LEVITATE) we opted for an approach whereby we did not use microsimulation as our primary source to assess direct impacts. Freight operators' main intentions are to increase the efficiency and to reduce operating costs, therefore by optimising the operational model it is possible to obtain reliable results and forecast the impacts in freight transport.

The key results obtained in this deliverable are: i) Automation is the main driving factor for reducing annual fleet costs for freight transport by up to 66% and ii) automation facilitates consolidation, which is crucial for reducing the mileage of freight operations by up to 60%. These results will be included in the final LEVITATE product which is the LEVITATE Policy Support Tool (PST).

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 primary objective to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, to maximise the benefits and to 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 shuttle, 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 established methods within a **new web-based policy support tool** to enable city and other authorities to forecast impacts of CCAM on urban areas. The methods developed within LEVITATE will be available within a toolbox allowing the impact of measures to be assessed individually. A Decision Support System will enable users to apply backcasting methods to identify the sequences of CCAM measures that will result in their desired policy objectives.

1.2 Work Package 7 and Deliverable 7.2 within LEVITATE

WP7 focuses on the impacts that the deployment of cooperative, connected and autonomous vehicles, particularly automated vans and trucks, are expected to have on logistics and freight transport. Forecasting of impacts will consider these components: (i) Automation in parcel delivery and (ii) Automation in consolidation.
Forecasting will be based on the methodology developed in WP3 and the scenarios developed in WP4 to identify and test specific scenarios regarding the impacts of CCAM on freight transport. More specifically, the objectives of WP7 are:

- To identify how each area of impact (safety, mobility, environment, economy, and society) will be affected by CCAM in freight transport, with focus on the transition towards higher levels of automation.
- To test interactions of the examined impacts in freight transport scenarios; and,
- To create a policy support tool (PST) to help authorities to make the right decisions on policy measures concerning the introduction of CCAM.

This report (Deliverable 7.2) presents the short-term impacts of connected and automated driving in freight transport and is based on impacts as identified and defined in WP3 and WP4 (Elvik et al., 2019, Zach et al., 2019). The specific nature of short-term context has been defined in D7.1 (Hu et al., 2019). The main methodological approaches to forecast the short-term impacts are operations research, simulation modelling, system dynamics, and Delphi. Operations research is the main methodology applied in this deliverable to estimate the direct impacts of freight fleet size, driven km, and vehicle operating costs, while the impacts on travel time is estimated via Delphi.

Table 1.1 shows an overview of the full list of impacts considered in the PST for WP7, along with a short description and the unit of measurement. Highlighted are the direct impacts that are described in this deliverable.

Table 1.1: Overview of the impacts in WP7. Highlighted are the short-term impacts for this deliverable.

Impact	Description / measurement	Unit of Measurement
Short term impacts / direct impacts		
Travel time	*Average duration of a 5Km trip inside the city centre*	*min*
Vehicle operating cost	*Direct outlays for operating a vehicle per kilometre of travel*	*€/km*
Freight transport cost	*Direct outlays for transporting a tonne of goods per kilometre of travel*	*€/tonne-km*
Medium term impacts / systemic impacts		
Congestion	*Average delays to traffic (seconds per vehicle-kilometer) as a result of high traffic volume*	*s/veh-km*
Long term impacts / wider impacts		
Road safety	*Number of potential crashes per vehicle-kilometer driven (temp. until crash relation is defined).*	*crashes/ veh-km*
Parking space	*Required parking space in the city centre per person*	*m^2/person*
Energy efficiency	*Average rate (over the vehicle fleet) at which propulsion energy is converted to movement*	*%*
CO_2 due to vehicles	*Concentration of CO_2 pollutants as grams per vehicle-kilometer (due to road transport only)*	*t/day*
Public health	*Subjective rating of public health state, related to transport (10 points Likert scale)*	-
Road safety	*Number of potential crashes per vehicle-kilometer driven (temp. until crash relation is defined).*	*crashes/ veh-km*
Parking space	*Required parking space in the city centre per person*	*m^2/person*

2 Sub-use cases

A stakeholder reference group workshop (presented in detail in D7.1 by Hu et al., 2019) involving city administrators and representatives from industry was held to gather views on the future of CCAM and possible (sub) use cases (SUC) of freight transport. A list of SUCs of interest for freight transport from the perspective of CCAM was developed. Within LEVITATE, this list was prioritized and refined within subsequent tasks in the project to inform the interventions and scenarios related to freight transport. In turn, these SUCs will be included in the LEVITATE Policy Support Tool (PST).

The prioritisation of the sub-use cases mainly took three input directions into account:

- Scientific literature: Indicating the scientific knowledge and the available assessment methodologies for the sub-use cases. However, this might not be directly linked to their importance / relevance for practice.
- Roadmaps: Indicating the relevance of sub-use cases from the industrial/ political point of view, independent of available scientific methodologies.
- SRG Workshop: Containing first-hand feedback for the sub-use cases but might only reflect the opinions of organisations and people who participated.

The automated freight transport related sub-use cases that were:

- **Automated urban delivery**: Future parcel delivery by automated vans and delivery robots.
- **Automated consolidation**: Extension of automated urban delivery by applying consolidation at city-hubs.
- **Hub-to-hub automated transport**: Effects of transfer hubs to facilitate automated trucks. (which will be described in D7.3 and D7.4)
- **Platooning on urban highway bridges**: Impacts of increasing the density of heavy freight transport on bridge infrastructure (which will be described in D7.3)

In this report (D7.2) we describe only the results for the first two SUC's.

2.1 Automated urban delivery

The automated urban delivery sub-use case compares the performance of parcel delivery in urban areas via manual delivery personnel and (semi-)automated concepts. While the automated road-based (delivery) vehicles are well-studied, the operation of delivery robots or micro-vehicles is still an under-researched topic (Baum et al. 2019). Studies show that using smaller, electrified vehicles and robots addresses several acute problems: emissions, navigation in confined inner-city areas and the limitation of working time for manual parcel delivery (Jennings et al., 2019, Figliozzi et al., 2020). There are concepts where the autonomous delivery robots are airborne drones (Dorling et al. 2017), but the operation of drones especially in crowded urban environment is controversial and legally challenging. Therefore, this not further considered in the project.

Based on the current manual delivery process, the envisioned automation technologies and concepts that will emerge in the next decades, we consider these delivery scenarios:

- **Manual delivery** (status quo) is used as a base scenario for comparison.
- **Semi-automated delivery** assumes that the delivery process is not fully automated yet. While the delivery van is automated, personnel are still undertaking the delivery task. However, since they do not need to switch between delivery and driving tasks, time can be saved during each stop.
- **Automated delivery** is where so-called robo-vans and small autonomous delivery robots replace all service personnel and operate beyond the road (to the off-loading areas using pavement, pedestrian area, etc.). The automated van functions as a mobile hub where they perform short delivery trips to end-customers, i.e., a hub-and-spoke setup with moving hubs. This human-less delivery process can be carried out during off-peak hours when road traffic volumes are lower and be extended to evening or nighttime delivery. For this concept, we assume that the parcel capacity of the van will be significantly reduced. The main reason is that it has to carry the delivery robots and the necessary equipment to load them.
- **Automated night delivery** is the same as above, but deliveries are limited to night time delivery only. Since the delivery time is restricted to night time only, this scenario will increase in the fleet size since the same volume of deliveries will have to be made in significantly less time compared to the previous scenario.

The delivery performance and the limiting factors are shown in Table 2.1.

Table 2.1: Performance of the delivery scenarios and their main limiting factors (red).

Delivery scenarios	**Sub-use case specific scenarios (Automated urban delivery)**				
	Delivery scenario parameters				
	Delivery shifts	Avg. parcels per shift	Avg. parcels per stop	Service time per stop	Delivery vehicle
Manual delivery	6:30 – 15:00	150	Variable	5 min	Van
Semi-automated delivery	6:30 – 15:00	180	Variable	4 min	Automated van
Automated delivery	6:30 – 15:00, 18:00 – 24:00, 0:00 – 6:00	100	Variable	10 min	Robo-Van
Automated night delivery	18:00 – 24:00, 0:00 – 6:00	100	Variable	10 min	Robo-Van

2.2 Automated freight consolidation

The automated consolidation sub use case is a continuation of automated urban delivery. In this setting, the parcel delivery companies will consolidate their parcels at city-hubs instead of operating independently and delivering parcels straight to their final recipients. Ideally, the city-hubs and the last-mile delivery operate on a white-label basis, i.e., the delivery vehicles are not bound to a specific delivery company but operate the service for all companies. This removes a lot of redundancy in the delivery system nowadays. In addition, since these city-hubs are closer to the city center than the original distribution centers, final delivery routes in a consolidated scenario are significantly shorter. This has a positive impact on the traffic and the environment (Allen et al. 2012, Quak et al. 2016). While the scientific works are more focused on finding the optimal locations for the hubs (Charisis et al. 2020), it is more of a political and urban planning problem in the real world.

We compare the following delivery scenarios:

- **Manual delivery** refers to the same scenario in the previous SUC
- **Automated delivery** refers to the automated delivery scenario in the previous SUC
- **Manual delivery with bundling at city-hubs** uses bundled parcel delivery via city-hubs, but both the servicing of city-hubs and the delivery to end-customers are done manually.
- **Automated delivery with bundling at city-hubs** is the final scenario that combines the automated delivery via robo-vans and the city-hubs for bundling.

In all automated scenarios, we assume that the delivery is done during day and night (c.f. automated urban delivery SUC), whereas the transport from distribution centers to city-hubs is done during the night via automated trucks. Solutions or prototypes for automatic loading and unloading already exist for packages and pallets (Cramer et al. 2020).

3 Methods

In WP3 the types of impacts were estimated and forecast using appropriate assessment methods, such as microsimulation, operations research and Delphi panel (Elvik et al., 2019). All these results relating to the relationships between sub-use cases, impacts and any intermediate parameters serve as input to WP8, specifically the Policy Support Tool (PST) that is being developed. The results will be integrated within the PST modules and functionalities so that impact assessment can be carried out by the users.

3.1 Operations research

Operations Research methods are widely used in freight transport (Lagorio et al, 2016) and calculates results for freight transport costs, fleet operation costs, and vehicle mileage. For the sake of simplicity and applicability of assessment methods, it is assumed that for the appropriate level of automation, adequate infrastructure exists (e.g., for receiving parcels at night). It is also assumed that the pure technological obstacles for the sub-use cases in consideration are solvable and do not hamper operations. 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). Compared to private passenger transport, freight transport is less time-critical and plannable on an operational basis, which makes operations research a viable approach for the automated delivery and automated consolidation SUCs. Vienna is taken as the basis for analysing these two SUCs due to the availability of high-quality data.

3.1.1 Data processing

Before looking into the methods for route planning, we describe the data processing for generating delivery addresses. First of all, the market shares of logistic providers in Vienna were estimated on the basis of recent reports and online sources[1][2][3][4]. They are shown in Table 3.1.

Table 3.1: Parcel volume for logistics providers in Vienna (thousand parcels per day).

Post AG	Amazon	DPD	GLS	UPS
46.6	41.2	0.6	1.0	0.6

[1] https://www.wienerzeitung.at/nachrichten/chronik/wien/936805-Die-jaehrliche-Paketlawine.html
[2] https://www.post.at/footer_ueber_uns_presse_pressearchiv_2018.php/presse/details/id/1371475
[3] https://www.post.at/footer_ueber_uns_presse_pressearchiv_2018.php/presse/details/id/1284450
[4] https://www.wienerzeitung.at/nachrichten/wirtschaft/oesterreich/2001176-75-Prozent-Marktanteil-fuer-Post-AG-und-DHL.html

Figure 3.1: Locations of the logistics centers.

The parcel volume was taken from a current parcel industry report (Wirtschaftskammer Wien, 2020). Based on this, delivery addresses were generated and randomly distributed but weighted according to the population density of the respective districts in the city of Vienna.

In 2020, the six logistic providers in Vienna delivered a total of 272,000 parcels per day from a total of nine logistics centers (Table 3.1 and figure 3.1). In general, these centres are located either on the outskirts of the city or outside of Vienna, where there is a good connection to the highway.

The delivery addresses were grouped into clusters of 200m diameter, which represent the stop points of the delivery routes, see Figure 3.2. An underlying assumption is this is that under manual delivery, the courier walks to several delivery addresses per vehicle stop (the vehicle is parked, and parcels are delivered to addresses within 200m of the vehicle, sometimes the delivery person is aided by a hand truck, dolly or trolley). In case of automated delivery, the autonomous delivery robots would be deployed from the stopped vehicle (mobile hub) and would deliver the parcels to the desired address.

Two cluster variants are used:

- Unconsolidated clusters: delivery addresses of the logistics providers are considered separately. This results in between 5500 and 22500 clusters per logistics provider, depending on their market share, with a potential demand of about 2 parcels per cluster.
- Consolidated clusters: All delivery addresses are considered together. This results in a total of approximately 27700 clusters, with a potential demand of approximately 8 parcels per cluster.

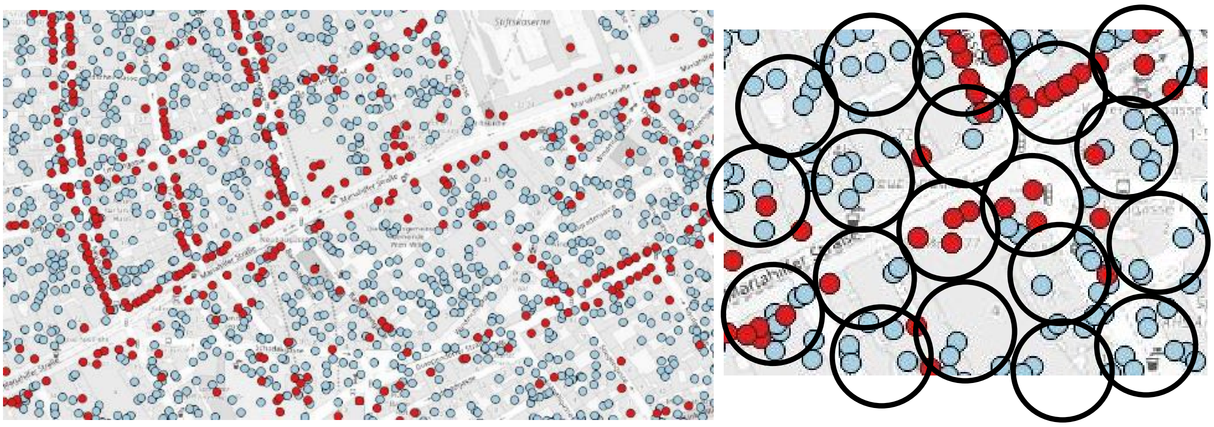


Figure 3.2: Delivery address generated for Vienna (left) and example for clustering (right). Blue points are residential addresses while red points are commercial addresses.

3.1.2 Optimisation algorithm

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, see example in Figure 3.3. 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. Finally, the required consolidation trips between the individual depots are calculated.

If the demand for parcels at a delivery address exceeds the capacity of a single delivery vehicle, we divide it into multiple virtual delivery addresses at the same location, with each of these having a maximum demand for parcels equal to the capacity of the delivery vehicle.

For the unconsolidated delivery, the unconsolidated clusters are used as customers. The nine logistics centers serve as depots. The assignment of addresses to depots is made according to districts. For logistics providers with two logistics centers, all addresses in districts 2, 19, 20, 21 and 22 are assigned to the northern logistics center, all other addresses to the southern logistics center. For logistics providers with only one logistics center, this center is responsible for all addresses in Vienna. Consolidation runs are not necessary with this variant. The difference between manual and automated delivery is mainly the vehicle capacity.

In the case of consolidated delivery, consolidated clusters are used as customers. The nine city-hubs in Vienna function as depots. The assignment of addresses to depots is performed by solving the Capacitated Facility Location Problem (Laporte et al., 2019), where the city-hubs are the facilities, and the districts are delivery areas. The assignment costs of an area to a depot are calculated using the average distance of delivery addresses within a delivery area to the depot. Consolidation trips are made separately for each logistic provider: all parcels of one provider are directly delivered to a specific city-hub via trucks from the nearest logistics center. For servicing the city-hubs, we assume that trucks with a capacity of 800 parcels are used. They are either manually operated or automated. For the delivery vans, we make no changes to the carrying capacity, which is 150 parcels for manually driven LDV's and 100 for automated LDV's (robo-vans). Each city-hub is assumed to have a capacity to handle 36000 parcels per day, so that the demand for Vienna is met.

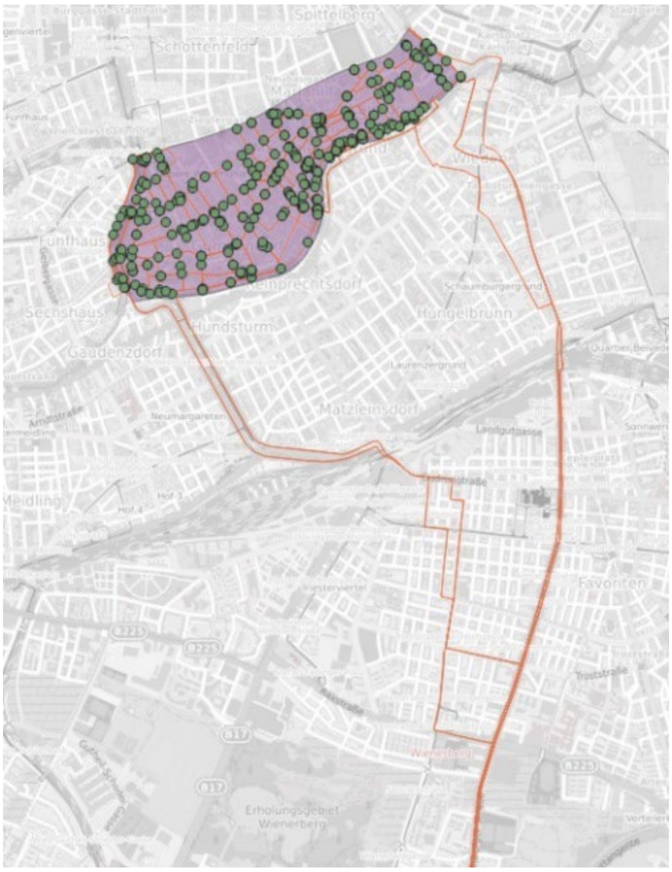


Figure 3.3: Example for calculated delivery routes in Vienna.

When all delivery tours are calculated, the number of routes and the sum of their lengths are used as input for the corresponding (cost and distance) impact indicators.

3.2 Delphi

3.2.1 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 pre-supposes 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, 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).

3.2.2 The Delphi method within LEVITATE

Within LEVITATE, the Delphi method was used to determine all impacts that cannot be defined by the other quantitative methods (traffic microsimulation, system dynamics, operations research, etc.). Initially, a long list of experts was identified for each use case (i.e., urban transport, passenger cars and freight transport), and contacted via an introductory e-mail asking them to express a willingness to participate. Those who responded positively participated in the main Delphi process, amounting to 70 experts in total (5 experts accepted to answer to 2 questionnaires). Experts come from various organisations such as research institutes, companies and universities (presented in Figure 3.4), where they have different job positions, such as directors, professors and managers (presented in Figure 3.5) and they come from different countries (presented in Figure 3.6).

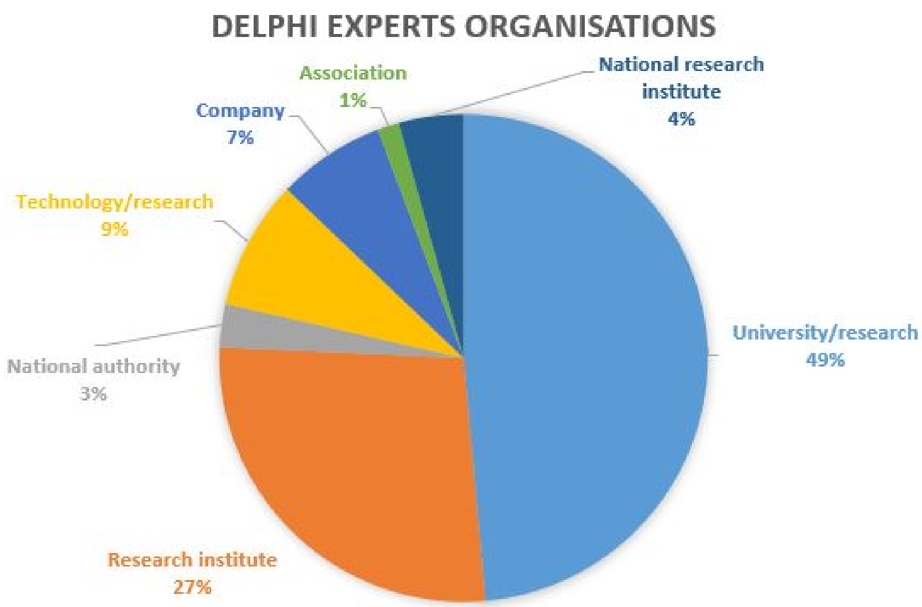


Figure 3.4: Delphi experts' organisations.

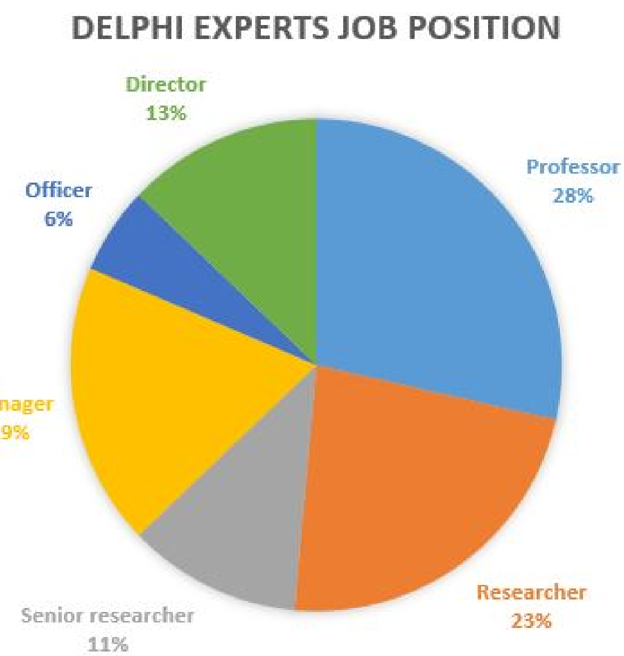


Figure 3.5: Delphi experts' job positions.

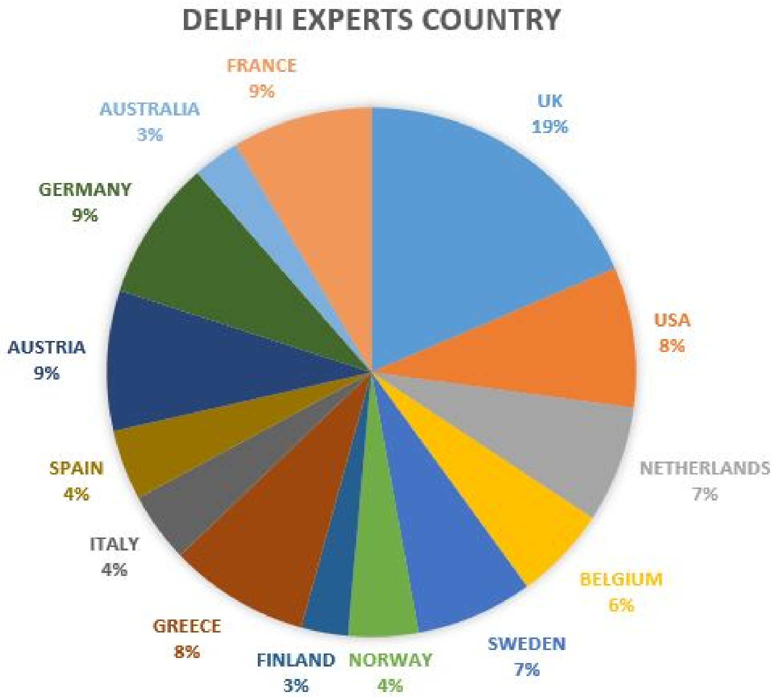


Figure 3.6: Delphi experts' countries.

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) policy 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 provided in the questionnaire. They were then asked to evaluate the potential influence of the proposed interventions on different impact areas. Their answers were then analysed in order to create (anonymous) summary data for the different CCAM related interventions. These results were distributed with the second-round questionnaire and gave respondents the opportunity to reflect on the first-round outcomes before providing their answers again. In some cases it led to respondents changing their first round responses to something conforming more to the answers provided by other respondents.

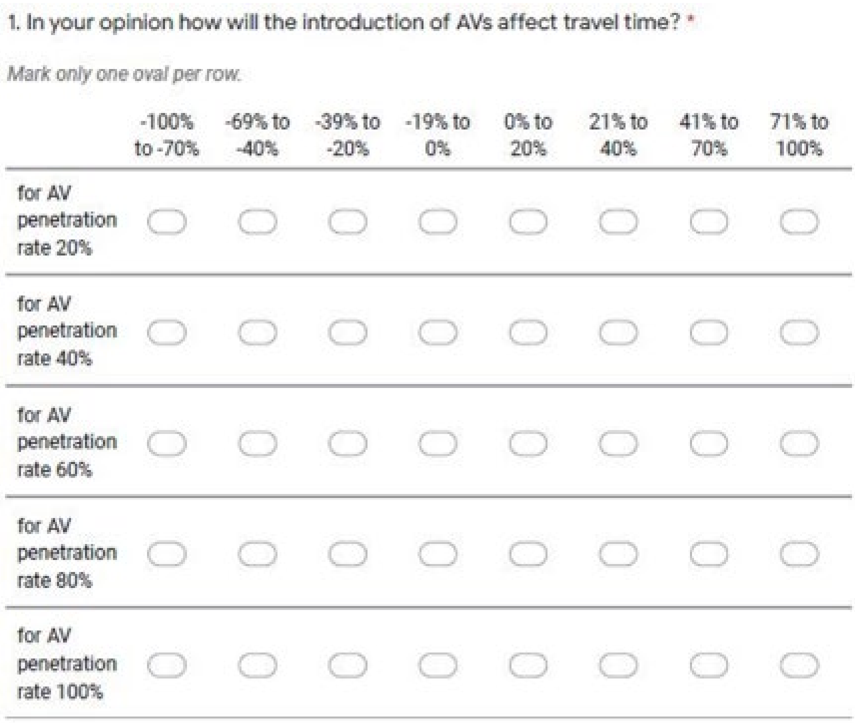
In each first round questionnaire, experts were asked about the influence of automation related interventions on the proposed impacts for different connected & automated vehicle (CAV) market penetration rates. The CAV market penetration rates used are 0 (the baseline scenario), 20, 40, 60, 80 and 100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

The impacts included for the Delphi estimates 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.
- Accessibility in transport: to which degree are transport services used by socially disadvantaged and vulnerable groups including people with disabilities (10 points Likert scale).

Respondents to the Delphi survey were asked to estimate the expected size of each impact relative to the AV market penetration rates (Figure 3.7). The impact sizes varied from -100 to +100 percent where the negative (minus sign) was either an improvement or a deterioration depending on the type of impact. For example, a negative effect on travel time would mean a reduction and thus an improvement, while 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 3.7: Example Delphi question

Participants were divided in seven groups. Each group had a different questionnaire related to a specific type of interventions based on their expertise (as presented in Table 3.2). Each questionnaire concerned 2-4 automation related SUCs, including the baseline scenario where no policy intervention is applied except the introduction of CAVs in the urban environment. The automated freight transport SUCs, that are included in the Delphi questionnaires are described in detail in Chapter 2. For LEVITATE WP7, 11 experts participated in the first Delphi round for the automated freight transport sub-use cases. The questionnaires were also separated with size limitations in mind, as passenger cars would constitute an immense single questionnaire if their sub-use cases were considered all at once.

Once the 1st Delphi round questionnaires were returned, these could be analysed. For each intervention and each impact, a table was created (e.g Table 3.3 its rows represented the AVs market penetration rates and the columns the number of experts that suggested a specific percentage of change).

Table 3.2: Delphi questionnaires and participants. Highlighted are the participant numbers for WP7 freight transport.

WP/Use Case	Questionnaire	SUCs	1st round participants	2nd round participants
WP5 / Urban transport	*Introduction of CAVs in urban transport*	*Baseline scenario*	*14*	*9*
		Point-to-point automated urban shuttle service (AUSS)		
		Anywhere-to-anywhere AUSS		
		Last-mile AUSS		
		E-hailing		
WP6 / Passenger cars	*Introduction of CAV dedicated lanes*	*Baseline scenario*	*10*	*6*
		CAV dedicated lane on the outermost motorway lane		
		CAV dedicated lane on the innermost motorway lane		
		CAV dedicated lane on the outermost motorway lane and on A-road		
		Dynamically controlled CAV dedicated lane		
	Introduction of CAVs parking behaviors	*Baseline scenario*	*10*	*6*
		CAVs parking inside the city centre		
		CAVs returning to origin		
		CAVs driving around		
		CAVs parking outside the city centre		
	Introduction of city toll	*Baseline scenario*	*10*	*7*
		Empty km pricing		
		Static city toll		
		Dynamic city toll		
	Introduction of parking space regulations	*Baseline scenario*	*10*	*5*
		Replace on-street parking space with space for public use		
		Replace on-street parking space with driving lanes		
		Replace on-street parking space with "pick-up/drop-off" parking space		
	Introduction of automated ridesharing and GLOSA	*Baseline scenario*	*10*	*6*
		Automated ride-sharing		
		Green Light Optimal Speed Advisory (GLOSA)		
WP7 / Freight transport	Introduction of CAVs in urban transport	Baseline scenario	11	8
		Automated urban freight delivery		
		Automated urban freight delivery with night shifts only		
		Automated freight consolidation		
		Hub to hub automated transfer		

Table 3.3: Example 1st round Delphi answers for public health in the baseline scenario

Centroids	-85%	-55%	-30%	-10%	10%	30%	55%	85%
AV MPR	-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	1	7	2	1	0	0
40%	0	0	1	5	4	1	0	0
60%	0	0	2	4	3	1	1	0
80%	0	0	3	1	4	1	2	0
100%	0	1	2	2	3	1	1	1

Once all experts' answers were introduced in the table, the average percentage of change could be determined for each AVs MPR. The percentage of aggregate change was calculated by the average of all experts' answers for a specific AV MPR. For example, in table 3.3 for 20% AVs MPR 1 expert proposed an impact of -39 to -20 percent, 7 experts proposed an impact of -19 to 0 percent, 2 experts proposed an impact of 0 to 20 percent and 4 experts suggested an impact of 21 to 40 percent. By multiplying the centroids of each percentage area (e.g. the centroid of 21 to 40 percent is 30 percent) by the number of answers and dividing the sum of all these products by the total number of participants we calculated the average percentage of change for 20% AVs MPR on public health (in detail (-30%*1 + 7*(-10%)+2*10%+4*30%)/11 = -4,14%). This percentage is the coefficient that will be used in the PST, only in case that a quantitative method could not provide input for an impact (Table 3.4). 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.

Table 3.4: Example table Delphi coefficients for public health

AV MPR	Aggregate change	Coefficients
20%	-4.14%	0.959
40%	-0.59%	0.994
60%	1.73%	1.017
80%	7.59%	1.076
100%	6.27%	1.063

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. In total, 8 out of the 11 participants of the 1st round participated in round 2. They were given the opportunity to propose different percentages in case they disagreed. These suggestions were then incorporated in the final coefficients introduced in the LEVITATE PST through a weighted average calculation to make sure that each expert contributes equally.

4 Obtained Impacts

4.1 Fleet size and driven km

For the automated delivery and automated consolidation SUCs, the primary influencing factors for the impacts are the fleet size and the driven km. Although they are not directly listed in the PST and therefore not listed in Table 1.1, they are fundamental for freight operations since other impact indicators are directly based on them.

Table 4.1 compares all delivery variants with respect to their fleet composition and driven km per day. The columns show the number of delivery trips, fleet size, average number of stops (parking operations) per trip, average trip length and mileage of all delivery trips. This is followed by the mileage of the consolidation trips by trucks (i.e., trips for delivering to parcels to the city-hubs), and finally the total mileage of all vehicles. Results are shown in Figure 4.1.

Table 4.1: Results for automated delivery and automated consolidation.

	Delivery via van / robo-van					Consolidation trips by trucks	**Total driven km**
	No of trips	**Fleet size**	Ø Stops per trip	Ø Trip length	Driven km	Driven km	
No consolidation							
Manual delivery	1,799	**1.799**	42.3	44.7 km	80,389 km	-	**80,389 km**
Semi-automated delivery	1,440	1.440	46.5	49.2 km	70,805 km	-	**70,805 km**
Automated delivery	2,692	**898**	28,9	39.4 km	10,6177 km	-	**106,177 km**
Automated night delivery	2,692	**1.795**	28.9	39,4 km	10,6177 km	-	**106,177 km**
Consolidated delivery							
Manual delivery with city-hubs	1,806	**1.806**	17.8	13.7 km	24,675 km	10.445 km	**35,120 km**
Automated delivery with city-hubs	2,716	**906**	12.5	11.9 km	32,347 km	10.445 km	**42,792 km**

We see that on the one hand, the mileage is significantly shortened by the consolidated delivery via the centrally located city-hubs, and on the other hand, mileage increases due to the lower capacities of the robo-vans for automated delivery. However, with automated delivery using smaller vehicles more delivery shifts (three as opposed to 2 in the day and 2 as opposed to 1 at night) can be introduced requiring fewer vehicles in the fleet at any given time. This has the potential to reduce the operating costs significantly, as will be discussed in the next section. We also note that the mileage driven for the for the automated delivery scenario is the highest. However, it is distributed more evenly throughout the day and night, as the delivery shifts time shows in Table 2.1. A breakdown by time of day, along with the impacts for the road safety, will be discussed in D7.4 (Hu et al. 2021).

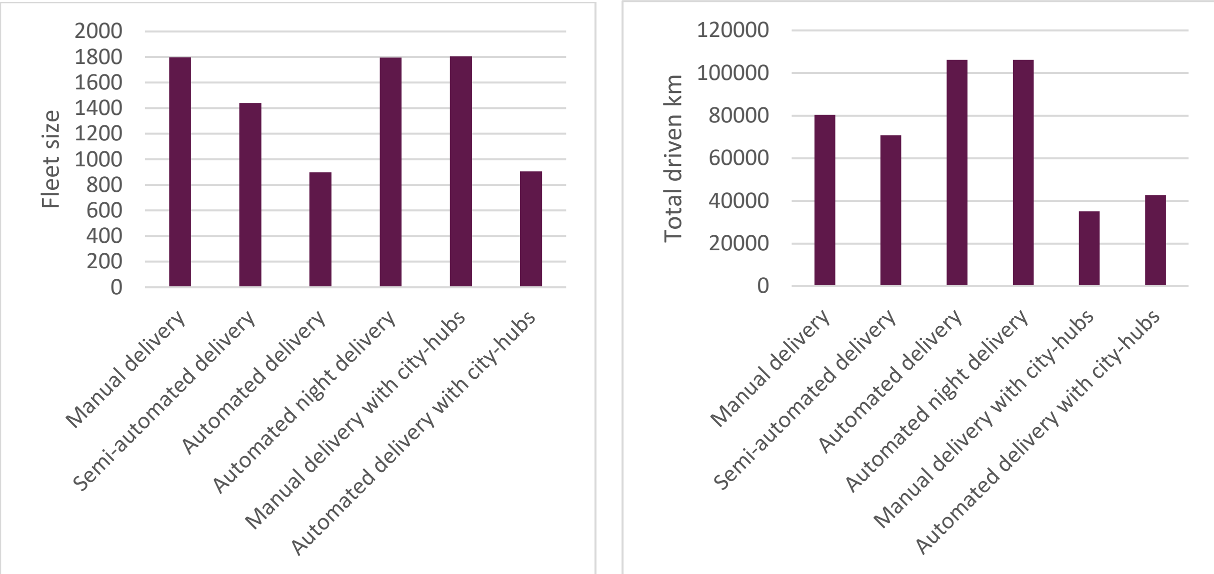


Figure 4.1: Fleet size (left) and total driven km (right).

4.2 Vehicle operating cost and freight transport costs

For assessing the vehicle operating cost, we make following assumptions.

Manual delivery:

- For a conventional delivery transporter, we assume acquisition costs of EUR 30,000 (model of Mercedes Vito). With a linear deprecation over 10 years, the costs are EUR 3,000 per year.
- Costs for insurance, maintenance and fuel are assumed to cost EUR 5,000 per year.
- The average salary of a driver for parcel delivery is around EUR 35,000 per year[5], and the employer pays EUR 45,500 per year due to additional tax and insurance.
- The total costs for a conventional delivery vehicle are therefore EUR 53,500 per year.

[5] https://www.stepstone.at/gehalt/Paketzusteller-in.html

Semi-automated delivery:

- Based on LEVITATE deliverable D3.2 (Elvik et al., 2020), we assume the costs for a level 5 automated van to be EUR 50,000. With a linear deprecation over 10 years, the costs are EUR 5,000 per year.
- Costs for insurance, maintenance and energy will be cheaper than a conventional vehicle. We assume a cost of EUR 3,000 per year.
- The salary of delivery staff / backup driver for emergency remains the same at EUR 45,500 per year.
- The total costs for vehicle in the semi-automated scenario are therefore EUR 53,500 per year, which is the same as for the manual delivery.

Fully automated delivery:

- For the robo-van which needs further equipment for handling the delivery robots, we assume the costs to be 70,000. With a linear deprecation over 10 years, the costs are EUR 7,000 per year.
- Costs for insurance, maintenance and energy are the same as the automated van in the previous scenario. We assume a cost of EUR 3,000 per year.
- The costs for the delivery robots (e.g., Starship) are highly speculative. According to Starship's Head of Data, one robot might cost around USD 5,500[6]. Adding service costs and assuming a linear depreciation over 3-4 years, we come to a cost basis of EUR 2,000 per year. We assume that one robo-van operates with six robots, therefore the total costs for the delivery robot fleet is EUR 12,000 per year.
- The robo-van operates completely without driver or delivery personnel. However, remote monitoring personnel will be necessary where it is assumed that one person can cover five delivery vans (ITF 2017). With an estimated annual salary of EUR 60,000, we obtain EUR 12,000 per year per robo-van.
- Applying these costs, we get EUR 34,000 per robo-van per year.

The costs per delivery vehicle are summarized in Table 4.2.

Table 4.2: Vehicle operating costs per delivery vehicle per year (EUR).

	manual	semi auto	full auto (robo-van)
Vehicle	3,000	5,000	7,000
Insurance, maintenance, fuel	5,000	3,000	3,000
Driver / delivery personnel	45,500	45,500	0
Delivery robot fleet	0	0	12,000
Monitoring personnel	0	0	12,000
Annual costs per vehicle	**53,500**	**53,500**	**34,000**

Using these numbers, we apply them on the results from Table 4.1 and obtain the impacts for the annual fleet cost (Million EUR), vehicle operating costs (EUR/km) and freight transport cost (EUR / tonne-km). For the freight transport cost, we assume an average parcel weight of 1.37kg per parcel (Wirtschaftskammer Wien, 2020). Table 4.3 and Figure 4.2 shows the results obtained for Vienna based on the current volume of packages delivered.

[6] https://sifted.eu/articles/starship-robot-delivery/

Please note that in the PST, the output is stated as vehicle operating cost and freight transport cost and expressed as a cost per kilometer or per ton —kilometer. This might leave the wrong impression that automated delivery appears to be even cheaper than it is forecast (due to the increased mileage) and that freight consolidation appears to be more expensive (due to the decreased mileage). Therefore, a fair comparison is the absolute annual fleet cost since this is the number that is relevant for the freight operators.

The expected impacts on the employment are mixed. While automation will cause automatable jobs to be at risk (Arntz et al., 2016), other jobs will be created. In general, it is expected that automation will lead to a shift of future job landscape (Bughin et al., 2018), but this is outside the scope of this document.

Table 4.3: Vehicle operating cost and freight transport cost given 5 freight CAV implementation scenarios.

	Fleet size	Driven km	Annual fleet cost (Million EUR)	Vehicle operating cost (EUR / km)	Freight transport cost (EUR / tonne-km)
Manual delivery	1,799	80,389 km	96.2	3.9	18.8
Semi-automated delivery	1,440	70,805 km	79.9	3.6	14.8
Automated delivery	898	106,177 km	30.5	0.9	6.8
Automated night delivery	1,795	106,177 km	61.0	1.9	13.5
Manual delivery with city-hubs	1,806	24,675 km	96.6	12.6	61.5
Automated delivery with city-hubs	906	32,347 km	30.8	3.1	22.4

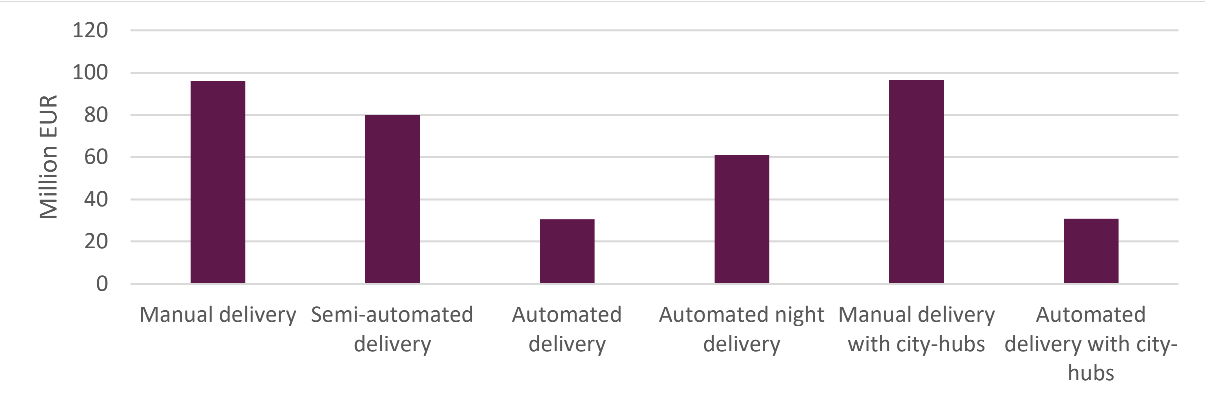


Figure 4.2: Annual fleet cost (Million EUR).

4.3 Delphi results on transport costs

In addition to the cost estimates derived through operations research, the effect of the automated and manual CAV scenarios on freight transport cost was also estimated by the Delphi questionnaire. In round 1 of the Delphi survey, the general experts' opinion is that all studied scenarios will reduce freight transport cost in the long term (Figure 4.3). More precisely, the reduction of freight transport cost after the introduction of the baseline scenario will reach 16.9 percent at 100% AVs market penetration. The automated freight transport scenarios that have the biggest impact are the automated freight consolidation and the fully automated delivery with night shifts only, leading to reductions of up to nearly 21 percent. The other two scenarios are deemed by the experts to have a lesser, although still large effect, namely a reduction of around 9 percent for the fully automated delivery and 16 percent for hub-to-hub automated transfer.

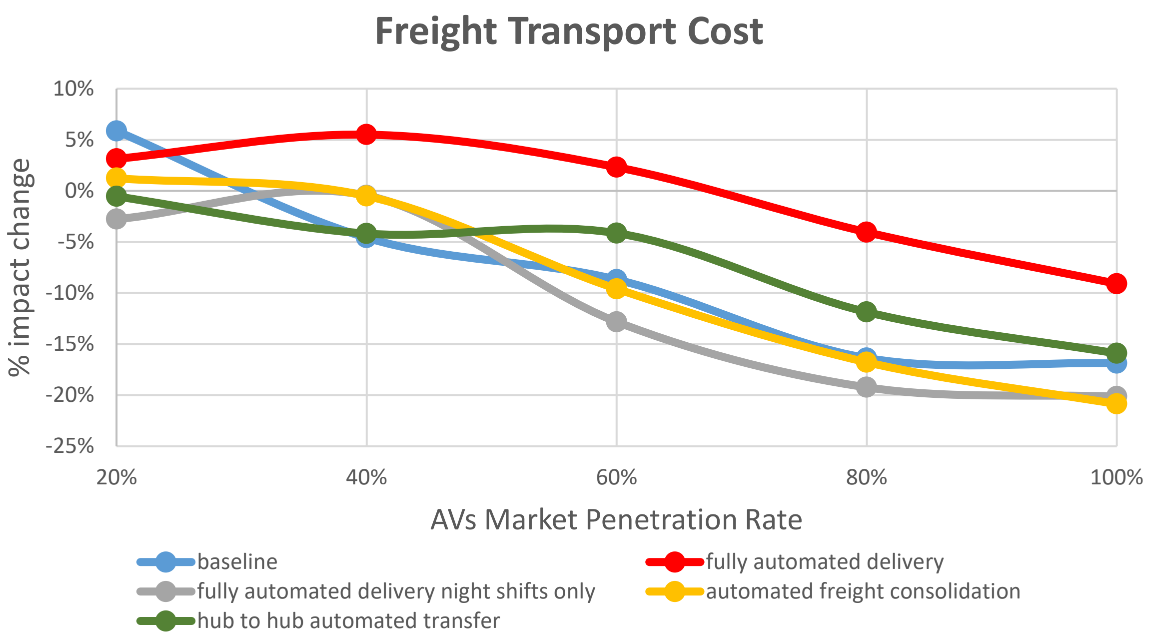


Figure 4.3: 1st round Delphi freight transport cost results

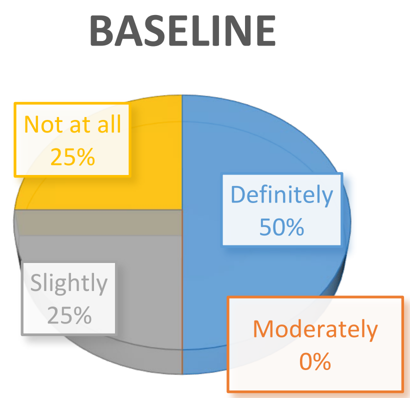


Figure 4.4: 2nd round Delphi results baseline scenario

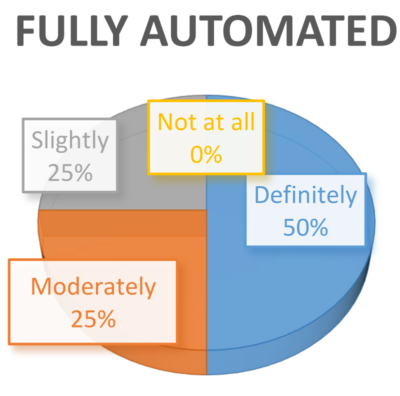


Figure 4.5: 2nd round Delphi results fully automated delivery

In the 2nd Delphi round 50 percent of participants stated that they definitely agreed with the round 1 results for both the baseline and automated freight transport scenarios (Figure 4.4andFigure 4.5). A further 25 percent moderately agreed with the automated freight scenarios. 25 percent of respondents suggested that they did not at all agree or slightly agreed with the round 1 results. Regarding the baseline scenario experts suggested that the introduction of AVs will in fact increase freight transport cost from 10 percent to 20 percent. and proposed higher reduction of vehicle operation cost for AV market penetration rate of 100% reaching -50% for all scenarios. The introduction of hub-to-hub automated transfer will reduce, more than in the 1st round results, the studied impact with an average of -10 percent to -20 percent. Regarding the other automated freight transport scenarios, 2 experts (25 percent) suggested that these interventions will increase by an average of 15 percent freight transport cost and 1 expert (12,5 percent) suggested a reduction of about 20 percent for all these interventions. Table 4.4 demonstrates the aggregate changes resulting for each SUC after experts' answers in round 1 and round 2 of the Delphi method. The biggest difference between round 1 and 2 results is observed in the baseline scenario especially for higher AVs market penetration rates.

Table 4.4: 1st and 2nd Delphi round aggregate changes for freight transport cost.

	Baseline		**Fully automated delivery**		**Fully automated delivery with night shifts only**		**Automated freight consolidation**		**Hub-to-hub automated transfer**	
AV penet ration rates	Aggregate change		Aggregate change		Aggregate change		Aggregate change		Aggregate change	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
20%	5.9%	7,5%	3.1%	2,4%	-2.8%	-3,1%	1.2%	2,4%	-0.5%	-3,3%
40%	-4.6%	-0,7%	5.5%	4,4%	-0.5%	-1,2%	-0.5%	0,9%	-4.2%	-6,2%
60%	-8.7%	-4,0%	2.3%	1,7%	-12.8%	-11,6%	-9.6%	-7,3%	-4.1%	-6,2%
80%	-16.4%	-10,0%	-4.0%	-3,7%	-19.2%	-17,0%	-16.8%	-13,7%	-11.9%	-12,3%
100%	-16.9%	-10,4%	-9.1%	-7,9%	-20.1%	-17,7%	-20.9%	-17,4%	-15.9%	-15,5%

The 2nd round results and experts' suggestions were used to define the Delphi final coefficients (Table 4.5). Since the OR results give a more accurate estimation on the vehicle operating cost, the values here are for reference purpose.

Table 4.5: PST coefficients for vehicle operating cost based on the Delphi 2nd round estimates

	Baseline		**Fully automated delivery**		**Fully automated delivery with night shifts only**		**Automated freight consolidation**		**Hub to hub automated transfer**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	7,5%	1,075	2,4%	1,024	-3,1%	0,969	2,4%	1,024	-3,3%	0,967
40%	-0,7%	0,993	4,4%	1,044	-1,2%	0,988	0,9%	1,009	-6,2%	0,938
60%	-4,0%	0,960	1,7%	1,017	-11,6%	0,884	-7,3%	0,927	-6,2%	0,938
80%	-10,0%	0,900	-3,7%	0,963	-17,0%	0,830	-13,7%	0,863	-12,3%	0,877
100%	-10,4%	0,896	-7,9%	0,921	-17,7%	0,823	-17,4%	0,826	-15,5%	0,845

4.4 Delphi results on travel time

The impact (in terms of percentage change) of the automated transport sub-use cases on travel time estimates is calculated using the Delphi method. According to the experts' answers in the first round of the Delphi, most scenarios tend to strongly reduce travel time as AVs market penetration rates increase (Figure 4.6). However, the baseline scenario will not considerably affect travel time. On the other hand, the automated freight transport scenario that affects travel time the most, is the introduction of fully automated delivery with nightshifts only which achieving estimated travel time reductions of around 22% at 80%, AV market penetration. The introduction of fully automated delivery will reduce travel time by some 7 percent when AVs market penetration rate reaches saturation. Similarly, the introduction of automated freight consolidation and hub to hub automated delivery will reduce travel times by respectively 15% and nearly 8 percent.

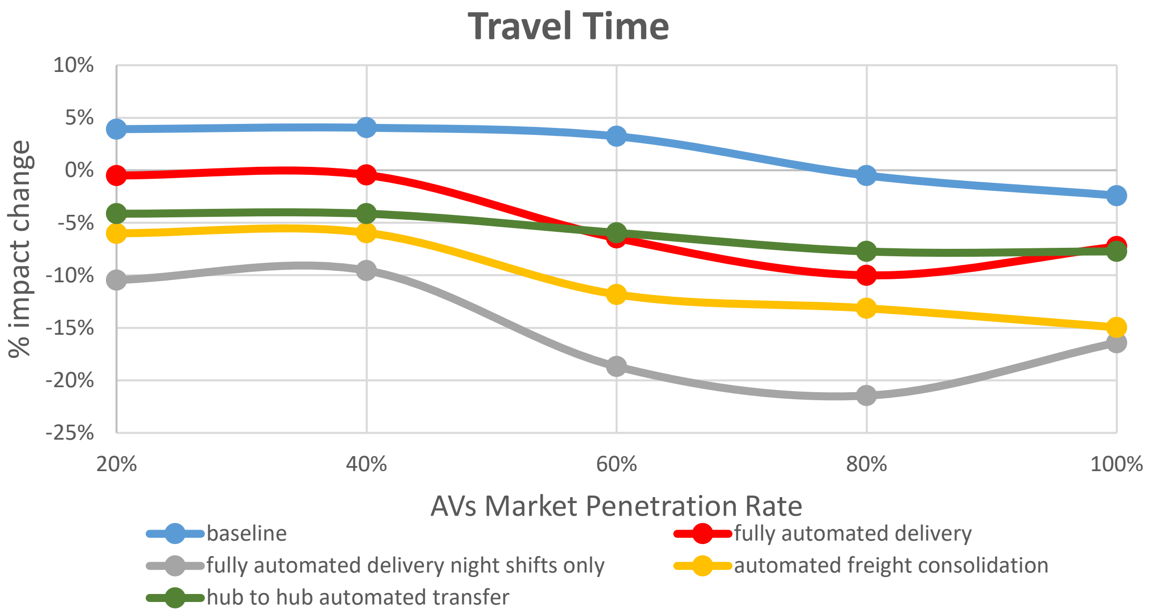


Figure 4.6: 1st round Delphi travel time results.

In the 2nd Delphi round 50 percent of participants stated that they definitely agreed with the round 1 results for both the baseline and automated freight transport scenarios (Figure 4.7 and Figure 4.8). A further 25 percent moderately agreed with the baseline scenario and the automated freight SUCs apart from the automated freight consolidation. 25% of respondents suggested that they did not at all agree with the round 1 results for baseline scenario and the automated freight SUCs apart from the automated freight consolidation. 25 percent of participants stated the slightly agreed with the automated freight consolidation results.

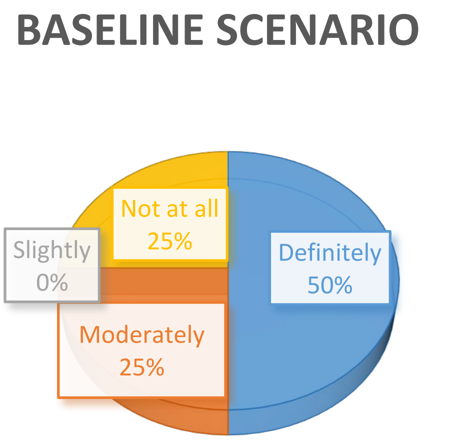


Figure 4.7: 2nd round Delphi results baseline scenario

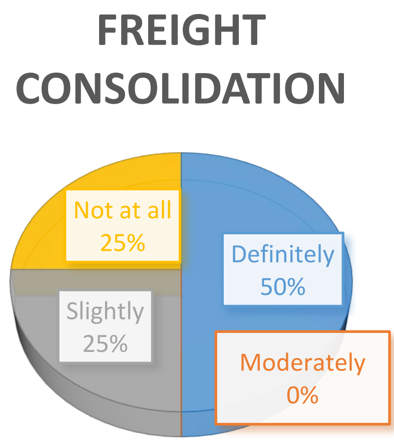


Figure 4.8: 2nd round Delphi results automated freight consolidation

Two experts suggested that all the studied scenarios will increase travel time in the long term with an average percentage of 20% or at least 5%. Regarding the scenarios of fully automated delivery with night shifts only and automated freight consolidation experts suggested that there will be a decrease of travel time, between five and ten percent. Table 4.6 demonstrates the aggregate changes resulting for each SUC after experts' answers in round 1 and round 2 of the Delphi method.

Table 4.6: 1st and 2nd Delphi round aggregate changes for travel time

	Baseline		**Fully automated delivery**		**Fully automated delivery with night shifts only**		**Automated freight consolidation**		**Hub-to-hub automated transfer**	
AV penet ration rates	Aggregate change		Aggregate change		Aggregate change		Aggregate change		Aggregate change	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
20%	3.9%	6.1%	-0.5%	1.7%	-10.5%	-7.7%	-6.0%	-4.2%	-4.1%	-2.9%
40%	4.0%	6.3%	-0.5%	1.7%	-9.5%	-7.0%	-6.0%	-4.2%	-4.1%	-3.2%
60%	3.2%	5.5%	-6.5%	-3.7%	-18.7%	-14.2%	-11.8%	-8.8%	-6.0%	-4.8%
80%	-0.5%	2.2%	-10.0%	-6.8%	-21.5%	-16.4%	-13.1%	-9.8%	-7.7%	-6.4%
100%	-2.4%	0.5%	-7.3%	-4.4%	-16.4%	-12.4%	-15.0%	-11.3%	-7.7%	-6.4%

The 2nd round results and experts' suggestions were used to define the Delphi final PST coefficients (Table 4.7), which will be used in the PST. The results indicate that during the transition phase will have a negative impact on the travel time, but the situation will improve once AV penetration rate reaches 100%. Also, fully automated delivery with night shifts only and automated consolidation will have the largest positive effect on travel time.

Table 4.7: Final PST coefficients for travel time.

	Baseline		**Fully automated delivery**		**Fully automated delivery with night shifts only**		**Automated freight consolidation**		**Hub to hub automated transfer**	
AV penetration rates	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	6,1%	1,061	1,7%	1,017	-7,7%	0,923	-4,2%	0,958	-2,9%	0,971
40%	6,3%	1,063	1,7%	1,017	-7,0%	0,930	-4,2%	0,958	-3,2%	0,968
60%	5,5%	1,055	-3,7%	0,963	-14,2%	0,858	-8,8%	0,912	-4,8%	0,952
80%	2,2%	1,022	-6,8%	0,932	-16,4%	0,836	-9,8%	0,902	-6,4%	0,936
100%	0,5%	1,005	-4,4%	0,956	-12,4%	0,876	-11,3%	0,887	-6,4%	0,936

5 Conclusion and future work

5.1 Conclusions

In this deliverable, assessment methods based on operations research showcased the impacts of automated urban delivery and automated consolidation on the fleet size, mileage of freight vehicles, operating costs, and freight transport costs. Automation in urban freight transport is an important milestone for city logistics, but it will most likely be very challenging due to the complex traffic situations. However, once this is possible, results show that automated delivery and automated consolidation will fundamentally change the way how parcels are distributed. Consolidation in particular will most likely only be economically viable with automation.

The results obtained by operations research indicate that the robo-van concept for automated urban delivery will increase the mileage of the delivery trips when compared to the current manual delivery situation. The main reason is the assumption that the vehicle capacity will decrease due to the delivery robots and additional equipment. By removing the driver who is the most expensive part of the manual delivery system, automated delivery has the potential to significantly reduce the costs which is in line with experts' estimations that delivery robots will reduce costs and delivery time (Jennings and Figliozzi, 2019). In general, the biggest advantage of automated freight transport is the possibility to deploy these when the demand for road capacity is low or at its lowest, for example at night. Without restrictions on working times, the road infrastructure can be utilised more efficiently by particularly freight transport by avoiding deliveries during peak traffic periods.

The current delivery system has a high redundancy since multiple delivery companies operate in the same area, thus one delivery address is often approached multiple times by different delivery companies. Therefore, consolidation through city-hubs is in the spotlight, especially white-label concepts where the infrastructure is shared among different logistics provider companies in order to reduce redundancy (Schodl et al., 2020). While the mileage will decrease significantly, the implementation is very challenging: Beside the expensive upkeep for the city-hubs, the overhead in the freight operation and the additional personnel requirement is significant when the delivery system is operated manually. Without automation, adding the additional consolidation step means that freight has to be transported to the city-hubs and then processed, before the actual delivery can begin. This alone causes a delay of several hours in the delivery process (which very critical for the Business to Business or B2B sector) and we must ask how the labour situation will change as a result of such a consolidated process. Extending the working times of current delivery personnel, particularly drivers, will be legally challenging whereas additional personnel means additional costs. Automated logistics solves this problem completely since servicing the city-hubs can be automated and shifted to the night, when all incoming parcels arrived. This can be seen as the critical enabler for freight consolidation.

Looking at the results obtained from the Delphi panel, there is a consensus among experts that the transport costs in all the reviewed SUCs will decrease as AV penetration rates increase. However, the order of magnitude is lower than the results obtained by operations research. Since the operations research model offers a more transparent view of the calculation process and the assumptions and parameters are changeable, we used that in the PST for assessing the transport costs, while the Delphi panel is a solid backup for impacts that are hard to quantify, namely as travel time, parking space, energy efficiency and public health. The latter three impacts are covered in D7.4.

5.2 Future work

A major remaining task in WP7 is to investigate the transferability of methods and models. While the operations research methodology is transferable when data on the city network, freight data, population data, etc. are given, it takes much time and effort to adapt a model or develop a new one. Therefore, performing a sensitivity analysis and finding the key parameters that have a direct impact on the results is the key to make the approach scalable and transferable.

The final goal would be to develop a meta-model that can forecast the results based on key parameters without running all details of the operations research methodology. This is a challenging topic that requires a large amount of real-world data, development and verification methods. Verification in particular is the hardest part since automated logistics are either at the theoretical study phase or at the beginning of testing phase. A reliable verification, after phasing-in period, is yet to be accomplished.

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