levitate

Guidelines and recommendations for future policy of cooperative and automated freight transport

Deliverable D7.5 – WP7 – PU

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Work package 7, Deliverable D7.5

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List of abbreviations

AUSS	Automated Urban Shuttle Service
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CCAM	Cooperative, connected and automated mobility
CATS	Connected and Automated Transport Systems
CCAM	Cooperative, Connected and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
CV	Connected Vehicle
DisA	Distraction Alert
DrowA	Drowsiness Alert
ERTRAC	European Road Transport Research Advisory Council
EU	European Union
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FORS	Fleet Operation Recognition Scheme
GDPR	General Data Protection Regulation
GLOSA	Green light optimal speed advisory
ISA	Intelligent Speed Assist
IVS	In-vehicle Signage
LCA	Lane Change Assist
LDW	Lane Departure Warning
LKA	Lane Keeping Assist
MPR	Market Penetration Rate
NHTSA	National Highway Traffic Safety Administration
NRC	National Research Council
PST	Policy Support Tool
SAE	Society of Automotive Engineers
SRG	Stakeholder Reference Group
SUC	Sub-Use Case
SSAM	Surrogate Safety Assessment Model
TTC	Time to Collision
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to everything
VKT	Vehicle Kilometres Travelled

About LEVITATE

Societal Level Impacts of Connected and Automated Vehicles (LEVITATE) is a European Commission supported Horizon 2020 project with the objective to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, to maximise the benefits and to utilise these technologies to achieve societal objectives.

Connected and automated transport systems (CATS), or recently the more accepted term Cooperative, Connected and Automated Mobility (CCAM), are expected to be introduced in increasing numbers over the next decade. Automated vehicles have attracted the public imagination and there are high expectations in terms of traffic safety, mobility, environment, and economic growth. With such systems not yet in widespread use, there is a lack of data and knowledge about impacts.

The potentially disruptive nature of highly automated vehicles makes it very difficult to determine future impacts from historic patterns. Estimates of future impacts of automated and connected mobility systems may be based on forecasting approaches, yet there is no agreement over the methodologies nor the baselines to be used. The need to measure the impact of existing systems as well as forecasting the impact of future systems represents a major challenge. The dimensions for assessment are themselves quite broad ranging from impacts on traffic safety to the environment and potentially including sub-divisions within the domains which adds to the complexity of future mobility forecasts.

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 back casting** 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 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 back casting methods to identify the sequences of CCAM measures that will result in their desired policy objectives.

Executive summary

Goals and impacts

Mobility of people and goods is the lifeline of the modern city. In planning for future urban mobility cities like Manchester and Vienna have set goals in which future mobility should contribute to a cleaner city environment, to easier, more comfortable, more cost-effective travel within the city, and to a better, more inclusive society with equal travel opportunities for all social groups. 'Smart mobility' - where various types of vehicles in the city, such as passenger cars, urban transport vehicles, freight vehicles, are connected to information systems that help them to navigate more efficiently and safely through city traffic – is seen as one of the prime movers of the transition towards smart cities. Within LEVITATE, important goals for future mobility have been identified for the environment, mobility, and for society & economy. A literature study has identified the direct, systemic and wider impacts that smart mobility may have on the city traffic network, and how these impacts are mutually connected.

In LEVITATE, several methods—including a literature study, microsimulation, meso-simulation, Delphi survey—have been used to study the expected impacts of the increasing presence of first- and second-generation automated vehicles in city traffic on the domains of environment, mobility, and society and economy. Levitate has also estimated the additional impacts of specific policy interventions (termed 'sub-use cases') such as automated urban shuttle services, or hub-to- hub freight transport, on these domains. These estimated effects are presented as effects over and above the effect resulting from the increasing presence of automated vehicles anticipated as part Cooperative, connected and automated mobility (CCAM).

Given the many uncertainties in prediction, it is obvious that any predicted values are associated with large uncertainty. For the WP7 results, it was decided not to estimate confidence intervals based on the standard error derived from repeated trail runs of models since these intervals would be broad and non-informative. Also, the estimation of these intervals would tend to be biased in itself since the input variables and assumptions in the models are very likely much stronger determinants of predicted values than the variability in sample runs.

Approach to summarizing LEVITATE results

The goal of this Deliverable is to summarize the more detailed results presented in D7.2-D7.4 and to provide an overview of the main expected trends for each selected impact. To quantify the impacts expected from an increasing penetration rate of connected and automated vehicles in the total vehicle fleet as well as the implementation of cooperative and automated freight transport, three primary methods were used: microsimulation, Delphi, and operations research. A number of SUCs related to particular developments in the freight transport sector were defined and these methods were applied to derive estimates of the impacts that these SUCs would have at different penetration rates of CAVs. To summarize these results, for each sub-use case an average (where applicable) is taken of its scenarios to derive an average percentage change for the respective sub-use case (see Table 3.1).

The impacts are presented as a percentage change from the Baseline scenario at 0% penetration of CAVs, where neither automated freight nor automated vehicles have been implemented in the network. These percentage changes are reported for increasing market penetration rates of automated vehicles throughout the entire vehicle fleet in the network, as used throughout LEVITATE.

The Baseline scenario refers to a "no intervention" scenario which is essentially the expected autonomous development of CAVs from human dependence to human independence. In the Baseline scenarios there is no cooperative and automated freight transport added to the network. The impacts of CAVs on network performance can be established by comparing the Baseline 100-0-0 scenario (100% human-driven/reliant vehicles) to the Baseline 0-0-100 scenario (0% human-driven/reliant vehicles). The specific effect or impact of the cooperative and automated freight transport scenario can be determined by comparing the baseline situation for any given penetration rate with the specific SUC results; the difference between the baseline and the SUC is the added effect created by implementing the specific SUC intervention in the simulated network.

Main conclusions

Overall effects of CAVs

Estimating the baseline impacts of an increasing share of connected and automated vehicles (CAVs) for Work Package 7 revealed the following main findings. The results are based on simulations run on the network of Vienna and for all vehicles in the network (including both freight vehicles & private cars).

- The increasing presence of connected and automated vehicles in the urban city area is estimated to have **positive impacts** on the city environment (less *emissions*, higher *energy efficiency*), and city society and economy (less *parking space*, lower *freight vehicle operating cost*) and on city mobility (less *congestion*).

- In Work Package 7, the increasing presence of automated vehicles in the city is estimated to have a **temporary negative impact** on *road safety* when penetration rates of automated vehicles are low. The negative impact found is primarily due to interactions between human-driven vehicles and automated vehicles, which are expected to have different driving styles (e.g. AVs adopting different headways) and different capabilities (e.g. human drivers' longer reaction times) which may lead to an initial increase in risks when many human drivers are still on the road. This result differs from the baseline results found in the road safety impact study (Weijermars et al., 2021) and discussed in WP5 and WP6, primarily due to two factors: 1) differences in the network (Vienna) and 2) the inclusion of freight vehicles. Because less data was available on the driving behaviour of autonomous freight vehicles, some parameters assumed the values of 1st generation CAVs and others were based on assumptions. This led to higher crash rate estimations when freight vehicles were included.

  Larger **positive impacts** on *road safety* are estimated once human-driven vehicles are replaced and second-generation automated vehicles make up at least 60% of the city's vehicle fleet. More broadly within LEVITATE, most estimates point to a large reduction in crashes with the introduction of automated vehicles including a small reduction at low penetration rates. At low penetration rates, the balance between the safety of automated vehicles (which are expected to crash less often than human-driven vehicles) and the potential risks of mixed traffic (when human-driven/less advanced automated vehicles are still on the road) is a point of attention for further research.

- The increasing presence of automated vehicles in the city is estimated to have **a slightly negative** impact on *public health* when traditional (human-driven) vehicles make up the majority of vehicles, followed by a **slightly positive** impact at full automation of the vehicle fleet.

Effects of SUCs: automated delivery, consolidation and hub-to-hub transport

Estimating the impacts of an increasing share of CAVs in the total vehicle fleet together with one of the three forms of automated freight transport revealed the following main findings:

- The **automated delivery** sub-use case is associated with additional benefits for energy efficiency, CO_2 emissions, congestion, public health and vehicle operating costs. The night-time-only automated delivery scenarios (see Appendix A) show additional benefits particularly for the two mobility indicators (travel time and congestion), due to less interaction with the larger daytime traffic volumes.
- The **automated consolidation** sub-use case is associated with additional benefits for energy efficiency, CO_2 emissions, congestion, travel time, public health and vehicle operating costs. Compared to automated delivery without consolidation at city hubs (the first sub-use case), further improvements in energy efficiency, operating costs, and a large reduction in total kilometres travelled are expected. This suggests that centrally located city-hubs can help realise a more efficient allocation of resources.
- The **hub-to-hub** sub-use case is expected to deliver additional benefits for energy efficiency, CO_2 emissions, congestion, travel time, public health, and freight vehicle operating costs.
- **All three automated freight SUCs** are predicted to marginally improve road safety compared to the baseline, particularly at lower penetration rates when less of the remaining vehicle fleet is automated.
- At the higher-level CAV penetration rates (above 80%), all the automated freight delivery SUCs require more parking space than the baseline without automated delivery. The Hub-to-Hub SUC even requires more parking space at 100% CAV penetration compared to the current situation (with 100% human-driven vehicles).
- The sub-use cases of automated delivery, hub-to-hub and especially automated consolidation are predicted positively impact public health. This positive expectation is likely based on the expected additional benefits of these sub-use cases for both road safety and emissions.
- Using data on freight delivery trips in Vianna, it was estimated that compared to manual freight delivery, completely automated delivery and automated delivery with city-hubs will have substantially reduced **annual fleet costs** (-68%).

Effects of truck platooning on bridges

- The largest effect of **truck platooning** on simple single span (beam) bridges as modelled in LEVITATE is observed for the criteria of braking forces. For bridges above

80m length, it has been estimated that the braking force is at least double of the baseline scenario.
- According to standard bridge models and standard traffic simulations within LEVITATE, the need for **strengthening structural resistance of bridges** arises for many existing bridge types and brings with it substantial costs
- For bridge strengthening, a model and guidelines for estimating the costs in relation to the initial construction costs have been developed (**D7.3**).
- As an alternative to strengthening bridges, **intelligent access control** can be used to arrange the increase of inter-vehicle distances for the bridge section to meet the code level and prevent. Headway have been recommended and these are presented in LEVITATE **D7.3** (Hu et al., 2021b). Forcing an increased inter-vehicle distance by intelligent access control will not diminish the ecological and economic benefits of truck platoons.

Recommendations freight transport

For freight transport several recommendations can be given (Hu et al., 2019):
- Passenger transport and freight transport should seek collaboration (e.g., via automated multi-purpose vehicles)
- Collaborative transportation, supported by city hubs and consolidation centres, are necessary to improve operational efficiency. CCAM, especially automated hub-to-hub transport and automated freight consolidation, will contribute significantly
- Multimodality and synchro modality are important factors to aim towards a sustainable logistic supply chain.
- All the above points require homogenous and shared data among operators, which is perhaps the most difficult challenge due to the competition between service providers and freight operators.

Strengths and limitations of Levitate

The followings observations pertain to strengths and limitations of research within WP7 LEVITATE. A potential *strength* of the LEVITATE project is that both smart city transport policy interventions and the associated impacts have been selected by a diverse group of stakeholders. A wide variety of impacts were studied at the same time and the project tried to capture interdependencies. The best available methods - microsimulation, mesosimulation, Delphi, and operations research - were used to study and quantify the expected impacts of mobility interventions intended to support CAV deployment and sustainable city goals. Within Levitate project these impacts provide essential input for developing a practical Policy Support Tool for city policy makers.

Concerning *limitations*, it should be pointed out there are general scientific difficulties in predicting impacts of connected and automated mobility due to uncertainties about propulsion energy, future capacity of power grids, employment, development of costs, and about the behaviour and acceptance with regard automated vehicles. The results of the models in LEVITATE are dependent upon specific assumptions. The simulation models used examined only two CAV profiles (first generation vs. second generation); future work may extend the number of profiles. The safety results of the microsimulation did not include crashes where vulnerable road users are involved.

1 Introduction

Vehicle automation technology is expected to impact many areas of society. Highly automated vehicle technologies, complying to SAE levels 4 and higher, are expected to stimulate new innovations and policy interventions across the transport sector. These could include, for example, new vehicle types, new transport services and changes to infrastructure. The LEVITATE project is directed at studying—and where possible, quantifying—the expected impacts of vehicle automation on society and in particular on mobility, safety, the environment, and the economy. This report provides a synthesis of the results achieved in Work Package 7 which studied the impacts of a number of sub-use cases within the broader domain of cooperative and automated freight transport. This specific chapter introduces the general scientific approach and methodology adopted by LEVITATE. Furthermore, it describes the aims of Work Package 7 and provides an overview of the structure of the report.

1.1 General Levitate approach

Within LEVITATE, a range of cooperative, connected and automated mobility (CCAM) applications and interventions are studied under three use cases: **automated urban transport**, **automated passenger cars** and **cooperative and automated freight transport**. These correspond to Work Packages 5, 6 and 7 respectively.

In each WP, a stakeholder reference group workshop was organised among city administrators, industry representatives and transport specialists to gather views on the future and impacts of CCAM on these three primary use cases. Part of the workshop aimed at identifying specific developments, applications or policy interventions within each sector (or use case). These were termed sub-use cases. Within LEVITATE, these lists were subsequently prioritized and refined subsequent project tasks in order to inform the interventions and scenarios related to urban transport, passenger cars or freight transport. The prioritisation of the sub-use cases mainly took three input directions into account: the scientific literature, roadmaps detailing the deployment of CCAM and the workshop among stakeholders. This resulted in the 13 sub-use cases listed in Table 1.1.

Table 1.1: Sub-use cases (SUCs) investigated in LEVITATE.

Urban transport (WP5)	Passenger vehicles (WP6)	Freight transport (WP7)
Point to point automated urban shuttle service connecting two modes of transport	Provision of dedicated lanes for AVs	Automated urban delivery
Point to point automated urban shuttle service **in a large-scale network**	Replace on street parking with other facilities	Automated consolidation
On-demand automated urban shuttle	Road use pricing	Hub-to-hub automated transport
Last mile automated urban shuttle	Parking price regulation	Truck platooning
	Green light optimal speed advisory (GLOSA)	
	Automated ride sharing	

Within LEVITATE, the impacts of the cooperative, connected and automated mobility (CCAM) sub-use cases are evaluated at three impact levels: direct, systemic and wider. Direct impacts are changes that are noticed by each road user on each trip (Elvik et al., 2020). These impacts are relatively short-term in nature and can be measured directly after the introduction of an intervention or technology, such as changes in travel time or costs. Systemic impacts are system-wide impacts within the transport system which are typically secondary effects resulting from direct impacts. These include measures such as congestion or modal split. Wider impacts are those aspects on which transport systems rely to make mobility possible and also those which are in essence a by-product of mobility. Examples of wider impacts are changes in land use and employment, energy demand and public health. These are inferred impacts measured at a larger scale and are the result of direct and system wide impacts. They are considered long-term impacts (Elvik et al., 2020). Table 1.2 presents the impacts considered within Levitate, their impact level and the policy area(s) to which they are most related.

Table 1.2: Overview of (estimated) impacts in relationship to policy, scale, term and method (WP7).

Quantified impacts see D7.2-7.4 (Hu et al., 2021)	**Impact level** see D3.1 (Elvik et al., 2019)	**Relevant policy areas**
Travel time	Direct	Mobility
Vehicle operating cost		Society, economy
Freight transport cost		Society, economy
Congestion	Systemic	Mobility, Economy, society
Truck platooning		Mobility
Road safety	Wider	Safety
Parking space		Mobility, economy
Energy efficiency		Environment, economy
Emissions		Environment
Public health		Society

In Section 2.4 we further describe how the impacts in Table 1.2 have been operationalised and studied in various methods.

Scenarios: baseline-only and policy intervention-scenarios
LEVITATE considers the impacts of two simultaneous developments: an expected growth in the popularity of connected and automated vehicles (CAVs) over time, as well as the policy intervention scenarios defined in the sub-use cases. These are defined in terms of scenarios, for which the impacts in Table 1.2 are estimated:

- **Baseline scenario:** growing penetration of connected and automated vehicles (CAVs) within the entire vehicle fleet in the network WITHOUT a policy intervention
- **Sub-use case scenarios:** growing penetration of connected and automated vehicles (CAVs) within the entire vehicle fleet in the network WITH a policy intervention implemented in the network (see Table 1.1)

For all scenarios it is assumed that the percentage of CAVs in the vehicle fleet will increase over time and that CAVs will be SAE level 5. As the exact time scale for the development and adoption of highly automated vehicles (SAE levels 4&5) is still undefined, this growth is quantified in so-called "deployment scenarios" at varying market penetration rates of CAVs (see *Table 1.3*). These penetration rates reflect the transition from a driver-dependant vehicle fleet (100% human-driven vehicles) to a driverless vehicle fleet (0% human-driven vehicles).

In addition, two types of CAVs are distinguished in the deployment scenarios to represent an expected evolution in technology (*Table 1.3*). Within LEVITATE, first first-generation automated vehicles have been defined as vehicles with limited sensing and cognitive ability. When compared to human driven vehicles these 1st generation CAVS are assumed to have longer headways (following gaps), earlier anticipation of lane changes and reaction times (more time required in give way situations). Second generation automated vehicles have been defined as having advanced sensing and cognitive ability utilising data fusion usage allowing greater confidence in taking decisions, shorter headways (small following gaps), earlier anticipation of lane changes than human driven vehicles and less time in give way situations (Roussou et al., 2021b).

In WP7 an important difference to the other WPs is that all automated freight vehicles have been modelled as first generation CAV only. These differences in driving style are implemented within the microsimulation models used in the impact quantification.

Table 1.3: CAV Baseline deployment scenarios used within LEVITATE

Vehicle type	**Deployment scenarios**							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Human-Driven Vehicle	100%	80%	60%	40%	20%	0%	0%	0%
1st generation CAV	0%	20%	40%	40%	40%	40%	20%	0%
2nd generation CAV	0%	0%	0%	20%	40%	60%	80%	100%
Human-driven freight vehicle	100%	80%	40%	0%	0%	0%	0%	0%
Freight CAV	0%	20%	60%	100%	100%	100%	100%	100%

1.2 Work Package 7

WP7 focuses on the impacts that the deployment of cooperative, connected and autonomous vehicles may have on freight transport operations. **Three** major cooperative and automated freight transport related **sub-use cases** were formulated:

1. **Automated urban delivery:** Future parcel delivery by automated vans and delivery robots.
2. **Automated consolidation:** Extension of automated urban delivery by applying consolidation at city-hubs.
3. **Hub-to-hub automated transport:** Effects of transfer hubs to facilitate automated trucks.

A **fourth sub-use case** concerns the **impact of platooning on bridges**. Since this SUC is rather unique and does not quite fit the methodology adopted to synthesize the results of the research on automated freight in Levitate, the results are separately presented and briefly discussed.

The expected impacts of these three cooperative and automated freight transport sub-use cases on the environment, economy, mobility, safety and society are described in detail in four deliverables (D7.1-7.4). In preparation for the quantitative analysis, the expected impacts were first evaluated with a literature review and stakeholder workshop and together with the expected future developments related to freight transport, impacts of current ADAS and definition of SUCs, described in Deliverable 7.1. Subsequently, the projected impacts of CAVs and, more specifically, the automated urban transport SUCs were estimated in a series of quantitative analyses and reported in Deliverables D7.2 (direct impacts), D7.3 (systemic impacts), and D7.4 (wider impacts). The purpose of this report, Deliverable D7.5, is to summarise the main impacts of the studied sub-use cases and to provide more general recommendations for policymakers. Based on these results described in D7.1-7.4 and on literature on the transition to smart mobility in smart cities and other general guidelines, recommendations are developed to potentially inform future policy on CAVs and automated urban transport.

Table 1.4: Methods used to evaluate and quantify the expected impacts of automation within the urban transport sector

Goal	Method	Explanation	Deliverable
Exploration	Literature review	Existing literature on CCAM/CAVs/ADAS	7.1
	Stakeholder workshop	A group of key stakeholders – international/ twinning partners, international organisations, road user groups, actors from industry, insurances and health sector support the project and participated in workshops	7.1
Quantifi-cation	Delphi study	The Delphi method was used to determine those impacts that cannot be defined by the other quantitative methods	7.2, 7.4
	Traffic micro-simulation	AIMSUM microsimulation of traffic at the city-district level (based on modelling individual vehicles)	7.3, 7.4
	Operations research	Operations research was used to calculate the fastest trip from a given depot to a number of customers and to upscale microsimulation results to the city-level	7.2, 7.4
	Bridge modelling	Bridge modelling was used to estimated effects of truck platooning on bridge wear	7.3
Synthesis & discussion	Synthesis	Major impacts summarized for the policy areas Environment, Mobility and Society/ Economy/ Safety	7.5
	Policy considerations	Recommendations & considerations for policymakers based on the wider literature	7.5

1.3 Purpose and structure of report

The purpose of this synthesis report is to present the expected impacts of a range of mobility policies in the freight transport domain against the background of increasing CAV deployment in the urban vehicle fleet on the environment, mobility, society, safety and economy.

This report is structured as follows; following this general introduction to the Levitate project, *Chapter 2* provides a more detailed theoretical and empirical background to the expected impacts of cooperative and automated freight transport, and it describes which approach was used to summarise the various impact results from earlier Levitate Deliverables D7.2, D7.3 and D7.4. *Chapter 3* presents the main summarised findings of the quantitative analyses which were reported in deliverables D7.2 to D7.4. In *Chapter 4*, strengths and limitations of the Levitate approach are discussed and broader policy considerations regarding the potential impacts of CCAM further discussed. In *Chapter 5*, final conclusions are drawn, and some limitations of the present approach are discussed.

2 Background

The transition towards cooperative, connected and automated mobility (CCAM) is expected to contribute to the goals of smart and sustainable cities. In Levitate, the impacts of CCAM – including those of cooperative and automated freight transport - on these city goals have been studied by various methods and for different sub-use cases. This Chapter describes the major policy goals towards which cooperative and automated freight transport may contribute (Section 2.1) and how the various distinct impacts on transport system are interrelated and related to the policy goals (Section 2.2). In Section 2.3, the expected impacts of cooperative and automated freight transport are described. The sub-use cases of freight transport which have been studied are further described in Section 2.4. The methods used are further explained in Section 2.5. The approach taken in this synthesis to summarise the impact results is explained in section 2.6.

2.1 Urban mobility and transport goals

To date, there is no standard European approach for defining goals and indicators for the further development of smart cities. Within the Levitate project (WP4), two existing city transport strategies from Greater Manchester in the UK, and Vienna in Austria have been looked at in more detail, specifically in terms of high-level goals on transport developments (Papazikou et al., 2020; D4.4). WP4 covers the effects of autonomous vehicle share on the goals set out by policymakers of these cities (Papazikou et al., 2020).

The Greater Manchester Transport Strategy 2040 follows the vision "World class connections that support long-term, sustainable economic growth, and access to opportunity for all". The strategy has seven core principles to be applied across their transport network (City of Manchester, 2017):

1. Integrated – allow individuals to move easily between modes and services
2. Inclusive – provide accessible and affordable transport
3. Healthy – promote walking and cycling for local trips
4. Environmentally responsible – deliver lower emissions, better quality vehicles
5. Reliable – confidence in arrival, departure and journey times
6. Safe and secure – reduce road accidents especially injuries and deaths
7. Well maintained and resilient – able to withstand unexpected events and weather conditions

Table 2.1 summarizes the Greater Manchester Transport Strategy 2040 goals and a method to measure the impacts. For example, under the policy field, the goal is to improve road safety, this will be measured by the number of injury or fatalities, as well as the perception of personal security by transport mode.

Table 2.1: Overview of goals of the City of Manchester for a viable transport system of the future and corresponding impact targets (City of Manchester, 2017).

Policy field	Policy goal	Measured impact
Environment	Reduced greenhouse gas emissions	CO2 and NO2 emissions
	Best use of existing infrastructure in order to reduce environmental impacts	Percentage of new homes having > level 4 accessibility to the public transport network
Mobility	More reliable journey times	departure/arrival time reliability by mode of transport
	Reduced congestion	Journey duration by mode
	Increase use of sustainable transport (reduce negative impact car use)	Modal split of sustainable transport
		Share of non-sustainable transport modes
Safety	Improved safety and personal security	Number of killed and seriously injured
		Perception of personal security by transport mode
Society	Greater health	Number of walking and cycling trips
	Better access to services	Sustainable transport catchment population for key locations – town centres/hospitals

The second relevant transport strategy for Levitate WP7 is the Viennese Urban Mobility Plan, under the "STEP 2025 Urban Development Plan". It includes the following goals (City of Vienna, 2015):

1. Fair – street space is allocated fairly to a variety of users and sustainable mobility must remain affordable for all.
2. Healthy – the share of active mobility in every-day life increases; accident-related personal injuries decline.
3. Compact – distances covered between work, home, errands and leisure activities are as short as possible.
4. Eco-Friendly – mobility causes as little pollution as possible, the share of eco-mobility in the trips made in Vienna and its environs is rising. The relative change in the modal shift will be largest in bicycle traffic. In absolute figures, the largest increase in the number of trips will be attributable to public transport.
5. Robust – mobility is as reliable and crisis-proof as possible. Mobility should be possible without necessarily owning a means of transport.
6. Efficient – resources are used in a more efficient way, helped by innovative technologies and processes.

The goals for Vienna span four policy domains and were subdivided into specific policy goals for each domain (Table 2.2), each with its own impact measure.

Table 2.2: Overview of goals of the City of Vienna for a viable transport system of the future and corresponding impact targets (WP4).

Policy field	Policy goal	Measured impact
Environment	Mobility causes as little pollution as possible	Modal split changes
Mobility	Resources are used in a more efficient way	Absolute final energy consumption of the Vienna transport system
	Distances covered between work, home, errands and leisure activities are as short as possible	The share of trips done on foot or by bike to shop for supplies or accompany someone as well as distances covered for leisure time activities
	Mobility is reliable and crisis-proof	Bicycle availability
Safety	Safe road travel	The number of traffic casualties and persons injured in traffic accidents
Society	Better health: The share of active mobility in every-day life increases	The share of people in the Viennese population who are actively in motion for 30 minutes daily as they run their daily errands
	Fairness: Street space is allocated fairly to a variety of users and sustainable mobility must remain affordable for all	The total sum of spaces for cycling, walking and public transport in all conversion and urban renewal projects

These two city transport strategies reveal that CCAM could contribute toward achieving these goals although specific policy will need to be adopted to make that achievable. For each of the Policy domains described above, one or more key impact indicators have been defined/operationalized for the Policy Support Tool that is intended to help policy makers' decision-making concerning interventions that may support automated driving.

2.2 Expected automation impacts

It is expected that CCAM will have substantial impacts on road transport. Deliverable D3.1 (Elvik et al., 2019) presented a taxonomy of potential impacts of CCAM which makes a distinction between direct, systemic and wider impacts. **Direct impacts** are changes that are experienced by each road user on each trip. **Systemic impacts** are system-wide impacts within the transport system and **wider impacts** are changes that occur outside the transport system, such as changes in land use and employment. Moreover, a distinction is made between **primary impacts** and **secondary impacts**. Primary impacts are intended impacts that directly result from the automation technology, whereas secondary impacts (rebound impacts) are generated by a primary impact.

Figure 2.1 presents the various impacts of the taxonomy and their expected interrelations (based on scientific literature and expert consultation). In the figure, impacts are ordered from those that are direct, shown at the top, to those that are more indirect or wider, shown further down in the diagram. The diagram is inspired by the detailed model of Hibberd et al. (2018)

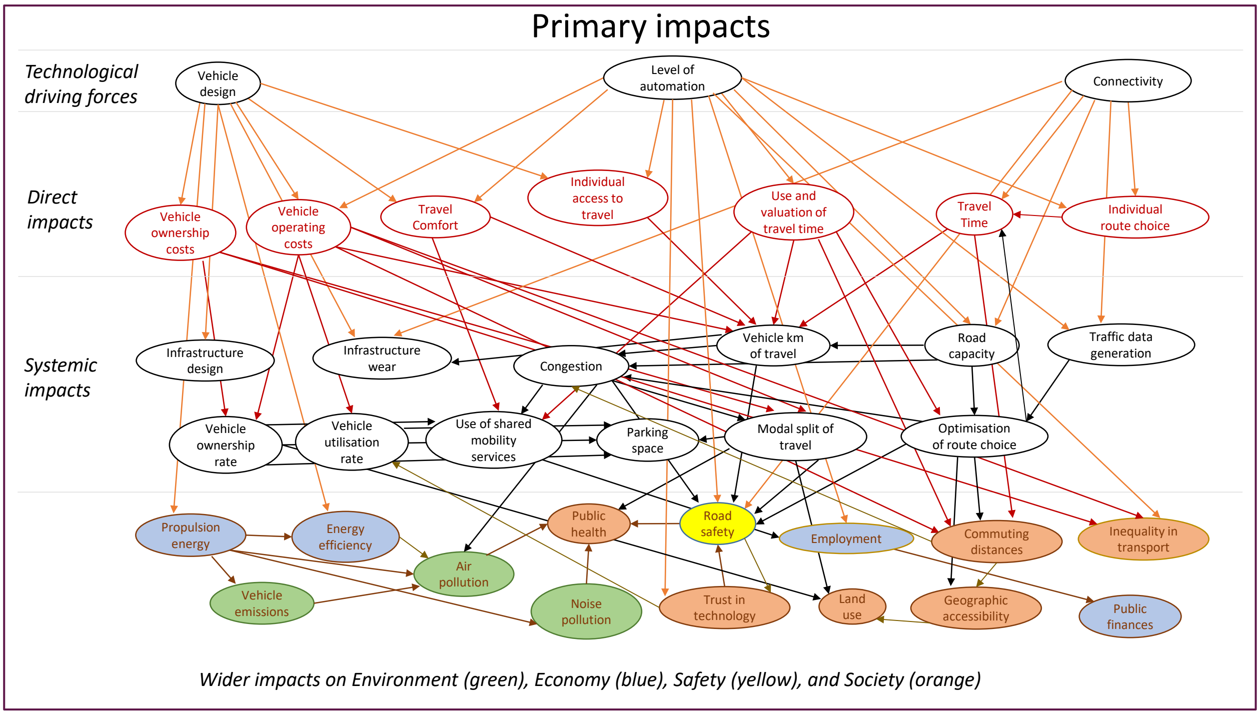

Figure 2.1: Taxonomy of impacts generated by transition to connected and automated vehicles

Figure 2.1 shows the different paths by which impacts are generated by automation technology. Three aspects of it are identified in *Figure 2.1*: vehicle design, level of automation (SAE 1 to 5), and connectivity (Elvik et al., 2019). These characteristics of technology can give rise to different impacts. For example, vehicle design - which includes aspects such as vehicle size, setup of electronic control units, powertrain (fossil fuel or electric) and ease of getting in or out the vehicle – will, through the technology built into connected and automated vehicles, influence both vehicle ownership cost and vehicle operating cost (Elvik et al., 2019). The choice of powertrain will influence propulsion energy and energy efficiency of the engine. Vehicle design may also influence infrastructure design and infrastructure wear, depending on, for example, the mass of the vehicle and its ability for vehicle to infrastructure communication (Elvik et al., 2019). Finally, vehicle design may influence travel comfort and individual access to transport. As an example, vehicles with high ground clearance and no ramps will be difficult to access for wheelchair users.

Another example of pathways in *Figure 2.1* concerns the primary impacts of CCAM on road safety. Road safety is influenced by level of automation, as human operator errors will be eliminated at the highest level of automation (there may still be software errors in computer programmes operating the vehicle, but there will be no driver who can make mistakes) (Elvik et al., 2019). The level of automation may also influence road safety indirectly, by way of trust in technology, in particular before the highest level of automation is attained. However, even fully automated vehicles will have to interact with non-automated road users, who may place excessive trust in the capabilities of the technology to detect them, brake or make evasive manoeuvres. Connectivity will influence safety by reducing or eliminating speed variation between vehicles travelling in the same direction and by shortening reaction times in case of braking (Elvik et al., 2019). Finally, road safety and in the end public health will be influenced by potential changes in the amount of congestion, vehicle kilometres of travel, changes in the modal split of travel and optimisation of route choice (Elvik et al., 2019).

2.3 Expected impacts of cooperative and automated freight transport

In the previous section (*Section 2.2*), a taxonomy of the impacts of automated vehicles was described and also how these impacts are interrelated. In this section, the focus is on the expected impacts on environment, mobility, society, safety and economy from automation in the freight transport sector. The findings below are taken from the literature study by Hu et al. (2019).

The Connected Automated Driving Roadmap (ERTRAC 2019) states that CCAM will provide the opportunity to revolutionize the operation of freight transport. If used properly, automated commercial freight vehicles could improve fleet efficiency, flexibility, and the total cost of ownership. It has also great potential to effectively reduce traffic congestion-related costs through vehicle platooning, improve driver behaviours, reduce driver costs, and increase fleet mobility as well as safety.

There is not much research on CCAM in urban freight since this is the most difficult part to be automated (ERTRAC 2019). The trends of city logistics indicate that the last mile delivery is one of the more expensive, least efficient and most polluting sections of the entire logistics chain (Gevaers et al 2014). With the introduction of CCAM, new business models and operational concepts will emerge that will bring large changes for the road freight transport sector. One of the major cost factors today is the driver or personnel in general (Panteia 2015). Although the automation of urban freight transport is substantially more difficult, and the implementation is not expected in the short or medium-term, it has more possibilities and opportunities to bring substantial changes to the logistic system.

An essential application of urban freight will be automated parcel delivery. These use much smaller than conventional delivery vans and operate off electricity. This addresses two current problems, namely emissions and restrictions of road vehicles in narrow and crowded areas typically found in older European city centres. On the parcel delivery side, there are lots of projects on (sidewalk) delivery robots (Hu et al., 2019) but the operation of delivery robots or micro-vehicles is still an under-researched topic (Baum et al. 2019). The technical capabilities, limitations, challenges and potential time- and cost-savings of current technologies are well described in a study by Jennings and Figliozzi (2019).

On the parcel receiving side, there are needs for compatible infrastructure for these delivery robots. The automated parcel locker system is a natural solution for this (Hu et al., 2019). These lockers are already commercially used where consumers can either receive or send a parcel from (Hu et al., 2019).

Within Levitate, WP7 estimated that cooperative and automated freight transport will impact primarily on the environment, mobility and road safety.

Environmental impacts
For freight transport, vehicle automation does not necessarily lead to direct environmental impacts. ERTRAC (2019) identifies vehicle design, drivetrain, energy composition, and operational efficiency as main factors that influence how environment-friendly and

sustainable future freight transport will be. It should be noted that these factors are not necessarily directly connected to CCAM. Essentially, there is not much difference between achieving the freight volume (expressed in tonne-kilometres) by vehicles driven by conventional drivers or automated transport (Hu et al., 2019).

Although a direct connection between CCAM and positive environmental impacts is ambitious, it is plausible that CCAM could contribute to environmental impact in a broader sense:

- For platooning, lots of scientific research has been done and these studies indicate that it can reduce fuel consumption (e.g., Mello & Bauer, 2019).
- For drivetrain and energy, there is a correlation between E-mobility and CCAM on the level of technology innovation. Therefore, CCAM indirectly reduce CO_2 emissions provided electric energy is generated in an environmentally friendly way.
- New business models and logistic concepts enabled by CCAM will likely increase the operational efficiency and therefore reduce energy consumption in general.

Studies have shown that using smaller, electrified vehicles and robots for urban freight transport may reduce emissions (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 Levitate project nor is it discussed in this WP7 synthesis report.

Mobility impacts

The Connected Automated Driving Roadmap states that CCAM will provide the opportunity to effectively reduce traffic congestion of freight transport through vehicle platooning (ERTRAC, 2019). Also, automated Light Goods Vehicles (LGVs) provide for more efficient delivery with first and last mile access to consolidation centres which will reduce urban congestion due to reduction of the number of trips in the city centre (Hu et al., 2019; 2021a). Below further explanation is given of this expected development.

Automated consolidation of freight transport, i.e., parcel delivery companies consolidating their parcels at city-hubs instead of operating independently and delivering parcels straight to their final recipients – will likely reduce travel or mileage of freight transport (Hu et al, 2021a). 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 will remove a lot of redundancy of trips in the delivery system (Hu et al., 2021a).Furthermore, since city-hubs are closer to the city centre than the original distribution centres, final delivery routes in a consolidated scenario will be significantly shorter producing positive impacts on the traffic and the environment (Allen et al., 2012; Quak et al., 2016).

Safety impacts

Safety is a critical issue since freight vehicles, largely composed of trucks, vans and other large vehicles, have the potential to cause severe crashes with a high injury rate. The fatality rate of crashes involving freight vehicles is relatively high compared to the number of collisions (Eurostat, 2015). This is the main driving factor behind the development of many ADAS which target improving road safety (see section 3.3 for a detailed description of these effects). Beyond ADAS, the introduction of level 3 and level 4 automation, especially in urban areas, still requires substantial research and testing. ERTRAC (2019) states that technology must be proven to ensure functioning without any problems in various climates and traffic conditions and that during the transition phase, trials in a controlled or specific area at specific times should be encouraged.

In the automated freight delivery scenarios, both non-consolidated and consolidated parcels are delivered by small delivery robots which generate a new set of interactions potentially impacting road safety. In an advisory report about an on-road test with delivery robots in the Netherlands, Van Petegem et al. (2018) identified potential road safety risks related to the interaction between such robots and other road users. While some of these risks specifically apply to the on-road test, others are more broadly applicable. The latter are related to the unpredictability of the robot's behaviour, its speed in comparison to pedestrians, its low height (others might not see the robot), and the robot blocking sidewalks (especially for wheelchairs and mobility scooters).

2.4 Sub-use cases

This section describes the automated urban freight transport sub-use cases that were studied in WP7.

Automated urban delivery
The automated urban delivery sub-use case compares the performance of manual delivery (using personnel) and (semi-)automated parcel delivery concepts in urban areas. . 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).
Based on the current manual delivery process, the envisioned automation technologies and concepts that will emerge in the next decades, the following scenarios were considered appropriate for automated urban delivery:

- **Manual delivery** (status quo) is used as a **baseline** 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 areas, 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 night-time 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 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 their main limiting factors are shown in *Table 2.3.* (Hu et al., 2021a).

Table 2.3: 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	Van
Semi-automated delivery	6:30 – 15:00	180	Variable	4	Automated van
Automated delivery	9:00 – 15:00, 18:00 – 24:00, 0:00 – 6:00	100	Variable	10	Robo-Van
Automated night delivery	18:00 – 24:00, 0:00 – 6:00	100	Variable	10	Robo-Van

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. Compared to the current delivery system this significantly improves efficiency. Furthermore, since these city-hubs are closer to the city centre than the original distribution centres, 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).

For the automated freight consolidation SUC the following delivery scenarios were considered:

- **Manual delivery** (status quo) refers to the same **baseline** scenario as in the previous SUC
- **Automated delivery** refers to the automated delivery scenario as 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, it was assumed that the delivery is carried out throughout the day and night, as was the case with the automated urban delivery SUC above. However, the transport from distribution centres 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).

Hub-to-hub

This sub-use case studies the impacts of AV truck terminals functioning as transfer hubs. The goal of these hubs is to facilitate the transition towards level 5 automation by supporting the operation of level 4 automated trucks that can operate on highways but not in urban environment. It is assumed that outbound freight containers from the city are passed to AV trucks at the terminal, which then take over the long-haul highway segment.

At an AV truck terminal of the destination city, the container is passed to a manually operated truck to bring it to the destination. An ideal location for such a terminal is on the city outskirts with direct or good access to the highway road network. *Figure 2.3* shows how this concept should work.

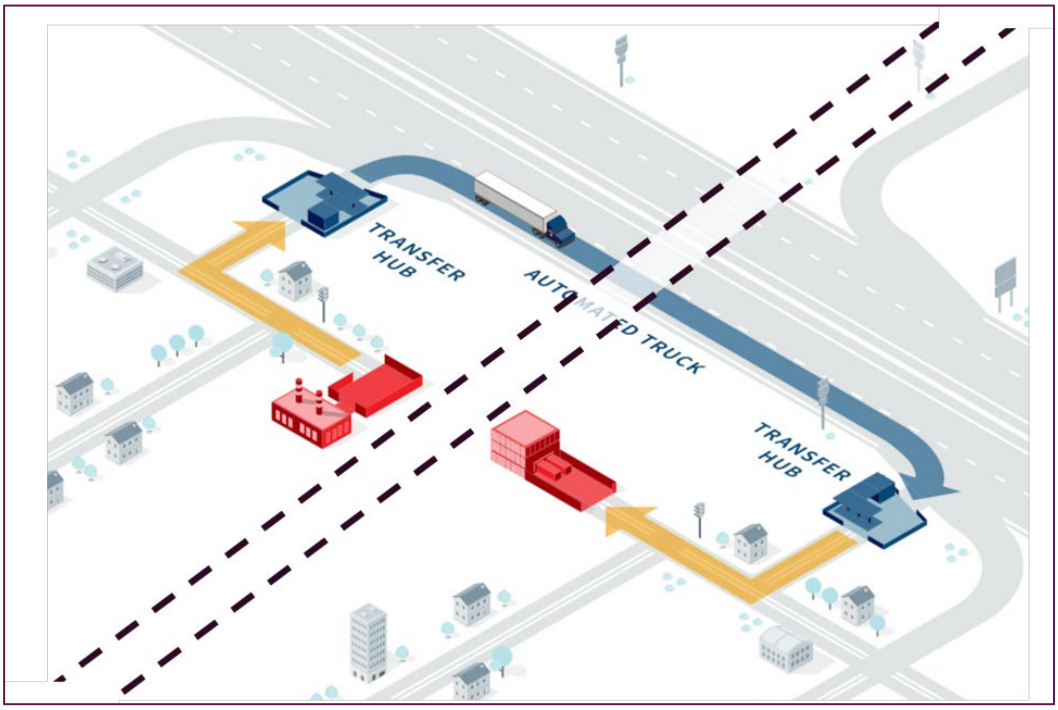

Figure 2.2: Function of the automated transfer hub. Human-operated trucks deliver the containers to the transfer hub (yellow arrow) and from there automated trucks carry them on to the highway (blue arrow).

The main benefit of deploying an AV truck terminal is that:

- Long-haul freight transport can relatively easily be automated and this can translate to significant cost reductions.
- For the urban highway, it is possible to reduce the usage during daytime and shift the freight transport towards night. This can be achieved by coordinating AV trucks to only depart during night hours.

A study by Berger (2016) shows that this concept is highly attractive for the long haul, where the driver wage accounts for one third of the total transport costs. It is also expected that the hub-to-hub connections will be dominated by autonomous trucks, while hub-to-delivery will be executed by hybrid and full-electric small to medium sized trucks (Novak, 2016).

For this SUC, a small area around a potential AV truck terminal including an urban highway segment with ramps was considered. Two scenarios are compared:

- **Status quo (Baseline)** where manual container trucks operate between their origin and destinations directly throughout the day.
- **Operation via transfer terminal:** During the day, manual trucks deliver their freight from origin to the AV truck terminal. At night, AV trucks ship the containers from the terminal to the destination terminals. Similarly, AV trucks from other

terminals arrive throughout the day and night, while the further transport into the city via manual trucks happen during the day.

Bridge platooning

Truck platooning on urban highway bridges is a special SUC in a sense that the assessment methods and the obtained impacts are different from the other SUCs. This SUC is for study purpose and will not be included into the Policy Support Tool (PST) estimator, but nevertheless it is a very important study subject. Although the damage is not a short-term effect and the probability of a potential failure is small, the possible damage in case of failure is enormous (Hu et al, 2021b). In Deliverable 7.3 a full technical description is given of the models and methods for the truck Platooning on urban highway bridges SUC (Hu et al., 2021b). In this synthesis a non-technical abbreviated description of methods is provided in the report and a summarised technical description is included in Appendix C.

The model for traffic loads on bridges is standardized and defined in the EN-1991-2 (Eurocode[1]). It is representing the effects of vehicle loading and is mainly used in the design of new bridges and with modifications in the assessment of the load bearing capacity of existing bridges (which are usually defined individually for each country respective to the bridge construction date). This traffic load model was derived based on axle-load measurements performed near Auxerre, France (Braml 2010, Sedlacek 2008) in 1986 and includes statistical assumptions for the future traffic volumes.

To determine the expected maximum bridge loading, traffic simulations were performed that calculated the bridge loading caused by many years of simulated traffic. This approach was used to compare the maxima of bridge loading in different traffic scenarios including also generic future load assumptions for truck platoons (Hu et al., 2021b).

The following types of traffic scenarios were analysed:

- **Current heavy traffic** (status quo) used as a **baseline scenario** for comparison.
- **Heavy traffic with truck platoons**: different truck-platoons compositions mixed into the current traffic.
- **Intelligent access control:** heavy traffic with mixed-in truck platoons and imposed restrictions of minimum vehicle distances within platoons depending on carrying capacity of bridges.

Bridge strengthening is an option to deal with increased traffic load requirements (such as caused by closely spaced trucks in a platoon), but it can be very costly. To avoid these costs, the option of intelligent access control is a possible alternative. The system of intelligent access control presumes communication between truck platoons and the road administration. The basic idea is that platoons dynamically adjust their headways (distance between vehicles) depending on the load-carrying capacity of bridges ahead of them, this to prevent overloading of the bridges. In the practical implementation, the road network should be divided into sections, and one required headway should be prescribed for each road section. This value should be governed by the most unfavourable bridge structure in each road section, which is probably the bridge with the largest span. The value of the

[1] EN 1991-2: Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges, accessed 10 november 2021 at: https://www.phd.eng.br/wp-content/uploads/2015/12/en.1991.2.2003.pdf

prescribed vehicle distance valid for current road section must then be communicated to truck platoons as they are travelling across different road sections. The communication of this information could be executed in real-time, or alternatively it could be provided prior to the journey for a selected route or parts of the road network (Hu et al., 2021b).

2.5 Assessment methods

The types of impacts that are presented in Deliverable 3.1 (Elvik et al., 2019) have been estimated using three main assessment methods, Delphi panel method, traffic microsimulation, and operations research. In addition to these main methods, for the special sub-use case of truck platooning on bridges a combination of bridge modelling and traffic simulations were used (Hu et al., 2021b).

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).

Traffic microsimulation was used to forecast short-term impacts to be able to develop relationships that can infer dose (in terms of introduction of sub-use case) and response (selected impact). Traffic microsimulation also provides further input to assess medium-term impacts by processing those results appropriately to infer such impacts.

In **WP7**, the traffic microsimulation framework AIMSUN was used to assess the traffic impacts such as congestion and road safety (Hu et al., 2021b) using the network of the city of Vienna. Compared to LEVITATE's WP5 (automated urban shuttles) and WP6 (passenger cars), microsimulation simulation played a smaller role in WP7 for three reasons (Hu et al., 2021b):

- Freight vehicles only take a small share of the traffic volume in urban areas and their impact is limited when compared to the overall traffic.
- Parameters of automated freight vehicles are still uncertain compared to automated passenger cars. Therefore, the results are less reliable.
- Freight operations are plannable; therefore, operations research is more suitable for assessing the fleet size and mileage.

The limitations in simulating automated freight vehicles are particularly relevant for the measurement of road safety impacts, due to their dependence on vehicle driving behaviour. Microsimulation was used to study the expected impacts of the freight SUCs on road safety on the Vienna city network. The frequency with which vehicles in the microsimulation entered potentially dangerous interactions (ie. traffic "conflicts") was measured using the Surrogate Safety Assessment Model (SSAM) developed by the Federal Highway Administration (FHWA). A prediction is subsequently made for the share of conflicts which would result in a crash using the probabilistic method developed by Tarko (2018).

As CAVs exhibit different driving behaviours, their behavioural parameters (eg. time gap, clearance, maximum deceleration) are adjusted for 1st and 2nd generation automated vehicles, leading to changes in the number of conflicts. For freight vehicles, less knowledge was available on the behavioural parameters of future automated freight vehicles; therefore, some parameters assumed the values of 1st generation CAVs and others were based on assumptions, leaving some uncertainty. For this reason, road safety results within LEVITATE have been estimated both including (Work Package 7) and excluding (Work Package 5 & 6) freight vehicles. Nevertheless, the road safety impacts of increasing automation in a mix of both passenger and freight vehicles are an interesting development, especially for these sub-use cases where the deployment of automated freight vehicles is varied.

Furthermore, in Work Package 7 microsimulation provides an estimation of traffic impacts for a reference delivery trip which serves as input for upscaling via operations research in the hybrid assessment approach (further explained below).

Operations research is widely used in freight optimization and calculates results for freight transport costs, fleet operation costs, and vehicle mileage (Lagoria et al., 2016). 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 was taken as the basis for analysing these SUCs due to the availability of high-quality data.

As explained in **D7.2**, in operations research first the data on delivery addresses in Vienna were generated, subsequently a method (optimisation algorithm) was applied to assess route planning, and finally, after all delivery trips were calculated, the number of routes and the sum of their lengths were used as input for the corresponding cost and distance impact indicators (Hu et al., 2021a). For the sake of applicability of assessment methods, it was assumed that for the appropriate level of automation, adequate infrastructure exists (e.g., for receiving parcels during night).

A more technical description of method is given below. Based on the estimated market shares of logistic providers and the reported parcel volumes in Vienna, delivery addresses were generated and randomly distributed but weighted according to the population density of the respective districts in the city of Vienna (Hu et al., 2021a). The underlying algorithm for calculating the delivery scenarios was based on optimising the routing of the delivery vehicles. In all delivery variants considered, the delivery points were assigned to a depot from which the parcels are delivered. Depending on the delivery scenario, this depot can be a logistics centre or a city-hub (in case of consolidated delivery). Subsequently, a problem instance of the Capacitated Vehicle Routing Problem (CVRP) (Toth and Vigo, 2014) was generated for each depot, with the delivery addresses acting as so-called customers. Finally, these instances were solved using the Savings algorithm (Clarke & Wright, 1964). Finally, the required consolidation trips between the individual depots were calculated. If the demand for parcels at a delivery address exceeded the capacity of a single delivery vehicle, it was divided 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 (Hu et. al., 2021a).

For the automated delivery and automated consolidation SUCs, a **hybrid assessment method** based on a combination of micro-simulation and operations research was applied. Micro-simulation was used to capture the traffic impacts of a typical delivery trip of one delivery vehicle. These impacts were then scaled up using operations research, see Figure 3.2.

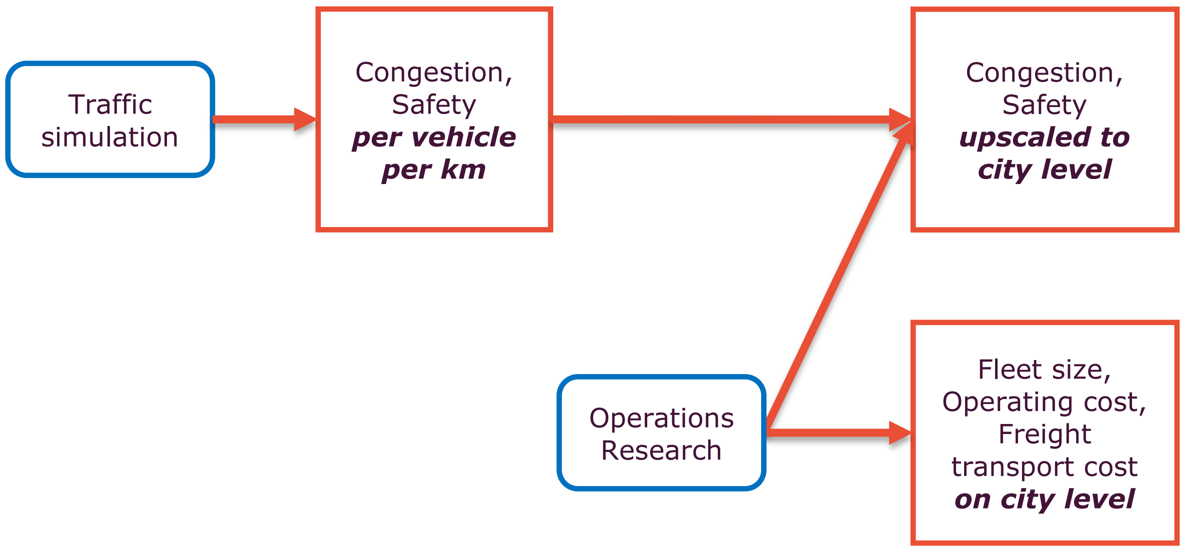

Figure 2.3: Flowchart for the hybrid assessment approach.

Assessing impacts of bridge platooning

Truck platooning on urban highway bridges is a special SUC in a sense that the assessment methods and the obtained impacts are different from the other SUCs. This SUC is for study purpose and will not be included into the PST estimator, but nevertheless it is a very important subject. For truck platooning, there already exist a good amount of scientific work, but the impacts on the bridge infrastructure is under-researched (Hu et al., 2021b). Although the damage is not a short-term effect and the probability of a potential failure is small, the possible damage in case of failure is enormous.

To determine the expected maximum bridge loading, traffic simulations were performed that calculated the bridge loading caused by many years of simulated traffic. This approach was used to compare the maxima of bridge loading in different traffic scenarios including also generic future load assumptions for truck platoons (Hu et al., 2021b). The following types of traffic scenarios were analysed:

- Current heavy traffic (status quo) used as a baseline scenario for comparison.
- Heavy traffic with **truck platoons**: different truck-platoons compositions mixed into the current traffic.
- **Intelligent access control**: heavy traffic with mixed-in truck platoons and imposed restrictions of minimum vehicle distances within platoons depending on carrying capacity of bridges.

To assess the impacts of bridge platooning the Ultimate Limit States (ULS) of midspan bending moment, the shear force and the horizontal force from braking were analysed. Their values in different traffic cases were compared in traffic simulations. To make the results on different bridges comparable, the impacts were not expressed in absolute values of bridge internal forces, but relative to the bridge internal forces caused by Eurocode load model LM1. The forces caused by LM1 load model are deterministic, since the load model is deterministic (Hu et al., 2021b).

The impact of simulated traffic was evaluated in terms of the probability of exceeding the effects of load model LM1. Since new bridges are designed for the loads of load model LM1, it was assumed that they have the respective load-carrying capacity. The definition of load model LM1 according to EN 1991-1 presumes that its exceedance probability in 50 years is 5%. This probability - 5% in 50 years - is regarded as the "code level" (Hu et al, 2021b). The resulting bridge forces were evaluated in terms of the probability, that they exceed the forces from Eurocode load models (Hu et al., 2021b). If the probability, that a resulting 50-years-extreme-value distribution exceeds the force from a Eurocode load model, is above 5% the structural safety can be regarded as reduced. Thus, higher exceedance probabilities mean lower structural safety.

2.6 Approach to synthesizing results

The goal of this Deliverable is to summarise the more detailed results presented in D7.2-D7.4 (Hu et al., 2021a, b, c). As has been explained in Section 1.2, the impacts expected from an increasing penetration rate of CAVs in the total vehicle fleet as well as the implementation of an automated freight services were studied using three primary methods: microsimulation, operations research and Delphi consultation. Within each methodology, a baseline and automated freight scenarios were defined and quantified (see *Section 2.4*).

For the purposes of this synthesis, the results estimated within Work Package 7 of LEVITATE have been condensed in order to provide an overall overview (Table 2.4). The full results, broken down per scenario, can be found in **Appendix A**. In Chapter 3, the quantified results of Work Package 7 are summarised per SUC in order to arrive at expected trends (% change) per impact (see Table 2.4; rightmost column). Given the many uncertainties in prediction, it is obvious that any predicted values are associated with large uncertainty. For the WP7 results, it was decided not to estimate confidence intervals based on the standard error derived from repeated trail runs of models since these intervals would be broad and non-informative. Also, the estimation of these intervals would tend to be biased in itself since the input variables and assumptions in the models are very likely much stronger determinants of predicted values than the variability in sample runs.

The following approach was used in order to summarize and structure the quantified results for WP7:

- Impacts are presented as a **percentage change** from the *Baseline 100-0-0 scenario*, where neither automated freight transport nor CAVs have been implemented in the network and all vehicles are human-driven. These percentage changes are reported across increasing market penetration rates of CAVs throughout the entire vehicle fleet in the network, as used throughout LEVITATE.
- The *Baseline* refers to a "no intervention" scenario which is essentially the expected autonomous development of CAVs from human dependence to human independence (see Section 1.1). In the Baseline scenarios there is no automated freight transport added to the network.
- The **impacts of CAVs alone** on network performance can be established by comparing the *Baseline 0-0-100 scenario* (0% human-driven vehicles) to the *Baseline 100-0-0 scenario* (100% human-driven vehicles).
- The specific **effect of an automated freight transport sub-use case** can be determined by comparing the *Baseline* situation at a given CAV penetration rate with the respective SUC results; the difference between the baseline and the SUC is the

added effect created by implementing the specific SUC intervention in the simulated network.

- For the **microsimulation** study, several scenarios were estimated for the two urban delivery sub-use cases: automated urban delivery and automated consolidation. These involve simulations conducted on both central and periphery networks within Vienna, varying the delivery time window (daytime vs. night-time), and semi-automated (staffed by delivery personnel) vs. fully-automated (robotic delivery) vehicles. As described in Deliverable D7.3 (Hu et al., 2021b), the urban and periphery results were scaled up to arrive at estimations for the entire city of Vienna. The results presented in Chapter 3 reflect the **combination of urban & periphery scenarios** for **fully-automated delivery vans**. The full breakdown of results per scenario can be found in **Appendix A**.

Table 2.4: Synthesized sub-use case scenarios from Deliverables 7.2-7.4

Method	Sub-use case	Scenarios	Synthesized results and measured effect
Microsimulation (Vienna network)	Baseline	• Manual delivery; Urban network • Manual delivery; Periphery network • Hub-to-hub network; no transfer hub	**Baseline; manual delivery** (combined urban & periphery): % change **Baseline; no transfer hub** (combined urban & periphery): % change
	Automated delivery	• Fully-automated: ○ Urban; daytime ○ Periphery; daytime ○ Urban; night-time ○ Periphery; night-time • Semi-automated	**Fully-Automated delivery** (combined urban & periphery): % change
	Automated urban consolidation	• Automated delivery with bundling at city hubs ○ Urban; daytime ○ Periphery; daytime ○ Urban night-time ○ Periphery; night-time • Manual delivery with bundling at city hubs	**Automated delivery with bundling at city hubs** (combined urban & periphery): % change
	Hub-to-hub automated transport	No scenarios	**Hub-to-hub automated transport (with transfer hub):** % change
Delphi study (expert survey)	Baseline	No scenarios	**Baseline:** % change
	Automated delivery	• Fully automated delivery • Fully automated delivery with night shifts only	**Fully automated delivery:** % change
	Automated consolidation	No scenarios	**Automated consolidation:** % change
	Hub-to-hub	No scenarios	**Hub-to-hub:** % change

In addition, the results of two quantitative methods of **Operations research** (D7.2) and **Bridge modelling** (D7.3) are treated separately in this synthesis. These methods do not quite fit in with the approach described above where impacts have been estimated for different market penetration rates of AVs. We have summarized the calculations and findings based on these quantitative methods separately in *Sections 3.4* and *3.5*. To be clear it should be pointed that the results of **operations research**, as is the case with the other methods, have been incorporated in the **Policy Support Tool (PST)** of LEVITATE.

3 Main findings: quantified impacts

This chapter presents a summary description of the impacts that were quantified in the LEVITATE Deliverables 7.2 to 7.4. The findings are presented for policy domains Environment (Section 3.1), Mobility (Section 3.2), Society – Safety – Economy (Sections 3.3 and 3.4). A distinct subject concerns the impact of truck platooning on bridges – findings on this are presented in Section 3.5. The sections 3.1 to 3.3 describe synthesised results in accordance with the approach described in Section 2.5. The findings in Sections 3.4 and 3.5 are based on quantitative analyses that differ from the general approach, in that the impacts are not estimated for different market penetration rates of automated vehicles. In addition to the summary in this chapter, a detailed overview of quantified impacts of D7.2 to 7.4 is added in Appendix A.

3.1 Impacts on the environment

In Work Package 7, two indicators were used to estimate impacts on the environment of freight transport: carbon dioxide (CO_2) emissions and energy efficiency (see *Table 3.1*). Their importance for the environment has been widely documented (e.g., EEA, 2020). Carbon dioxide emissions are the primary driver of global climate change; it is widely recognised that in order to decrease the negative impacts on climate change, the world needs to urgently reduce these emissions. Improving the efficiency of services and technologies in urban transport that use energy from fossil fuels will help reduce emissions.

Table 3.1: Environmental impact definitions

Impact	Definition	Methodology
Energy efficiency	*Average rate (over the vehicle fleet) at which propulsion energy is converted to movement*	Delphi
CO_2 due to freight vehicles	*Concentration of CO_2 pollutants as grams per vehicle-kilometre (due to road freight transport only)*	Microscopic simulation

Table 3.2 presents an overview of the estimated effects resulting from an introduction of a number of automated freight transport services (represented by the SUCs)on energy efficiency and the CO_2 emissions. The sub-use cases considered were automated delivery, automated consolidation and hub-to-hub delivery and are fully described in D7.1. The estimates are based on results from the Delphi study and the AIMSUN microsimulation modelling study on the Vienna road network.

Table 3.2: Estimated impacts of automated freight transport services on CO_2 emissions and energy efficiency: Delphi and microsimulation results. Measured in terms of percentage change with respect to the Baseline 100-0-0 scenario.

		Market penetration rate: AVs in Background vehicle fleet (Human-driven vehicle - 1st Generation AV - 2nd Generation AV)								
		100-0-0	**80-20-0**	**60-40-0**	**40-40-20**	**20-40-40**	**0-40-60**	**0-20-80**	**0-0-100**	
Impact	**Sub-use Case**	%	%	%	%	%	%	%	%	**Method**
Energy efficiency of freight	Baseline	0,0	-3,7	6,5	8,2	11,9	16,0	16,0	16,0	Delphi
	Automated delivery	0,0	6,1	7,8	11,1	14,8	20,4	20,4	20,4	
	Automated consolidation	0,0	7,4	12,5	16,6	20,7	25,2	25,2	25,2	
	Hub-to-hub	0,0	5,6	7,8	13,5	18,2	18,2	18,2	18,2	
CO_2 emissions of freight*	Baseline; manual delivery	0	-21	-50	-80	-90	-100	-100	-100	Micro-simulation (Vienna)
	Automated delivery	-100								
	Automated consolidation	-100								
	Hub-to-hub	-100								

Note * -CO_2 emissions are for freight vehicles only. The contribution of freight to overall emissions is small and the impact of the SUC too small to be meaningful so only effects on freight transport are modelled. Also, the emission impacts modelled for the SUCs assumes 100% electric powered freight vehicles from the outset CO2 emissions are eliminated (the baseline scenario assumes that human-driven vehicles are still traditionally fuelled by fossil fuel derivatives)

Delphi results

According to the experts, the baseline development of the energy efficiency of freight vehicles (used for road transport) is positive; in the baseline, energy efficiency improves by 6% to 16% once human-driven vehicles are reduced to 60% or lower of the vehicle fleet and replaced by first- and second-generation AVs.

The expected impacts on energy efficiency of the three-freight service SUCs, namely automated delivery, automated consolidation and hub-to-hub, are all positive. Compared to the baseline development, experts estimate that the introduction of automated delivery, automated consolidation and hub-to-hub in freight vehicles will further improve energy efficiency. Especially the estimates for automated consolidation are positive withenergy efficiency being 1.5 to 2 times higher compared to the baseline.

Microsimulation results
For the automated delivery and automated consolidation SUCs, the CO_2 emissions caused by the freight vehicles were estimated on the basis of the total driven kilometres presented in D7.2 (Hu et al., 2021a). The impact on the overall emissions including the background traffic would be not visible since the share of the freight vehicles is too low. Therefore, we only consider the freight vehicles here. The microsimulation results in Table 3.2 indicate the following:

- The baseline results for CO_2 emissions of freight vehicles show large reductions (50%) when the share of human-driven vehicles is at 60%- and first-generation automated vehicles is at 40%. Larger reductions of 80% to 100% are achievable when share of human-driven vehicles drops to 20% and below and second-generation vehicles increase to 100%. This gradual reduction reflects the transition in the microsimulation from a freight vehicle fleet which is 100% human-driven and diesel-fuelled, to a fleet which is 100% autonomous and electric (assumed to be emission-free).
- In each of the three sub-use cases, a 100% reduction of emissions occurs once electric freight vehicles fully replace conventional vehicles. In LEVITATE it is assumed that all freight AVs will be electric and therefore emission-free while the manual freight vehicles use internal combustion engines fuelled by diesel, which is the standard at the moment. As the automated freight sub-use cases are implemented at all penetration rates, even when all other vehicles are human-driven (100-0-0), this complete reduction in freight emissions is also predicted at all penetration rates.

3.2 Impacts on mobility

This section presents the main findings of the studied impacts on mobility. For the area of freight transport, two mobility indicators - average travel times in the network and congestion experienced by freight transport vehicles - were studied (*Table 3.3*). The size of these impacts is estimated from two methodologies: the Delphi expert panel and the AIMSUN microsimulation modelling using the Vienna road network.

Table 3.3: Mobility impact definitions

Impact	Definition	Methodology
Travel time	*Average duration of a 5Km trip inside the city centre*	Delphi
Congestion for freight vehicles	*Average delays to traffic (seconds per vehicle-kilometre) as a result of high traffic volume, measured for freight vehicles only.*	Microscopic simulation

Table 3.4 presents the estimated impacts on the mobility (expressed for travel time and congestion) of freight transport vehicles under baseline conditions and for the three sub-use case conditions. In this table for each impact the % effects are reported in respect to Baseline 100-0-0. The difference between the baseline effect and the specific SUC under consideration, and given the penetration rate, is the effect of the SUC itself. In this table a decrease in travel time and congestion (denoted by a "-") implies a favourable effect.

Table 3.4. Estimated impacts of automated freight transport services on travel time and congestion, measured in terms of percentage change with respect to the Baseline 100-0-0 scenario.

		Market penetration rate: AVs in Background vehicle fleet (Human-driven vehicle - 1st Generation AV - 2nd Generation AV)								
		100-0-0	80-20-0	60-40-0	40-40-20	20-40-40	0-40-60	0-20-80	0-0-100	
Impact	**Sub-use Case**	%	%	%	%	%	%	%	%	**Method**
Travel time	Baseline	0,0	6,1	6,3	5,5	2,2	0,5	0,5	0,5	Delphi
	Automated delivery	0,0	1,7	1,7	-3,7	-6,8	-4,4	-4,4	-4,4	
	Automated consolidation	0,0	-4,2	-4,2	-8,8	-9,8	-11,3	-11,3	-11,3	
	Hub-to-hub	0,0	-2,9	-3,2	-4,8	-6,4	-6,4	-6,4	-6,4	
Congestion for freight vehicles (delay per veh-km)	Baseline; no automated delivery	0,0	-15,5	-6,6	-4,8	-7,9	-17,2	-11,6	-8,7	Micro-simulation (Vienna)
	Automated delivery	-42,4	-38,9	-42,2	-49,0	-35,6	-46,1	-49,9	-42,3	
	Automated consolidation	-42,4	-38,9	-42,2	-49,0	-35,6	-46,1	-49,9	-42,3	
	Baseline; no transfer hub	0,0	-9,3	-11,3	-17,5	-19,6	-22,7	-23,7	-24,7	
	Hub-to-hub; with transfer hub	0,0	-11,3	-17,5	-21,6	-23,7	-24,7	-24,7	-26,8	

Delphi results

According to the experts participating in the Delphi consultation, in the baseline condition travel times in the network will increase by 5to 6% when automated vehicles are first introduced (20-60% of vehicle fleet) before settling back to roughly the starting conditions (less than 1% increase) once all vehicles are automated. Compared to the partly unfavourable development of travel under baseline conditions, all three sub-use cases are associated with more favourable developments for travel time. Under the three SUCs the estimated travel times are reduced once conventional (human-driven) vehicles are down to 40% of vehicle fleet. The most positive expectations are for the automated consolidation SUC, where it is estimated that travel time reductions of between 9% and 11% are possible once CAVs make up more than 60% of the fleet. The hub-to-hub case is expected to reduce travel time by 3% to above 6% once second-generation vehicles make up 40% or more of the fleet. The automated delivery is expected to reduce travel time by about 4%-7% once second-generation vehicles make up 20% or more of the fleet.

In brief, all three SUC's are expected to result in more favourable development of travel time, i.e., less travel time, when compared to the baseline scenario. Automated consolidation shows the most promising results with regard to reduction of travel time. The reduction in travel time peaks once human-driven vehicles are reduced to 20% and below and tends to remain constant after that.

Microsimulation results

According to the AIMSUN microsimulation results using the Vienna road network:

- In the manual delivery baseline scenario, the congestion delays experienced by delivery vehicles vary between a 5-17% reduction when automated vehicles are introduced into the network. The reduction in congestion is lowest when the vehicle fleet is roughly equally split between human-driven and autonomous vehicles (60-40-0 and 40-40-20).

- The sub-use cases of automated delivery and consolidation are associated with a 36% to 50% reduction in congestion experienced by delivery vans under the eight penetration rate scenarios. This is substantially more than in the baseline scenario, suggesting that both forms of automated delivery will bring additional benefits for congestion levels in urban environments similar to the one modelled in this study.
- While the automated delivery and consolidation sub-use cases exhibit the same normalized congestion per vehicle kilometre, the automated consolidation sub-use case is expected to reduce the total kilometres travelled due to more efficient routing/logistics. This suggests that the total amount of congestion delays experienced may further be reduced with consolidation.
- A shift to night-time-only delivery (see nighttime scenarios in Appendix A), which could be facilitated with driverless delivery vehicles, is expected to result in a large (over 90%) reduction in congestion experienced by the delivery vans due to the much lower traffic volumes during night-time hours.
- The estimated developments in congestion for the hub-to-hub SUC shows a slight improvement (less congestion) when a transfer hub is implemented compared to the baseline condition with no transfer hub.

3.3 Impacts on society, safety & economy

In this section the main findings on the wider impacts of automated freight transport services in city areas that experience increasing numbers of connected and automated vehicles are presented. *Table 3.5* presents the expected impacts on the interconnected policy domains of society (health, and access to services), road safety and economy. The impacts on road safety are based on results from the AIMSUN microsimulations whereas the remaining impacts are estimates from the results of the Delphi study.

Table 3.5: Society, safety & economy impact definitions

Impact	Definition	Methodology
Freight vehicle operating cost*	*Direct outlays for operating a vehicle per kilometre of travel (€/km)*	*Delphi*
Parking space	*Required parking space in the city centre per person (m2/person)*	*Delphi*
Public health	*Subjective rating of public health state, related to transport (10 points Likert scale)*	*Delphi*
Road safety	*Number of predicted crashes per vehicle-kilometre driven*	*Microsimulation***
* *In section 3.4 freight vehicle costs have also been estimated using operations research methodology* ** *Post processing done with SSAM + Tarko (2018) crash prediction method*		

As we have explained earlier, society, safety and economy are highly interrelated policy areas (see *Section 2.2*). For example, both road safety and public health have an important social dimension as well as a well-established economic dimension. Economic indicators such as vehicle operating costs and parking space have a direct economic value but will also have an impact on access to mobility and therefore on various social and cultural activities, and collective well-being (and will also have effects that extend to other domains).

Table 3.6: Estimated impacts of automated freight transport services on society and economy, measured in terms of percentage change with respect to the Baseline 100-0-0 scenario.

		Market penetration rate: AVs in Background vehicle fleet (Human-driven vehicle - 1st Generation AV - 2nd Generation AV)								
		100-0-0	**80-20-0**	**60-40-0**	**40-40-20**	**20-40-40**	**0-40-60**	**0-20-80**	**0-0-100**	
Impact	**Sub-use Case**	%	%	%	%	%	%	%	%	**Method**
Vehicle operating cost (freight)	Baseline	0,0	7,5	-0,7	-4,0	-10,0	-10,4	-10,4	-10,4	Delphi
	Automated delivery	0,0	2,4	4,4	1,7	-3,7	-7,9	-7,9	-7,9	
	Automated consolidation	0,0	2,4	0,9	-7,3	-13,7	-17,4	-17,4	-17,4	
	Hub-to-hub	0,0	-3,3	-6,2	-6,2	-12,3	-15,5	-15,5	-15,5	
Parking space required	Baseline	0,0	-1,4	-1,3	-5,0	-11,5	-11,6	-11,6	-11,6	Delphi
	Automated delivery	0,0	-7,9	-4,6	-6,8	-5,1	-4,0	-4,0	-4,0	
	Automated consolidation	0,0	-4,3	-2,8	-2,8	-4,2	-3,8	-3,8	-3,8	
	Hub-to-hub	0,0	-1,6	-1,5	-3,3	0,0	1,4	1,4	1,4	
Public health	Baseline	0,0	-5,3	-2,1	0,0	5,2	4,0	4,0	4,0	Delphi
	Automated delivery	0,0	2,9	4,7	8,8	8,8	8,4	8,4	8,4	
	Automated consolidation	0,0	6,0	7,7	9,4	14,4	18,5	18,5	18,5	
	Hub-to-hub	0,0	6,6	10,0	12,0	17,8	15,7	15,7	15,7	
Road safety: crash rate	Baseline; manual delivery	0,0	7,5	14,0	16,1	4,3	-19,5	-37,0	-48,7	Micro-simulation (Vienna)
	Automated delivery	-2,6	-4,2	10,2	4,9	4,6	-19,8	-41,0	-50,2	
	Automated consolidation	-2,6	-4,2	10,2	4,9	4,6	-19,8	-41,0	-50,2	
	Baseline; no transfer hub	0,0	11,5	23,1	11,5	0,0	-11,5	-34,6	-61,5	
	Hub-to-hub; with transfer hub	0,0	7,7	11,5	-3,8	-11,5	-23,1	-46,2	-61,5	

Delphi results

The Delphi consultation was used to obtain results for expected developments in the area of vehicle operating costs, parking space and public health (See *Table 3.6*). As explained before, for each impact the percentage effects reported are in respect to the Baseline 100-0-0. The difference between the baseline effect and the specific SUC under consideration, and given the penetration rate, is the effect of the SUC itself. For most impacts in this table a decrease (denoted by a "-") implies a positive effect. However, for public health the opposite holds true.

According to the Delphi consultations, vehicle operating costs will be reduced, especially when human-driven vehicles are reduced to 20% or less of the entire vehicle fleet. Under baseline conditions, the results show that vehicle operating costs of freight transport will be reduced by about 10% when the entire vehicle fleet is automated. The automated consolidation SUC is associated with larger reductions in vehicle operating costs than baseline increase in automation alone; cost reductions between 13% and 17% are expected once human-driven vehicles take up 20% or less of the vehicle fleet. Hub-to-hub is also associated with stronger reductions than the baseline, 12 to 15% reduction once human-driven vehicles represent a fifth or less of the fleet. The automated delivery is associated with slightly less of a reduction than the baseline.

According to expert consultation, in the baseline scenario parking space requirements will be reduced by nearly 12% once human-driven vehicles are reduced to 20% or lower. Looking at the impacts estimated for the three freight sub-use cases, all three are associated with a reduction of required parking space. However, in all cases the impact is smaller than in the baseline, implying that the automated delivery van SUCs will require more parking space than the scenario with automation but without a fully-automated, unstaffed delivery van system. The hub-to-hub scenario with 100% CAV penetration is even predicted to require slightly more parking space than the baseline situation with only human-driven vehicles.

Regarding public health, a negative estimate implies a decline in public health. In the expected baseline development, a small deterioration in public health is expected when the presence of CAVs is still low (20% to 40% penetration) followed by a small improvement in public health (4% to 5%) as the penetration of second generation CAVs increases. The automated consolidation and hub-to-hub freight transport SUCs are anticipated to generate substantial added improvements in public health (8% to 10%) once human-driven vehicles are below 60%, and to further improve (by up to 18%) once the entire vehicle fleet is automated. The automated delivery sub-use case is expected to generate a more modest improvement in public health, starting at 3% when human-driven vehicles are still at 80% and rising to above 8% once automated vehicles are in the majority.

Microsimulation results

Microsimulation was used to study the expected impacts of the freight SUCs on road safety for all vehicles (freight and passenger) in the Vienna city network. The estimated crash rates (predicted crash rates per vehicle kilometer) are affected by behavioural parameters determined for the microsimulation, which affect how human-driven or automated vehicles drive in the network. For freight vehicles, less knowledge was available on the behavioural parameters of future automated freight vehicles; therefore, some parameters assumed the values of 1st generation CAVs and others were based on assumptions, leaving some uncertainty. For this reason, road safety results within LEVITATE have been estimated both including (Work Package 7) and excluding (Work Package 5 & 6) freight vehicles; this revealed that the inclusion of freight vehicles led to higher crash rates (1-28% higher) at most penetration rates, depending on the network (Weijermars et al., 2021). Nevertheless, the road safety impacts of increasing automation in a mix of both passenger and freight vehicles are an interesting development, especially for these sub-use cases where the deployment of automated freight vehicles is varied.

Taking into account that the inclusion of automated freight vehicles can somewhat inflate the estimated crash rates, the results for the city of Vienna show:

- In the baseline situation, road safety is predicted to take a turn for the worse when the first generation of automated vehicles is introduced and there is a lot of interaction between human-driven vehicles and (two types of) automated vehicles. Due to different driving styles of human drivers and automated vehicles, some extra risks in mixed traffic are an expected development during the transition from human to non-human-driven vehicles.
- Road safety improves once no human-driven vehicles are left in the simulation (from a 60% penetration of second-generation vehicles and above), resulting in roughly half as

many crashes per vehicle-kilometre when the entire vehicle fleet is made up of 2nd generation automated vehicles.

- Compared to the baseline, the introduction of both automated delivery and automated consolidation shows marginal additional benefits for road safety. Especially at lower penetration rates of automated vehicles in the entire fleet, the addition of automated delivery reduces the crash rate. This is likely due to the higher total amount of automation in the network as delivery vehicles are no longer partially human-driven. The difference with the baseline becomes minimal at higher penetration rates, when the entire vehicle fleet is already automated.
- Compared to the no hub-to-hub baseline, the hub-to-hub SUC is also associated with improved road safety performance. The added benefit is particularly large in the middle of the transition phase, before all vehicles have become 2nd generation CAVs

In summary, the road safety results of this network, including freight transport, suggest that mixed human-driven and automated traffic can bring about some extra safety risks. However, once the entire vehicle fleet is automated, substantial safety improvements are expected. While the automated freight SUCs showed some marginal additional improvements compared to the baseline, general levels of vehicle automation appear to be the largest driver of changes in road safety.

3.4 Additional impacts economy: annual fleet costs

Using data on delivery trips in Vienna and operations research methods, Hu et al. (2021b) estimated the impacts of automated delivery and automated consolidation on mileage, annual fleet costs and freight transport costs. For the automated delivery and automated consolidation SUCs, the primary influencing factors for the economic impacts are the fleet size and the driven km. These factors are fundamental for freight operations since other impact indicators are directly based on them (Hu et al., 2021a).

Based on delivery trips in Vienna estimated by the operations research (Hu et al., 2021a), *Table 3.7* compares the delivery variants with respect to their fleet composition and driven kilometres 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.

Table 3.7: Results for automated delivery and automated consolidation.

SUC Scenario	Delivery via van / robo-van					Consolidation trips by trucks	**Total driven km**
	No of trips	Fleet size	Stops per trip	Trip length (km)	Total driven km	Driven km	
No consolidation							
Manual delivery	1799	1799	42,3	44,7	80.389 km	-	80.389 km
Semi-automated delivery	1440	1440	46,5	49,2	70.805 km	-	70.805 km
Automated delivery	2692	898	28,9	39,4	10.6177 km	-	106.177 km
Automated night delivery	2692	1795	28,9	39,4	10.6177 km	-	106.177 km
Consolidated delivery							
Manual delivery with city-hubs	1806	1806	17,8	13,7	24.675 km	10.445 km	35.120 km
Automated delivery with city-hubs	2716	906	12,5	11,9	32.347 km	10.445 km	42.792 km

It can be seen that on the one hand, the mileage is significantly shortened by the consolidated delivery via the centrally located city-hubs. 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.

For assessing the impact on vehicle operating cost, Hu et al. (2021a) made a number of assumptions (fully described in Appendix D), and these are summarized in Table 3.8.

Table 3.8: 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, Hu et al. (2021a) applied them on the results shown in Table 3.7 to obtain the impacts for the annual fleet cost (expressed in Million EUR), vehicle operating costs (EUR/km) and freight transport cost (EUR / tonne-km). For the freight transport cost, they assumed an average parcel weight of 1,37kg per parcel (Wirtschaftskammer Wien, 2020). Table 3.9 and shows the results obtained for the modelled Vienna network based on the current volume of packages delivered.

Table 3.9: Vehicle operating cost and freight transport cost given 5 freight CAV implementation scenarios.

SUC Scenario	Fleet size	Driven km	Annual fleet cost (Million EUR)	Vehicle operating cost (EUR / km)	Freight transport cost (EUR / tonne-km)
Manual delivery	1799	80.389 km	96,2	3,9	18,8
Semi-automated delivery	1440	70.805 km	79,9	3,6	14,8
Automated delivery	898	106.177 km	30,5	0,9	6,8
Automated night delivery	1795	106.177 km	61,0	1,9	13,5
Manual delivery with city-hubs	1806	24.675 km	96,6	12,6	61,5
Automated delivery with city-hubs	906	32.347 km	30,8	3,1	22,4

Based on the data in *Table 3.9*, *Figure 3.1* illustrates the annual fleet costs for the different SUC considered for freight delivery.

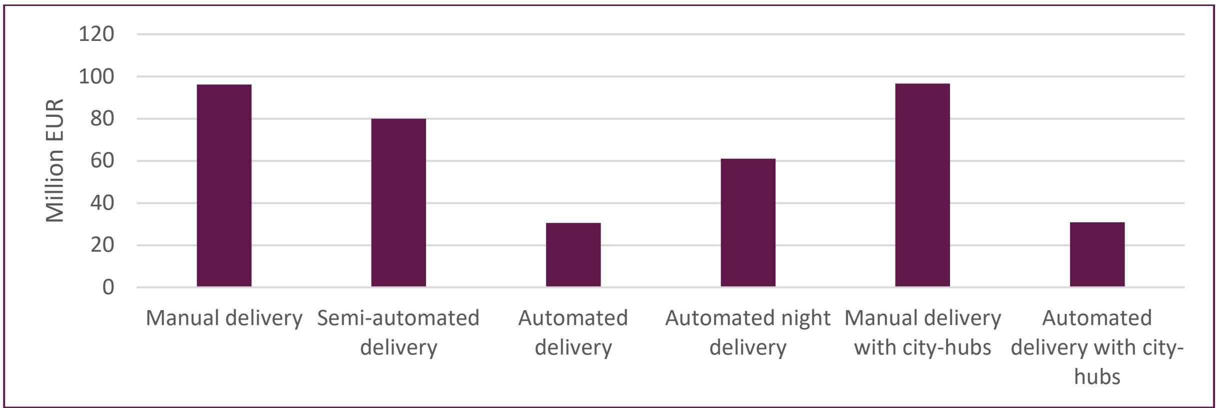

Figure 3.1: Annual fleet cost (Million EUR).

This shows that manual freight delivery has significantly higher costs (96,2 million) and completely automated delivery significantly lower costs (30,5 million). Automated delivery with city-hubs can reduce annual fleet costs by up to 68%.

3.5 Impacts of truck platooning

Within WP7 it was decided to include a sub-use case dealing with automated freight vehicles moving in platoons over bridges, this to establish the impacts on bridge loading and on internal bridge forces, particularly bridges with long spans and under high loads resulting from closely spaced platoons of fully loaded heavy goods vehicles. Since this SUC is unique and does not quite fit the methodology adopted to synthesize the results of the research on automated freight in Levitate, the results are separately presented and briefly discussed.

The change in traffic composition due to platoons is expected to lead to higher internal bridge forces. The baseline scenario include all traffic cases without platooning. As expected, the traffic cases without traffic congestion produced quite low internal bridge forces and therefore have limited impact on current bridge structures.

In this section we summarise – in a mostly non-technical way - the impacts of heavy traffic on bridge internal forces (baseline) and the impacts of introducing truck platoons. The full technical description of model and assumptions is given in Hu et al. (2021b).
The following general effects were reported under the baseline condition (Hu et al., 2021b):

- The traffic simulations without congestion produced relatively low internal bridge forces and the exceedance probabilities for bending moment and shear force remained far below the critical code level
- The congestion events introduced a significant increase of bridge internal forces, and especially on bridges with longer spans.

Impacts of truck (HGV) platooning
In simulating the effects of platooning on bridge loading a simply-supported single-span bridges was considered. The bridge was modelled as a single beam supported at both ends, with free rotation (also see Appendix D for the bridges that were considered).
The main impacts of platooning on bridges can be summarised as follows (Hu et al., 2021b):

- After the platoons were introduced into to the simulated traffic, the bridge internal forces increased significantly in bridges with longer spans. Figure 3.2 shows the increase of probabilities of exceeding the load effects of LM1 load model. The red curve is the traffic case with platooning (baseline), and four curves representing results with 20%, 40%, 60% and 80% platooning penetration rate are shown.
- Even at a low penetration rate of 20% truck platooning already shows a large increase of exceedance probabilities. The increase of exceedance probabilities for increasing bridge spans does not differ for penetration rates of 20%, 40%, 60% or 80% (see Figure 3.2)
- Starting from a bridge span length of 60 m, the "code level" of exceedance probabilities is exceeded. In that case , the structural safety of the affected bridges would be compromised, assuming that their load-carrying capacity is on par with the Eurocode requirements, i.e., without additional reserves.

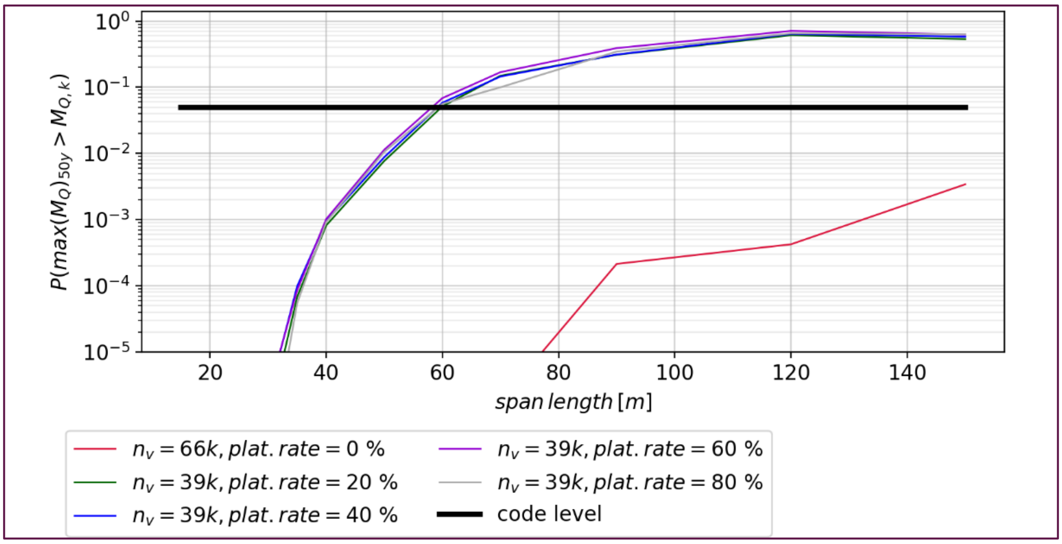

Figure 3.2: Bending moment exceedance probabilities for traffic mix A, constant congestion distances (C_5), P_{cong}=0.99, P_{flow}=0.999, traffic volume of 39000 vehicles/day and different platooning penetration rates.

- The largest effect of platooning is observed for the criteria of braking forces. The extremely short distances within a platoon and the sequence of truck platoons lead to high forces in case of braking. This is because the trucks in a platoon need to brake with almost the same deceleration, so that all platoon vehicles decelerate with approx. 5 m/s². For bridges above 80 m length, the braking force is at least the double that of the baseline scenario.
- Forcing an increased inter-vehicle distance by intelligent access control will not diminish the ecological and economic benefits of truck platoons.
- It can be concluded that there may be a need to strengthen existing bridges with $\alpha_Q = 1$ and with a span length of 55 m for bending moment and 60m for shear force ULS; for existing bridges with resistance at resistance level of $\alpha_Q = 0.8$, strengthening needs would arise sooner, starting from bridge spans of 40 m.

4 Discussion

This chapter summarises the main findings on the expected impacts after introducing CCAMs and cooperative, connected and automated freight transport. The strengths and limitations of the theoretical and empirical work underlying these impacts are discussed, and policy considerations in the broader context of the transition to smart urban mobility are presented.

4.1 Main findings

Below we summarise main findings for WP7:

- The increasing participation of connected and automated vehicles in the urban city area is estimated to have positive impacts on the **city environment** (less emissions, higher energy efficiency), and **city society and economy** (less parking space, lower freight vehicle operating cost) and on **city mobility** (less congestion).
- The road safety impacts estimated for the baseline condition in WP7 differ from the baselines in WP5 and 6 as a result of different road networks being applied and the inclusion of freight vehicles in the estimation. Contrary to the results in WP5 and 6, WP7 results reveal that in the baseline the increasing presence of automated vehicles in the city is estimated to have a **temporary negative impact on road safety** when penetration rates of automated vehicles are low. **Positive road safety impacts** of the increasing presence of automated vehicles are estimated once human-driven vehicles are replaced and second-generation automated vehicles have reached penetration levels above 60% of the city vehicle fleet. Because less data was available on the driving behaviour of autonomous freight vehicles, assumptions needed to be made in the behavioural parameters for autonomous freight vehicles. This led to higher crash rate estimations when freight vehicles were included. More broadly within LEVITATE, most estimates point to a large reduction in crashes with the introduction of automated vehicles including a small reduction at low penetration rates.
- The increasing presence of automated vehicles in the city is estimated to have negative impact on **public health** when traditional (human-driven) vehicles still make up the majority of vehicles (80%-60%). The sub-use cases of automated delivery, hub-to-hub and especially automated consolidation will positively impact public health. This positive expectation is likely based on the expected additional benefits of these sub-use cases for both road safety and emissions.
- The **automated delivery** SUC is associated with additional benefits for energy efficiency, CO_2 emissions, road safety, public health and vehicle operating costs.
- The **automated consolidation** sub-use case is associated with additional benefits for energy efficiency, CO_2 emissions, travel time, public health, road safety, and vehicle operating costs.
- The **hub-to-hub** use case is expected to deliver additional benefits for energy efficiency, CO_2 emissions, congestion, travel time, road safety, public health, and freight vehicle operating costs.

- Given the higher-level CAV penetration rates (above 80%) all the automated freight delivery **SUCs require more parking space** than the baseline without automated delivery. The Hub-to-Hub SUC even requires more parking space at 100% CAV penetration compared to the current situation (with 100% human-driven vehicles).
- The largest effect of T**ruck Platooning** is observed for the criteria of braking forces. For bridges above 80 m length, the braking force is at least the double of the baseline scenario.
- The need for **strengthening structural resistance of bridges** arises for existing bridges with $\alpha_Q = 1$ starting from span length of 55 m for bending moment and 60 m for shear force ULS; for existing bridges with resistance at resistance level of $\alpha_Q = 0.8$, strengthening needs would arise sooner – starting from bridge spans of 40 m.
- For bridge strengthening, a model and guideline for estimating the costs in relation to the initial construction costs have been developed (**D7.3**).
- As an alternative to strengthening bridges, **intelligent access control** can be used to arrange the increase the headways between HGV in a platoon in order to meet the code level and prevent potential failures. The preferred increases of inter-vehicle distances have been calculated for different bridges and circumstances and are reported in Levitate **D7.3** (Hu et al., 2021b)
- Forcing an increased inter-vehicle distance by intelligent access control will not diminish the ecological and economic benefits of truck platoons.
- Based on delivery trips in Vienna estimated by the operations research, the mileage of freight transport was substantially shortened by consolidated delivery via the centrally located city-hubs.
- Using delivery trips in Vienna estimated by the operations research, compared to manual freight delivery (96.2 million), completely automated delivery (30,5 million) and automated delivery with city-hubs (30,8 million) will have much lower **annual fleet costs** (-68%).

Mobility

The results confirm the hypothesis that freight traffic will only have a small effect on the overall congestion in the urban environment since its share of the traffic volume is relatively low. For the SUCs automated urban delivery and automated consolidation, the impact on congestion caused by the changes in the delivery procedure was minor, i.e., not statistically significant, despite the shift from fewer larger vehicles to smaller automated vehicles. There are however other benefits to consider; an obvious advantage of automated freight transport is the ability to utilise the off-peak hours and the night-time, allowing passenger transport more space during the peak hours and thereby reducing the demand for limited road capacity. This potential benefit is supported by findings in Jennings et al. (2019) and Figliozzi et al. (2020), where the on-road travel could be significantly reduced in scenarios where the service areas are near to the depot.

Wider impacts on Society, Safety and the Economy

The estimates for the wider impact on road safety were less positive than perhaps may have been expected from the results in WP5, WP6, and LEVITATE's road safety working paper (see Weijermars et al., 2021). As mentioned before, these differences are related to two factors:

1. Differences in the network characteristics (eg. road design, fleet composition) between Vienna (WP7), Athens (WP5), Manchester (WP6), Santander (WP6) and Leicester (WP6).
2. The inclusion of freight vehicles in the estimation, about which less is known regarding their behaviour as automation increases. Some of the parameters dictating their driving style assumed the values of 1st generation CAVs and others were based on assumptions. In other networks, the inclusion of freight vehicles in the crash rate estimations lead to 1-28% more crashes per vehicle-kilometer, depending on the network and penetration rate (Weijermars et al., 2021)

In WP7 baseline conditions it was estimated that road safety was negatively affected when first generation CAVs are introduced. The low penetration levels of CAVs result in unfavourable interactions between human-driven vehicles and CAVs, a phenomenon that is supported in some literature which has found that during the early transition phase to a fully automated traffic system crash rates may well increase at first. In earlier simulation studies it has been found that the introduction of automated vehicles in mixed traffic conditions may increase risk (Shi et al., 2020), especially when the market penetration of these vehicles is lower than 40% compared to traffic flow consisting of human drivers only (Yu et al., 2019). The Levitate WP7 results show that road safety steadily and significantly improves once human-driven vehicles are reduced and finally omitted from the simulations. The automated freight SUCs of automated delivery, consolidation, and hub-to-hub improved traffic safety further compared to the baseline development.

Within LEVITATE more positive estimates for road safety were derived in WP5 (urban transport) and WP6 (passenger cars), where crash rates also decreased slightly at low penetration rates. At low penetration rates, the balance between the safety of automated vehicles (which are expected to crash less often than human-driven vehicles) and the potential risks of mixed traffic (when human-driven/less advanced automated vehicles are still on the road) is a point of attention for further research.

As has been reported in a special working paper on road safety impacts within LEVITATE (Weijermars, 2021), the estimated road safety impacts differ between city network, and differ dependent upon the presence or absence of freight transport in simulation models. The presence or absence of freight vehicles strongly influences model crash results (Weijermars et al., 2021). The roads safety results in WP7 are solely based on the Vienna network, and include freight transport vehicles in the simulation models, whereas freight vehicles were excluded in the models used in LEVITATE Work packages 5 (passenger cars) and 6 (urban transport). As Weijermars et al. (2021) noted, there can be some doubt as to whether there is sufficient knowledge about automation of freight transport to enable valid simulation of this category of vehicles. Despite this concern and in the absence of immediate alternatives, it was decided to include freight vehicles (light & heavy goods vehicles) in the microsimulation models of WP7 which focusses on the effects of changes to freight transport. Since the model outputs allow for comparisons of relative differences between baseline and (SUC) penetration scenarios that are all based on the same traffic input parameters, it was felt that this was preferable to having no estimates at all.

Important however, is that the absolute values of the tested indicators (travel time, delay etc) for any given WP7 scenario can only be seen as indicative and these values have not been validated nor calibrated and must be treated with caution.

The wider impacts on parking space, energy efficiency and public health were based on a two-round Delphi panel process. While the experts expected energy efficiency and public health to improve with the increasing AV penetration rate, the situation on parking space was mixed. From the Delphi results, the baseline scenario would decrease the demand for parking space with more AVs on the street. However, the automated freight transport measures such as automated delivery or hub-to-hub automated transport are expected to require more parking space than the baseline. As observed by Hu et al. (2021c) this finding is rather surprising since freight consolidation and night-time delivery are expected to increase the efficiency and remove the redundancy of the freight system (Hu et al., 2021c).

There are several reasons for the positive expert expectations about improvement in public health though automated freight transport. First of all, CCAM in general has the potential to improve public health if proper policies and regulatory frameworks are implemented. AVs are likely to improve road safety and may help reshape cities to promote healthy urban environments (Rojas-Rueda et al. 2020). In addition, the local emissions caused by freight transport will be reduced to zero due to the assumption that AVs will be driven by fossil-free fuels. This might not be a direct contribution of vehicle automation since manual electric freight vehicles would have the same effect. However, the significant reduction of fleet operation costs by CCAM as shown by Hu et al. (2021) will accelerate the transition towards emission-free automated freight transport and logistics.

A particular SUC that was dealt with in WP7 was the effect of truck platooning on urban (highway) bridges. This is a special SUC in that the assessment methods and the obtained impacts are different from the other SUCs. This SUC is for study purposes and will not be included in the PST estimator, but nevertheless it has an eminent importance. For truck platooning, there already exist a good amount of scientific work, but the impacts on the bridge infrastructure is under-researched. Although the potential damage is not a short-term effect and the probability of a potential bridge failure resulting from truck platooning is not high, we have to be aware that if a failure occurs, the consequences are disastrous (c.f. Caprioglio bridge collapse, 2020). Therefore, two measures for dealing with the upcoming truck platoons enabled by CCAM are discussed. The results indicate that intelligent access control and an associated increase of the headways between trucks will be required to meet the EU code levels on certain bridge spans. For bridge strengthening, a model and guideline for estimating the costs in relation to the initial construction costs are given. Note that the economic and environmental impacts by truck platooning such as fuel savings are well-researched topics (Humphreys et al. 2016) and were not dealt with in Levitate (Hu et al., 2021b).

4.2 Strengths and Limitations

The Levitate project has strengths and limitations. A potential strength of the Levitate project is that the future development of urban smart cities policy interventions and policy impacts have been selected by a diverse group of stakeholders. The best available methods – microsimulation, mesosimulation, Delphi, and other methods – were used to study and quantify expected impacts of mobility interventions to support connected and automated vehicles and sustainable city goals and to deliver input for a practical Policy Support Tool for city policy makers. The knowledge of Levitate is above all intended to contribute to policy-making for smart city traffic development.

Below we describe some limitations of the Levitate studies, first some general limitations or difficulties concerning predicting future trends and second some limitations that are more specifically related to specific methods used.

Limitations in predicting future trends

Research evidence is not available for all potential impacts of connected and automated vehicles identified in Levitate. The Levitate research can inform policy makers about a number of potential impacts of connected and automated vehicles. Specific potential impacts of connected and automated vehicles that are difficult to predict with any confidence are the following (Elvik et al., 2020):

- Whether there will be a widespread transition from individual to shared mobility. There is no consensus on whether individual use of motor vehicles will continue at present levels or be replaced by various forms of shared mobility. This will largely be impacted by the policy measures of the cities and national authorities. Therefore, the LEVITATE project aims to support the authorities finding the most beneficial policies on the way towards an automated transport system.
- It is not clear what type of propulsion energy connected and automated vehicles will use. Some researchers expect the introduction of connected and automated vehicles to be associated with a transition to electric propulsion.
- Connected and automated vehicles are vulnerable to cyber-attacks. However, the risk of such attacks cannot be quantified, and it would go beyond the scope of LEVITATE. Only potential scenarios can be described.
- The costs of connected and automated vehicles are highly uncertain. It is not clear that connected and automated vehicles will be as affordable as current motor vehicles. The costs of automation technology may influence the level of inequality in access to transport. However, there is evidence that it will result in a significant cost reduction for operators once drivers are no longer needed.
- Behavioural adaptation to connected and automated vehicles, in particular during the transition period before full market penetration. While some studies suggest various forms of behavioural adaptation, predicting its form and impacts is impossible or speculative.
- Changes in employment are difficult to predict. While full automation will eliminate the need for drivers, other potential changes in employment are less known.

Given the many uncertainties in prediction it is obvious that any predicted values are associated with large uncertainty. It was decided not to estimate confidence intervals for the results in Appendix A based on the standard error derived from repeated trail runs of models since these intervals would be broad and non-informative. Also, the estimation of these intervals would tend to be biased in itself since the input variables and assumptions in the models are very likely much stronger determinants of predicted values than the variability in sample runs.

Specific method-related limitations

There are some remarks to be made about the possible limitations or nuances of modelling results in WP7:

- The impacts estimated using AIMSUM microsimulation for WP7 are based on the road network of Vienna. The simulation modelled both passenger vehicles and and freight vehicles (light goods vehicles & heavy goods vehicles). The parameters for vehicle performance and driver behaviour are derived, where possible, from literature. The parameters for automated freight vehicles, however, lacked sufficient basis in the literature and are therefore largely left at their human-driven levels with a few exceptions. For this reason, the freight vehicles in the simulation may behave more similarity to human-driven freight vehicles than would be expected of truly automated freight vehicles. As discussed earlier, this limitation is particularly relevant for the road safety estimations.
- The results of the microsimulation models and bridge modelling depend upon specific assumptions. For example, in LEVITATE the simulation models used examined two CAV driving style profiles were assumed (first vs. second generation); future work may extend the number of driving style profiles.
- The assumptions on CAV parameters and their values were based on a comprehensive literature review, including both empirical and simulation-based studies as well as discussions in meetings with experts, conducted as part of LEVITATE project.
- At the time of modelling the AIMSUN micro-simulation software used in LEVITATE was limited to the simulation of motor vehicles on the road network, so pedestrians and cyclists are not included in the simulations. Road safety impacts were however estimated separately for VRUs in a Baseline development.
- In LEVITATE it was assumed that all freight AVs will be electric and therefore emission-free while the manual freight vehicles use internal combustion engines fuelled by diesel, which is the standard at the moment
- The microsimulation modelling in WP7 was based partly on the Vienna city network, which means that results are most transferable to those urban conglomerates which have structural and dynamic characteristics that are similar to these.
- The micro-simulation was only applied on the model of a small network area, a full city model could be used in future work to verify the upscaled results.
- In the study on bridge platooning impacts the results were evaluated for simply-supported single-span bridges with dimensions that were regarded as typical for particular bridge types. These results are intended to provide an indication only. Results for actual bridge structures may deviate from these, as each bridge is different.

4.3 Policy considerations and discussion

The sub-use cases or policy interventions studied in the LEVITATE project are part of a wider transition to smart mobility and smart cities. In this section we will reflect on a number of relevant broader policy issues surrounding the introduction of automated transport systems in urban areas since it is clear that these wider developments towards smart mobility will also affect the specific use cases. The text in Section 4.3 is identical to that described in D5.5 and 6.5 and the reason for that is that these issues are not only relevant to public and private transport but also to freight transport.

Planning and governance of automated mobility in urban environments
Implementing new forms of connected and automated mobility is a highly complex process, particularly in the urban environment. Many different actors in city governance, industry and the general population will need to come together to deal with these challenges. Although there may be a strong push from industry to implement new smart mobility services, there are still many uncertainties that lie beyond the powers or competence of any one single stakeholder to fully control or address. Adequate legislation and technical standards are expected to lag behind CAV deployment trials and pilots (in other words, technology develops faster and legislation and standards etc. have to follow). It is important to anticipate these developments and to start the processes necessary for adopting standards and legislation that will be necessary to regulate large scale CAV deployment. An example we can learn from is the advent of the motor car. This occurred in a largely unregulated transport environment, and which introduced many negative impacts which in time, and to this day, needed mitigation. Safe systems are about prevention and this pleads for a pro-active approach, also with respect to standards, legislation and regulation.

There is enthusiasm about the transition towards smart mobility, but not surprisingly opinions vary. Fraedrich et al (2018) carried out a survey among city planners in 24 German cities. Half of the respondents believed that shared autonomous vehicles could positively contribute to urban planning objectives, but only 10% reported that private autonomous cars could contribute to those objectives. According to the respondents, implementation of automated vehicles would require preparatory action in the fields of transportation planning, traffic control, road infrastructure, urban planning, citizen participation, test fields and data standards and requirements. Additional interviews with city planning experts led to four major insights namely:

- Cities themselves are a major driving force;
- for city renewal or redevelopment, public transport is a major goal;
- there is concern about the possibility of an increase of private car use in cities;
- city goals are not always directly aligned with other stakeholders seeking to push automated vehicle technology.

In the USA, McAslan et al. (2021) have looked at plans for autonomous vehicles amongst Metropolitan Planning Organizations (MPOs). One key area that requires attention is public engagement in the management of emerging technologies. This element seems critical to advancing CAVs in a way that addresses issues of equity and mobility justice (and others). Equity, accessibility, and other such goals are often promoted by industry, but ultimately the realisation of these is ultimately a planning and policy decision (McAslan et al., 2021). Several of the studied Regional Transportation Plans had policies to address issues of equity and accessibility. However, MPOs need to engage stakeholders (e.g., the public, industry, etc.) and make issues such as equity or other valued public goals a priority. Left to market forces alone, it is likely that these potential benefits will not be realised and could even worsen (McAslan et al., 2021).

Many authors have stressed that industry and economy forces tend to push towards implementation of automated driving, but this technology push should be balanced by an equally strong orientation on the social-ethical (or the non-technical) dimension of the new technology. In other words, how it is governed, how it is perceived by citizens from various social strata, whether it complies with ethical guidelines and whether it really provides the expected benefits for the city (Fraedrich et al., 2019; McAslan et al, 2021; Habibzadeh et al, 2019, Milakis & Muller, 2021). In recognition of this, authors have suggested that new types of national, local or city governance (or management) are needed to steer the transition towards automated mobility in a responsible way (e.g., Aoyama & Leon, 2021; McAslan et al., 2021; Milakis & Muller, 2021).

Milakis & Muller (2021) suggest that policy makers need new tools for long term planning to accommodate uncertain urban futures. They argue in favour of new participative anticipatory governance instead of traditional governance which is typically supported by forward looking exploratory deployment scenarios with short term implications. They suggest a research agenda that is more oriented on citizens than consumers, more focused on long term than only short term and more based on citizen participation than traditional short-sighted scenario analysis. Their emphasis on normative scenario analysis (i.e., backcasting) aligns well with the LEVITATE project.

McAslan et al. (2021) argue for anticipatory governance looking at future scenarios, using flexible planning mechanisms, and where monitoring and learning are built in the planning process, and the public is actively engaged.

Aoyama & Leon (2021) conclude that cities are part of multi-scalar governance frame-works where new rules, regulations, strategies, and standards are negotiated and enacted. They identified four key roles for cities in the governance of the emerging autonomous vehicle economy: regulator, promoter, mediator, and data-catalyst. They cite the example of the city of Pittsburgh which, in recent years, has shifted away from a role of being promotor to a new role of being mediator. The initial emphasis of the city government on the promotion of the autonomous vehicle economy has decreased and has given way to an acknowledgment of the need to build more equitable relationships between various stakeholders in the city area. Another example of a city taking up a different governance role is Boston. In recent years, Boston's city government has become very active as a data- catalyst; the city takes an active approach in exploring partnerships on data collection and developing a shared research agenda that includes not only vehicle testing, but also business model exploration, experiments with connected transportation infrastructure, and research on autonomous mobility and its implications on Boston's workforce.

Planning for future urban city mobility: four types of readiness
At the city level, policy makers and planners face four major areas where preparation is needed to enable future use of CAVs (Alawadhi et al., 2020).

1. Infrastructure readiness - the road infrastructure needs to be adapted in order to facilitate proper functioning of automated vehicle systems.
2. Digital readiness - the digital infrastructure needs to be set in place, including a framework, technical standards and procedures for cybersecurity and data privacy.

3. Legal readiness - there needs to be clarity about how legal responsibilities and liabilities may be solved and how problems in this area may be avoided.
4. Social readiness - the social understanding, acceptance and approval of the new forms of mobility amongst various citizen groups and stakeholders in the urban area seems critical.

Road infrastructure readiness
Road infrastructure will have to be adapted in order to be ready, readable, and cooperative in all situations and weather conditions (Gruyer, 2021). CAVs require highly visible road edges, curves, speed limit and other signage (Liu et al.,2019). For the EU it is important to have uniform road markings. The roadside digital infrastructure needs to meet various connectivity requirements.

The lack of sufficiently visible road markings is at the moment an obstacle for some manufacturers for the reliable functioning of autonomous vehicles (Rendant & Geelen, 2020). The reliability of systems such as ISA and LDWA, are dependent on these for reliable functioning. Other infrastructural aspects have to do with harmonisation of the road infrastructure (colour, reflective materials, etc.). In Europe this will likely have a positive influence on the roll-out of CAVs (Rendant & Geelen, 2020). The development of camera technology and image processing algorithms is so fast that future systems will likely be able to deal with lower quality markings. Upgrading road markings to support self-driving vehicles may not be necessary (Rendant & Geelen, 2020).

In the Inframix project, so-called ISAD levels ("Infrastructure Support Levels for Automated Driving") were developed in which an impetus is given to define the minimum infrastructure (physical and digital) required to enable certain self-driving functions. Such an approach makes sense to clarify what level of automation is possible on a given road section (Rendant & Geelen, 2020).

A special infrastructure topic concerns the extra burden on bridges caused by automated truck platooning. In order to minimize the failure probability of structural bridge integrity, medium-term measures such as structural strengthening and intelligent access control should be considered. Within LEVITATE a start has been made to develop methods to assess the impacts of these measures (Hu et al. 2021b).

Readiness to address cybersecurity and data privacy concerns
The successful operation of CAVs and their expected impact depend significantly on their management and addressing risks associated with them (Lim & Taeihagh, 2018). Two of these risks are privacy and cybersecurity. The ability of CAVs to store and communicate personal data may conflict with data privacy laws. Cybersecurity is at stake when communication networks crucial for safe operation of CAVs can be hacked. Lim & Taeihagh (2018) conclude that within the EU a proper implementation of the General Data Protection Regulation (GDPR) can ensure privacy protection. These researchers argue that CAVs are especially vulnerable to cyber-attacks due to their ability to store highly sensitive data and transmit such data on external communication networks. The GDPR also provides guidance on how organisations can comply with legal requirements (Mulder & Vellinga, 2021). These authors emphasize a three-step approach to cyber-security based on GDPR: first a data protection impact assessment (DPIA), secondly data protection by design, and finally data protection by default. Data protection by design and by default are legal obligations set in Article 25 of the GDPR. A DPIA can contribute to, amongst others, complying with these two obligations.

To address cybersecurity the EU enacted the first EU-wide legislation on cybersecurity, the NIS directive in August 2016 and has also released voluntary cybersecurity guidelines. In December 2016 the EU agency for Network and Information Security released best practices guidelines for the cybersecurity of connected vehicles. Cybersecurity and security concerning private data are important for building trust in and social acceptance of AVs (Lim & Taeihagh, 2018, also Seetharaman et al, 2020). The GDPR also provides guidance on how organisations can comply with legal requirements (Mulder and Vellinga, 2021).

Vitunskaite et al. (2019) studied practices of cybersecurity in the cities of Barcelona, London and Singapore. They observe the following: "The real difficulty for observing security stems from the complexity of the smart city ecosystem and involvement of a high number of competing actors and stakeholders. As the cities are still developing, many fail to take these risks into account and develop an appropriate third-party management approach. One of the key symptoms of this deficiency is lack of appropriate standards and guidance, clearly defined roles and responsibilities and a common understanding of key security requirements. The case studies of Barcelona, Singapore and London has emphasised and corroborated the importance of technical standards, cyber security measures and an effective third-party management approach." (Vitunskaite et al., 2019; p. 23)

In another paper on cybersecurity in the smart city, Habibzadeh et al. (2019) observe that it is common knowledge in the literature about public administration that information technology implementation projects are often derailed by non-technical challenges; issues of politics, bureaucracy, liability and other non-technical factors slow down the implementation of technology that is available. Also, with respect to security in the smart city it is often the case that new technologies have arrived and are deployed whereas personnel practices, security policies, and other agency practices and municipal practices tend to lag behind - resulting in a so called "security debt" (Habibzaheh et al., 2019; p. 4). These authors recommended that cities unambiguously define security roles of individuals in city administration, that they actively value security leadership, and that the cities form and maintains specialised security teams to carry out routine security measures such as training, firmware updates, developing emergency response plans, maintaining communications with different vendors and service provider

Khan et al. (2020) have studied the various cyber-attacks on automated vehicles and possible mitigation strategies from a perspective of the communication framework of CAVs. Based on the literature review, the leading automotive company reports, and the study of relevant government research bodies, Khan et al. (2020) have described the CAVs communication framework for all possible interfaces in the form of a flow-chart. The authors argue that this description has a three-fold value: first, it is imperative to have a systematic understanding of the CAVs communication framework; second, it is beneficial for monitoring, assessing, tracking, and combating potential cyber-attacks on various communication interfaces; third, it will facilitate the development of a robust CAVs cybersecurity- by-design paradigm by application developers. Important recommendations from their analysis are (Khan et al., 2020):

- CAVs and connected infrastructure require a continuous surveillance system to alert relevant operation centres immediately about any data or vehicle breaches
- system designers need to stay up to date with the advances in attacks on the CAV-embedded system
- manufacturers need to integrate security into every part of their designs

- in a coordinated approach to CAV cybersecurity ideally a shared problem-solving approach involves both road operators (as customers) and suppliers such as automotive manufacturers, equipment manufacturers, data aggregators and data processors

Using risk analysis, Meyer et al. (2021) looked at 6 scenarios of cyberattacks on autonomous and connected vehicles. They recommend prevention measures to make it more difficult to manipulate vehicles' speeds and to protect individual data about travel patterns. To stimulate vehicle developers to invest in prevention of cyber-attacks, developers must have sufficient incentives and potentially be held liable for successful cyberattacks. However, it is probably impossible to prevent all such attacks. Therefore, measures that limit the consequences of such attacks will be necessary. Such measures include safety measures in vehicles to protect the occupants in traffic accidents and measures that make vehicles easier to remove in case they do not function. The last category of measures includes installing kill switches that make it possible to turn of the vehicle manually, thus overriding the autopilot and making the vehicle possible to move by four adults when it is turned off manually (Meyer et al., 2021).

Legal readiness
The EU has not yet amended its legal framework to incorporate AV-related liability and insurance risks, but it is exploring solutions to these issues. In 2016 the European Commission launched GEAR 2030 in order to explore solutions to AV-related liability issues. In May 2016 European Parliament Members recommended that the EC should create a mandatory insurance scheme and an accompanying fund to safeguard full compensation for victims of AV accidents and a legal status should be created for all robots to determine liability in accidents (Taeihagh & Lim, 2019).

Looking at recent developments in the five major areas for legal reform the following conclusions can be drawn:

- *Admission and testing:* various countries and states have applied different legal rules for admission and testing of automated vehicles[2]; in the future comparative review of these regulations and associated experiences and outcomes should lay the groundwork for a more uniform approach in the EU and internationally (Lee & Hess, 2020);
- *Liability:* the possible theoretical and legal solutions to liability and insurance have been outlined by various authors (Evas, 2018; Mardirossian 2020; Bertolini & Ricaboni, 2021; Vellinga, 2019) and further discussion between stakeholders and the development of specific cases of litigation will determine the legal option that is chosen;
- *Human-machine interaction*: in this particular area a lot of research is still needed to answer questions on which design of the human-machine interface will allow safe and reliable control of the vehicle, in all possible circumstances and involving different traffic situations and different internal states of the driver. Uniform standards can only be formulated once this research has been carried out and main conclusions have been agreed upon by all stakeholders involved (Kyriakidis et al., 2019; Morales-Alvarez et al., 2020; Carsten & Martens, 2018);

2. Published/collected on websites like: https://globalavindex.thedriverlesscommute.com/; https://www.ncsl.org/research/transportation/autonomous-vehicles-legislative-database.aspx

- *Road infrastructure:* both within EU and USA work has been done to formulate general definitions of the new road classes that are needed to support automated and autonomous vehicles (Rendant & Geelen, 2020; Liu et al., 2019; Saeed et al., 2020). ISAD levels (Infrastructure Support Levels for Automated Driving) give an impetus to define the minimum infrastructure (physical and digital) required to enable certain self-driving functions (Rendant & Geelen, 2020); for conventional road infrastructure recognition of road geometry and signs is important and maintenance is crucial for this; as yet there are no norm or standards in EU referring to traffic sign machine readability (Lyvritis et al., 2019);
- *Digital infrastructure:* connected cars require that every vehicle's location and journey history be recorded and saved, but the current level of IT security cannot prevent yet that data may be accessed by unwanted third parties. Thus, the development of cybersecurity is of the utmost importance for the development of connected and autonomous driving (Medina et al., 2017). At the moment the automotive industry lacks a standard approach for dealing with cybersecurity (Burkacky et al./McKinsey, 2020, 2020). The EU, through the European Union Agency for Network and Information Security (ENISA) had proposed good practices that should be considered (Medina et al., 2017); and
- *Specific issues concerning electric vehicles*: The costs of battery technology, the number of charging stations and the charging wait time are main variables that will influence electrification of vehicle fleet (Mahdavian et al., 2021). It has been estimated that converting all passenger cars in the USA to electric vehicles would consume 28% more power than the US currently produces (Mahdavian et al., 2021).

Readiness to engage social and ethical concerns

Introducing automated mobility will raise important social and ethical questions. In many publications on smart mobility in the smart city it has been emphasised that active education and engagement of citizens in policy development and decision making is crucial for the successful implementation of CAVs, CCAM (e.g., Alawadhi et al., 2020; Bezai et al., 2021; Briyik et al., 2021; Chng et al., 2021; Horizon 2020 Commission Expert Group, 2020; McAslan et al. 2021; Milakis & Muller, 2021; Ayoma & Leon, 2021). User acceptance of automated vehicles will depend upon how the new automated mobility is perceived, how it will be used (shared or not, handling of privacy etc.) and what it will cost (Bezai et al., 2021). Worldwide city management will have to provide and manage new technology that serves the needs of the city, i.e., the needs of its citizens: "New technologies are not ends in themselves but have to adapt to what serves the city. In the end, it is the municipalities that have to implement it" (Freadrich et al., 2018; p. 8).

The Horizon 2020 report on Ethics of connected and automated vehicles gives the following recommendations for preparing and engaging the public for CAVs (Horizon Commission Expert Group, 2020; p. 68):

- inform and equip the public with the capacity to claim and exercise their rights and freedoms in relationship to AI in the context of CAVs
- ensure the development and deployment of methods for communication of information to all stakeholders, facilitating training, AI literacy, as well as wider public deliberation
- investigate the cognitive and technical challenges users face in CAV interactions and the tools to help them surmount these changes

Interestingly, Chng and colleagues (2021) investigated citizen perceptions on driverless mobility by performing Citizen Dialogues, these are structured discussion meetings using both qualitative and quantitative methods, designed to be informative, deliberative and neutral to generate critical but unbiased insights. These dialogues were attended by more than 900 citizens in 15 cities across North America, Europe and Asia with the following outcomes:

- public transport was the preferred implementation model for driverless mobility, followed by ride-sharing and private car ownership
- the levels of trust and acceptance of automated vehicles tended to be lower at higher levels of vehicle automation
- citizens have reservations about whether industry will sufficiently safeguard citizens' interests; government should seek to support trust in industrial developments through regulation and oversight
- the citizens prefer their government to take active roles in driverless mobility and to set standards and regulations that safeguard and promote their interests

4.4 Future Challenges for urban freight transport

The growing importance of urban freight transport is linked to the growth of the urban population or urbanisation, a major phenomenon of the 21st century (Hu et al.; 2019). More than half of the world's population now lives in cities, with one in five people living in a city with a population exceeding 1 million inhabitants. The UN estimates that by 2030 the world will have 41 megacities with more than 10 million inhabitants and about 70% of world's population will live in urban areas by 2050 (United Nations, 2015). Together with the growing e-commerce sector, this will lead to an increasing demand for freight transport services and create new challenges for the supporting infrastructure and associated logistics.

The ERTRAC roadmap on urban freight states that topics related to freight traffic, and to the exploration of potential synergies between passenger and freight transport at the urban level are major focal points (ERTRAC, ALICE, 2015). There are important challenges related to the use of land for urban freight, and the location of logistics activity in and around the urban environment. Further exploitation of the potential of integrating urban freight and passenger transport systems will optimise the use of road, rail and inland waterways infrastructures in space and time, and contribute to healthier cities in terms of less traffic and congestion. This requires a paradigm shift towards integrated freight/passenger mobility planning and exploring more opportunities and new business models for the integration of urban freight with private or public transport at infrastructure and vehicle levels.

To achieve the best possible future and best outcome for urban freight transport the following developments are crucial (Hu et al., 2019):

- Passenger transport and freight transport should seek collaboration (e.g., via automated multi-purpose vehicles)
- Collaborative transportation, supported by city hubs and consolidation centres, are necessary to improve operational efficiency. CCAM, especially automated hub-to-hub transport and automated freight consolidation, will contribute significantly
- Multimodality and synchro modality are important factors to aim towards a sustainable logistic supply chain.
- All the above points require homogenous and shared data among operators, which is perhaps the most difficult challenge due to the competition between service providers and freight operators.

5 Conclusions and recommendations

5.1 Conclusions

The section provides an overview of the primary conclusions that can be drawn from WP7.

Overall effects of CAVs

Estimating the baseline impacts of an increasing share of connected and automated vehicles (CAVs) for Work Package 7 revealed the following main findings, estimated by simulations run for the city of Vienna and a Delphi study using experts in the field:

- The increasing presence of connected and automated vehicles in the urban city area is estimated to have **positive impacts** on the city environment (less *emissions*, higher *energy efficiency*), and city society and economy (less *parking space demand*, lower *freight vehicle operating cost*) and on urban mobility (less *congestion*).

- In Work Package 7, the increasing presence of automated vehicles in the city is estimated to have a **temporary negative impact** on *road safety* when penetration rates of automated vehicles are low. The negative impact found is primarily due to interactions between human-driven vehicles and automated vehicles, which are expected to have different driving styles (e.g. AVs adopting different headways) and different capabilities (e.g. human drivers' longer reaction times) which may lead to an initial increase in risks when many human drivers are still on the road. This result differs from the baseline results found in the road safety impact study (Weijermars et al., 2021) and discussed in WP5 and WP6, primarily due to two factors: 1) differences in the network (Vienna) and 2) the inclusion of freight vehicles. Because less data was available on the driving behaviour of autonomous freight vehicles, less behavioural parameters were adjusted and autonomous freight vehicles may behave more similarly to human-driven freight vehicles. This led to higher crash rate estimations when freight vehicles were included.

  Larger **positive impacts** on *road safety* are estimated once human-driven vehicles are replaced and second-generation automated vehicles make up at least 60% of the city's vehicle fleet. More broadly within LEVITATE, most estimates point to a large reduction in crashes with the introduction of automated vehicles including a small reduction at low penetration rates. At low penetration rates, the balance between the safety of automated vehicles (which are expected to crash less often than human-driven vehicles) and the potential risks of mixed traffic (when human-driven/less advanced automated vehicles are still on the road) is a point of attention for further research.

- The increasing presence of automated vehicles in the city is estimated to have **a slightly negative** impact on *public health* when traditional (human-driven) vehicles make up the majority of vehicles, followed by a **slightly positive** impact at full automation of the vehicle fleet.

Effects of SUCs: automated delivery, consolidation and hub-to-hub transport

On top of the baseline impacts of increasing CAV penetration, the automated freight sub-use cases yielded some additional effects:

- The **automated delivery** sub-use case is associated with additional benefits for energy efficiency, CO_2 emissions, road safety, congestion, public health and vehicle operating costs. The night-time-only automated delivery scenarios (see Appendix A) show additional benefits particularly for the two mobility indicators (travel time and congestion), due to less interaction with the larger daytime traffic volumes.
- The **automated consolidation** sub-use case is associated with additional benefits for energy efficiency, CO_2 emissions, road safety, congestion, travel time, public health and vehicle operating costs. Compared to automated delivery without consolidation at city hubs (the first sub-use case), further improvements in energy efficiency, operating costs, and a large reduction in total kilometres travelled are expected. This suggests that centrally located city-hubs can help realise a more efficient allocation of resources.
- The **hub-to-hub** sub-use case is expected to deliver additional benefits for energy efficiency, CO_2 emissions, road safety, congestion, travel time, public health, and freight vehicle operating costs.
- All three automated freight SUCs are predicted to (marginally) improve **road safety** compared to the baseline, particularly at lower penetration rates when less of the remaining vehicle fleet is automated.
- At the higher-level CAV penetration rates (above 80%), all three automated freight SUCs are expected to require slightly more **parking space** (less reduction) than in the baseline without automated delivery. The hub-to-hub SUC is even expected to slightly increase parking space requirements at 100% CAV penetration compared to the current situation (with 100% human-driven vehicles).
- The sub-use cases of automated delivery, hub-to-hub and especially automated consolidation are predicted positively impact **public health** compared to the baseline. This positive expectation is likely based on the expected additional benefits of these sub-use cases for both road safety and emissions.
- Using data on freight delivery trips in Vianna, it was estimated that compared to manual freight delivery, completely automated delivery and automated delivery with city-hubs will have substantially reduced **annual fleet costs** (-68%).

Effects of truck platooning on bridges

Connected and automated freight vehicles are expected to facilitate truck platooning, and as a result potentially test the strength of bridges. The study of truck platooning on bridges yielded the following main conclusions:

- The largest effect of **truck platooning** on simple single span (beam) bridges as modelled in LEVITATE is observed for the criteria of braking forces. For bridges above 80m length, it has been estimated that the braking force is at least double of the baseline scenario.
- According to standard bridge models and standard traffic simulations within LEVITATE, the need for **strengthening structural resistance of bridges** arises for existing bridges with $\alpha_Q = 1$ starting from span length of 55 m for bending moment and 60 m for shear force ULS; for existing bridges with resistance at resistance level of $\alpha_Q = 0.8$, strengthening needs would arise sooner – starting from bridge spans of 40 m.

- For bridge strengthening, a model and guidelines for estimating the costs in relation to the initial construction costs have been developed (**D7.3**).
- As an alternative to strengthening bridges, **intelligent access control** can be used to arrange the increase of inter-vehicle distances for the bridge section to meet the code level and prevent. Headway have been recommended and these are presented in LEVITATE **D7.3** (Hu et al., 2021b). Forcing an increased inter-vehicle distance by intelligent access control will not diminish the ecological and economic benefits of truck platoons.

5.2 Policy recommendations

The introduction of CCAM and the implementation of interventions (sub-use cases) in the area of public transport is part of a wider transition towards smart and sustainable cities (Alawadhi et al., 2020; Aoyama & Leon, 2021; Bezai et al., 2020; Chng et al., 2021; Lim & Taeihagh, 2018; Vitunskaite et al., 2019; Mahdavian et al., 2021; McAslan et al., 2021; Medina et al., 2017; Milakis & Müller, 2021; Seuwou et al., 2019; Taeihagh & Lim, 2019). A successful transition will largely be impacted by the policy measures of the city, local and national authorities. Therefore, the LEVITATE project aims to support the authorities finding the most beneficial policies on the way towards an automated transport system.

Based on recent literature dealing with the transition from a 100% human driver vehicle population to a 100% autonomous system without any human drivers, and the results of the LEVITATE project, in particular WP7, the following recommendations can be suggested to make city managers and policy makers aware of what is to be done to support this transition and the overall success of Cooperative, Connected and Automated Mobility (CCAM) and use cases:

- City managers and policy makers should take into account four major areas of readiness for CCAM (autonomous driving): technology readiness, infrastructure readiness, legal readiness and the readiness to address social acceptance and ethical/social value issues (e.g., Alawadhi et al., 2020; Bezai et al., 2020)
- Commercial (technology) push alone will not safeguard the expected social benefits of CCAM (cooperative, connected and automated vehicles); new types of governance and planning are called for with a stronger engagement of citizen groups and city stakeholders, a stronger focus on long term implications, and lesser reliance on traditional forecasting and traffic models (e.g., McAslan et al, 2021; Milakis & Müller, 2021)
- More anticipatory engaging styles of governance will not spontaneously develop; an anticipatory governance capacity has to be built (e.g., McAslan et al., 2021)
- Good legislation, guidance and guidelines for CCAM in Europe is already partly available (e.g., the GDPR, White Paper, Horzon Group report on Ethical guidelines). Authorities need to be aware of these and use these to survey what implications they have for planning and policy making at the city level (e.g., Mulder & Vellinga, 2021)
- There are many regulatory gaps for CCAM; using their own experiences and policy and planning orientations city managers, policy makers and planners should cooperate and contribute to the national and international debate about how these gaps should be resolved (e.g., Aoyama & Leon, 2021)
- Automation in freight transport causes its unique problems such as the additional burden on bridges caused by truck platoons with short headways. In order to minimize the failure probability, measures such as structural strengthening of single span beam bridges and intelligent access control should be considered (Hu et al., 2021b).

- The transition towards CCAM is as much a social and cultural phenomenon as a technological phenomenon; ultimately a lot if not all depends upon trust in new technology and trust will be easier to build if citizens have an active voice in what happens in their neighbourhoods (e.g., Chng et al., 2021, Medina et al., 2017; McAslan et al., 2021)
- The transition towards CCAM requires building of and participation in new broad alliances and platforms where many different actors from industry, and interest and citizen groups are present
- The risks concerning cybersecurity need a full understanding of the total digital communication framework and all interfaces of connected and automated vehicles; security-by-design is one of the most general and important principles to follow (e.g., Khan et al. 2020)
- The risks concerning cybersecurity cannot be solely managed by legislation and technocratic controlling strategies but demand social awareness, social education and cultural change in companies and citizens and third-party management (e.g., Khan et al., 2020; Vitunskaite et al., 2019)
- Backcasting is one of the analytic methods that can help policy makers to make better informed decisions about how new technology can be implemented to achieve the expected benefits (e.g., Milakis & Müller, 2021). For this reason, Levitate has included a backcasting capability as part of the PST.

Research in these various areas – new governance style, cybersecurity measures and culture, cooperation between varied stakeholder groups, regulatory gaps, citizen engagement, ethical concerns - can help develop a better understanding of problems and issues, possible solutions, and to better informed policy decisions.

For freight transport a number of recommendations can be given (Hu et al., 2019):

- Passenger transport and freight transport should seek collaboration (e.g., via automated multi-purpose vehicles)
- Collaborative transportation, supported by city hubs and consolidation centres, are necessary to improve operational efficiency. CCAM, especially automated hub-to-hub transport and automated freight consolidation, will contribute significantly
- Multimodality and synchro modality are important factors to aim towards a sustainable logistic supply chain.
- All the above points require homogenous and shared data among operators, which is perhaps the most difficult challenge due to the competition between service providers and freight operators.

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Appendix A Full results

A.1 Environmental impacts

		Market penetration rate: AVs in Background vehicle fleet (Human-driven vehicle - 1st Generation AV - 2nd Generation AV)								
Impact	**Sub-use Case**	**100-0-0**	**80-20-0**	**60-40-0**	**40-40-20**	**20-40-40**	**0-40-60**	**0-20-80**	**0-0-100**	**Method**
Energy efficiency	Baseline	0,0%	-3,7%	6,5%	8,2%	11,9%	16,0%	16,0%	16,0%	Delphi
	Automated delivery	0,0%	6,1%	7,8%	11,1%	14,8%	20,4%	20,4%	20,4%	
	Automated delivery during night-time only	0,0%	7,7%	5,7%	10,1%	11,8%	11,8%	11,8%	11,8%	
	Automated consolidation	0,0%	7,4%	12,5%	16,6%	20,7%	25,2%	25,2%	25,2%	
	Hub-to-hub	0,0%	5,6%	7,8%	13,5%	18,2%	18,2%	18,2%	18,2%	
CO_2 emissions	Baseline	0%	-21%	-50%	-80%	-90%	-100%	-100%	-100%	Micro-simulation (Vienna)
	Automated delivery	-100%								
	Automated consolidation	-100%								
	Hub-to-hub	-100%								

A.2 Mobility impacts

Impact	Sub-use Case	Scenario	Market penetration rate: AVs in Background vehicle fleet (Human-driven vehicle - 1st Generation AV - 2nd Generation AV) 100-0-0	80-20-0	60-40-0	40-40-20	20-40-40	0-40-60	0-20-80	0-0-100	Method
Travel time	Baseline		0,0%	6,1%	6,3%	5,5%	2,2%	0,5%	0,5%	0,5%	Delphi
	Automated delivery		0,0%	1,7%	1,7%	-3,7%	-6,8%	-4,4%	-4,4%	-4,4%	
	Automated delivery during night-time only		0,0%	-7,7%	-7,0%	-14,2%	-16,4%	-12,4%	-12,4%	-12,4%	
	Automated consolidation		0,0%	-4,2%	-4,2%	-8,8%	-9,8%	-11,3%	-11,3%	-11,3%	
	Hub-to-hub		0,0%	-2,9%	-3,2%	-4,8%	-6,4%	-6,4%	-6,4%	-6,4%	
Congestion of freight vehicles	Baseline; manual delivery	Combined urban & periphery	0,0%	-15,5%	-6,5%	-4,7%	-7,8%	-17,2%	-11,5%	-8,6%	Micro-simulation (Vienna)
		Urban network	0,0%	-18,7%	-8,3%	-7,5%	-11,5%	-22,4%	-14,4%	-11,9%	
		Periphery network	0,0%	2,1%	3,1%	10,1%	12,6%	11,5%	3,8%	9,1%	
	Semi-automated delivery	Combined urban & periphery; daytime	-17,4%	-12,5%	-16,4%	-27,4%	-7,4%	-22,9%	-28,0%	-17,2%	
	Automated delivery	Combined urban & periphery; daytime	-42,4%	-38,9%	-42,2%	-49,0%	-35,6%	-46,1%	-49,9%	-42,3%	
		Urban network; daytime	-19,0%	-13,0%	-17,4%	-30,6%	-6,9%	-25,2%	-31,3%	-18,1%	
		Periphery network; daytime	-9,1%	-9,8%	-10,1%	-10,8%	-9,1%	-9,4%	-10,8%	-11,5%	
		Combined urban & periphery; night-time	-92,0%	-91,8%	-93,9%	-92,0%	-92,2%	-92,4%	-93,5%	-92,6%	
		Urban network; night-time	-92,4%	-92,2%	-94,5%	-92,5%	-92,5%	-92,9%	-94,0%	-92,9%	
		Periphery network; night-time	-90,2%	-89,2%	-90,6%	-90,2%	-90,9%	-90,6%	-89,9%	-90,9%	
	Automated consolidation	Combined urban & periphery; daytime	-42,4%	-38,9%	-42,2%	-49,0%	-35,6%	-46,1%	-49,9%	-42,3%	
	Hub-to-hub transport	Baseline; no transfer hub	0,0%	-9,3%	-11,3%	-17,5%	-19,6%	-22,7%	-23,7%	-24,7%	
		With transfer hub	0,0%	-11,3%	-17,5%	-21,6%	-23,7%	-24,7%	-24,7%	-26,8%	

A.3 Societal impacts

			Market penetration rate: AVs in Background vehicle fleet (Human-driven vehicle - 1st Generation AV - 2nd Generation AV)								
Impact	**Sub-use Case**	**Scenario**	**100-0-0**	**80-20-0**	**60-40-0**	**40-40-20**	**20-40-40**	**0-40-60**	**0-20-80**	**0-0-100**	**Method**
Vehicle operating cost	Baseline		0,0%	7,5%	-0,7%	-4,0%	-10,0%	-10,4%	-10,4%	-10,4%	Delphi
	Automated delivery		0,0%	2,4%	4,4%	1,7%	-3,7%	-7,9%	-7,9%	-7,9%	
	Automated delivery during night-time only		0,0%	-3,1%	-1,2%	-11,6%	-17,0%	-17,7%	-17,7%	-17,7%	
	Automated consolidation		0,0%	2,4%	0,9%	-7,3%	-13,7%	-17,4%	-17,4%	-17,4%	
	Hub-to-hub		0,0%	-3,3%	-6,2%	-6,2%	-12,3%	-15,5%	-15,5%	-15,5%	
Vehicle operating cost	Automated delivery		-77%								Operations research
	Automated consolidation		-21%								
Parking space required	Baseline		0,0%	-1,4%	-1,3%	-5,0%	-11,5%	-11,6%	-11,6%	-11,6%	Micro-simulation (Vienna)
	Automated delivery		0,0%	-7,9%	-4,6%	-6,8%	-5,1%	-4,0%	-4,0%	-4,0%	
	Automated delivery during night-time only		0,0%	-4,0%	-5,4%	-8,7%	-9,4%	-7,9%	-7,9%	-7,9%	
	Automated consolidation		0,0%	-4,3%	-2,8%	-2,8%	-4,2%	-3,8%	-3,8%	-3,8%	
	Hub-to-hub		0,0%	-1,6%	-1,5%	-3,3%	0,0%	1,4%	1,4%	1,4%	
Road safety: crash rate	Baseline; manual delivery	Combined urban & periphery	0,0%	7,5%	14,0%	16,1%	4,3%	-19,5%	-37,0%	-48,7%	
		Urban network	0,0%	5,5%	12,7%	14,5%	0,0%	-20,0%	-36,4%	-49,1%	
		Periphery network	0,0%	11,5%	15,4%	19,2%	15,4%	-19,2%	-38,5%	-50,0%	
	Automated delivery	Combined urban & periphery	-2,6%	-4,2%	10,2%	4,9%	4,6%	-19,8%	-41,0%	-50,2%	
		Urban network	-3,6%	-9,1%	7,3%	0,0%	5,5%	-18,2%	-41,8%	-50,9%	
		Periphery network	0,0%	3,8%	15,4%	15,4%	3,8%	-23,1%	-38,5%	-46,2%	
	Automated consolidation	Combined urban & periphery; daytime	-2,6%	-4,2%	10,2%	4,9%	4,6%	-19,8%	-41,0%	-50,2%	
	Hub-to-hub transport	Baseline; no transfer hub	0,0%	11,5%	23,1%	11,5%	0,0%	-11,5%	-34,6%	-61,5%	
		With transfer hub	0,0%	7,7%	11,5%	-3,8%	-11,5%	-23,1%	-46,2%	-61,5%	
Public health	Baseline		0,0%	-5,3%	-2,1%	0,0%	5,2%	4,0%	4,0%	4,0%	Delphi
	Automated delivery		0,0%	2,9%	4,7%	8,8%	8,8%	8,4%	8,4%	8,4%	
	Automated delivery during night-time only		0,0%	2,3%	3,8%	4,9%	8,2%	11,8%	11,8%	11,8%	
	Automated consolidation		0,0%	6,0%	7,7%	9,4%	14,4%	18,5%	18,5%	18,5%	
	Hub-to-hub		0,0%	6,6%	10,0%	12,0%	17,8%	15,7%	15,7%	15,7%	

Appendix B Cost assumptions vehicle operating costs

For assessing the vehicle operating cost (Section 3.4), Hu et al. (2021a) made the 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[3], 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.

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[4]. 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.

[3] https://www.stepstone.at/gehalt/Paketzusteller-in.html
[4] https://sifted.eu/articles/starship-robot-delivery/

Appendix C Bridge models & technical overview

Given the bridge models used in bridge modelling in D7.3 (simply-supported beam), the quasi-static traffic load effects are determined only by the bridge span; they do not depend on the type of bridge structure (Hu et al., 2021b). On the other hand, the effects of permanent loads (bridge self-weight) depend very much on the bridge type. In the sub-use case of truck platooning, the following bridge types were considered (the short notations are used in the remaining document) (see Figure A, Hu et al., 2021b):

- RCS: reinforced concrete slab,
- PCT: prestressed concrete T-beam bridge,
- PCB: prestressed concrete box-girder,
- CBG: composite bridge: steel girders + concrete slab,
- CBB: composite bridge: steel box-girders + concrete slab,
- SGO: steel bridge: steel girders with steel orthotropic deck,
- SBG: steel box-girder bridge.

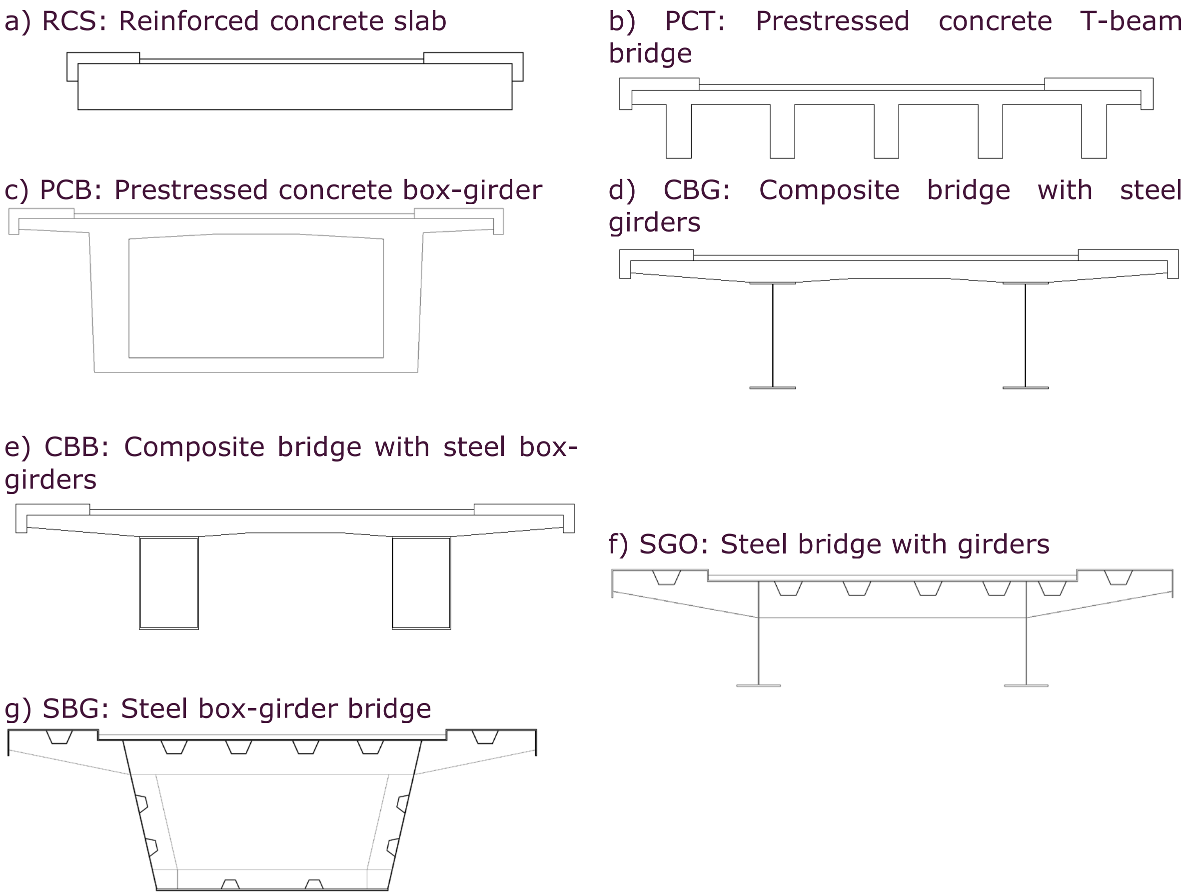

Figure A: Cross-section schemes of the considered bridge types.

Given the simple bridge models used in D7.3 (Hu et al, 2021b), the consideration of different bridge types is reduced to the evaluation of the permanent load (self-weight). In all cases, apart from the self-weight of the load-bearing elements, additional permanent loads (road surface, edge beams) are considered with 300 kg per m² of the bridge surface. All bridges were modelled with a bridge deck width of 10.5 m (incl. edge beams), carrying two lanes. Table A shows the basic properties of the analysed bridge models. Besides bridge type and span length, the permanent load μ is listed, as well as the fundamental resonant frequency f_0.

Table A: Basic properties of analysed bridge models

Type	Span [m]	μ [t/m]	f_0 [Hz]
RCS	15	29.4	5.65
RCS	15	22.8	4.17
RCS	20	38.2	4.30
RCS	20	29.4	3.18
PCT	20	16.8	5.83
PCT	20	14.9	3.77
PCT	25	19.2	4.78
PCT	25	16.7	3.17
PCT	30	21.6	4.04
PCT	30	18.4	2.72
PCT	35	24.0	3.49
PCT	35	20.1	2.38
PCT	40	26.4	3.07
PCT	40	21.9	2.10
PCB	40	21.1	3.20
PCB	50	23.7	2.57
PCB	60	26.8	2.12
PCB	70	30.4	1.80
PCB	90	37.1	1.38

Type	Span [m]	μ [t/m]	f_0 [Hz]
CBG	30	11.6	2.70
CBG	35	11.8	2.40
CBG	40	12.0	2.15
CBG	50	12.5	1.80
CBB	40	13.4	2.05
CBB	50	14.0	1.75
CBB	60	14.5	1.52
CBB	70	15.0	1.35
SGO	35	6.1	2.61
SGO	40	6.3	2.40
SGO	50	6.6	2.08
SGO	60	6.9	1.84
SBG	70	7.0	1.73
SBG	90	7.7	1.44
SBG	120	9.0	1.14
SBG	150	10.5	0.94

Technical overview of modelling HGV platooning effects

Access control

The basic purpose of **intelligent access control** is to increase the inter-vehicle distance of truck platoons before entering the bridge (Hu et al., 2021b). The congestion caused by intelligent access control was evaluated based on the time required to break and reform a truck platoon, i.e., extending the inter-vehicle distances before the bridge and reclaiming the platooning distance afterwards. This process takes time and causes delay to the traffic on the lane where the platoon operates. The delay mainly depends on the length of the platoon, the change of the inter-vehicle distance and the cruising speed of the platoon.

The process for extending the distance can be regarded as follows. The first truck in the platoon maintains the cruising speed and all follower trucks decelerate until distance between the first and second truck reaches the desired distance. Then the second truck regains the original cruising speed. After the distance between the second and third truck reaches the desired distance, the third truck regains the original cruising speed, and so forth. The process of reforming the platooning is analogous. The first truck decelerates until the gap to the second truck is reduced to platooning distance. Then the second truck decelerates, and so forth.

Traffic Model

A traffic model was adopted that was used for evaluation of traffic loads on bridges (Freundt et.al. 2011) and consecutively for adjustment of load models on bridges. This model includes 5 truck types (one 2-axle truck type, two 4-axle and two 5-axle truck types), a crane and a personal car. The intended application of this model is the description of heavy traffic on intercity highways.

Since the sub-use case intends to give a general analysis of the potential impact of truck platooning on urban bridges, it is sufficient to use simplified bridge models. In the simulation, simply-supported single-span bridges were considered. The bridge is modelled as a single beam supported at both ends, with free rotation. Given the simple bridge models that were used, the consideration of different bridge types was reduced to the evaluation of the permanent load (self-weight). In all cases, apart from the self-weight of the load-bearing elements, additional permanent loads (road surface, edge beams) are considered with 300 kg per m² of the bridge surface. All bridges were modelled with a bridge deck width of 10.5 m (incl. edge beams), carrying two lanes (Hu et al., 2021b)

Measured impacts

The traffic flow exerts different forces on the bridge, which must be transferred by the bridge structure into the subgrade. Usually, the engineers divide the traffic forces on road bridges into vertical (weight of vehicles) and horizontal (braking, acceleration, centrifugal force) forces, which are also so defined in the different standardisations like EN 1991-2 (Hu et al, 2021b). The change in traffic composition due to platoons is expected to lead to higher bridge internal forces, as described in section 3.2 in D7.3 (Hu et al., 2021b).

Three main impacts of these basic forces were measured: the midspan bending moment and the shear force at the support(s) and the braking force. The Ultimate Limit States (ULS) of midspan bending moment and shear force and the horizontal force from braking are the main impacts measured in traffic simulation models. Their values in different traffic cases are compared.

EN 1991-2 prescribes the consideration of braking and acceleration forces, centrifugal forces, and lateral forces from skew braking and skidding. Among these forces, the braking force is the most relevant one in most cases. Therefore, the study focused on the evaluation of braking forces.

If bridge strengthening is needed, the limit states of bending moment and shear force are expected to determine the overall strengthening cost in the most cases and the cost estimates can be used as a first estimate in decision making (Hu et al., 2021b). The EuroCode recommends the use of load model LM1 in assessment of existing bridges but allows its reduction using the ɑ_Q factors to account for less demanding traffic compositions. Assuming that existing bridges fulfil the requirements on their positive assessment, three cases of bridge resistance levels were considered for the calculation of rough estimates of strengthening needs (Hu et al., 2021b):

- $\alpha_Q = 1$: Bridge is able to carry exactly 100% of the LM1 load model
- $\alpha_Q = 0.9$: Bridge is able to carry exactly 90% of LM1 load model
- $\alpha_Q = 0.8$: Bridge is able to carry exactly 80% of LM1 load model

Exceedance probability

The impact of simulated traffic is evaluated in terms of the probability of exceeding the effects of load model LM1. Since new bridges are designed for the loads of load model LM1, it is assumed that they have the respective load-carrying capacity. The definition of load model LM1 according to EN 1991-1 presumes that its exceedance probability in 50 years is 5%. Therefore, this probability (5% in 50 years) is regarded as the "code level". The resulting bridge forces are evaluated in terms of the probability, that they exceed the forces from Eurocode load models (Hu et al., 2021b). If the probability, that a resulting 50-years-extreme-value distribution exceeds the force from a Eurocode load model, is above 5% the structural safety can be regarded as reduced. Higher exceedance probabilities mean lower structural safety Hu et al., 2021b).

Assumptions

The following assumptions were made in the modelling of traffic flow, in the bridge assessment, and in the cost estimates (Hu et al., 2021b, p. 21):

Traffic flow on bridges

- Traffic flow is a random stationary process; evolution of the traffic flow over time is not considered.
- Vehicle speed is constant and all vehicles in one lane share the same speed.
- Vehicles do not change lanes while on the bridge.
- Most vehicles comply with the prescribed limits of gross vehicle weight. Vehicles that violate the prescribed limit do so in an appropriate manner – the excess weight is not very large. That means, a certain percentage of vehicles with gross weight slightly over 40 tons occurs, but for example a single vehicle with 60 tons does not (except for special vehicles that have the permit).
- Traffic composition and congestion properties as discussed in Hu et al (2021b).The distribution of the number of vehicles between lanes is assumed as 80%-20% (Freundt et.al. 2011) for a two-lane urban highway in the case of low traffic intensity.
- Braking scenarios occur always in one lane only; the case that an obstacle spanning more than one lane occurs, is not considered, similarly to Eurocode.
- When a vehicle starts braking, the vehicles behind it start braking at the same time (driver reaction time is neglected).
- Each vehicle brakes with constant deceleration and the distance to previous vehicle at the end of braking manoeuvre is close to 0.
- First vehicle decelerates with $a_1 = 5.04\ m/s^2$