Application of the Decision Support Tool on Selected Use Cases

Levitate Deliverable D 8.3

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

Application of the Decision Support Tool on Selected Use Cases

Levitate Deliverable D 8.3

Please refer to this report as follows:
Hu, B., Zach, M., Müller, J., Richter, G., Ralbovsky, M., Chaudhry, A., Haouari, R., Singh, M., Roussou, J., Ziakopoulos, A., (2022). Application of the Decision Support Tool on Selected Use Cases, Deliverable D8.3 of the H2020 project LEVITATE.

Project details:	
Project start date: **Duration:** **Project name:**	01/12/2018 42 months LEVITATE – Societal Level Impacts of Connected and Automated Vehicles
Coordinator:	Andrew Morris, Prof – Prof. of Human Factors in Transport Safety Loughborough University Ashby Road, LE11 3TU Loughborough, United Kingdom
	This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824361.

Report details:	
Version: **Dissemination level:** **Due date:** **Submission date:**	 PU (Public)

Lead contractor for this deliverable:
AIT Austrian Institute of Technology

Report Author(s):	Hu, B., Zach, M., Müller, J., Richter, G., Ralbovsky, M., Austria Chaudhry, A., Haouari, R., Singh, M., United Kingdom Roussou, J., Ziakopoulos, A., Greece

Revision history

Date	Version	Reviewer	Description
21/05/2022	Preliminary draft		
30/05/2022	Final Report		

Legal Disclaimer

All information in this document is provided "as is" and no guarantee or warranty is given that the information is fit for any particular purpose. The user, therefore, uses the information at its sole risk and liability. For the avoidance of all doubts, the European Commission and CINEA has no liability in respect of this document, which is merely representing the authors' view.

© 2022 by LEVITATE Consortium

Table of contents

Executive summary

The aim of the LEVITATE project is to prepare a new impact assessment framework to enable policymakers to manage the introduction of cooperative, connected, and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives. As part of this work, the LEVITATE project seeks to forecast societal level impacts of cooperative, connected, and automated mobility (CCAM), by developing an open access web-based Policy Support Tool (PST).

In this deliverable, we apply the impact assessment methods of the PST on selected use cases which have been identified through the so-called *backcasting city dialogues*. This is a qualitative approach which was applied in WP4 of the LEVITATE project by screening city strategic development papers and engaging discussions with city authorities. Essentially, it is a process of analysing the (future) city goals, then elaborating the influencing factors, and finally identifying the corresponding policy measures in order to reach the desired goals.

In this deliverable, we build on the qualitative results of this approach and complete it with the quantitative impact assessment methods of the PST. Since the identified measures can be very specific and go beyond the general scope of the sub-use cases (SUC), they are addressed in so-called *case studies (CS)*. All CS of the LEVITATE project are included in this document, which is another main output beside the interactive PST estimator tool.

Last mile automated shuttle service
The last mile automated shuttle service is implemented in a way that the operational areas of the shuttles are reduced to smaller zones in the periphery of the city. In each zone, there is a good train and/or metro station that provides a frequent connection to the city centre. The shuttle service is not allowed to travel to other zones to avoid trips across the city. The desired effect of this restriction is that the shuttle service is mainly used in combination with public transport, although use for monomodal trips within the zones is not prohibited.

The introduction of a shuttle service is a typical "pull" measure as it increases the attractiveness of public transport without reducing the attractiveness of owning a car. The introduction of last-mile shuttles is likely to require financial support from the public sector, as no private operator will voluntarily restrict its business to the generally less lucrative urban periphery. The mesoscopic simulation integrates the simulation of rebound effects, such as induced transport demand due to better traffic flow. However, other effects, such as pursuing activities in other locations or moving to other places, are not considered in the simulation.

Automated ride sharing
Automated ridesharing (ARS) service is a significant intervention due to the importance of potential impacts that could result from combining automation and on-demand shared mobility services. Impacts on vehicle ownership, congestion, land use, modal shift and emissions may be of particular interest to various stakeholders, such as transport

planners, service operators, and cities, to assess the societal effects and evaluate the costs in relation to benefits. For this case study, an automated ride-sharing service that provides door-to-door service was considered.

The ARS is evaluated using microsimulation modelling based on the city centre network of Leicester and Manchester. The impact of this service was analysed under short term deployment scenarios where AVs are integrated into a ride-sharing service and share the road with conventional vehicles, i.e., analysing the current situation with ARS.

The impacts of both scenarios are analysed under different levels of demand that the ARS could serve and compared with the current situation (baseline scenario) through both networks. The passenger preference to use the service for individual or shared rides (i.e., willingness to share (WTS)) was also considered in the implementation of this SUC. The impact of the proposed service was studied under different combinations of demand rates that will be served by ARS and different levels of passenger WTS in order to identify the effect of these factors on mobility, safety, and the environment.

Road use pricing

Road-use pricing (RUP) refers to charges for the use of infrastructure, including distance and time-based fees, road tolls and various charges with the scope to discourage the access or long-stay of vehicles within an area. The different scenarios are based on

1) varied tolling charges,
2) dynamic or static tolling,
3) specific adaptions to the pricing levels based on
    a) residential status of car owners in the tolling area and
    b) the classification of roads as side-roads.

For each of these scenarios, the deployment of two driving profiles for automated vehicles (i.e., first and second-generation AVs, with the former being more conservative while the latter are expected to be more aggressive) is tested for four different vehicle fleet compositions to represent the expected increasing prevalence of automated passenger cars along the timeline. Introduction of road-use pricing for passenger cars is a "push" measure as it decreases the attractiveness of using a car within the area of the tolling zone and its surroundings.

The results show that the zonal RUP measure extends its intended effects similarly into the environment of the tolling zone. These effects of a shift from passenger car use towards more sustainable modes of transport is slightly less strong for connected automated vehicles than for conventional cars. Exempting the residents of the tolling zone from toll payment leads to considerable rebounds, however, the optimal degree of such an exemption is a matter of more detailed traffic supply and demand considerations, as well as social equity. Road-class based tolling to discourage traffic in side-roads (e.g., residential areas) leads to significant amplification of key policy impacts even at moderate pricing levels and provides a finely tuneable tool for policy measure implementation.

GLOSA – Green light optimal speed advisory

GLOSA is one emerging vehicle to infrastructure application that optimises traffic flow on signalised road networks reducing simultaneously emissions. It is a significant technology-based intervention due to the important potentially positive environmental and mobility impacts. Smoother traffic flows, less congestion and reduced emissions constitute a promising basis for the various stakeholders, transport planners and cities, to be interested in assessing the societal effects and evaluate the costs in relation to benefits.

The results obtained via microscopic simulation on the traffic model of Greater Manchester follow the outcomes of other studies presenting positive overall impacts on environment, traffic and safety due to implementation of GLOSA. With the suitable traffic management and other policies in place, GLOSA application can potentially act as a very useful tool towards uninterrupted flows, lower travel times and delays that can be in turn translated to fewer fuel consumption and air pollution.

Automated delivery and automated consolidation

Automated logistics will bring disruptive changes to the parcel delivery industry. The direct effect is that human labour will be replaced by automation, both for the driving task and the task of parcel handover. This could be achieved by the so-called ‘robo-van’ concept where an automated van functions as a mobile hub and small autonomous delivery robots perform short delivery trips to end-customers. On one hand, this system can utilise the off-peak hours and night for delivery where the road network is less crowded, despite increasing the total mileage of the delivery trips when compared to the current manual delivery system. The main reason is the assumption that the vehicle capacity will decrease due to the delivery robots and additional equipment. On the other hand, consolidation through city-hubs will reduce redundancy and therefore the freight mileage. Automated logistics will be a big support for the implementation of such systems since servicing the city-hubs can be automated and shifted to the night as well, which is not possible for conventional manual delivery systems nowadays.

Regarding the methodology, we show that the operations research approach and the resulting simplified macro approach are transferable to other cities. If the corresponding data (demographic and parcel data) are available, the error inherent in the simplified macro approach is very small, therefore it is qualified for an easily transferable quick assessment.

Platooning on urban highway bridges

Automated driving enables the formation of truck platoons, with several trucks driving synchronously and using small vehicle distances (headways) in order to take advantage of the lower aerodynamic resistance of this formation. The traffic loads that are considered in the design of new bridges are derived from measured sequences of axle loads using statistical evaluations and extrapolating assumptions that consider future traffic. With traffic flows changed by the introduction of automated driving and truck platooning, the question arises, whether the load models used in bridge design are appropriate to represent the traffic loads in the new conditions. Another urgent question that arises with the introduction of truck platooning, is whether the existing bridges that were designed using current traffic load models can safely carry the new traffic flows.

The urban traffic simulated in this case study produces maxima of bridge internal forces, which were much less critical than with the previously simulated intercity traffic. For the most relevant limit states of bending moments and shear forces in main girders, the results are optimistic. However, the effect of truck platooning on bridge internal forces is still significant and may cause an increase of their expected maxima. The results are optimistic in the sense that this increase is not likely to exceed the level of LM1 requirements, for which the bridges are designed. The situation is different in case of braking forces, where structural measures would be needed.

1. Introduction

1.1 Background

Connected, cooperative, and automated mobility (CCAM) services and technologies 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 safety, mobility, environment and economic growth. With such systems not yet in widespread use, there is a lack of data and knowledge about impacts.

Furthermore, 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 forecast the impact of future systems represents a major challenge.

Finally, the dimensions for assessment are themselves very wide, including safety, mobility and environment but with many sub-divisions adding to the complexity of future mobility forecasts.

The aim of the LEVITATE project is to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives.

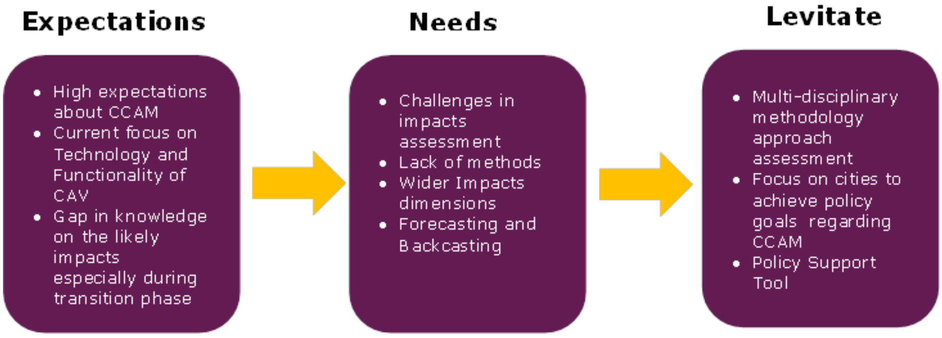


Figure 1.1: Motivation and scope of the Levitate project

1.2 Levitate Project

Societal **Lev**el **I**mpacts of Connec**t**ed and **A**utoma**t**ed Vehicl**e**s (LEVITATE) is a European Commission supported Horizon 2020 project with the objective to prepare a new impact assessment framework to enable policymakers to manage the introduction of connected and automated transport systems, maximise the benefits and utilise the technologies to achieve societal objectives.

Specifically LEVITATE has four key objectives:

1. 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
2. To develop a range of **forecasting and backcasting** scenarios and baseline conditions relating to the deployment of one or more mobility technologies that will be used as the basis of impact assessments and forecasts. These will cover three primary use cases – automated urban shuttle, passenger cars and freight services.
3. 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.
4. To incorporate the established methods within a **new web-based policy support tool** to enable city and other authorities to forecast impacts of CCAM on urban areas. The methods developed within LEVITATE will be available within a toolbox allowing the impact of measures to be assessed individually. A Decision Support System will enable users to apply backcasting methods to identify the sequences of CCAM measures that will result in their desired policy objectives.

1.3 Purpose of this Deliverable

The purpose of the present deliverable is to apply the *policy support tool (PST)* to specific examples in order to acquire quantifications of the expected impacts of specific CCAM interventions. In particular, we consider the specific use cases which have been identified through the so-called *backcasting city dialogues (BCD)* in detail. The BCD is a qualitative approach which was applied in WP4 of the LEVITATE project by screening city strategic development papers and discussing with city authorities. Essentially, it is a process of analysing the (future) city goals, then elaborating the influencing factors, and finally identifying the corresponding policy measures in order to reach the desired goals.

In this deliverable, we build on the qualitative results of this approach and complete it with the quantitative impact assessment methods of the PST. Since the identified measures can be very specific and go beyond the general scope of the sub-use cases (SUC), they are addressed in so-called *case studies (CS)*. All CS of the LEVITATE project are included in this document, which is another main output beside the interactive PST estimator tool.

2. Impact Assessment and Backcasting

This section summarises some parts of the work performed earlier in the project, which can be considered as base for the case studies reported in this deliverable.

2.1 City goals & Backcasting approach

From a cities' perspective the advent of connected and automated vehicles (CAVs) is not a strategic goal by itself. Rather, they are welcome if they are able to contribute to the defined smart city goals and have to support a liveable city.

Defining a *desirable vision* in a quantitative way is the essential starting point for the *backcasting process* that has been one of the methodological pillars of LEVITATE. From that vision the idea is to work backwards, via *influencing factors* (that are impacting the goals and indicators of the vision), to *policy interventions* which address these factors and thereby contribute towards the vision. Generating this series of logical links is a central part of the process, as it highlights feasible paths of interventions, steering into the desired direction.

In the context of the LEVITATE project, the definition of feasible visions has been extended beyond the simple approach of specifying only certain targets, by also considering a wider range of indicators across four dimensions (safety, society, environment and economy). An overview of proposed goals and indicators is given in Table 1. The list is organised along the four chosen dimensions, which provide a high-level structure (even if certain goals might be assigned to more than one dimension).

Table 2.1: Consolidated proposed goals and indicators for LEVITATE

Dimension	Policy Goal	Indicator
Safety	Protection of Human Life	Number of injured per million inhabitants (per year)
		Number of fatalities per million inhabitants (per year)
	Perceived Safety	Standardised survey: subjective rating of (overall) safety
	Cyber Security	Number of successful attacks per million trips completed
		Number of vulnerabilities found (fixed) (per year)
Society	Reachability	Average travel time per day (dispersion; goal: equal distribution)
		Number of opportunities per 30 minutes per mode of transport
	Use of Public Space	Lane space per person
		Pedestrian/cycling space per person

Dimension	Policy Goal	Indicator
	Inclusion	Distance to nearest publicly accessible transport stop (including MaaS)
		Affordability/discounts
		Barrier free accessibility
		Quality of access restrictions/scoring
	Satisfaction	Satisfaction with active transport infrastructure in neighbourhood (walking and/or cycling)
		Satisfaction public transport in neighbourhood
Environment	Low Noise Levels	Standardised survey: subjective rating of main sources of disturbing noise
	Clean Air	Emissions directly measurable: SO2, PM2,5, PM10, NO2, NO, NOx, CO, O3
	Efficient Settlement Structures	Building volume per square kilometre (total and per built-up area)
		Population density (Eurostat)
	Sustainable Behaviour	Rate of energy consumption per person (total)
		Rate of energy consumption per person (transport related)
Economy	Prosperity	Taxable income in relation to purchasing power
	Fair Distribution	GINI index

Table 2 summarises the mapping of LEVITATE goals and indicators to key quantitative targets that can be used to identify a vision in LEVITATE context, for the two examples of Vienna and Greater Manchester, after analysing corresponding material on the city strategies. Note that for this mapping, only the most obvious indicators (out of those listed in Table 1) have been considered – which does not mean that other indicators are irrelevant.

Defining a quantified vision by a (prioritised) set of goals and targets in a formal way as discussed here seems to be straightforward. It is clear, however, that in reality this might be a quite lengthy and complex process. With the approaches followed in Zach, Rudloff & Sawas (2019), it has been demonstrated that it is possible to identify “regions” in indicator space that are close to such an idealised vision and consistent in terms of correlations between various target indicators – despite the limitations which are due to the high sparsity in the available data set.

Table 2.2: Mapping of LEVITATE goals and indicators to quantitative targets defining a vision

Dimension	Policy Goal	Indicator	Target Vienna	Target Greate Manchester
Safety	Protection of Human Life	Number of injured per million inhabitants (per year)	(decline)	as close as possible to zero (2040)
		Number of fatalities per million inhabitants (per year)	(decline)	as close as possible to zero (2040)
Society	Use of public space	Lane space per person		
		Pedestrian/cycling space per person	(increase)	
Environment	Clean air	Emissions directly measurable: SO2, PM2,5, PM10, NO2, NO, NOx, CO, O3	Greenhouse gas emissions -50% (2030), -85% (2050)	Robust low carbon pathway to 2050 at which Greater Manchester can become carbon neutral.
	Sustainable behaviour	Rate of energy consumption per person (total)	-30% (2030), -50% (2050)	
		Rate of energy consumption per person (transport related)	-40% (2030), -70% (2050)	Sustainable modes (walking, cycling or public transport) will increase from 39% in 2019 to 50% in 2040
Economy	Prosperity	Taxable income in relation to purchasing power	(increase)	(economic goals identified, but no clear mapping possible)
	Fair distribution	GINI index	(decline)	

2.2 Backcasting city dialogues

The specification of "desirable visions" is important to disclose conflicting goals and to allow a city to become aware about which goals should be prioritised in this respect, e.g. should economic goals be prioritised over societal goals. This enables cities to develop a clearer definition of its desired future and a more realistic assessment of the feasibility of reaching multiple goals. As mentioned before, such a vision can then form the starting point for a backcasting exercise marking out a transformation pathway including appropriate policy interventions steering the development.

The flow chart in Figure 2 gives an overview on the steps in the backcasting process, the used inputs and the expected outputs (Zach, Sawas, Boghani, & de Zwart, 2019) as performed in LEVITATE. The cornerstones of this process were repeated interactive sessions with City representatives, referred to as *City Dialogues*.

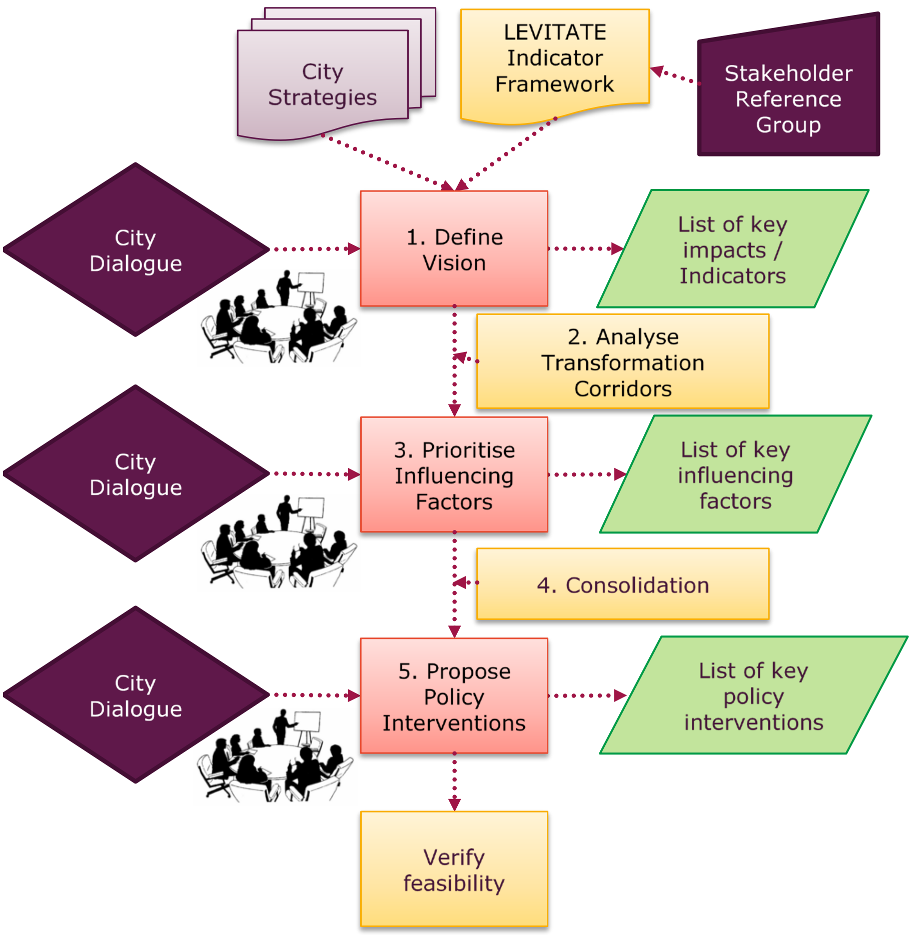


Figure 2.1: Flow chart for the steps of backcasting process in LEVITATE

Figure 2.2 further illustrates the steps detailing the relationship between vision, influencing factors and policy interventions. The main outputs of this process are shown as the three pillars, where the direction of arrows indicates the backwards propagation:

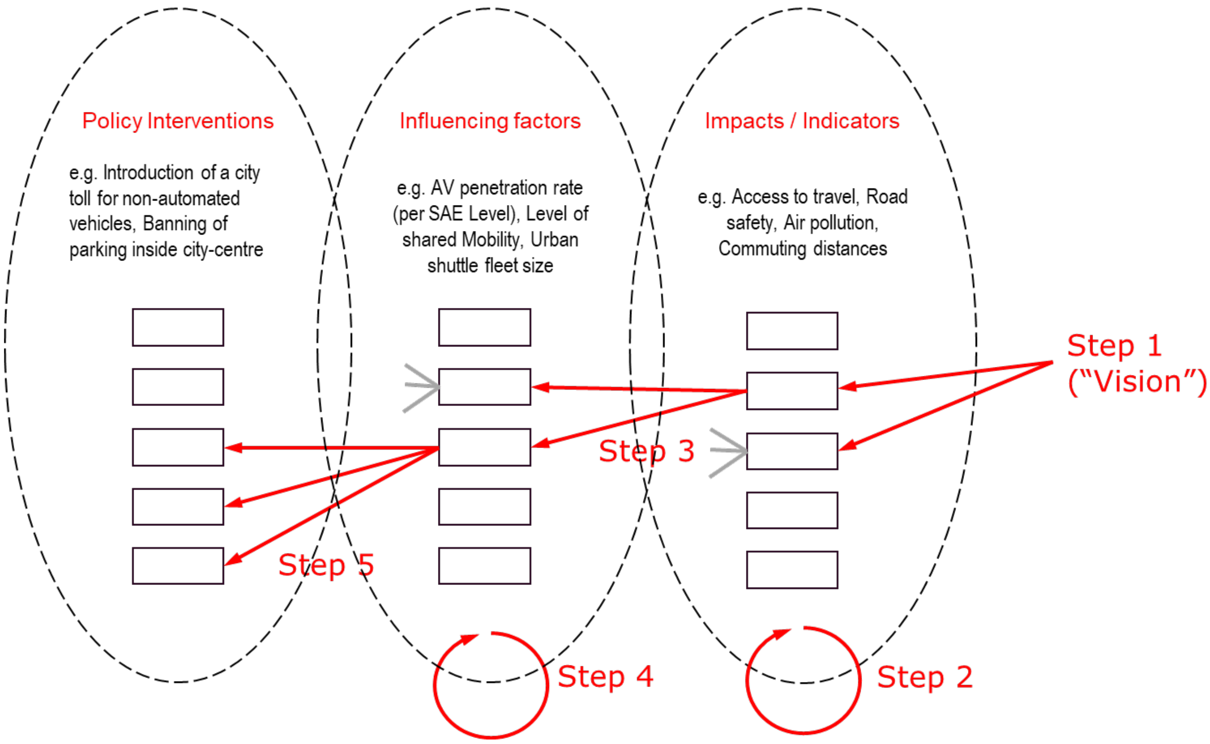


Figure 2.2: LEVITATE backcasting steps – three-pillar view

1. A set of – simplified and focused – most important goals are specified by selecting and prioritizing a subset of LEVITATE indicators. For these indicators, specific target values and target dates should be assigned, and historic data up to the present time should be available.
2. These visions are consolidated and cross-checked for consistency, based on previous data modelling work and mapping of visions. Constraints for feasible transformation corridors can be indicated, based on the time-based development in the past and the "direction" (in the indicator space) towards the desired vision.
3. Influencing factors are selected and prioritized. They are related to indicators via *expected* impact relationships: For each indicator, one or several factors are derived as indicated by the arrows. Also, the values of these influencing factors might be quantified where possible.
4. Internal consolidation within LEVITATE ensures that the identified influencing factors are consistent with respect to the plans and possibilities in WP5 – WP7, where the sub use cases to be considered have been defined.
5. Finally, the most promising policy interventions are selected and prioritized, again working backwards from the desired changes in the influencing factors.

Note that the CCAM use cases, applications and interventions that are analysed in LEVITATE cover both the middle and the left pillar (influencing factors and policy interventions). In addition, it was determined during the city dialogues that a strict distinction between these two is not always possible or useful.

A typical challenge for the selection of influencing factors and policy interventions is the question how far the considered interventions are specific to CCAM (and therefore within scope of LEVITATE). Since the expected impact areas of CCAM have been considered already in definition of LEVITATE indicator framework and feasible visions, relevance to CCAM should be ensured to a certain degree "from the start". It can still happen, however, that for a certain goal, influencing factors and, even more, policy interventions can be derived that have no strong (at least no direct) relation to CCAM (in particular if we can expect only a very limited contribution of CCAM towards that goal). Nevertheless, such influencing factors and policy interventions might be considered as relevant because of following aspects:

1. Implementation of CCAM leads (or better: is expected to lead) to changes in several other system parameters – within or outside the transport domain; such changes might then require or facilitate adaption of policies. As an example, less need for parking space in certain areas (as consequence of CCAM) might allow for re-assignment of public space (as policy intervention).
2. Important and general policy goals like reduction of air pollution and CO2 production can be considered as "weakly" dependent on CCAM itself (compared to all other influencing factors for those goals) – but taking into consideration the possible impacts of CCAM on several factors like modal split, additional amount of travel, travel time or propulsion type, significant contributions of CCAM towards these goals could be demonstrated. These factors in turn can be controlled by suitable policy interventions.

It should be noted here that feasible policy interventions will of course also be defined by the city's sphere of influence: Several developments (e.g. driven by technology and the market) are out of direct control by any federal government, regional government or municipal authorities (except if market regulations are considered e.g. by restricting a service to certain conditions); other interventions might be controlled only at a higher level (federal government, EU level) but can hardly be influenced on city level. In such a case it will still be essential for cities to know how to respond to corresponding changes (for example in the market penetration of level-5 AVs).

Finally, the prioritization of policy interventions might result from a trade-off between the effect on identified influencing factors and the contribution to policy goals on the one hand, and the feasibility (in terms of costs, political resistance etc.) on the other.

The interactive backcasting approach (implemented as city dialogue) has been performed for three cities in LEVITATE: Vienna, Greater Manchester and Amsterdam. At this point, the results for Vienna are briefly summarized, since they are relevant for some of the case studies reported in this deliverable.

The overall city goal of Vienna is to reduce greenhouse gas emissions per capita by 35% by 2030 and 80% by 2050 (compared to 1990). The main sub-goals in the field of mobility related to LEVITATE are (Wien, 2019):

1. Per capita CO2 emissions in the transport sector fall by 50% by 2030, and by 100% by 2050.
2. Per capita final energy consumption in the transport sector falls by 40% by 2030, and by 70% by 2050.
3. By 2030, private motor vehicle ownership falls to 250 vehicles per 1,000 inhabitants.
4. The share of trips in Vienna made by eco-friendly modes of transport, including shared mobility options, rises to 85% by 2030, and to well over 85% by 2050.

5. The number of traffic casualties and persons injured in traffic accidents declines further (although this target if no further specified).
6. The share of green spaces in Vienna is maintained at over 50% until 2050.
7. The volume of traffic crossing the municipal boundaries falls by 10% until 2030.

Starting from these highest priority targets, related influencing factors and policy interventions were discussed. The results are shown in the overview diagram in Figure 2.3. This illustration is again based on the three pillars view, where the process starts from the right hand side (vision identified by means of impacts and indicators), then defines related influencing factors and finally leads to a specification of most promising policy interventions (on the left side).

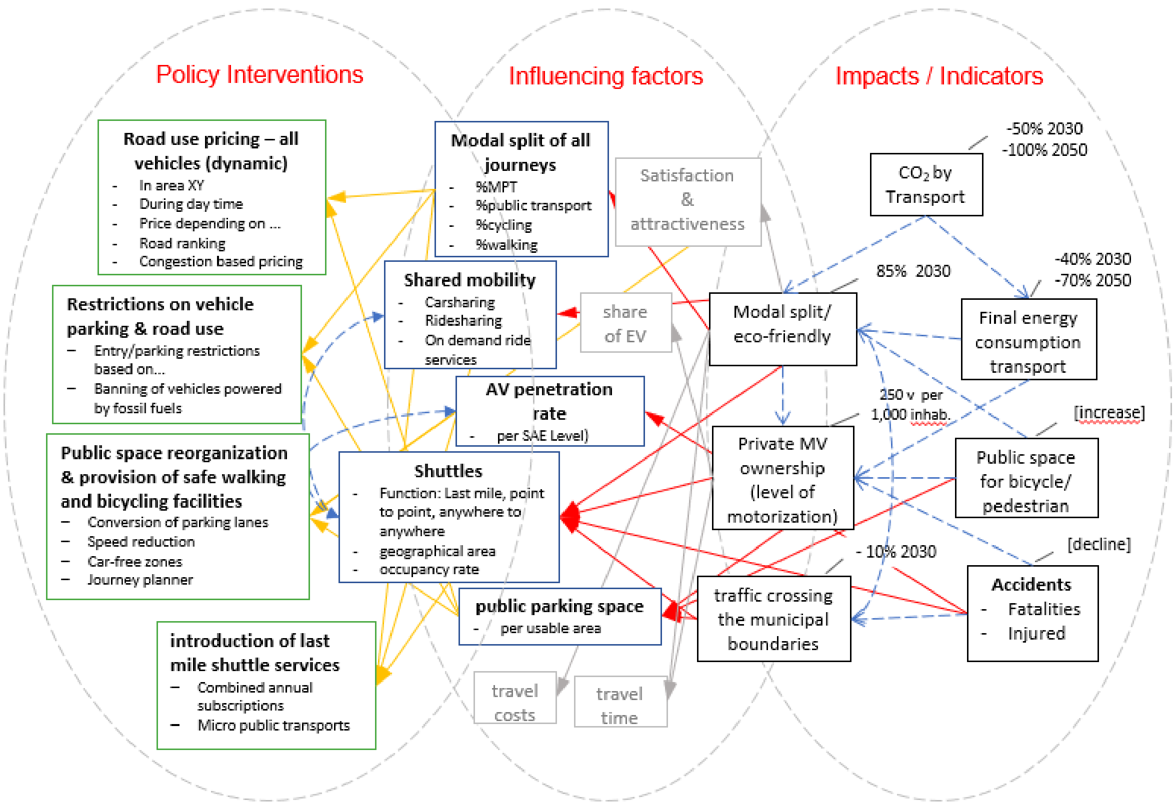


Figure 2.3: Backcasting for Vienna – Overview of results

For Vienna, the following areas of policy interventions were proposed and discussed in more detail; depending on the intervention and impact types these proposals are now being further assessed by several methods in the LEVITATE project (for example, microscopic simulations, mesoscopic simulations and system dynamics):

- *Road use pricing (dynamic) for all vehicles*: This measure could be linked with several influencing factors such as shuttles, modal split of all journeys and AV penetration rate. From an expert´s point of view, it is conceivable that it will be used to achieve some of the city's goals in 2030-2050. These goals are for example decreasing the share of private motor vehicle (MV) ownership and the volume of traffic crossing the municipal boundaries. Road use pricing might be influenced by area, time of day, price, road ranking and congestion. Therefore, road use pricing should be carefully considered by the city to determine in which areas and at what time of day a road pricing is most effective. It could be conceivable in areas such as the city centre, in a certain residential area or in a certain district. Regarding road ranking, "30 zones" (residential zones with speed limit of 30 km/h) might have the highest price in order to prevent misuse of residential areas for transit.

- *Restrictions on vehicle parking & road use*: Parking is one of the main problems when using a car in Vienna. The higher the proportion of MV owners, the more parking spaces and more space for car traffic will be required. In the city centre, the problem is even bigger due to scarce space. A restriction on road use and parking could be considered as a more drastic step compared to the measure of road use and parking pricing.
- *Public space reorganization & provision of safe walking and bicycling facilities*: In order to distribute the public space fairly and increase the attractiveness for active modes of transport, several measures for reorganization of space were discussed: conversion of parking lanes into areas for walking, cycling or "flexible zones" (conversion into driving lanes was not seen as an option to follow as it would counteract the goals); speed reduction in residential areas; car-free zones with restrictions; rezoning (changes in intended land use). This policy intervention impacts several influencing factors, such as: satisfaction & attractiveness, public parking space and modal split of all journeys.
- *Introduction of last mile automated shuttle services*: The final measure discussed was the provision of faster, more cost-effective and convenient public transportation. The influencing factors associated with this measure are: AV shuttles, AV penetration rate and modal split of all journeys. This policy intervention focusses on the following sub-measures: (public) last-mile shuttles, e.g. areas around northern stations of the metro line U1; AV service instead of so called "B busses" (lower priority bus lines with longer intervals); combined annual subscriptions and multimodal public transportation packages; better coordination between different modes of transportation; micro public transport (covered by last-mile shuttles).

Out of these *specific* policy interventions that have been proposed, *Road use pricing* and *Last mile shuttle services* have been analysed in more detail in dedicated case studies, as will be reported in sections 4.1 and 4.2.

3. Levitate Case Studies

During the initial stage of the LEVITATE project, the sub use cases (SUCs) to be handled in the project were identified by consulting stakeholders, gathering existing scientific works, and screening the ERTRAC Connected Automated Driving Roadmap. The final list of SUCs is shown in Table 4.1. These SUCs were handled in detail in the work packages 5,6,7 of the project and the results were documented in the corresponding deliverables D5.2 – D5.5 (Roussou et al. 2021, Goldenbeld et al., 2021), D6.2 – D6.5 (Chaudhry et al. 2021, Goldenbeld et al., 2021) and D7.2 – D7.5 (Hu et al. 2021, Goldenbeld et al., 2021).

Table 3.1:List of sub-use cases handled in the project.

Passenger cars	Urban transport	Freight Transport
Dedicated lanes for AVs	**Point to point automated shuttles** • Automated shuttles connecting two modes • Automated shuttles in a large-scale network	**Automated urban delivery** • Semi-automated delivery • Fully-automated delivery
Parking regulation • Parking price regulation • Removing half on-street parking spaces • Replace on-street parking with other facilities	**On-demand automated shuttles**	**Automated consolidation** • Consolidated delivery via white label city-hubs
Road use pricing • Static toll • Dynamic toll • Exemptions for residents	**Last mile automated shuttles**	**Hub to hub automated transfer**
Green light optimised speed advisory (GLOSA)		**Truck platooning** • Effects of truck platooning on highway bridges
Automated ride sharing		

This section presents the six case studies (CS) in Levitate. CS are another major outcome of the project beside the dynamic PST estimator. The PST estimator uses the results of the SUCs to provide an interactive tool to assess the impacts of policy measures. This can be seen as a *dynamic output* of the project results. In comparison, CS are *static outputs* of the project results.

The aim of CS is to address specialized topics in the WPs 5,6,7 that are beyond the scope of the SUCs. Although the SUCs are based on specific cities, they are considered from a more general perspective in order to showcase the methodologies developed in LEVITATE. Since the SUC results are used for the PST estimator, they are subject to a standardized output for the different impacts dimensions so that they are incorporated into the dynamic PST estimator tool. For these reasons, the scope of the SUCs is more limited.

For the CS we lift these limitations and address scenarios and settings that are too specific for SUCs, or we consider impacts that are not part of the PST estimator. For these reasons, we performed a total of six CS, two for each of the WPs 5,6,7:

- **Urban transport** (WP5):
    - Last mile shuttles (Vienna)
    - Automated ride sharing (Leicester)
- **Passenger cars** (WP6):
    - Road use pricing (Vienna)

    - GLOSA – Green light optimal speed advisory (Leicester)
- **Freight transport** (WP7):
    - Automated delivery and automated consolidation (Vienna and Manchester)
    - Platooning on urban highway bridges (Vienna)

3.1 Last mile automated shuttles

Urban mobility is currently experiencing major upheavals. Innovative technologies and services are emerging and being successfully implemented worldwide. These mobility innovations aim to provide users and operators with more efficient and safer modes of transport while reducing harmful emissions and alleviating persistent problems such as severe urban congestion.

The automated urban shuttle services (AUSS) for the last mile aims to provide a shuttle system that complements public transport in the periphery of a city. Leaving it up to the operator to decide on the definition of the area of operation usually results in the service being offered in areas where there is already sufficient public transport provision (Schmöller, Weikl, Müller, & Bogenberger, 2015). This results in cannibalization of public transport and other active modes (cycling, walking) - and can further degrade transport in densely populated areas. With this case study we want to understand and describe in which peripheral areas the AUSS fleet is used and how. Another focus is to characterize the users in order to be able to transfer the results to other cities.

3.1.1 Model and Methodology

The mesoscopic MATSim simulation model for Vienna is described in detail in (Müller J. , Straub, Richter, & Rudloff, 2022) and (Müller, et al., 2021). In short, the simulation area covers about 4,100 square kilometers with a population of about 2.3 million including the 1.7 million inhabitants of Vienna (Eurostat, 2020). We used a 12.5% sample of the mobile population which corresponds to around 200,000 agents in the whole simulation area. By simulating traffic in the vicinity of at minimum 30 kilometers from the city center, large parts of the Vienna metropolitan area are covered. The road network for the simulations comprises of 156,000 links, and various facilities like workplaces, schools, shopping areas, and leisure areas.

MATSim requires an initial set of travel diaries of the agent plans that have fixed activity locations and a fixed sequence of activities. Since these parameters do not change over simulation iterations and in the scenario simulations. To simulate traffic on the road network, two main data inputs are needed. The first is travel diaries with detailed origin-destination matrices, mode choice, and various socioeconomic indicators. This information comes from the national transport survey Österreich Unterwegs 2013-2014 which is representative at the municipality level within the city of Vienna (Tomschy, et al., 2016). The second input dataset are the locations of facilities or points of interest extracted from OpenStreetMap. They are necessary to indicate locations when disaggregating the origin-destination relations for the districts to specific activity locations (facilities) categorized by housing, work, education, shopping, recreation, and errands. These data are supplemented with population density maps to spatially map the facilities along with the potential places of residence and work for the simulated agents.

Thus, disaggregating the activity location survey information means selecting appropriate points of interest from the specified community area code. This selection is done by applying an optimization algorithm based on the travel times and travel distances specified in the travel survey data. As a result, we obtain optimal matching locations for each agent's activity sequence within the set of possible locations for each activity type.

After the synthetic population is generated, the plans are fed into an inter-modal routing algorithm to generate the paths a trip will take. This is done using Austrian Institute of Technology's (AIT) proprietary inter-modal routing algorithm *Ariadne* (Prandtstetter, Straub, & Puchinger, 2013).

MATSim works with a scoring function to evaluate the success of an agent's travel diary at the end of the day. The basic logic behind this utility function is to consider times spent at an activity positively and penalize all travel times according to the mode. The scoring parameters for each mode are estimated from a stated and revealed preference survey (Jokubauskaitė, et al., 2019) (Hössinger, et al., 2020). The model is calibrated by the modal split for each trip according to the travel diaries given in the Österreich Unterwegs 2013/2014 survey. After adjusting the constant of the mode utility functions, we achieved a deviation from the observed data of less than 1% for each mode.

Implementation of the on demand AUSS sub-use case

In the MATSim framework, the on-demand AUSS is implemented with the module for the dynamic vehicle routing problem (dvrp) (Maciejewski & Nagel, 2011).This module performs the matching between agents with AUSS vehicles allowing AUSS to be treated as automated taxis or car-sharing vehicles. In contrast to private cars, these vehicles can be shared, and they do not need to be taken back to the agent's home. The last mile AUSS are implemented with an area-based operational scheme which means that there are no stops defined in advance but instead passengers can be dropped off at any point within the area.

Assumptions

The AUSS fleet consists of vehicles with a capacity of up to 4 people. A higher capacity of vehicles would technically be possible to implement but it is assumed that the flexible pick up and drop off of people will lead to longer detours of trips resulting in fewer acceptance of the service. The AUSS vehicles are at the beginning of each iteration located at their initial spots which have been randomly generated. These initial links function as depots comparable to taxi stands. Idle vehicles will return to these depots. Every three hours, the demand will be generated, and the vehicles will be relocated accordingly. The raster used for the demand generation consists of cells with an edge length of 500m.

The maximum waiting time for a shuttle is set to 10 minutes. If a shuttle will not pick up the agent after this time, it will abort the trip and evaluate this plan accordingly bad. The boarding time for a shuttle is set to 1 minute.

The different car fleet partitioning of CAV of the 1st generation (cautious CAV) and CAV of the 2nd generation (aggressive CAV) will be reflected by assigning different utility functions for private cars to shares of the population. Using a CAV1 will be treated as 80% of the value of travel time savings (VTTS) of a private car, and a CAV2 as 75% the car's VTTS. The private cars will remain the same in regards of their driving behavior on the road. As the throughput of roads will increase with a higher automation rate due to more densely packed moving vehicles, the simulation model parameter "flow capacity factor" of the road network was adapted to account for this effect. The flow capacity factor is generally set to the percentage of population that is simulated (in our case 12.5%) as it represents the relative number of vehicles that can pass a link (Llorca & Moeckel, 2019).

The VTTS for riding an AUSS shuttle is set to 75% of a private car's VTTS following studies from literature (Ho, Mulley, Shiftan, & Hensher, 2015) (Fosgerau, 2019). Agents will be charged a time-based fare of 0.30 EUR/min. The rationale behind setting the parameters for CAV1, CAV2 and AUSS is based on studies on the estimation of the VTTS for automated vehicles and shuttles. Whereas (Lu, Rohr, Patruni, Hess, & Paag, 2018) found no differences in the VTTS between drivers and passengers of a car, (Fosgerau, 2019) and (Ho, Mulley, Shiftan, & Hensher, 2015) conclude that the VTTS for a passenger can be regarded as about 75 % of the rate for car drivers. We follow in our model these latter findings and slightly increase the VTTS for CAV1 as the driving experience is assumed to be not as convenient as with a CAV2.

3.1.2 Scenarios

The AUSS shuttle service is implemented to operate in 16 zones which are in the periphery of the city as shown in Figure 3.1. For each of the zones, one AUSS fleet is defined as a new transport mode. This implementation is necessary to prevent inter-zonal trips with the vehicles. Starting locations for the AUSS were randomly selected inside these 16 zones. The routing becomes by the implementation of 16 additional modes very complex and it would require a lot of iterations until an agent would get the correct AUSS mode chosen for his/her plan. Therefore, the choice of transportation modes is restricted in the way that only the AUSS mode could be used, which operates in the zone of destination or origin of an agent's trip.

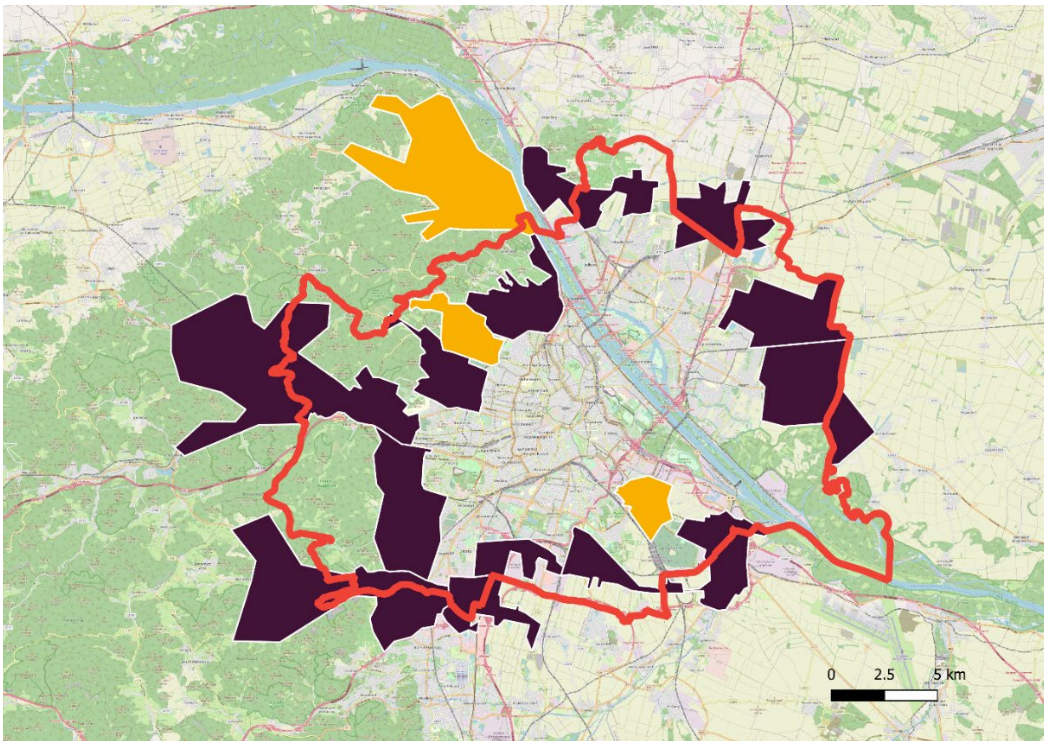


Figure 3.1: Last mile shuttles Vienna. The yellow zones indicate the areas of analysis.

The zones are chosen in the way that at least one train or subway station with good connections to the inner city was within one zone. Zones also include larger areas when continuous settlement is evident in the periphery.

Two different fleet sizes of 1,118 and 2,338 vehicles are simulated, in addition to two of the eight settings of market penetration rates (Table 4.2): the no automation (A) and full automation (H) market penetration rate. The AUSS fleet sizes have been created in dependence of the number of facilities (locations where agents can perform an activity) in the zones.

Table 3.2: Market penetration rates and their flow capacity factors. Scenarios with setting A (no automation) and H (full automation) are presented in this case study.

Type of Vehicle	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Human-Driven Car	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%
Flow capacity Factor	0.1150	0.1205	0.1262	0.1317	0.1368	0.1413	0.1413	0.1413

3.1.3 Zone descriptions

Zone Simmering

The zone Simmering is located around the S- and U-Bahn station “Simmering” in the 11th district of Vienna. In addition to the good connection with subway services, a good connection of busses and trams ensure direct connections to the center and other peripheral areas in less than 30 minutes. In the modal split, the attractive service becomes very visible (Figure 3.1). The 11th district is characterized by an average population density of 4200 people/km^2 which is about the Viennese average. The average age of 39.2 years is the lowest in Vienna. The share of academics is comparatively low at less than 15% (Stadt Wien, Simmering in Zahlen - Statistiken, 2022).

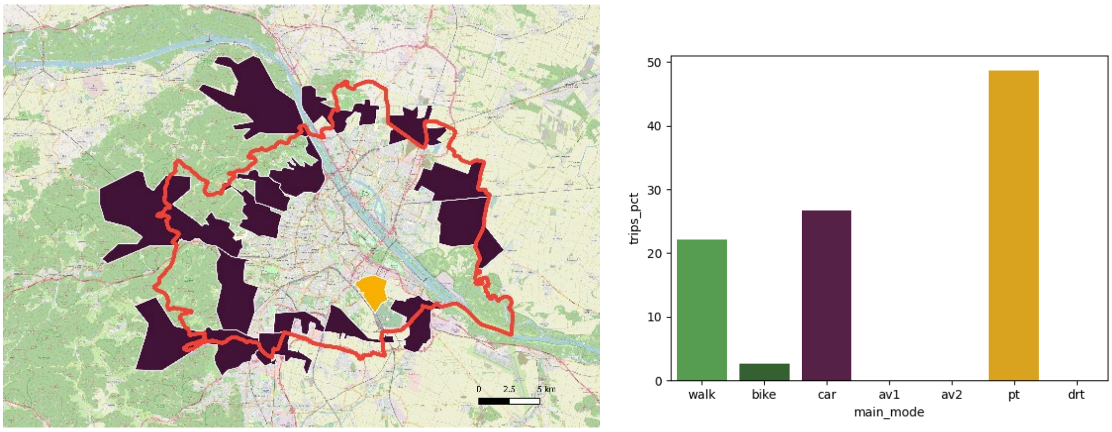


Figure 3.2: left: Simmering indicated on the map as yellow zone; right: modal split in the baseline (no automation, no AUSS).

Zone Währing

The zone Währing is located North-West of the S-Bahn station "Gersthof" in the 18th district of Vienna. Some less frequent bus lines connect the outer areas in the district with the S-Bahn and the further away subway lines. The 18th district is characterized by an average population density of around 8000 people/km^2 but the denser parts are located outside of the zone. Due to the rather poor public transit connection and absence of frequent subway lines, people do most of their trips by car (Figure 3.2). The average age of 41.7 years corresponds to the average age in Vienna. Almost 50% of the population are academics (Stadt Wien, Währing in Zahlen - Statistiken, 2022).

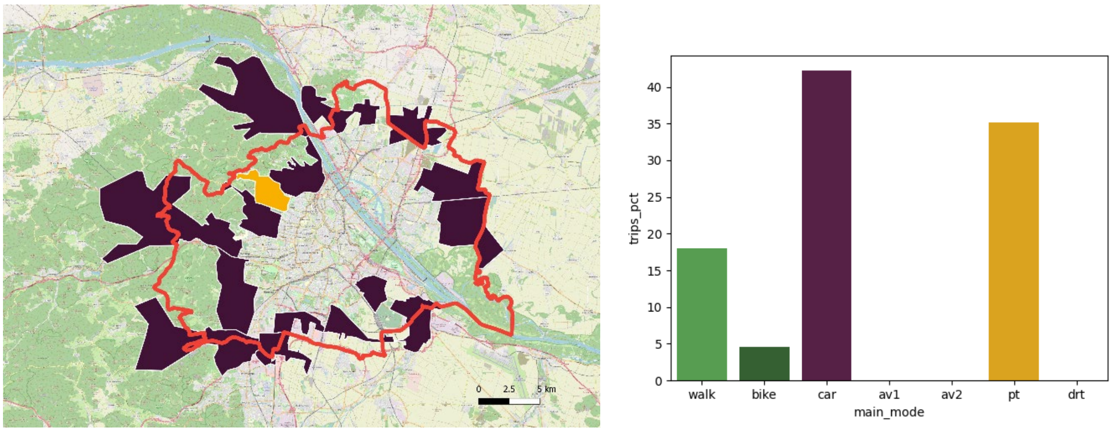


Figure 3.3: left: Währing indicated on the map as yellow zone; right: modal split in the baseline (no automation, no AUSS).

Zone Klosterneuburg

The zone Klosterneuburg covers the area of the town right outside of the city of Vienna. There is a frequent train service connection to the Vienna city, but trips to the city center take more than 30 minutes including changing times. Car is the dominant mode of transport used for trips in and out of the zone (Figure 3.3). The covered area of the zone is one of the largest considered in the last-mile shuttle scenarios, as people mainly do not live in multi-storey houses, but in less dense houses. This is also reflected in the population density, which at 360 persons/km² is less than 10% of the density in Vienna. The average age is 44.9 years (Amt der NÖ Landesregierung, 2022).

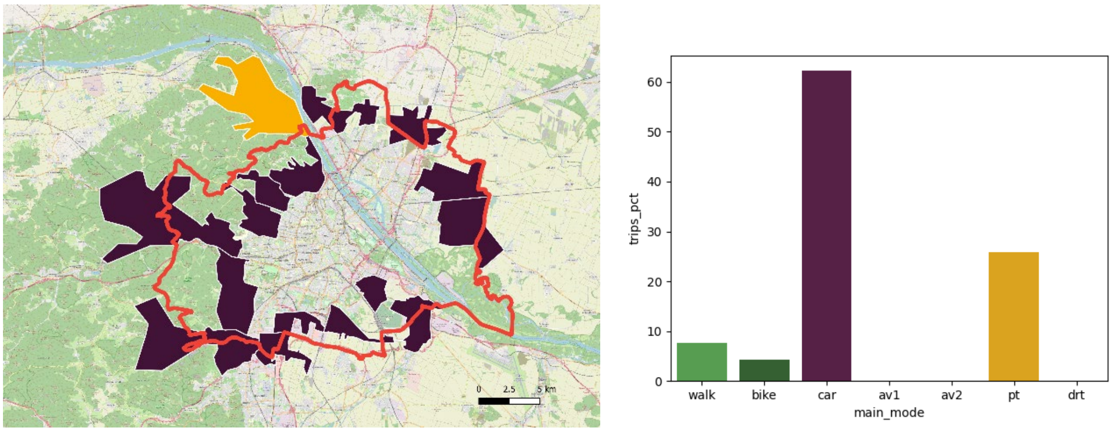


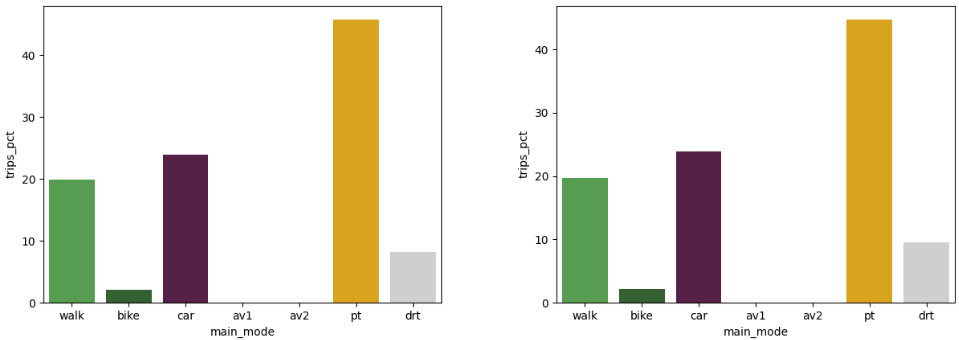
Figure 3.4: left: Klosterneuburg indicated on the map as yellow zone; right: modal split in the baseline (no automation, no AUSS).

3.1.4 Impacts

Three impacts are described in this case study. Whereas modal split and modal shift are presented by the zone, the socio-demographic characteristics are described per parameter. At the end of the analysis of the socio-demographics, the results from the transferability approach are described. In all figures and tables, the last mile AUSS is referred to demand responsive transport (drt) service since drt is the general technical term of the implemented mode in the simulation.

Modal split: Simmering

The modal split for the last mile AUSS reaches up to 12% in the scenario with a large fleet size and full automation of the private car fleet (Figure 5). A large fleet size has a similar impact than the full automation of private vehicles. The better use of the AUSS vehicles can be explained with a better traffic flow in the road network. Doubling the fleet size does lead to about 25% more trips with AUSS. AUSS trips can also be considered as public transit since they are meant to be used as public transit connection for the first and last mile. This means in consequence that the public transit increases in all scenarios.



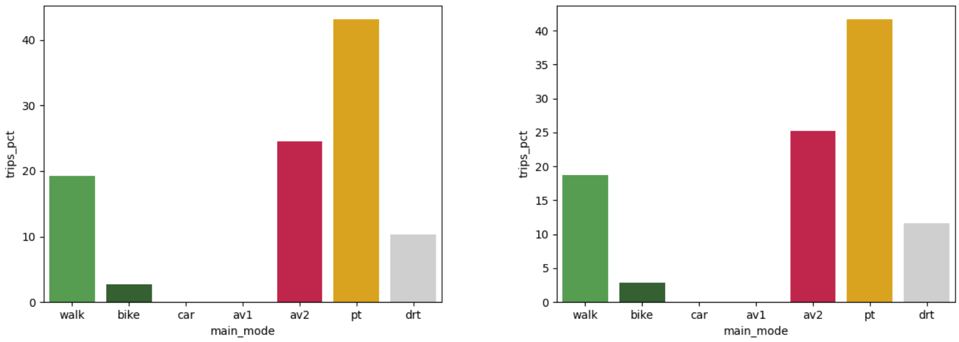


Figure 3.5: Modal Split for zone Simmering. top left: scenario A (no automation), small fleet; top right: scenario A (no automation), large fleet; bottom left: scenario H (full automation), small fleet; bottom right: scenario H (full automation), large fleet.

Modal split: Währing

The modal split for the last mile AUSS reaches up to 9% in the scenario with a large fleet size and full automation of the private car fleet (Figure 6). A large fleet size has slightly less impact than the full automation of private vehicles. Doubling the fleet size does only lead to a small increase of trips with AUSS which means that the demand is already fulfilled with a small fleet size. Similar as in Simmering, considering AUSS as part of the public transit means an increase of public transit trips.

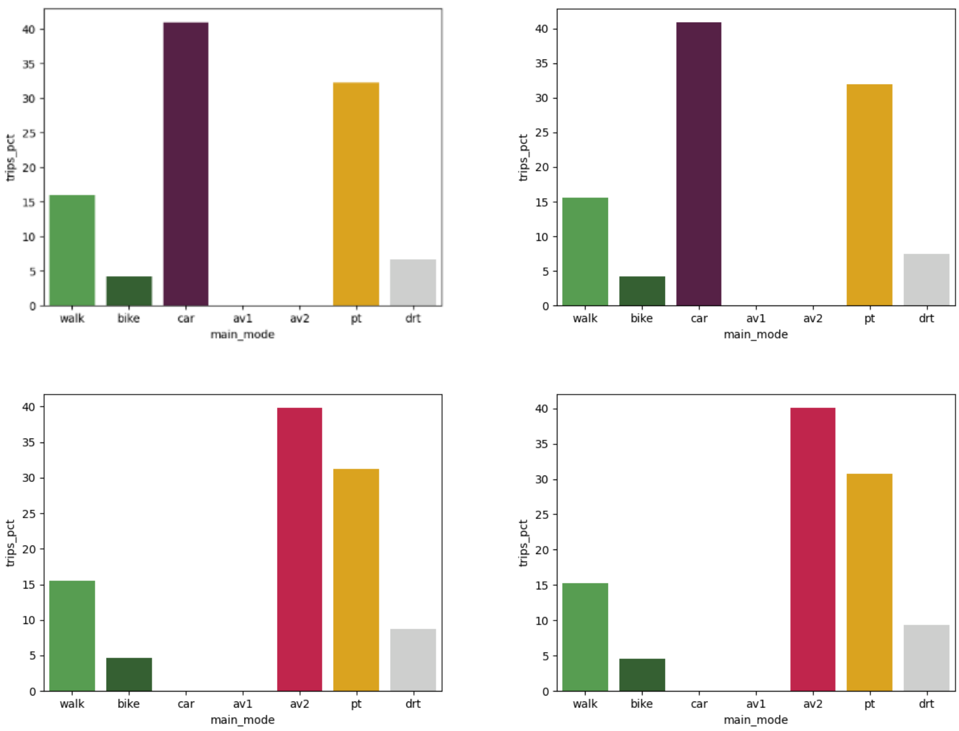


Figure 3.6:Modal Split for zone Währing. top left: scenario A (no automation), small fleet; top right: scenario A (no automation), large fleet; bottom left: scenario H (full automation), small fleet; bottom right: scenario H (full automation), large fleet.

Modal split: Klosterneuburg

The modal split for the last mile AUSS in Klosterneuburg is the highest compared to the other two zones and reaches up to 20% in the scenario with a large fleet size and full automation of the private car fleet (Figure 7). A large fleet size has a slightly higher impact than the full automation of private vehicles. The reason is assumed to come from the fact that the traffic flow in the less dense area of the town is not significantly improved by the higher automation of private vehicles. Doubling the fleet size does lead to an around 25% increase of trips with AUSS. Considering AUSS as part of the public transit means a strong increase of public transit trips since the level of the conventional public transit remains on a similar level compared to the baseline.

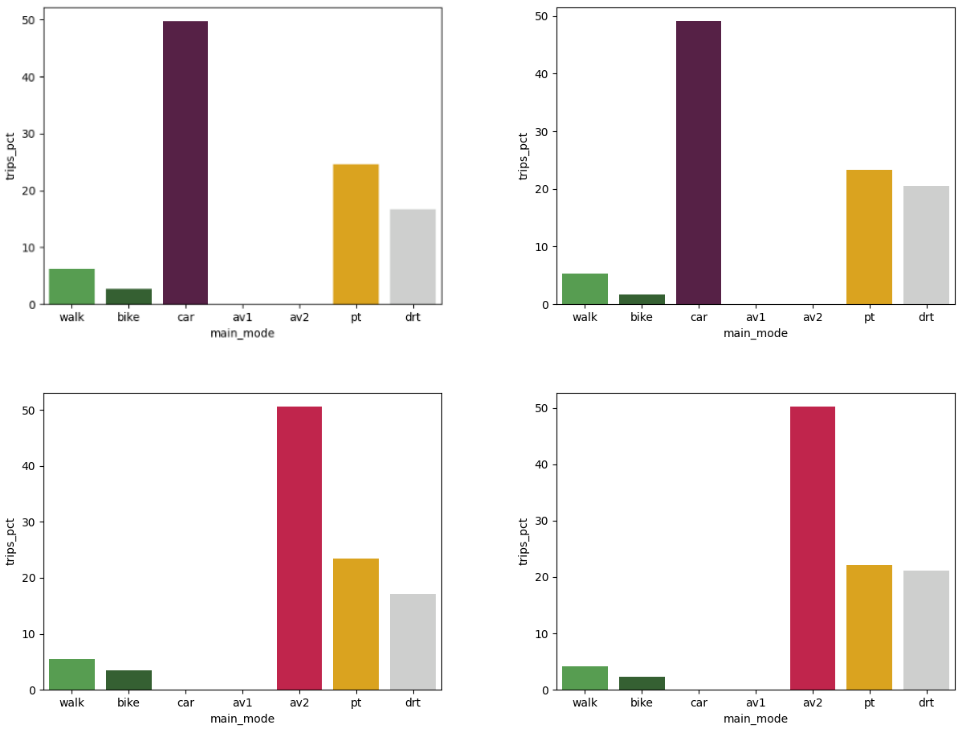


Figure 3.7: Modal Split for zone Klosterneuburg. top left: scenario A (no automation), small fleet; top right: scenario A (no automation), large fleet; bottom left: scenario H (full automation), small fleet; bottom right: scenario H (full automation), large fleet.

Modal shift: Simmering

In these sections, the modal shift for the three zones is described in more detail. The reference scenario is the according baseline scenario when no last mile AUSS is implemented. The visual presentation of the mode shifts is similar for all scenarios which is why only the full automation and large AUSS fleet is shown. The number are percentage in relation to the reference main mode of the row. For instance, if the figure shows a change of 10%, it means that 10% of the trips that were done in the reference scenario indicated in the row are done in the analyzed scenario by the mode indicated in the column.

The main mode of most of the trips remain the same (Figure 8). For the walk trips, a comparatively high share shifts to the new shuttle service. Most of the AUSS trips in the analyzed scenario are done in the baseline by public transport. This does not necessarily mean that they are entirely replaced since the main mode AUSS is the higher hierarchy in the classification. The percentage of car trips that are replaced by the new service appears on the first sight low but can still have a large impact since car trips are in average longer than trips with any other mode.

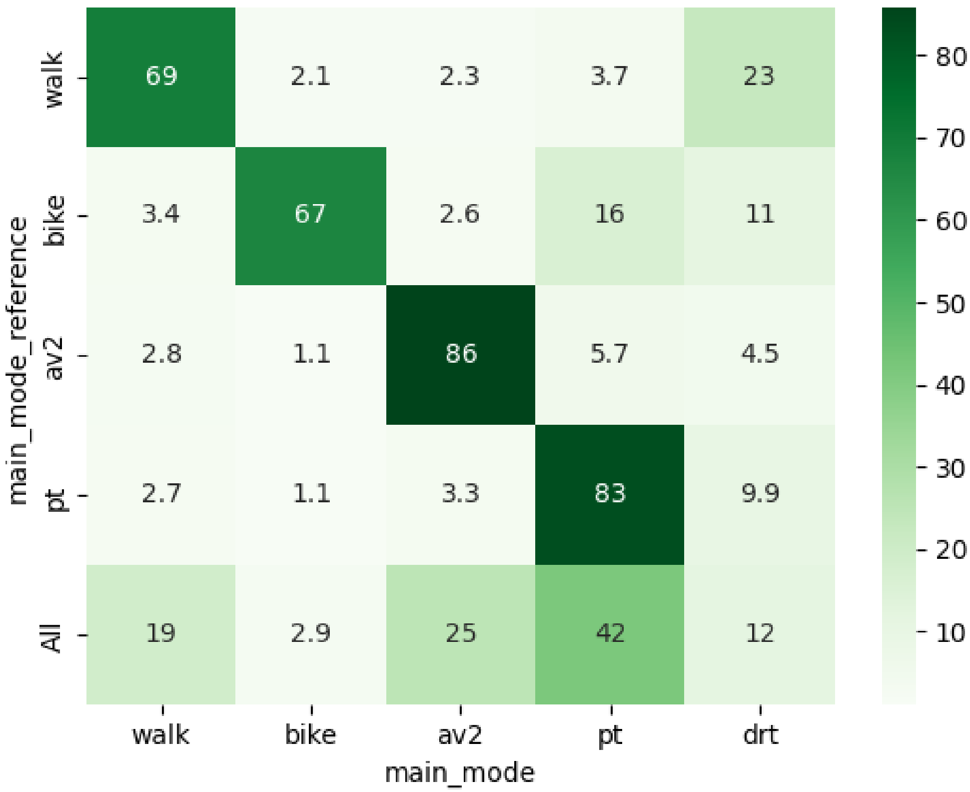


Figure 3.8: Modal Shift for Simmering in scenario H (full automation), large scale. The scale is in percentage of trips in relation to the reference mode (indicated in the row).

Modal shift: Währing

A very similar result to the zone of Simmering is found in Währing. Again, the introduction of the last mile AUSS does not lead to drastic mode shifts for most modes (Figure 9). For the walk and bike trips, a comparatively high share shifts to the new shuttle service. In the same way as in Simmering, most of the AUSS trips in the analyzed scenario are done in the baseline by public transport. The percentage of car trips that are replaced by the new service is also in this zone on the first sight quite low.

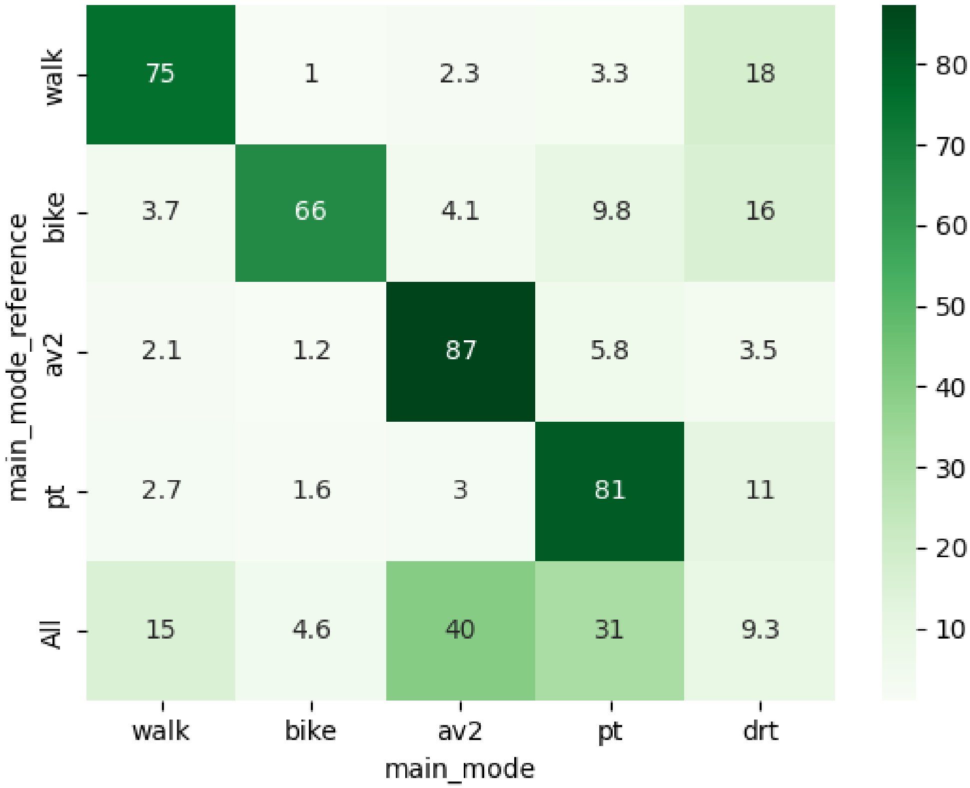


Figure 3.9: Modal Shift for Währing in scenario H (full automation), large scale. The scale is in percentage of trips in relation to the reference mode (indicated in the row).

Modal shift: Klosterneuburg

For the zone Klosterneuburg, a different pattern for mode shifts is apparent (Figure 10). The introduction of last mile AUSS influences the walk and bike trips. Although these active modes do not have a large share, they are expected to be partially converted to drt trips. The cannibalization of these trips by AUSS is not surprising because they are mostly trips within the zone. The AUSS shuttle provides a convenient option to replace the longer walk and bike trips in this area with a high spatial expansion. The comparatively high shift of public transit trips towards the last mile AUSS are likely to come from intermodal trips (AUSS+public transit) which are categorized as AUSS due to the hierarchy in the main mode definition. Though a lot of car drivers do not change their behavior, AUSS can attract about 10% to use the service. This is remarkable especially in the context that most of the trips (around 60%) are done in the baseline by car.

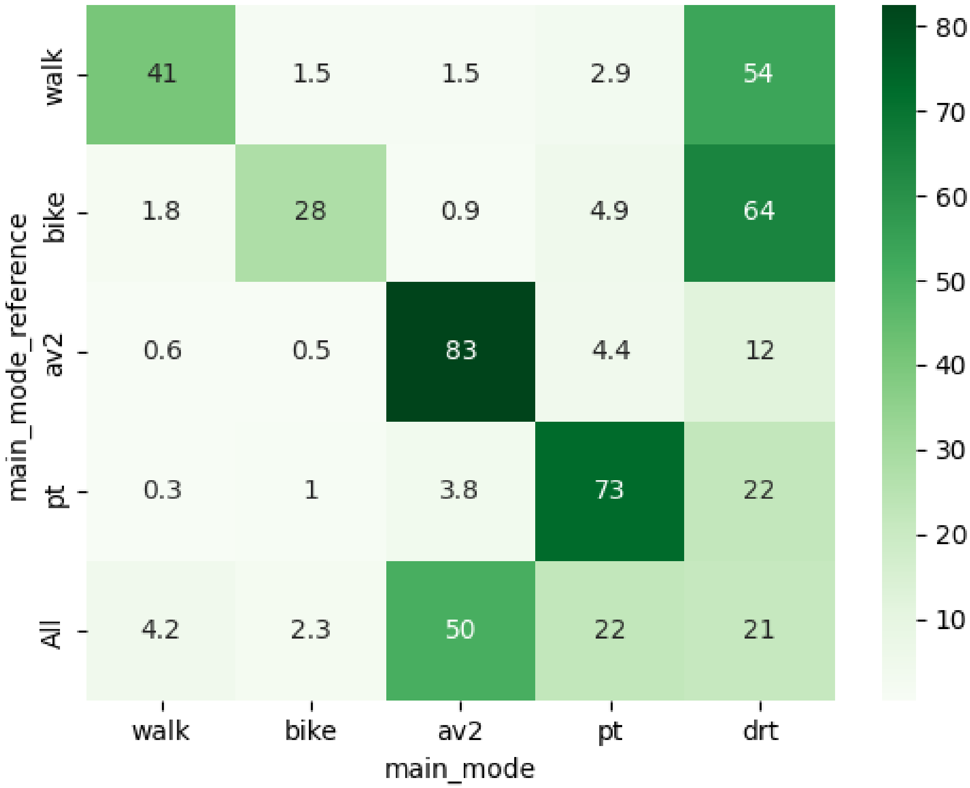


Figure 3.10: Modal Shift for Klosterneuburg in scenario H (full automation), large scale. The scale is in percentage of trips in relation to the reference mode (indicated in the row).

3.1.5 Conclusions

The last-mile AUSS would be very popular in the suburbs of Vienna. In the considered scenarios, a modal shift towards this new service of up to 20% can be achieved. In the zones within the city limits, the modal split reaches up to 12%. The analysis of modal shifts shows that a high share of active modes (walking, bike) are cannibalized according to their modal split. The shift from walking and bicycling trips is more pronounced in the suburbs, where trips within the zones are also replaced by the last mile AUSS. When public transit is considered as part of conventional public transportation, this segment will increase compared to the baseline scenarios.

A detailed analysis on the socio-demographic data dealing with car and bike availability, employment status, gender, etc. is presented in the full case study report (Müller 2022). From these data, it is also possible to transfer the results to other zones or cities on the basis of the user characteristics and how their socio-demographics explain the usage of last mile AUSS.

3.2 Automated ride sharing

This case study investigates the impacts of introducing CAVs as a shared mobility service on mobility and the environment through microsimulation assessment methods. The proposed service combines ridesharing and fully autonomous vehicles operating in two different networks: the city centre area of Leicester and a suburban area in Greater Manchester (United Kingdom) and Leicester (United Kingdom). The proposed service is considered to be a door-to-door service, with shared autonomous vehicle (SAVs) picking up passengers from their origins and dropping them off at their destinations within a certain time frame. A SAV could be used for individual or shared rides within this service, depending on the passengers' willingness to share (WTS) their rides with others. The WTS factor could significantly impact the overall performance of the service and the network. For this reason, the impact due to this factor is investigated at various aggregated levels of WTS.

3.2.1 Model and Methodology

The methodology used for this case study is based on operational research and microsimulation methods. Traffic simulation has been widely applied to estimate the potential impacts of connected and automated vehicles. As identified in LEVITATE Deliverable on Impact Assessment Methods (Elvik et al., 2020), many studies have used microsimulation technique to estimate the potential impacts of CATS on traffic performance indicators. Within this case study, the traffic microsimulation method is used to model and analyse the impact of automated shared mobility service.

Operational research mainly consists of optimisation algorithms for vehicle routing problem (VRP), where the goal is to calculate the optimal route or set of routes at the lowest possible cost (or often also the shortest possible distance or time). For this case study, the automated ridesharing service is modelled as a Vehicle Routing Problem with Pickup and Delivery with Time Window (VRPPDTW) (Mahmoudi & Zhou, 2016), which is a variant of the VRP that considers time frames and different pick up/drop off locations of trip requests. The optimisation process assigns trip requests with SAVs and generates optimised routes for SAVs, which will be used as input to the microsimulation model. It also provides other factors such as fleet size and empty travelled distance that will help assess the efficiency of the service.

By performing the optimisation process to solve the problem, a set of data have been extracted from the micro-simulation model of the study areas and used to generate input to the optimisation process, such as depots' locations, trip requests, pick up and drop off time windows, etc. It was assumed that demand for this new service would replace a share of personal vehicle demand. Google's OR-Tools (Perron & Furnon, 2019) was used to solve the VRPPDTW problem to assign routes for SAVs to pickup and drop-off passengers. The details of implementation method are presented in the deliverables of WP6: D6.2 (Haouari et al., 2021), D6.3 (Sha et al., 2021) and D6.4 (Chaudhry et al., 2021).

Leicester city center model

A traffic microsimulation model (developed using AIMSUN software) of the city of Leicester, was used to evaluate the impacts of ARS introduction. The Leicester city centre network is around 10,2km² and consists of 788 nodes and 1 988 sections with an OD matrix of 183x183. The traffic demand for passenger cars, large good vehicles (LGV) and heavy good vehicles (HGV)are 23 251 trips, 3 131 trips and 16 trips, respectively. Public transport service was also considered for this network with around 73 bus lines. The network is presented in Figure 3.11.

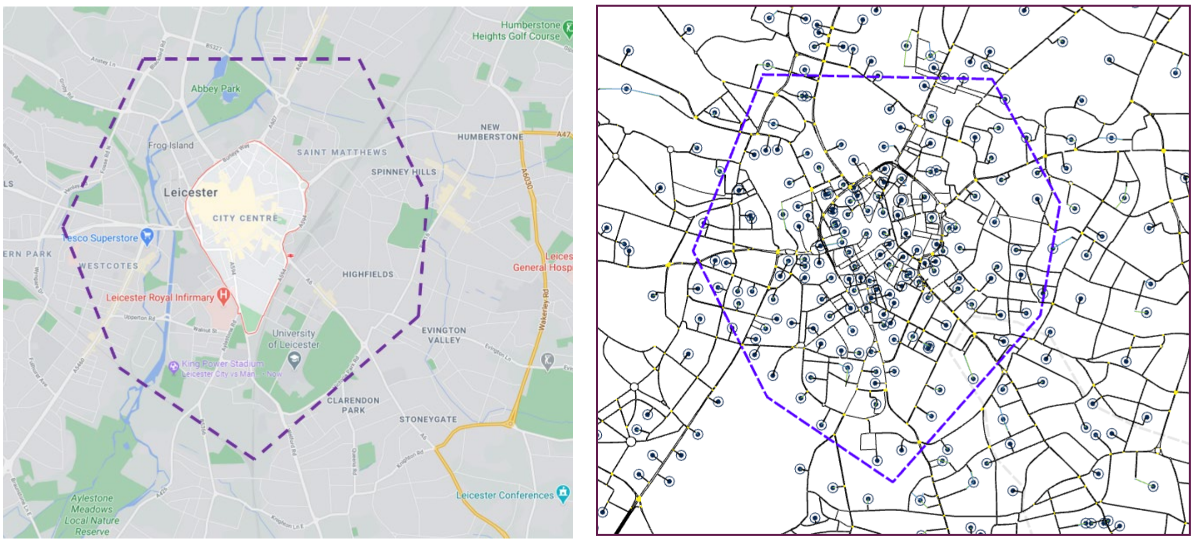


Figure 3.11: The Leicester city centre network in AIMSUN software

Manchester

To illustrate the potential benefits of the proposed ride-sharing service, a calibrated and validated microsimulation model (developed using AIMSUN simulation platform) was used. The network is around 13km² and it is part of the Great Manchester Area (UK). The model contains 308 nodes and 732 road sections, and of 58x58 centroids OD matrix. Traffic data of evening peak hours (1700 – 1800) was used, with an estimated traffic demand of 23 226 car trips, 1 867 large goods vehicles (LGV) trips, and 63 heavy goods vehicle (HGV) trips.

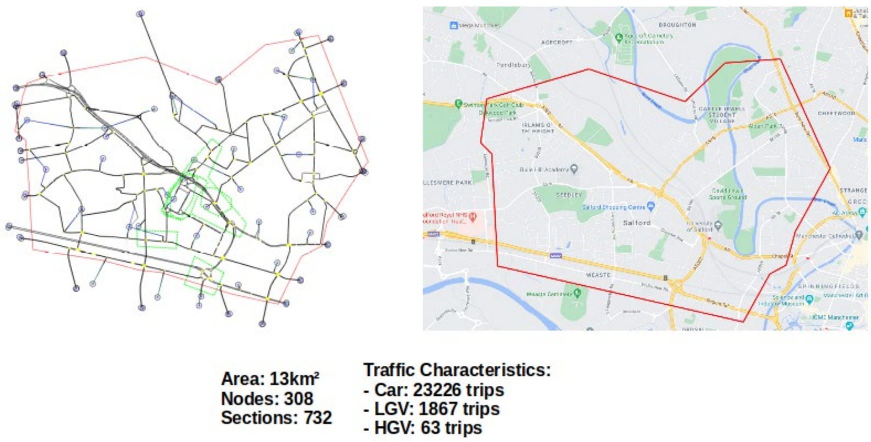


Figure 3.12: The Manchester network in AIMSUN software

CAV modelling
Within the Levitate project, two types of CAVs were considered: 1st and 2nd Generation CAVs. Both types are assumed to be fully automated vehicles with level 5 automation. The main idea behind modelling these two types is based on the assumption that technology will advance over time. Therefore, 2nd Generation CAVs will have improved sensing and cognitive capabilities, decision making, driver characteristics, as well as anticipation of incidents compared to 1st Generation CAVs. The main assumptions made on CAVs characteristics are as follows:

- 1st Generation CAV: limited sensing and data processing capabilities, long gaps, early anticipation of lane changes than human-driven vehicles and longer time in give way situations.
- 2nd Generation CAV: advanced sensing and data processing capabilities, data fusion usage, small gaps, early anticipation of lane changes than human-driven vehicles and less time in give way situations.

These characteristics were defined through various model parameters in AIMSUN Next (Aimsun, 2021) including reaction time, time gap, acceleration and deceleration characteristics, parameters related to lane changing and overtaking behaviour and several others. More details on the parametric assumptions and key values of parameters could be found in (Chaudhry et al., 2022a).

The ARS is evaluated using microsimulation modelling based on the city centre network of Leicester (United Kingdom). The impact of this service was analysed under short term deployment scenarios where AVs are integrated into a ride-sharing service and share the road with conventional vehicles, i.e., analysing the current situation with automated ridesharing service.

3.2.2 Scenarios

Within this case study, the impact of an automated on-demand mobility service was studied under the following scenarios:

Baseline scenario
Baseline scenario models the traffic with the current situation, without any automated ridesharing services or automation considered.

Automated ride-sharing service
In this scenario, an automated ride sharing service is introduced into an urban environment with a traditional vehicle fleet in the background traffic. For this scenario, the automation is only considered for the SAV fleet, while the other vehicle types in the network are considered to be human-driven vehicles. It was assumed that demand for this new service would replace a share of personal vehicle demand. A share of 5% has been assumed. Concerning the travellers willing to share their rides (WTS), three levels were considered: 0%, 50%, and 100%. The combination of the different levels of demand to be served by SAVs, WTS and CAV technologies (1st and 2nd Generation CAVs) gives the following sub-scenarios:

1. 5% demand for 1st generation shared CAVs: 5% of the total private vehicle travel demand (trips) is replaced by SAVs trip, with a variable WTS (0%, 50%, 100% of travellers).

2. 5% demand for 2nd generation shared CAVs: 5% of the total private vehicle travel demand (trips) is replaced by SAVs trip, with a variable WTS (0%, 50%, 100% of travellers).

Assumptions
The following assumptions have been made for this case implementation:

- In case CAV and SAVs are EVs, the battery capacity can support full-day operations.
- Parking spaces are enough for all SAVs in each station,
- The pick-up and drop-off locations and behaviour will not be addressed in this sub-use case,
- Preference for ridesharing is presented as a parameter with two statuses (Yes, No),
- Cancellation of assigned SAV is not allowed,
- An SAV request refers to one traveller.
- The capacity of a SAV (4-seater car),

3.2.3 Impacts

This chapter summarises the optimisation and simulation results of the introduction of an automated ridesharing service. The mobility and environmental impacts are the main focus of this case study. Fleet size, driven km, as well as travel time and delay are considered for assessing the impact on mobility, while Carbon Dioxide (CO_2), Nitrogen Oxides (NOx) and Particulate Matter (PM) are used as indicators for environmental impact.

Fleet size and driven km
Table 4.2 presents the optimisation results for the Manchester and Leicester network for the different passenger willingness to share (WTS) studied within this case study. The results indicate that the fleet size required to replace conventional personal vehicle trips gradually decreases as more passengers are willing to share their rides. The decrease in the number of required SAVs is associated with an increase in the number of conventional vehicles that one SAV can replace. Regarding SAV driven kilometres, the results show that a higher WTS reduced the total and empty travelled distance covered by the SAV fleet in both networks. The results also revealed that with a higher willingness to share, the empty driven kilometres will be gradually decreaseed.

Table 3.3: Optimisation results for Manchester and Leicester network

Network	No of trips	Willingness to share	Optimal SAV Fleet size	SAV Replacement Rate *	SAV Total Driven km	Empty driven km
Manchester	1134	0%	682	1,66	5924,95	2998,50
		50%	570	1,9	5344,72	2435,30
		100%	435	2,6	4420,16	1554,17
Leicester	937	0%	730	1,28	3792,63	2084,05
		50%	663	1,41	3574,37	1880,42
		100%	547	1,71	3167,84	1529,42
(*) Number of personal vehicles replaced by one shared AV (SAV)						

The network total distance travelled results obtained from microsimulation are shown in Table 4.2 and Figure 4.3. It suggests that the impact of automated ride sharing deployment depends on CAVs technology (1st or 2nd generation CAVs) as well as the passengers' willingness to share (their preference of using this service as an individual or shared trip service).

Table 3.4: Impact on total distance travelled due to ride sharing service for Manchester and Leicester network

Willingness to share	Manchester		Leicester	
	km	% Change (*)	km	% Change (*)
Baseline	56545,82	---	50958,65	---
1st Generation SAV				
0%	52228,40	-7,64%	52689,45	3,40%
50%	54455,28	-3,70%	51694,12	1,44%
100%	55444,51	-1,95%	49760,92	-2,35%
2nd Generation SAV				
0%	53104,99431	-6,09%	51891,07	1,83%
50%	55017,08885	-2,70%	52922,35	3,85%
100%	54668,5475	-3,32%	51952,69	1,95%

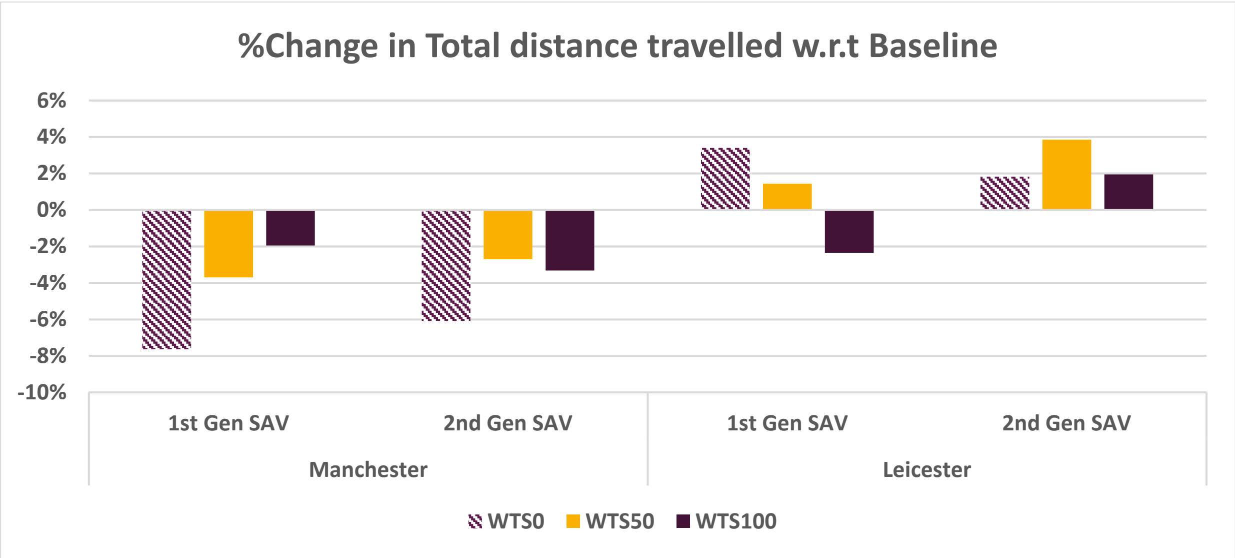


Figure 3.13: percentage change in total travelled distance with regards to baseline scenario in the case automated ridesharing mixed with conventional for Manchester and Leicester network (5% SAV demand)

The results showed an increase of the total of the total driven kilometer.

Impact on congestion

The average delay and travel time have been chosen as key KPIs to estimate the impact on congestion for this case study.

Introducing an automated ridesharing service has triggered an increase in delay and travel time in both networks compared to their corresponding baseline (current situation). The results also indicate that the increase in the studied KPIs is strongly, inversely related to the rate of travellers' willingness to share their trips as well as the CAV technology, since the increase reduces with the high level of WTS and with advanced CAV (2nd generation CAVs).

The results suggested that with a low willingness to share, there is an increasing impact on delay time compared with a high willingness to share rate. For example, under full MPR (0-0-100), the delay time decreases from 101,37 sec/km (+29%) with 20% willingness to share to 104,54 sec/km (+3%) when all served travellers are willing to share their rides. One of the most important potential reasons for the increasing impact on delay time is the increased number of trips and the empty VKT caused by making repositioning trips to reach new travellers. The circulating behaviour of shared vehicles (SAV) could also explain this increasing trend since they tend to use low capacity and/or secondary roads to reach their destinations, causing more traffic congestion (Overtoom et al., 2020). The results suggest that this negative impact could be reduced if more travellers are willing to use the proposed service as a shared-trip instead of an individual-trip service.

Table 3.5: impact on traffic flow due to ride automated ride sharing service for Manchester network

Willingness to share	All	%Change(*)	Passenger Car + SAV	%Change(*)	Freight vehicle	%Change(*)
Baseline	21556,7	--	19319,6	--	2237,1	--
1st Generation SAV						
0%	19609,4	-9,0%	17563,1	-9,1%	2046,3	-8,5%
50%	20239	-6,1%	18100,3	-6,3%	2138,7	-4,4%
100%	20599,8	-4,4%	18426,8	-4,6%	2173	-2,9%
2nd Generation SAV						
0%	19908,5	-7,6%	17832,3	-7,7%	2076,2	-7,2%
50%	20507,1	-4,9%	18341,3	-5,1%	2165,8	-3,2%
100%	20398,9	-5,4%	18250,8	-5,5%	2148,1	-4,0%
(*) Percentage change with regards to baseline						

Table 3.6: impact on average number of vehicles due to automated ride sharing service for Leicester network

Willingness to share	All	%Change(*)	Passenger Car + SAV	%Change(*)	Freight vehicle+ PT	%Change(*)
Baseline	24340,3	--	21301,6	--	3038,7	--
1st Generation SAV						
0%	24418,4	0,36%	21321,4	0,10%	3097	1,92%
50%	23963	-1,75%	20930	-1,92%	3033	-0,19%
100%	23243,3	-5,09%	20304,1	-5,16%	2939,2	-3,27%

The increase in travel time is mainly caused by additional empty trips due to SAVs causing negative impact on traffic flow. Another contributory factor is the circulating behaviour of SAVs that tend to use low capacity and/or secondary roads to reach their destinations impacting the overall network performance. These results are in line with the findings of Overtoom, Correia, Huang, & Verbraeck (2020).

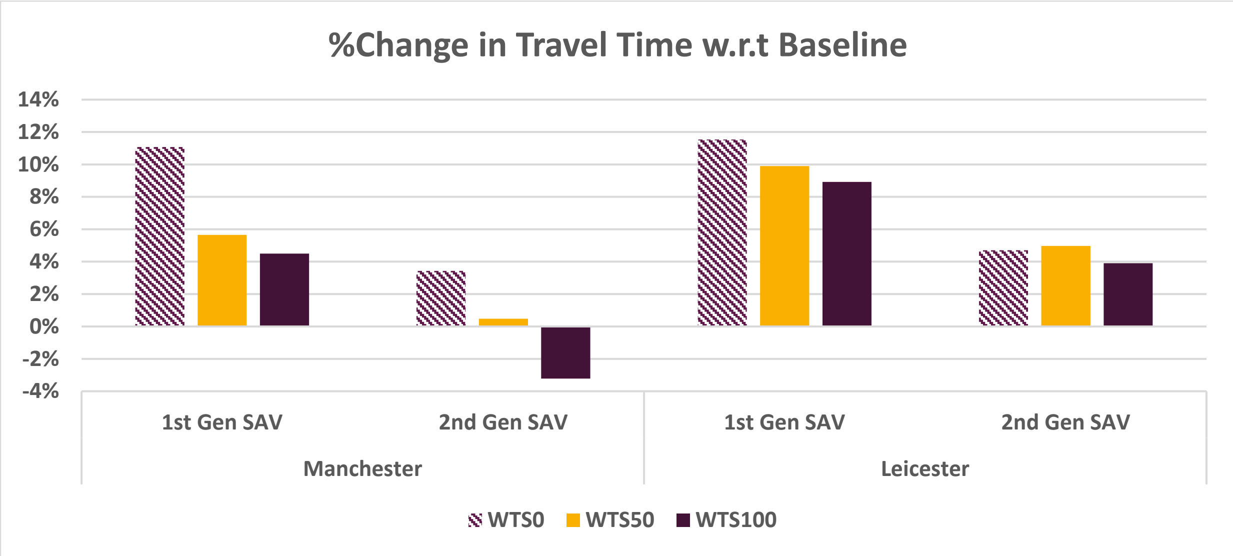


Figure 3.14: percentage change in average travel time with regards to baseline scenario in the case automated ridesharing mixed with conventional for Manchester and Leicester network (5% SAV demand)

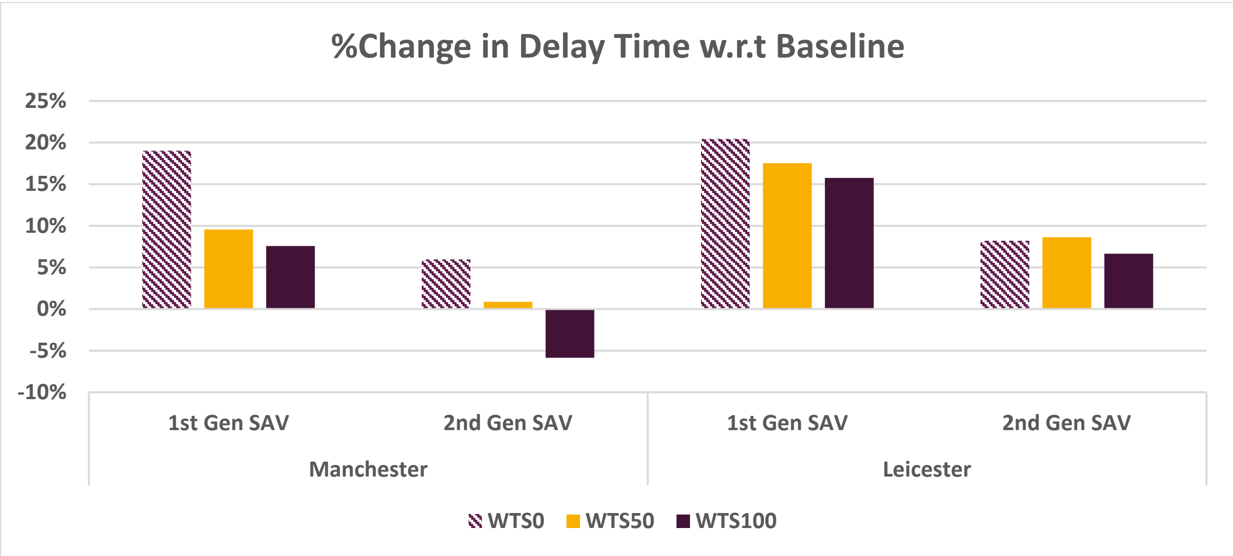


Figure 3.15: percentage change in average delay time with regards to baseline scenario in the case automated ridesharing mixed with conventional for Manchester and Leicester network (5% SAV demand)

Environmental Impacts

The environmental impacts were directly obtained from the AIMSUN Next microscopic simulation for automated ridesharing. AIMSUN Next simulation provides four emission models, out of which Panis, Broekx, and Liu (2006) emission model has been chosen for LEVITATE project. The Panis et al. (2006) emission model computes instantaneous pollution emissions caused by acceleration or deceleration and speed for all the vehicles in the simulation (AIMSUN, 2021). More specifically, this model considers three emission indicators named Carbon Dioxide (CO2), Nitrogen Oxides (NOx) and Particulate Matter (PM).

The emission results are displayed in Tables 3.7 and 3.8 in terms of percentage changes with regard to baseline (current situation). Table 3.7 represents the results where SAVs are assumed to be combustion engine vehicles, while Table 3.8 represents the results for electrical SAVs.

Table 3.7: Percentage change in CO2, NOx and PM emissions with respect to baseline scenario- combustion engine SAV.

Willingness to share	Manchester			Leicester		
	CO2	NOx	PM10	CO2	NOx	PM10
1st Generation SAV						
0% WTS	0.94%	5,23%	-4,03%	6,20%	6,79%	6,91%
50%WTS	0.47%	2,38%	-2.28%	4,29%	5,68%	4,25%
100% WTS	0.20%	1,60%	-1.37%	2,87%	5,90%	1,84%
2nd Gen SAV						
0% WTS	-0,71%	2,69%	-4,90%	2,93%	3,85%	3,04%
50%WTS	-0,38%	1,71%	-2,81%	3,55%	3,29%	4,52%
100% WTS	-1,40%	-0,04%	-3,18%	2,32%	2,71%	2,82%

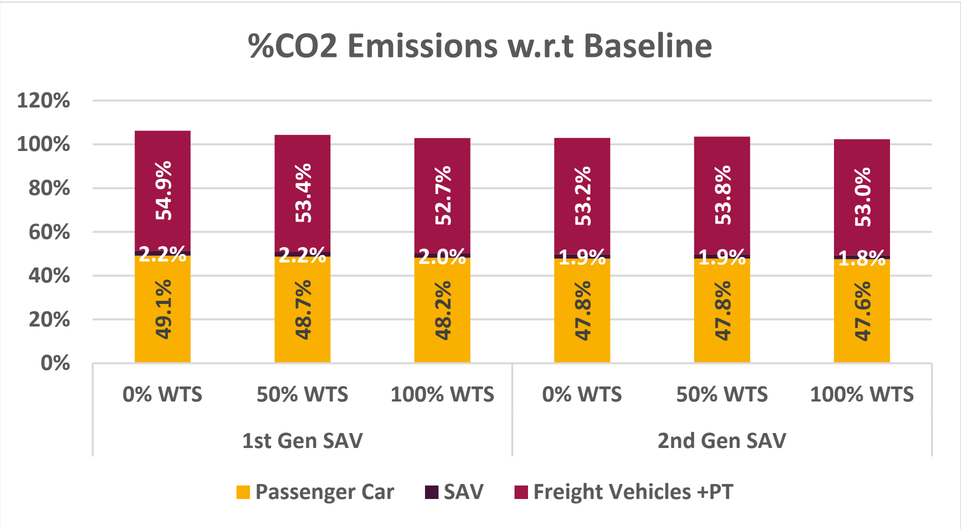
Table 3.8: Percentage change in CO2, NOx and PM emissions with respect to baseline scenario for Manchester and Leicester networks- Electrical SAV fleet.

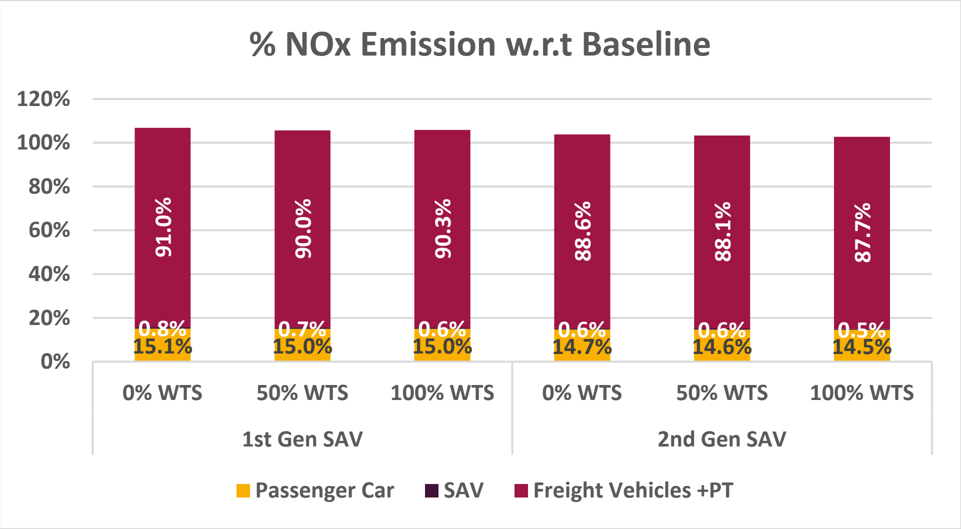
Willingness to share	Manchester			Leicester		
	CO2	NOx	PM10	CO2	NOx	PM10
1st Generation SAV						
0% WTS	-2,11%	4,15%	-7,06%	3,98%	6,12%	4,27%
50%WTS	-2,34%	1,45%	-5,25%	2,12%	5,02%	1,74%
100% WTS	-2,26%	0,08%	-4,03%	0,90%	5,29%	-0,48%
2nd Gen SAV						
0% WTS	-3,46%	1,76%	-7,66%	0,99%	3,27%	0,84%

50%WTS	-2,90%	0,86%	-5,50%	1,63%	2,72%	2,28%
100% WTS	-3,64%	-0,77%	-5,63%	0,55%	2,18%	0,72%

The results show that the three indicators are increasing for the Leicester network. The results also indicate that emissions are reducing with increased passenger willingness to share (WTS) and advanced CAV technology (2nd Generation CAVs). The additional emissions are mainly caused by an improvement in traffic conditions that allows more freight vehicles and public transport into the network, especially with the introduction of 2nd Generation SAVs, which explains why even with SAV electrification, a slight increase could still be observed (Table 3.8). As shown in Figure 4.4 the majority of the additional emissions are attributed to fright and public transport.

Regarding the Manchester network, with 1st Gen combustion engine SAVs (Table 4.6), the results show a slight increase in CO2 and NOx emissions and a decrease in PM10 emissions. While with 2nd Gen combustion engine SAVs, a reduction in terms of CO2 and PM10 emissions and a slight increase in NOx emission which is generally attributed to freight vehicles. The reduction is linked to the reduction of the number of vehicles entering the network caused by congestion.





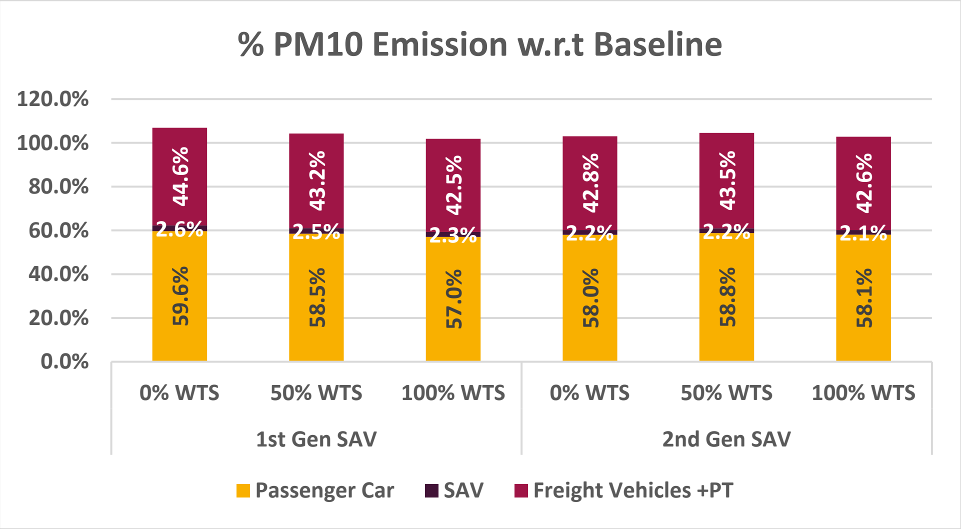


Figure 3.16: Percentage of emission with regards to Baseline scenario for Leicester city centre network

3.2.4 Conclusions

In this case study we studied the automated ride sharing (ARS) service for Leicester and Manchester, where we applied a hybrid methodology for impact assessment. It consists of operations research for the pickup and delivery of passengers and the calculation of the routes performed by the shared autonomous vehicle (SAVs). Microsimulation was used to assess the traffic impacts.

The results are very consistent and shows that the success of the ARS highly depends on the willingness to share (WTS) rate of the population. With a higher WTS, the required fleet size is smaller, the driven km and the travelled distance are lower. These numbers directly affect the impacts on congestion and the environment impacts, where a high WTS benefits the traffic system and a low WTS brings more disadvantages than improvements.

3.3 Road use pricing

With technical progress and the increasing level of automation realized in modern passenger cars, the behaviour and interplay of those vehicles and other road users is bound to change. While conventional vehicles do require parking space at the source and destination of their trips, future implementations of CAVs may not be bound by this constraint. Cities and road authorities in general still require some means to regulate the access of passenger cars to certain areas of governance. For conventional vehicles in densely populated areas this is partly possible by setting the price of parking spaces, which is a widely implemented policy measure. For the anticipated case of CAVs not requiring such parking spaces in the same manner, an adaptive measure based on flowing vehicle traffic becomes necessary to maintain regulatory influence. A flexible road use pricing (RUP) scheme is one of such possible measures.

The presented case study aims at understanding better the practicability of RUP policy implementation and the mitigation of possible unwanted impacts. This is done by comparing policy implementation scenarios against reference scenarios regarding their conditional changes of modal splits. This conditional change is equivalent to the modal shifts.

3.3.1 Model and Methodology

For this CS, the same mesoscopic MATSim simulation model for Vienna is used as in Section 3.1. We use the agent-based activity-chain simulation by defining a tolling area to cover all streets inside the typical ring-road surrounding the inner-city region of an old European city (Vienna, Austria). Within MATSim, RUP is implemented with the "roadpricing" module. A set of transport network links together with sone time-window and price attributes defines the tolling rates for the utilisation of those links and therefore the tolling area within the whole transport network. The module allows pricing based on certain events taking place for each simulated agent that is using a tolled mode of transport, which can be either entering onto a link out of mentioned set or traversing of a given distance on a link.

Assumptions

To analyse the implementation measure of RUP, deployment of automated passenger cars considers each vehicle as a privately owned car. These vehicles are not capable to relocate or carry out rides on their own, thus providing autonomy and driving capabilities only when the owner is aboard.

The travel modes available in the simulation model to sufficiently describe the diverse travel activities are "car" (conventional passenger car), "av1" (automated car, generation 1), "av2" (automated car, generation 2), "pt" (public transport), "bike" (cycling) and "walk". To consider the main transport mode of a trip, the travel mode is classified hierarchically as suggested in the KOMOD manual (Fellendorf, et al., 2011) for any given locomotion between two places of agent activity, with these activities resembling fixed intermediary stops along a daily plan or journey.

The different car fleet partitioning (section 2.4) of CAV of the 1st generation (av1) and CAV of the 2nd generation (av2) is reflected by assigning different utility functions for private cars to shares of the population. Using a AV1 will be treated as 80% of the value of travel time savings (VTTS) of a private car, and a AV2 as 75% the car's VTTS. The private cars will remain the same in regards of their driving behaviour on the road. As the throughput of roads will increase with a higher automation rate due to more densely packed moving vehicles, the simulation model parameter “flow capacity factor” of the road network was adapted to account for this effect. The flow capacity factor is generally set to the percentage of population that is simulated (in our case 12.5%) as it represents the relative number of vehicles that can pass a link (Llorca & Moeckel, 2019).

The rationale behind setting the parameters for AV1 and AV2 is based on studies on the estimation of the VTTS for automated vehicles and shuttles. Whereas (Lu, Rohr, Patruni, Hess, & Paag, 2018) found no differences in the VTTS between drivers and passengers of a car, (Fosgerau, 2019) and (Ho, Mulley, Shiftan, & Hensher, 2015) conclude that the VTTS for a passenger can be regarded as about 75 % of the rate for car drivers. We follow in our model these latter findings and slightly increase the VTTS for AV1 as the driving experience is assumed to be not as convenient as with a AV2.

Zonal segmentation

The whole model region was segmented into distinct ring-shaped domains as depicted in the schematic view in Figure 2.1. The investigation area is defined to lie inside the city limits (everything including domain intra-peripheral and inwards) which is delineated by the investigation perimeter.

A major assumption of the employed model is that such domain structures can be defined for most cities with a comparable structure and evolution.

The four defined domains are:

1. **City centre (CC)**: mostly reduced vehicle traffic areas, restricted entry is common
2. **Inner city (IC)**: containing a densely populated belt around CC with lots of habitation areas
3. **Intra peripheral (IP)**: domain outwards from IC up to the city limits which enclose the actual investigation area; habitation regions, some commercial, light industrial areas, larger recreational zones
4. **Extra peripheral (XP)**: the remainder of the model area, defining the outer boundary and conditions for the inner investigation area

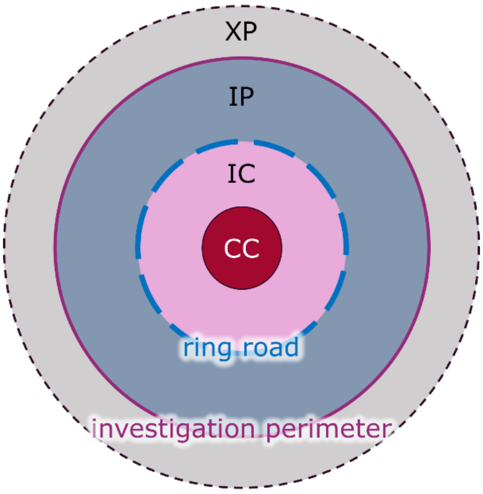


Figure 3.17: Schematic view of the four city domains used for mobility investigations. The domains are city centre (CC), inner city (IC), intra peripheral (IP) and extra peripheral (XP).

For this case study, the area to model RUP implementation scenarios is shown in Figure 2.2 and lies within the inner-city domain and inside the “Gürtel” ring-road of Vienna. Due to conclusions drawn from earlier work on the RUP sub-use-case, an additional belt of 250 metres in width surrounding the tolling area was defined as a region of special interest. This belt allows to study potential traffic displacement effects that might occur due to the introduction of RUP measures.

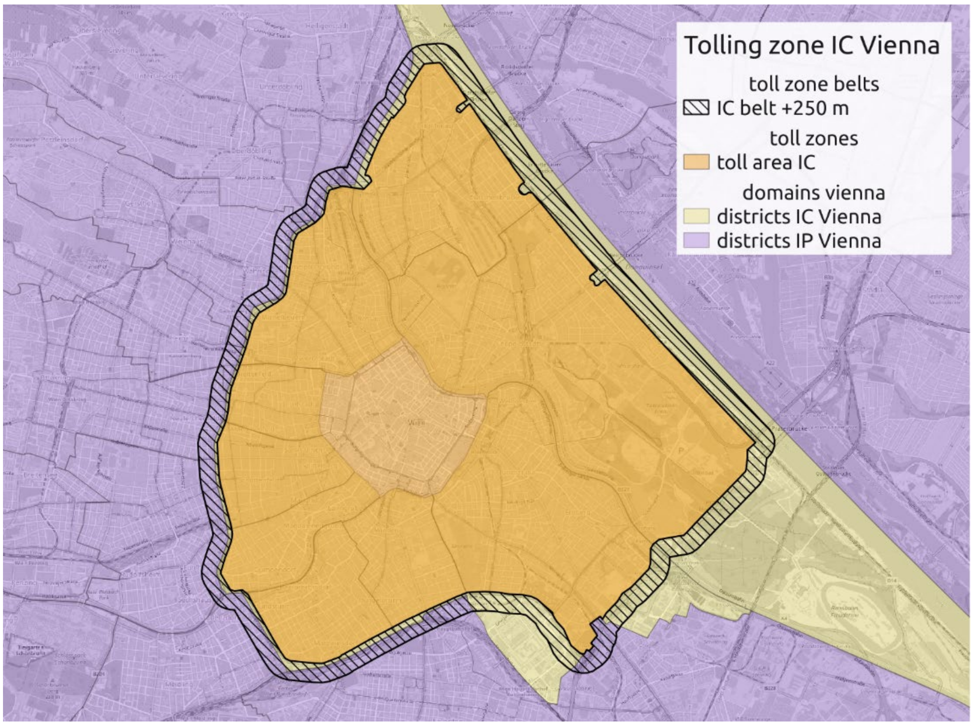


Figure 3.18: The RUP implementation zone as defined for the analyses, within the inner-city domain of Vienna. A surrounding belt area is 250 metres wide and used to study traffic displacement effects.

3.3.2 Scenarios

Car fleet partitions

As was defined throughout the whole project of LEVITATE, different scenarios for the path of increasing adoption of automated passenger cars were chosen to consider the effects on various impacts. Table 2.1 gives an overview of all those scenarios while highlighting those scenarios that were used for the present case study (A, B, E and H).

Table 3.9 The CAV market penetration rate scenarios and the respective shares of AV generations and the anticipated increasing road network throughputs given as flow-capacity-rate. Four highlighted scenarios were used in the case study.

Type of Vehicle	A	B	C	D	E	F	G	H
Conventional "car"	100%	80%	60%	40%	20%	0%	0%	0%
1st Gen. CAV "av1"	0%	20%	40%	40%	40%	40%	20%	0%
2nd Gen. CAV "av2"	0%	0%	0%	20%	40%	60%	80%	100%
Flow capacity rate	0.1150	0.1205	0.1262	0.1317	0.1368	0.1413		

A higher prevalence of CAVs also results in a higher throughput of the road traffic, which is expressed by respective values of the "flow capacity rate".

Static and dynamic tolling

On entry into this area a tolling scheme is applied for all passenger cars, which can be either a **static toll** to be paid once upon entry, or a **dynamic toll** to be paid per traversed unit distance while traveling inside the tolling area.

The different scenarios that were simulated were based on (i) varied tolling charges of {0, 5, 10, 100} €, (ii) dynamic or static tolling, (iii) specific adaptions to the pricing levels based on (a) residential status of car owners in the tolling area and (b) the classification of roads as side-roads. For each of these scenarios, the deployment of two CAV driving profiles (i.e., first and second generation) was also tested for four different vehicle fleet partitionings to represent the expected increasing prevalence of automated passenger cars along the timeline.

Tolling exemption for residents

Accounting for practicability regarding the introduction of RUP measures requires the consideration of exemptions for resident car-owners within the area where such measures are to be implemented. To that effect simulation studies were made to exempt said residents from the payment of tolls and to allow them less restricted access to their homes when using a passenger car. We simulated "standard tolling" (100% toll), and "exemption for residents" (0% toll).

Tolling based on road-class

Facilitating modern location-based service technology e.g., by utilizing navigation systems, a more fine-grained adjustment of RUP measures becomes available. These location aware systems allow the tolling to be defined for regions within the tolling area that charge different prices for residential areas and side roads, while still retaining predictable costs for the vehicle users.

For that matter the roads within tolling area were separated into side roads and arterials. While the arterials were charged at each scenario's defined price levels, the side-roads were charged at levels of 100 % to 200 % of the general price, resulting in uniform tolling or doubled tolling for side roads

3.3.3 Impacts

Two impacts are described in this case study. The modal split and modal shift are presented by the zone. In the figures and tables, the transport mode of a conventional passenger car is designated as *"car"*, while the modes of connected automated vehicles of generation 1 and 2 are designated by *"av1"* and *"av2"*, respectively, which are the terms used in the implemented simulation.

Modal split
In the context of the analyses presented here, the modal split is the relative number of trips that were classified as being of a certain mode, given as percentage. An exhaustive analysis based on these indicative values has been done for the sub-use-case on RUP in accordance with the requirements for the PST and is found in deliverables D6.2 and D6.3. This impact reflects merely a static image of one scenario's trips for a defined trip-set of interest (e.g., for a certain area).

To draw conclusions regarding the major changes between two scenarios, it is necessary to inspect the *transitions in modal split* that take place for each trip and mode between two such compared scenarios. These transitions are summarized in the modal shift.

Modal shift
In this section, the modal shift from a reference scenario of no tolling measures (baseline) to an analysed scenario for different zones is described in more detail. The reference scenario is an according scenario where usually a measure is not implemented, or an earlier stage along the timeline is assumed. The number are percent in relation to the reference main mode of the row. For instance, if a modal shift cell shows a change of 10%, it means that 10% of the trips that were done in the reference scenario indicated in the row mode are done in the analysed scenario by the mode indicated in the column. A modal shift comparison (e.g., Figure 3.1) therefore follows the changes "from mode of given row to expected mode in column". The bottom row described by "All" means for all the modes in the reference scenario and holds the final *modal split* (not the modal shift) of the analysed scenario. If not stated otherwise, the modal shift data will henceforth refer to the relative numbers of trips either starting or ending in the designated area.

To understand the model predictions outlined in the following, it is necessary to look at the initial traffic changes and modal displacements, that happen upon the very introduction of tolling measures. Since traffic phenomena are not bound to a single site or area, the introduction of RUP measures will also have effects on the surrounding environment. Parking price implementations in cities have shown an undesired displacement effect of parking vehicles being pushed to areas just outside the border of charged areas. To understand if the introduction of RUP is likely to have such an effect with respect to trip start and destination points, a closer investigation of the outer boundary of the tolling zone (the +250m belt, as depicted in Figure 2.2) is given in the following.

RUP introduction effects

A first impression of the tolling introduction effects regarding the traffic displacements in the belt outside the tolling zone. Here, the comparison is made between the reference case of no tolling measures (baseline) and a mild tolling level of 5 € and 10€, respectively, see Table 3.1.

Table 3.10: description of mode shift comparison.

Scenarios	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Baseline	belt+250m	A (100-0-0)	None	0 €	–	–
Comparison 1	belt+250m	A (100-0-0)	Static	5 €	100 %	–
Comparison 2	belt+250m	A (100-0-0)	Static	10 €	100 %	–

The main diagonal cells in Figure 3.12 show that for walking and public transport trips, very little shift to another mode is to be expected. 15,2 % of bicycle trips turn into public transport use, while for car trips this shift to public transport is 11,5 %. It is worth mentioning however, that the bike trips only account for a very small share of the total trips (i.e., they have a small modal split).

Similarly, Figure 3.13 shows a more pronounced effect; almost 18 % of bicycle trips are changed to pt and walking is chosen in 4,4 % of cases instead. Car use declines even stronger (to 66% percent of the initial car trips), while 21 % of this shift to PT use.

Figure 3.19: Mode shift for applying static toll 5€.

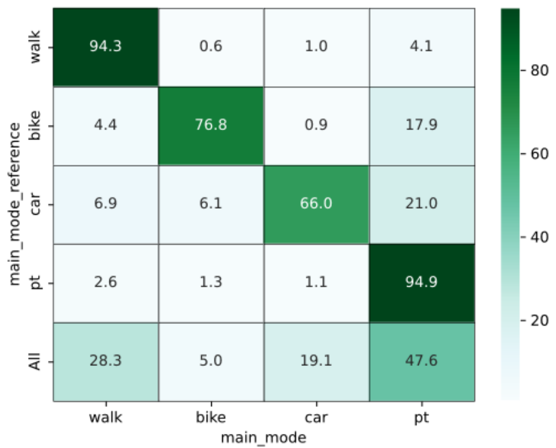


Figure 3.20: Mode shift for applying static toll 10€.

Although these numbers consider the belt zone surrounding the actual tolling area where the RUP measure is implemented, a considerable modal shift towards an intended outcome is taking place in this outside area as well.

To verify the effects of the previous static tolling RUP implementation, the application of the dynamic tolling measure is shown in Figure 3.3 for the equivalent moderate pricing level. The consequences are very similar, except for the car mode, which remains unchanged more often (75 %) in the dynamic tolling implementation.

Table 3.11: description of mode shift comparison.

Scenarios:	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Reference:	belt+250m	A (100-0-0)	None	0 €	--	–
Comparison:	belt+250m	A (100-0-0)	Dynamic	10 €	100 %	–

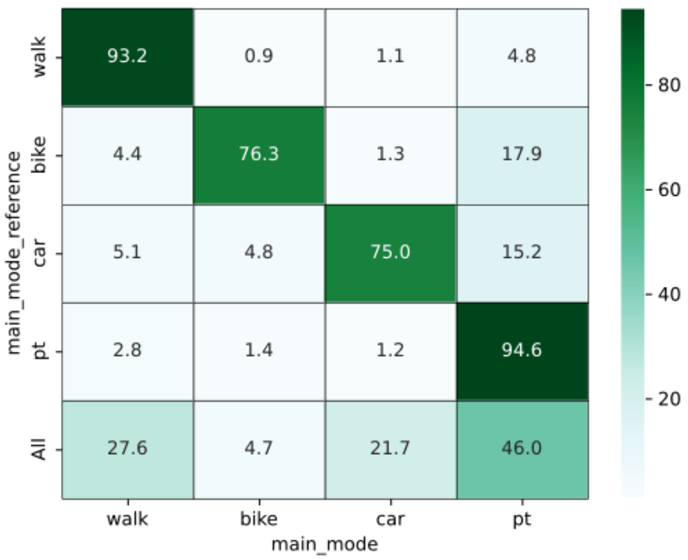


Figure 3.21: Mode shift comparison of 2 scenarios, corresponding to Table 3.3

The less pronounced effects of dynamic tolling measures have become apparent in earlier phases of the project and can be attributed to the "softer" cost impacts when some passenger cars simply "graze" the tolling area. This in turn leaves more room for adaptions of the individual agents in the simulation which leads to softer constraints regarding behavioural changes.

Tolling exemption effects

The given section outlines the consequences of the realistic implementation scenarios of exempting the residential car owners within the tolling area from payment of road pricing fees. For that purpose, a maximum effect has to be considered for only human-driven CVs on the road, when tolling is implemented but fully excluding the residents from toll-payment.

Table 3.12: description of mode shift comparison.

Scenarios	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Baseline	tolling	A (100-0-0)	Static	100 €	100 %	–
Comparison	tolling	A (100-0-0)	Static	100 €	0 %	–

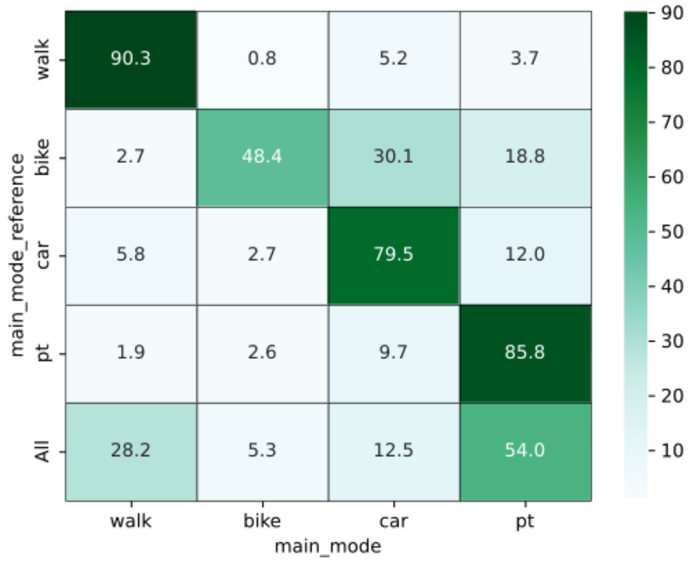


Figure 3.22: Mode shift comparison of 2 scenarios, corresponding to Table 3.8.

A greater share of bike trips migrates to the modes car and pt, and 12 % of car trips shift to pt, while a considerable part of pt trips reverts back to car use. Total effects on the modal split can be seen when comparing the last row ("All") from Figure 3.5 (describing the modal split of the current reference scenario) with the last line in Figure 3.8. Car trips increase from 3,8 % to 12,5 %, while bike and pt use decrease as well.

Given the previous changes in modal choice, the question arises if the situation is the same for the case of full automation where only CAVs are present. Figure 3.9 describes this comparison for the changes from an implemented prohibitive tolling level paid equally by all, to the full exemption only for residents.

Table 3.13: description of mode shift comparison.

Scenarios:	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Reference:	tolling	H (0-0-100)	Static	100 €	100 %	–
Comparison:	tolling	H (0-0-100)	Static	100 €	0 %	–

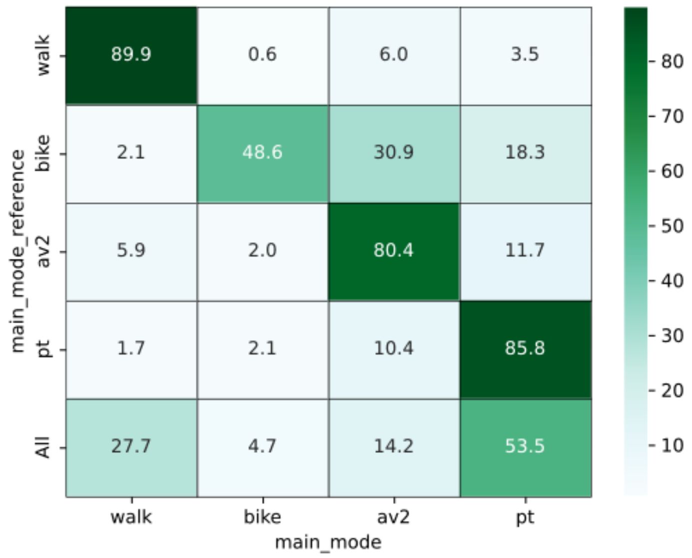


Figure 3.23: Mode shift comparison of 2 scenarios, corresponding to Table 3.9.

Comparison with the changes described in Figure 3.8 shows the consistency of comparable effects. Again, the effects are attenuated by the higher convenience of CAVs when compared to CVs, with an overall mode split of 14,2 % for CAVs (av2), which was 12,5 % for CVs (car).

Overall, the inclusion of tolling exemption for residents shows rebounds of slight losses in sustainable transport choices. It is however vital to the aspects of acceptability and social fairness and equality, to include those exemptions in policy implementations at an appropriate level.

Road class-based tolling

The complexity of discriminating between different road class areas allows only to implement the dynamic tolling scheme for the road class (RC) based pricing implementation.

To investigate the basic effect of this RC-based tolling scheme, Figure 3.10 shows the comparison for the case of no tolling vs. the introduction of RC-based tolling, with the price of traversing side-roads set to 200 % of the basic tolling price at a moderate level (10 €).

Table 3.14: description of mode shift comparison.

Scenarios:	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Reference:	tolling	A (100-0-0)	None	0 €	--	--
Comparison:	tolling	A (100-0-0)	Dynamic	10 €	100 %	200 %

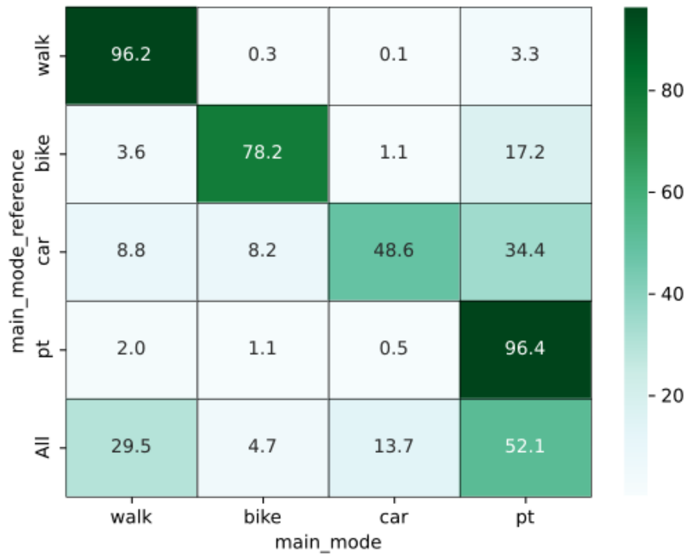


Figure 3.24: Mode shift comparison of 2 scenarios, corresponding to Table 3.10

When considering Figure 3.1, where the same dynamic tolling level was set for the belt area without additional side-roads charge, the effect of comparable mode shifts is much stronger for the current case This indicates a "good effect amplification" capability of the RC-based tolling approach even at reasonably low pricing levels.

It is required to understand the consequences of shifting from an implemented tolling scenario to the additional introduction of increased prices for side-roads. Such comparison is depicted in Figure 3.11.

Table 3.15: description of mode shift comparison.

Scenarios:	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Reference:	tolling	A (100-0-0)	Dynamic	10 €	100 %	100 %
Comparison:	tolling	A (100-0-0)	Dynamic	10 €	100 %	200 %

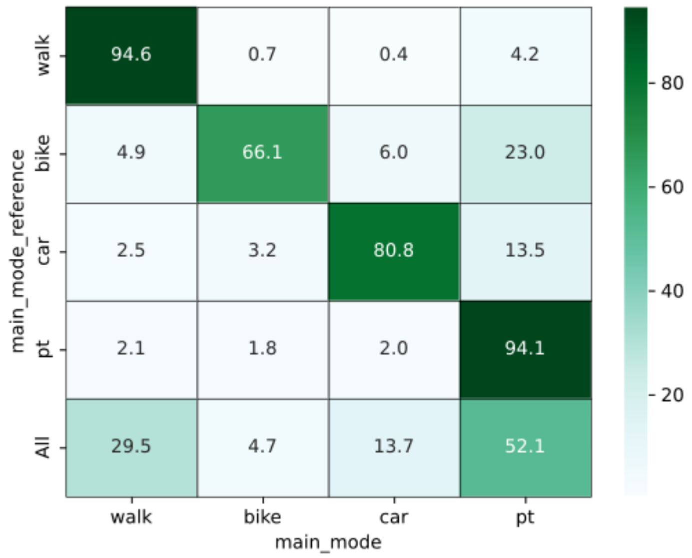


Figure 3.25: Mode shift comparison of 2 scenarios, corresponding to Table 3.11

While mode choice stays mostly the same for walk and pt, car and bike shifts mainly to pt. Although the discrimination is just based on 2 road classes, additional effects are significant.

Figure 3.12 displays the extreme case comparison of what modal shifts occur when the maximum prohibitive tolling is implemented and an additional price raise to 200 % is introduced for side-roads.

Table 3.16: description of mode shift comparison.

Scenarios:	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Reference:	tolling	A (100-0-0)	None	0 €	--	--
Comparison:	tolling	A (100-0-0)	Dynamic	100 €	100 %	200 %

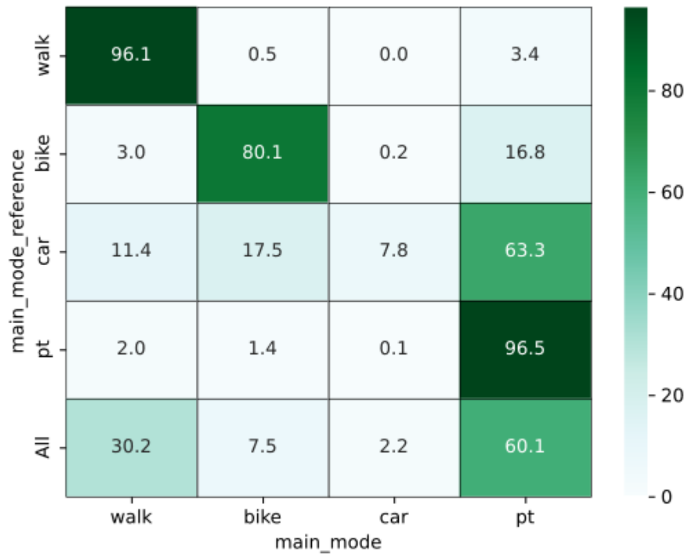


Figure 3.26: Mode shift comparison of 2 scenarios, corresponding to Table 3.12

While being a comparison that tests the ranges of possible adaptions, this analysis shows the strongest effect possible within the simulated models. Even more trips are shifted to bike and PT, while car traffic is diminishing.

Comparing those modal shifts to the case depicted in Figure 3.5 (which is an equivalent static tolling implementation) shows even stronger effect for the current case, which is unusual, when considering previous dynamic tolling scenario analyses. This again points towards good measure amplification for the RC-based approach.

Isolating the effect of just the introduction of RC-based tolling into a prohibitively tolled area is analysed in Figure 3.13.

Table 3.17: description of mode shift comparison.

Scenarios:	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Reference:	tolling	H (0-0-100)	Dynamic	100 €	100 %	--
Comparison:	tolling	H (0-0-100)	Dynamic	100 €	100 %	200 %

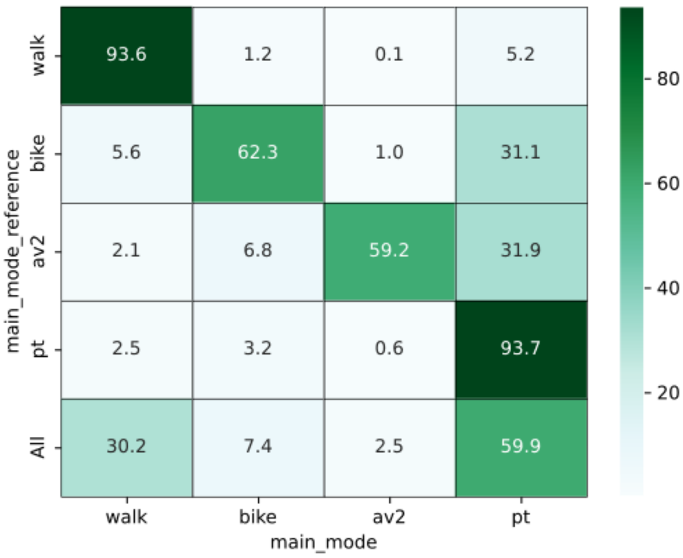


Figure 3.27: Mode shift comparison of 2 scenarios, corresponding to Table 3.13

This comparison shows the mode change of 40,8 % of the few remaining CAV trips to leave an overall mode split of only 2,5 %. Negligible change towards the modal choice of CAV can be seen. A still strong shift from bike towards pt (31,1 %) is apparent as well.

Realistic application cases

For an estimation of the likely mode shifts in implementation scenarios that are close to realistic implementation, the analyses of this following section are presented.
It is assumed that a moderate tolling level of 10 € is not too far from the range of likely tolling levels. Also, the tolling exemption factor for residents will likely tend to be close to 0 % for acceptability and equality reasons, which fully exempts residents from RC-based tolling.

At first, in Figure 3.14 the mostly prevalent current vehicle fleet partitioning is considered, which is similar to the scenario of **exclusively human-driven CVs**.

Table 3.18: description of mode shift comparison.

Scenarios:	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Reference:	tolling	A (100-0-0)	None	0 €	--	--
Comparison:	tolling	A (100-0-0)	Dynamic	10 €	0 %	200 %

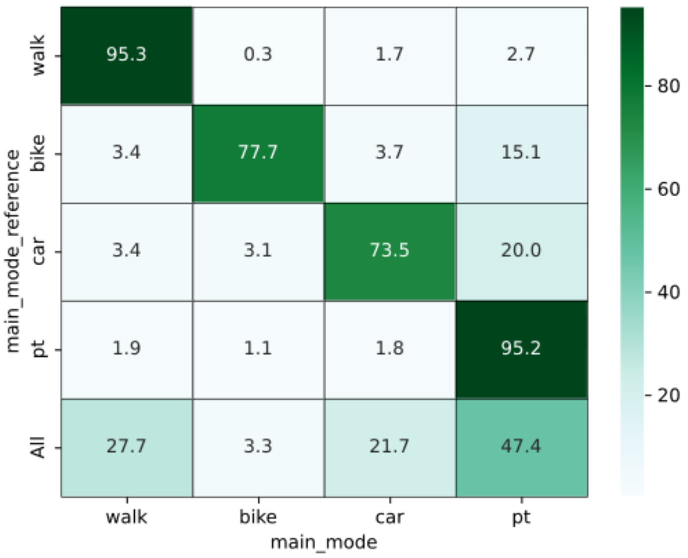


Figure 3.28: Mode shift comparison of 2 scenarios, corresponding to Table 3.14

Due to the very homogeneous situations, the modal shifts for this scenario show very similar numbers as for the development for only CAVs. Modal shifts show trends intended by policy implementers at moderate levels that are likely transport-system compatible with respect to changed demand situations.

To understand the **introduction phase of CAVs** that exhibits a starting increase in automation levels of passenger cars, the time evolution scenario B (see Table 2.1) with implemented realistic tolling is compared against the prevalent current situation without tolling in Figure 3.15.

Table 3.19: description of mode shift comparison.

Scenarios:	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Reference:	tolling	A (100-0-0)	None	0 €	--	--
Comparison:	tolling	B (80-20-0)	Dynamic	10 €	0 %	200 %

Figure 3.29: Mode shift comparison of 2 scenarios, corresponding to Table 3.15

The higher attractiveness of CAV utilisation shows small effects, which tends towards a slightly higher total modal split of total passenger car trips (CV and CAV generation 1). However, at the low level of only 20 % CAVs, the effects of their introduction are just beginning to influence the model-wide traffic behaviour.

Considering a further step along the evolution of CAV introduction, scenario E (see Table 2.1) was chosen to represent a **state beyond the middle of** the expected **transition to higher automation**. In the following Figure 3.16, implemented realistic tolling is compared against the prevalent current situation without tolling.

Table 3.20: description of mode shift comparison.

Scenarios:	Area	Fleet partitioning	Toll type	Toll level	Resident toll level	Toll side roads
Reference:	tolling	A (100-0-0)	None	0 €	--	--
Comparison:	tolling	E (20-40-40)	Dynamic	10 €	0 %	200 %

Figure 3.30: Mode shift comparison of 2 scenarios, corresponding to Table 3.16

While the trends of the previous evolution steps regarding the more popular use of CAVs mostly continue, mode choices for walking and biking become slightly more frequent again. This, however, appears to be due to net losses in the pt mode. Since this scenario is already quite far progressed along the possible timeline, and the outlined changes appear to be not very grave, the possibility for adaptions to implemented policy measures along the path is considered available.

3.3.4 Conclusions

RUP implementations

A more detailed analysis of the RUP implementation possibilities shows for the investigated scenarios, that the RUP measure implementation has a uniform transfer effect on the direct vicinity of the tolling area, where the modal shift changes affect the environment in a positively correlated manner. One could also say the tolling area stretches its effects outwards similarly, which differs in behaviour from e.g., parking fees, where resource problems are condensed at the boundaries of implementation areas. While RUP introduction encourages a modal shift away from passenger car use to more sustainable modes of transport, it does slightly less so for the more attractive CAVs.

Tolling exemption for residents

RUP exemption of the residents leads to considerable rebounds from the no-exemption scenarios, depending on the initial extent level of implemented tolling (higher tolling levels have more pronounced effects). For the maximum tolling levels tested, about 30 % of cycling trips (which are a small part of all trips) revert to passenger car trips. Interestingly however, a considerable part of cycling trips changes to pt, when residents are exempt from RUP. This surprising effect also happens for car trips at a maximum level of approximately 12 % changing to pt, which indicates avoidance of re-emerging travel-time costs (i.e., due to congestion) within and around the tolling area.

Road-class based tolling

Due to the implementation by dynamic tolling per travelled distance, effects are comparable, but slightly weaker than in the case of static tolling. Once the technical hurdles of real-life applications have been overcome, effects of this RUP implementation can be better tailored to given geographical conditions. The measure leaves more flexibility for the passenger car users. However, applying additional tolls to side-roads results in another considerable amplification of the modal shifts towards desired and more sustainable modes of transport. Investigated realistic application scenarios do significantly exhibit the effects intended by the RUP policy measure.

3.4 GLOSA - Green light optimal speed advisory

Green Light Optimal Speed Advisory (GLOSA) is a Day 1 C-ITS signage application enabled by the C-ITS service "Signalised Intersections". The application utilises traffic signal information and the current position of the vehicle to provide a speed recommendation in order for the drivers to pass the traffic lights during the green phase and, therefore, reduce the number of stops, fuel consumption, and emissions. The distance to stop, the plans for signal timing and the speed limit profile for the area are taken into account to calculate the speed recommendation displayed to the driver. GLOSA service is provided through ETSI G5 into the on-board computer of the vehicle or via mobile network into a smartphone app.

In this case study, we show that GLOSA is a significant intervention due to the important potentially positive environmental and mobility impacts. Smoother traffic flows, less congestion and reduced emissions constitute a promising basis for the various stakeholders, transport planners and cities, to be interested in assessing the societal effects and evaluate the costs in relation to benefits.

3.4.1 Model and Methodology

Microsimulation

Traffic simulation has been widely applied to estimate the potential impacts of connected and automated vehicles. As identified in LEVITATE Deliverable on Impact Assessment Methods (Elvik et al., 2020), many studies have used microsimulation technique to estimate the potential impacts of CATS on traffic performance indicators. It is envisaged that the microsimulation approach can be used to calculate the direct impacts of CAVs. In most cases, a commercially available traffic microsimulation tool (such as AIMSUN, VISSIM, Paramics or SUMO) is used along with an external component. The microsimulation tool is applied to represent the infrastructure and creates the traffic in the predefined road system, while the external component aims to simulate the CATS functionalities.

Two types of CAVs were considered in this study: 1st Generation CAVs and 2nd Generation CAVs. Both types are assumed to be fully automated vehicles with level 5 automation. The main idea behind modelling these two types is based on the assumption that technology will advance with time. Therefore, 2nd Gen CAVs will have improved sensing and cognitive capabilities, decision making, driver characteristics, and anticipation of incidents etc. In general, the main assumptions made on CAVs characteristics are as follows:

- 1st Generation: limited sensing and cognitive ability, long gaps, early anticipation of lane changes than human-driven vehicles and longer time in give way situations.
- 2nd Generation: advanced sensing and cognitive ability, data fusion usage, confidence in taking decisions, small gaps, early anticipation of lane changes than human-driven vehicles and less time in give way situations.

These characteristics were defined through various model parameters in AIMSUN Next including reaction time, time gap, acceleration and deceleration characteristics, parameters related to lane changing and over taking behaviour and several others. The default car-following model in AIMSUN is based on Gipps model (Gipps,1981,1986).

Various parameters of the car-following model were adjusted to implement HDV and CAV behaviours. The assumptions on CAV parameters and their values were based on a comprehensive literature review, including both empirical and simulation-based studies (Cao et al., 2017; Eilbert, Berg, & Smith, 2019; Goodall & Lan, 2020; De Souza & Stern ,2021; Shladover, Su, & Lu ,2012), as well as discussions in meetings with various experts within the project. Some guidance on the behaviours was also obtained through studies on adaptive cruise control (ACC) and cooperative ACC (CACC) systems.

Traffic impact of CAVs were assessed in mixed traffic conditions that contain, in addition to passenger cars, freight and public transport (PT) vehicles. The automation of freight vehicles was also considered; however, due to limited knowledge on automation of freight vehicles, only a few parameters were adjusted to model the behaviours of freight CAVs.

Delphi method

The Delphi method is a process used to arrive at a collective, aggregate group opinion or decision by surveying a panel of experts. This concept was developed by the RAND Corporation for the military in order to forecast the effects of new military technology on the future of warfare, and then continued to make multiple practical applications of this method (Dalkey & Helmer, 1963). The Delphi methodology is based on a repetitive interview process in which the respondent can review his or her initial answers and thus change the overall information on each topic (Hsu & Sandford, 2007). This presupposes that the participants will be willing to not only give answers on the topics but also to repeat the interview in possibly more than two cycles. The Delphi method has three different dimensions: the exploratory Delphi aiming at the forecast of future events, the normative Delphi, in order to achieve policy consensus on goals and objectives within organisations or groups and the focus Delphi in order to gain feedback from stakeholders in some policy outcome (Garson, 2012). The Delphi method presents the following characteristics and features: anonymity of experts which assures free expression of opinions provided by the experts. This method helps to avoid social pressure from dominant or dogmatic individuals or even from the majority or minorities. At any point, experts can change their opinions or judgments without fear of being exposed to public criticism, providing controlled feedback as experts are informed about views of other experts who participate in the study (Profilidis & Botzoris, 2018).

Within LEVITATE, the Delphi method is used to determine all impacts that cannot be defined by the other aforementioned quantitative methods (traffic simulation, system dynamics, etc.). Initially, a long list of experts was identified for each use case (i.e., urban transport, passenger cars and freight transport), and contacted via an introductory mail asking them to express the willingness of participation. Those who responded positively participated in the main Delphi process, amounting to 70 experts in total (5 experts accepted to answer to 2 questionnaires). Experts come from various organisations such as research institutes, companies and universities where they have different job positions, such as directors, professors and managers) and they come from different countries.
More detail of Delphi method can be found in LEVITATE Deliverable2, 3 and 4 (Haouari et al., 2021; Sha et al., 2021; Chaudhry et al., 2021).

Network

The traffic microsimulation model that is used for this CS was provided by Transport for Greater Manchester. The model of Greater Manchester provides a sufficiently large and complex transport network with signalised intersections and other various road sections, rendering it suitable for the specific experiment. For implementing GLOSA, a corridor near the Salford area was selected in Manchester including three signalized intersections (Figure 3.25) where the distance between first and second intersection is around 400m whereas that between second and third intersection is around 800m. The impact of GLOSA was analysed under fixed time coordinated traffic control at these study locations signals.

Figure 3.31: Test corridor in Manchester network for GLOSA application.

GLOSA Algorithm
The GLOSA Algorithm was developed based on reviewing some of the previously developed algorithms in literature (Stevanovic et al, 2013) with modifications as deemed adequate for the test network. The key steps describing the functionality are presented in Table 3.2.

Before applying the GLOSA algorithm on the test network, the impact of activation distance (the distance from the intersection at which GLOSA service is activated) and frequency of GLOSA notifications to CAVs was analysed. The activation distance was kept to 400m while GLOSA was applied on each time step. Minimum speed threshold was kept as 50% of speed limit as also used in several other studies (Katsaros et al.,2011, Masera et al.,2019) while upper limit was kept as speed limit +5mph.

Table 3.21: Steps involved in GLOSA system operation.

Step 1. GLOSA system in vehicle searches for a traffic signal controller downstream
Step 2. If a traffic signal controller downstream is detected, go to step 3, else go to step 1
Step 3. GLOSA system in vehicle collects data on vehicle position and speed
Step 4. Get Map Data Message (MAP) information about the lane and turning restrictions. (GLOSA application generates geometry from MAP message to determine the vehicular position and determine the corresponding lane number)
Step 5. Calculate vehicle's distance to stop bar at the intersection approach
Step 6. Determine the existing queue length at the current moment
Step 7. Collect current signal phase and timing information (SPAT) from the controller at the current moment for corresponding lane of the approach at the intersection.
Step 8. Calculate the time required to arrive at the intersection
Step 9. Determine the phase at the arrival time
-If the current phase is Green, check if vehicle is arriving at Green? If yes, go to step 10, If not go to step 11.
-If the current phase is Red check if vehicle is arriving at Green. If yes, go to step 10, if not go to step 14.
Step 10. Vehicle is arriving at Green. Send advisory message to maintain current speed
Step 11. Vehicle is not arriving at green. Calculate advisory speed to arrive at current green phase
Step 12. Is advisory speed ≤ speedMax and advisory speed ≥speed Min, If yes go to step 13, else go to step 14
Step 13. speed up to advisory speed
Step 14. Calculate the advisory speed to arrive at junction on next green phase by using current queue length and queue dissipation time.
Step 15. If the advisory speed ≥speed Min and advisory speed ≤ speedMax (where speedMin=50% speed limit), If yes go to step 16, else go to step 17
Step 16. Slow down to speedMin
Step 17. Exit (vehicle will have to stop)

3.4.2 Scenarios

Traffic microsimulation is applied as one of the main methods to assess the traffic related impacts, including travel time, delay time, traffic volume, traffic emissions and safety. The vehicle type and the deployment scenarios are shown in Table 3.15.

Table 3.22: CAV Deployment scenarios.

CAV Deployment Scenarios								
Type of Vehicle	A	B	C	D	E	F	G	H
Human-Driven Vehicle - passenger vehicle	100%	80%	60%	40%	20%	0%	0%	0%
1st Generation (Cautious) CAV - passenger vehicle	0%	20%	40%	40%	40%	40%	20%	0%
2nd Generation (Aggressive) CAV -- passenger vehicle	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%

The deployment of CAVs in the network was tested from 0% to 100% in 20% increments to keep the number of scenarios manageable for the simulation runs. The fleet composition included passenger, freight, and public transport vehicles and the automation was considered for both passenger and freight vehicles. Each scenario (A, B, …) will need to be run 10 times, i.e., 10 replications per scenario within Aimsun Next modelling environment. Random seeds in all 10 replications under each scenario were kept same.

The following assumptions were made in the frame of GLOSA application:

- The quality of communication between signals and vehicles is ideal and all messages are delivered successfully and without delay.
- Only CAVs are GLOSA equipped (not the HDVs) and all CAVs comply with the recommended speed.
- GLOSA is applied at each simulation step.
- All CAVs will have the capability to communicate with traffic controllers.
- All CAVs are electric whereas human-driven vehicles are non-electric.

The test scenarios on GLOSA implementation and CAV deployment are as follows:

- Baseline scenario – No GLOSA, CAV market penetration from 0% to 100% in 20% increments.
- Scenario 1 – GLOSA on intersection 1,
- Scenario 2 – GLOSA on intersections 1 and 2, and
- Scenario 3 – GLOSA on intersection 1, 2 and, 3.

Simulations were run for the peak hours performing 10 replications under each scenario. The analysed impacts included:

- Travel Time
- Delays
- Number of Stops
- Emissions
- Total Conflicts (Safety Impacts)

3.4.3 Impacts

In this section we describe the most relevant impacts of GLOSA, which is congestion, amount of travel, road safety, and energy efficiency. A full list of impacts is in the CS documentation (Chaudhry et al. 2022).

Congestion

With the implementation of GLOSA system, considering advisory speeds sent by GLOSA are accurate and the drivers comply with them, the expectation is that such a technology will generate smoother traffic flow and reduce the number of stops and delays.

The simulation results from testing GLOSA system on one (case 1), two (case 2), and all three intersections (case 3) on the study network clearly showed decrease in delays with respect to no policy intervention (without GLOSA) scenario (Figure 4.6).

Maximum reduction in delays was observed when GLOSA was applied to all three intersections in the study corridor as compared to case 1 and case 2. It is important to note that the trend with respect to increasing MPR of CAVs, in all cases, is attributed to the baseline trend (no policy intervention curve). The increase in delays with increasing percentage of second generation CAVs is due to having increased number of vehicles in the network (having shorter headways led to increased number of vehicles entering the network during the simulation period).

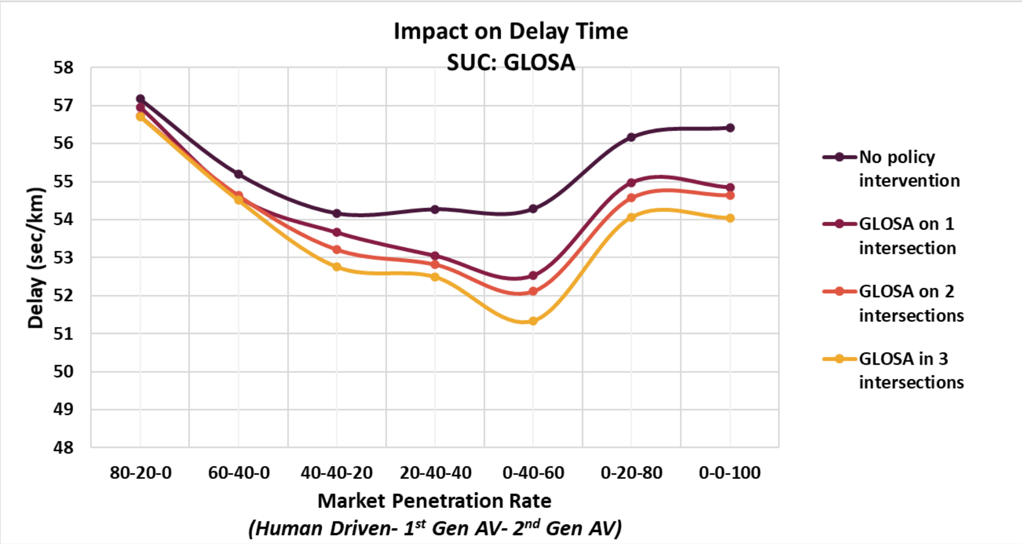


Figure 4.5: Impact on Delay due to MPR of CAVs and implementation of GLOSA system

Table 4.4 presents percentage change in delay (due to GLOSA) with respect to respective MPR baseline scenario. The results showed a maximum reduction of 5.4% at 0-40-60 MPR scenario while almost 4.2% reduction was observed at 100% MPR.

Table 4.4: Percent change in average delay time w.r.t corresponding Baseline under GLOSA implementation scenarios

Penetration Rate	GLOSA on 1 intersection	GLOSA on 2 intersections	GLOSA in 3 intersections
80-20-0	-0,4%	-0,8%	-0,8%
60-40-0	-1,1%	-1,0%	-1,3%
40-40-20	-0,9%	-1,8%	-2,6%
20-40-40	-2,2%	-2,7%	-3,3%
0-40-60	-3,2%	-4,0%	-5,4%
0-20-80	-2,1%	-2,8%	-3,7%
0-0-100	-2,8%	-3,1%	-4,2%

Amount of travel by microsimulation

The microsimulation results on total distance traveled showed an irregular trend with increasing MPR of AVs. However, on average, implementation of GLOSA shows an increase in distance travelled when compared with the baseline curve. Additionally, the results also suggest increase in distance travelled with implementation on multiple intersections in the study network (Figure 4.6). In terms of microsimulation output, this suggests an improved flow with more vehicles being able to complete their journey during the simulation period.

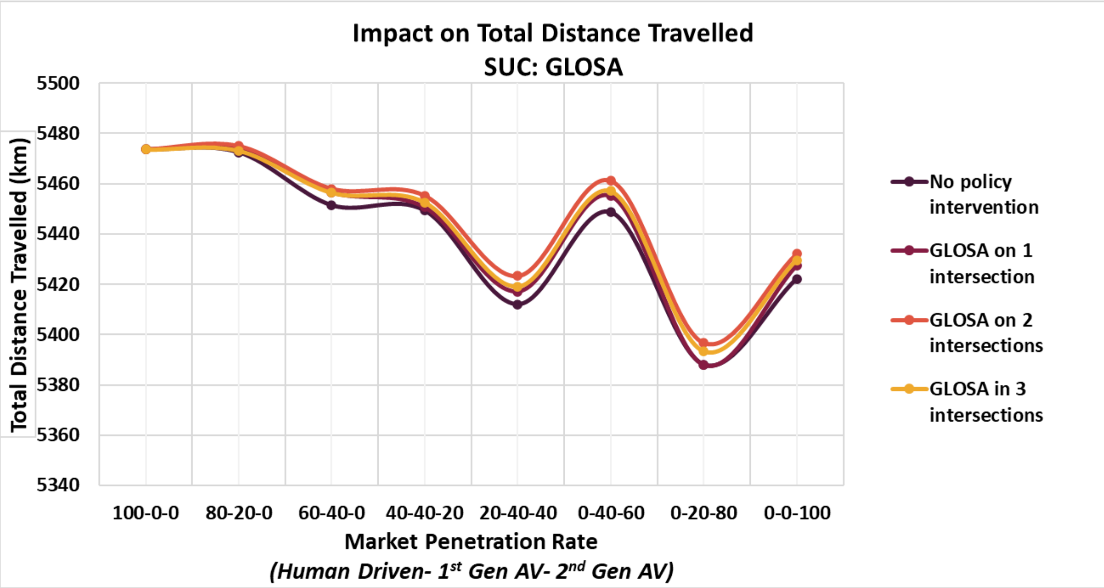


Figure 4.6: Impact on Total Distance Travelled due to MPR of CAVs and GLOSA

Table 4.5 presents percentage change in total distance travelled due to implementation of GLOSA system, calculated by taking the difference of impact between with and without GLOSA scenarios at each MPR of AVs. Overall, there is not a significant change in distance travelled with implementation of GLOSA system under all implementation scenarios, as shown in Table 4.5.

Table 4.5: Percent change in total distance travelled w.r.t corresponding Baseline for GLOSA

Penetration Rate	GLOSA on 1 intersection	GLOSA on 2 intersections	GLOSA in 3 intersections
80-20-0	0,03%	0,05%	0,01%
60-40-0	0,10%	0,12%	0,09%
40-40-20	0,02%	0,11%	0,06%
20-40-40	0,09%	0,21%	0,13%
0-40-60	0,12%	0,23%	0,16%
0-20-80	0,00%	0,16%	0,10%
0-0-100	0,10%	0,18%	0,14%

Amount of travel by Delphi

The general experts' opinion was that the introduction of AVs in the urban environment will progressively increase the amount of travel, reaching 36,4% in the long term (Figure 4.7). Regarding the GLOSA scenario, experts' answers indicated that there will be an improvement of 10% to 16% on amount of travel, depending on AVs market penetration rate.

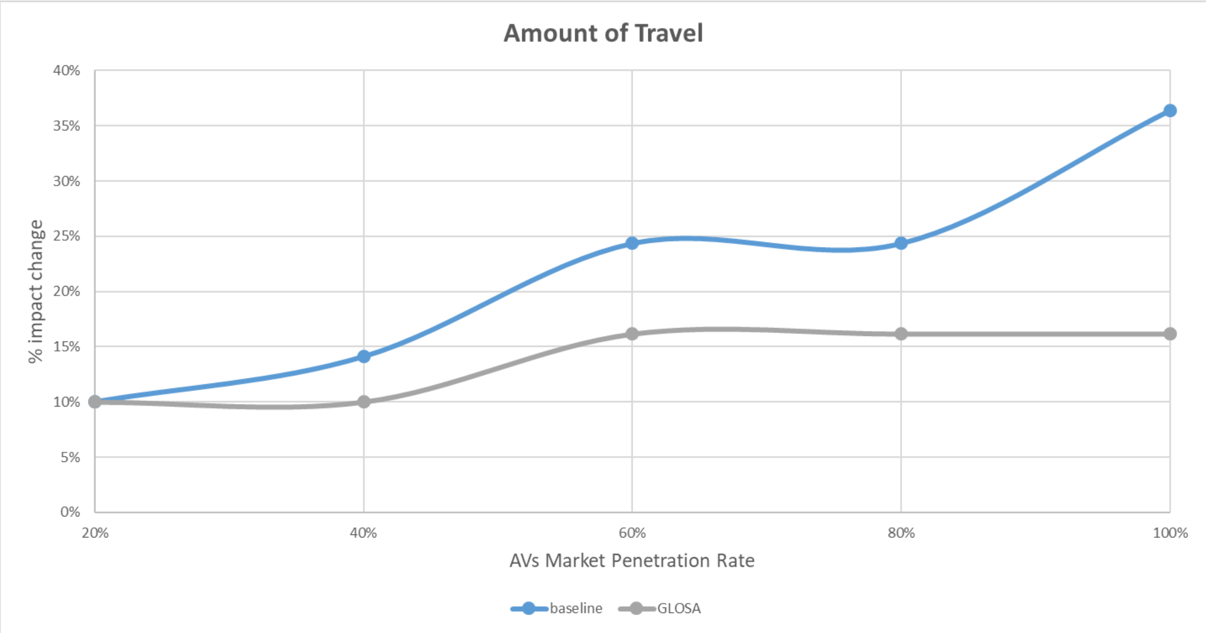


Figure 4.7: 1st round Delphi amount of travel results for GLOSA scenarios

The majority of 2nd round participants stated that they definitely (16%) or moderately (50%-67%) agree with the resulted 1st round trends for the baseline scenarios. Some experts (17%-33%) stated that the 1st round impact of the baseline scenario on the amount of travel is overestimated and proposed an average improvement of 10%. According to 50% of experts GLOSA will not at all affect the studied impact (Figure 4.8).

Figure 4.8: 2nd round Delphi amount of travel results for baseline and GLOSA

Road safety

The general introduction and increasing penetration levels of Connected and Automated Vehicles (CAVs) will likely impact road safety in several ways, both directly and indirectly. These general impacts for the baseline scenario are described in Weijermars et al (2021) and are summarized below.

CAVs are expected to have a lower risk of being involved in a crash than human drivers, as they are expected to obey traffic rules, to not make mistakes that human drivers make, to have lower reaction times and to exhibit less variability in driving behaviour. On the other hand, some new potential risks might be introduced by automated vehicles, such as system failures, cyber security issues, and issues related to transition of control or mode confusion. In addition, some rebound/indirect effects can be expected, caused by changes in broader factors that in turn affect road safety. Examples of these indirect impacts include changes in road safety due to changes in total distance traveled, modal split, route choice and changes in the behaviour of other road users.

The impact of CAVs on road safety is also not a static figure but is expected to develop over time as CAVs will likely become progressively safer and the penetration rate of different types of CAVs is expected to increase over time.

The following subsections discuss additional road safety impacts specific to the present sub use case on GLOSA. In the first subsection, the expected impacts are described. In the second section, the impacts are quantified in terms of crash rate predictions (using microsimulation) and the safety impacts of modal split changes (using system dynamics and mesoscopic simulation). Unfortunately, not all additional impacts can be reliably estimated within the LEVITATE project due to the absence of real-world data.

Potential road safety impacts
The introduction of specific measures such as the ones proposed in the current sub-use case can cause additional impacts to the general impacts of CAVs. These specific impacts will be explored in the following sections, with each section describing either a new sub-use case specific impact or changes to the general impacts inherent to the current sub-use case.

Changes in traffic flow
GLOSA is expected to result in smoother traffic flow, which will likely decrease the number of crashes and therefore increase road safety. However, simulation research (Stevanovic et al., 2015) has shown that the number of conflicts only significantly decreases when GLOSA times are fixed, and the penetration rate is 100%. For lower penetration rates the study found no changes in the total number of conflicts, as well as increases in the total number of conflicts. The study also showed that GLOSA affected the proportion of conflict types. With GLOSA, the number of rear-end crashes decreased while the number of lane change crashes increased. We expect similar results for the current sub-use case. In the GLOSA app scenario, we expect to see smoother traffic flows sooner, because the GLOSA penetration rates will likely increase more quickly than the AV penetration rates. The changes in traffic flow will be quantified using microsimulation.

Speed differences
In some situations, GLOSA-equipped vehicles might drive comparably slow. Previous studies have linked speed differences between vehicles to increased crash rates (Aarts & Van Schagen, 2006). Additionally, speed differences might cause irritation in human drivers, resulting in dangerous manoeuvres and accidents. A study (Rijkswaterstaat Adviesdienst Verkeer en Vervoer, 2001) regarding the implementation of intelligent speed assistant (ISA) systems found that drivers exhibited aggressive driving behaviours in response to the 'slow' driving vehicles. This impact will partially be quantified using

microsimulation, because speed differences can be simulated. However, we are not able to model specific driver behaviours within the LEVITATE project.

Copying behaviour (human drivers)
Human drivers might adapt their behaviour due to other vehicles being equipped with GLOSA. A driving simulator study (Preuk, Dotzauer, & Jipp, 2018) has shown that drivers mimicked the behaviour of GLOSA-equipped vehicles when they had received detailed information about the system compared to drivers that only received general information or no information about the system. The study also showed smaller minimum TTCs for drivers that received detailed information about the system compared to the other groups. In the current SUC, mimicking the behaviour of GLOSA-equipped might smoothen traffic flow and thereby improve for road safety, while shorter TTCs might cause road safety issues. However, both effects are only to be expected if human drivers are well informed about GLOSA and its functionalities and are able to recognize GLOSA-equipped vehicles. We expect that it will take some time after the initial implementation of GLOSA until human drivers are well-informed about the system. Therefore, the effects are only expected with higher penetration rates (assuming that higher penetration rates are linked to a longer period of GLOSA implementation). Also, we only expect these effects when interacting with AVs, because we do not assume that human drivers will be able to recognize non-AVs using GLOSA. Unfortunately, we are not able to quantify the described driver behaviours within LEVITATE.

Interactions with the GLOSA app
In the GLOSA app scenario, human drivers are able to use a GLOSA app in order to make use of the speed advices. However, in contrast with people driving in AVs, human drivers have to monitor the GLOSA app and manually adjust their driving speed. This might lead to mental overload and distraction, which can negatively affect driving skills and thereby decrease road safety (Stelling-Kończak & Hagenzieker, 2012; SWOV, 2020). Additionally, humans likely need more time to respond to potentially changing speed advices, which might compromise the accuracy of GLOSA and result in dangerous situations. Unfortunately, we are not able quantify these expected driver behaviours within the LEVITATE project.

Quantification
The effects on road safety of increasing automation of the vehicle fleet together with implementation of Green Light Optimal Speed Advisory (GLOSA) are quantified using microsimulation in AIMSUN combined with the SSAM tool which identifies potentially dangerous traffic interactions (traffic 'conflicts'). A prediction for the resulting change in car crashes is made by using the methodology explained in the working paper of "Road safety related impacts within the LEVITATE Project" (Weijermars et al., 2021) for both a no policy intervention (baseline) scenario as well as the GLOSA scenarios discussed:

1. <u>No policy intervention</u>: baseline scenario of increasing penetration of automated vehicles without GLOSA
2. <u>GLOSA on 1 intersection</u>: GLOSA is implemented at 1 intersection in the network
3. <u>GLOSA on 2 intersections</u>: GLOSA is implemented at 2 intersections in the network
4. <u>GLOSA on 3 intersections</u>: GLOSA is implemented at 3 intersections in the network

The estimated percentage change in crashes is presented in Figure 4.21.

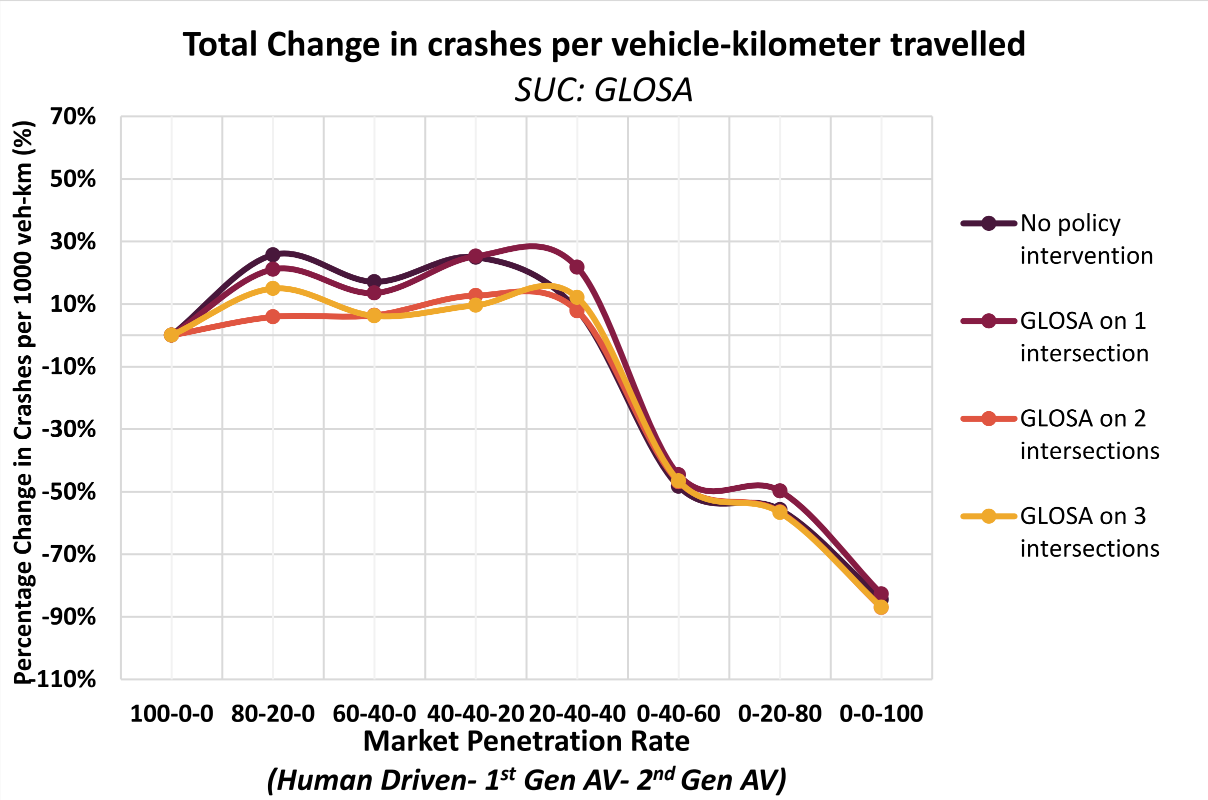


Figure 4.21: Impact of Green Light Optimal Speed Advisory (GLOSA) scenarios on the predicted crash rate with increasing automation in the vehicle fleet, compared with a baseline no policy intervention scenario without GLOSA Crash rate is reported in percentage change from 100-0-0 scenario and simulated for the Greater Manchester area (UK) network.

Under the No policy intervention (baseline) scenario, the results show an increase in crash rates at lower MPR scenarios with 1st and 2nd Generation CAVs. This could potentially be due to disruptions in the traffic stream caused by the inclusion of CAVs in the network, and the resulting interactions between human-driven vehicles and CAVs. Because human-driven vehicles and automated vehicles have different driving styles (e.g., different headways) and different capabilities (e.g., human drivers' longer reaction times), this may lead to an initial increase in risks when many human drivers are still on the road. As CAVs become a major part of the fleet composition in the higher MPR scenarios and human-driven vehicles are no longer present (from 0-40-60 scenario), a significant improvement in safety can be observed. Similar trends were also reported by an earlier study investigating the safety impacts of GLOSA system through surrogate safety assessment (Stevanovic et al.,2015).

With regard to safety impact due to GLOSA, a lower crash rate was found for the implementation of the GLOSA system at multiple intersections as opposed to a single intersection implementation. This difference is most prominent at scenarios with low MPR of 1st and 2nd Gen CAVs, suggesting that its implementation is particularly useful in mixed (human-driven and automated) traffic scenarios.

Energy efficiency
Energy efficiency is defined as the average rate (over the vehicle fleet) at which propulsion energy is converted to movement (%). The impact on energy efficiency of the introduction of automation in the urban environment is calculated using the Delphi method.

According to the Delphi method results all scenarios will improve energy efficiency. More precisely, GLOSA will have the biggest impact on energy efficiency, leading to an increase of 31,2%. The baseline scenario will also progressively increase energy efficiency, reaching 15,2%.

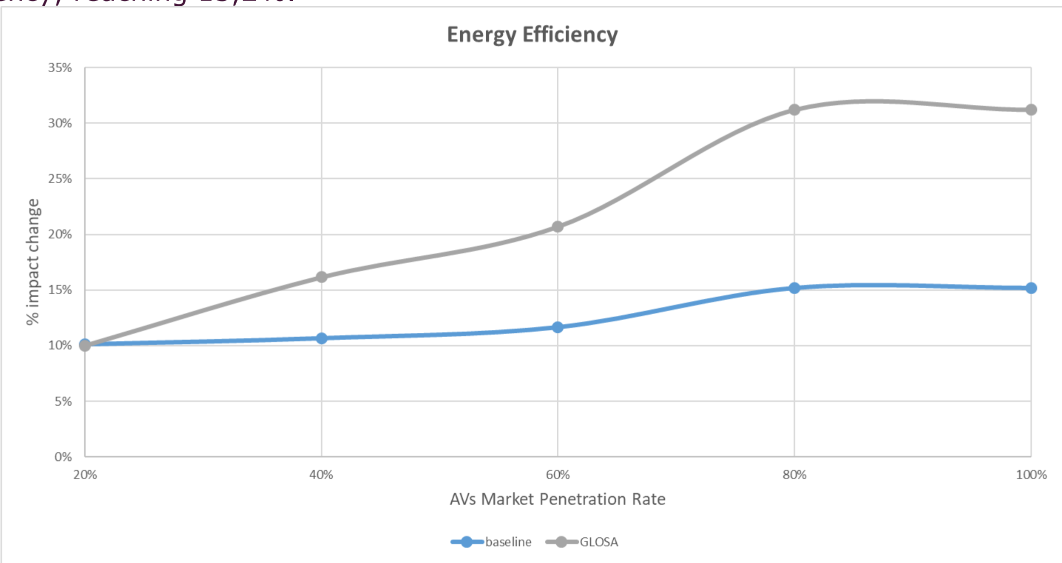


Figure 4.22: 1st round Delphi energy efficiency results for GLOSA scenarios

In the 2nd Delphi round questionnaires, the majority of experts definitely (33%) or moderately (33%) agreed with the resulted curves. Two experts (33%) suggested that the proposed trends are overestimated and suggested an average increase of 5%-10% of energy efficiency for all scenarios.

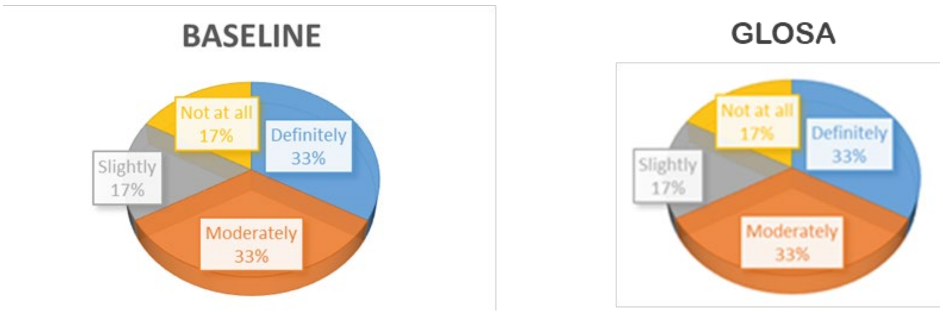


Figure 4.23: 2nd round Delphi energy efficiency results for baseline and GLOSA

Table 4.7: Final PST coefficients for energy efficiency for GLOSA scenarios

penetration rates	Baseline		GLOSA	
	Aggregate change	PST coefficients	Aggregate change	PST coefficients
20%	9,8%	1,098	9,4%	1,094
40%	10,3%	1,103	14,8%	1,148
60%	11,1%	1,111	18,7%	1,187
80%	14,2%	1,142	27,9%	1,279
100%	14,2%	1,142	27,9%	1,279

3.4.4 Conclusions

A range of impacts for GLOSA were analysed through microsimulation and Delphi. The findings on the impacts are summarised as follows:

Congestion
The delays were found to reduce with the application of the GLOSA system with fixed-time signal controllers. The implementation of the GLOSA system on multiple intersections showed further improvement in reducing delays as compared to GLOSA system implementation on a single intersection along the study corridor.

Amount of travel
Microsimulation results showed an increase in total distance travelled with the implementation of the GLOSA system on the test network as compared to the baseline (without GLOSA) scenario. Implementation on more intersections along the test corridor was found to result in increased distance travelled as compared to implementation on single or two junctions, indicating improvement in traffic flow, reduction in travel time, or overall improvement in traffic performance. From Delphi results, there was a mixed opinion on the impact of GLOSA on the amount of travel. The first round, results indicated a slight increase with increasing MPR of AVs in the short term; however, in the second round, almost 50% of the participants predicted no effect on the amount of travel.

Road safety
The surrogate safety assessment of GLOSA system showed improvement in safety (lower crash rate) with the GLOSA implementation at multiple intersections in the test network, particularly at low CAV MPR scenarios, as compared to baseline scenario (without GLOSA) and single intersection implementation.

Energy efficiency
Most of the experts predicted largest impact on energy efficiency due to implementation of GLOSA, with an expected increase of almost by 31%.

3.5 Automated delivery and automated consolidation

The goal of this CS is to investigate the transferability of the OR methodology on the parcel delivery for the cities of Vienna and Manchester. For automated delivery and automated consolidation, the primary factors for the impacts are the fleet size and the driven km. They are fundamental for freight operations since other impact indicators are directly based on them, such as annual fleet cost, freight transport cost, CO2 emissions and congestion. For the cities Vienna and Manchester, we perform a detailed analysis of the delivery performance based on demographic data and parcel data. First the impacts are obtained by operations research methods that calculate for each delivery tour the vehicle stops and vehicle kilometers. Then we use a simplified macro approach which can generate approximative results without the necessity to run a full city model and perform detailed calculations.

In this CS, we compare the following delivery scenarios:

- **Manual delivery** (status quo) is used as a baseline scenario for comparison.
- **Automated delivery** uses so-called 'robo-vans'[1] and small autonomous delivery robots to replace the service personnel. Robo-vans function as mobile hubs while the delivery robots perform short delivery trips to end-customers. 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.
- **Manual consolidated delivery** uses bundling at white-label city-hubs, i.e., the delivery vehicles are not bound to a specific delivery company but operate the service for all companies. This removes the redundancy in the delivery system nowadays. In this scenario, both the servicing of city-hubs and the delivery to end-customers are done manually.
- **Automated consolidated delivery** is the final scenario that combines the automated delivery via robo-vans and the city-hubs for bundling.

Through all delivery variants, we compare the fleet composition and driven km per day. Results show that on the one hand, the mileage is significantly shortened by the consolidated delivery via the centrally located city-hubs, and on the other hand, mileage increases due to the lower capacities of the robo-vans for automated delivery. Congestion caused by the freight vehicles to the overall traffic is not significant, since their share of the traffic volume is minimal. However, automated freight delivery can utilise the off-peak hours and the night-time, therefore giving passenger transport more space during the peak hours and reducing tension in the traffic.

There are concepts where the autonomous delivery robots are airborne drones (Dorling et al. 2017), but the operation of drones especially in crowded urban environment is controversial and legally challenging. Therefore, this not further considered in the project.

[1] https://www.starship.xyz/press_releases/robovan-by-starship-technologies-and-mercedes-benz-vans-future-proof-local-delivery/

3.5.1 Model and Methodology

The methodology used in this case study is based on operations research, which is widely used in freight transport (Lagorio et al, 2016) and calculates results for freight transport costs, fleet operation costs, and vehicle mileage. They mainly consist of optimisation algorithms for route-planning, also commonly known as the vehicle routing problem (VRP), where the goal is to calculate the optimal route or set of routes at the lowest possible cost (and often also the shortest possible time) from a given depot to a number of customers (Toth and Vigo, 2014). Compared to private passenger transport, freight transport is less time-critical and plannable on an operational basis, which makes operations research a viable approach for the automated delivery and automated consolidation. The detailed description of the methos is described in Deliverable D7.2 (Hu et al. 2021).

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

The delivery performance and the limiting factors are shown in Table 4.2. For manual delivery, the working time is limited to 8 hours and one shift. Automated delivery can be done in three shifts, but we assume that the robo-van can carry less parcels due to carrying additional equipment and the delivery bots.

Table 3.23: Performance of the delivery scenarios and their main limiting factors (red).

Delivery scenarios	Sub-use case specific scenarios (Automated urban delivery)				
	Delivery scenario parameters				
	Delivery shifts	Avg. parcels per shift	Avg. parcels per stop	Service time per stop	Delivery vehicle
Manual delivery	6:30 – 15:00	150	Variable	5 min	Van
Automated delivery	6:30 – 15:00, 18:00 – 23:59, 0:00 – 6:00	100	Variable	10 min	Robo-Van

3.5.2 Scenarios

Vienna

Vienna has around 1.9 million inhabitants and a parcel volume of 250 million in 2019 (Wirtschaftskammer Wien, 2020). Based on this, delivery addresses were generated and randomly distributed but weighted according to the population density of the respective districts in the city of Vienna, see Figure 3.14. In 2020, the six logistic providers in Vienna delivered a total of 272,000 parcels per day from a total of nine logistics centers, see Figure 3.15. In general, these centres are located either on the outskirts of the city or outside of Vienna, where there is a good connection to the highway. Potential locations for city-hubs are located nearer to the city center, which are required for the consolidated delivery.

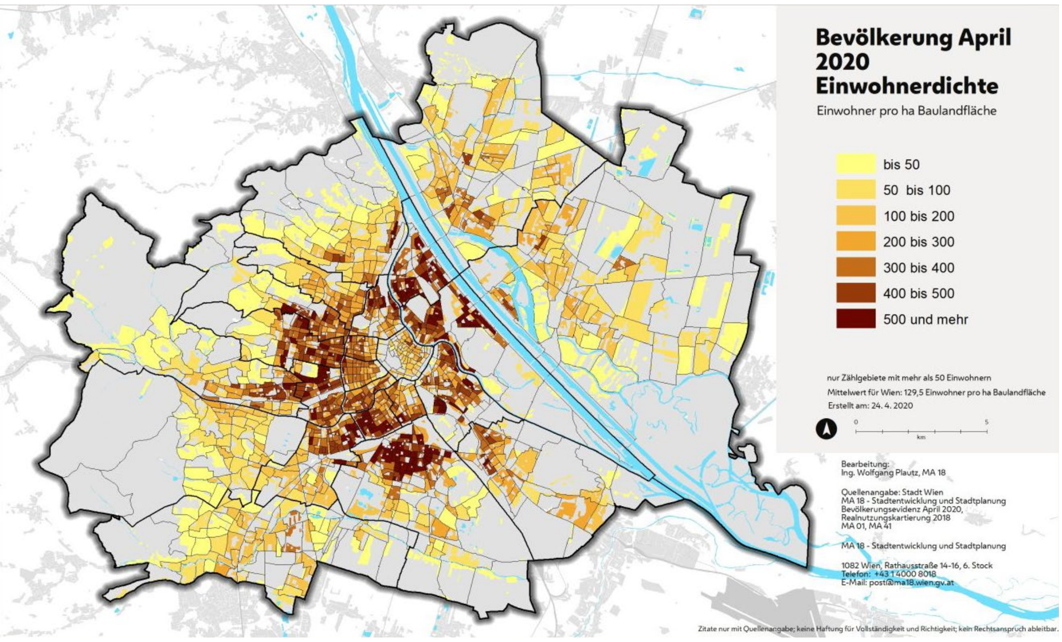


Figure 3.32: Population density of Vienna (© MA 18, MA 18/C. Fürthner).

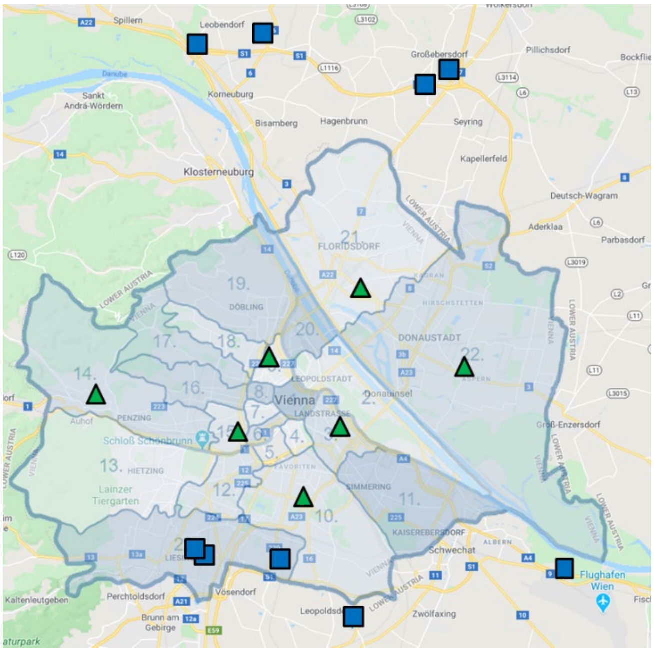


Figure 3.33: Vienna with the locations of the logistics centers (blue squares) and locations of potential city-hubs (green triangles).

Manchester

Manchester city has around 550 thousand inhabitants and an annual parcel volume of 14 million (based on parcel volume in UK, Copenhagen Economics, 2019). This corresponds to a daily volume of 44 thousand parcels. Similar to Vienna, this volume is distributed across Manchester based on population density, see Figure 4.13. The locations of logistic centers, as well as potential city-hubs (from discussions with TfGM) are shown in Figure 4.14. The delivery addresses and delivery routes can be calculated in the same manner as in Vienna.

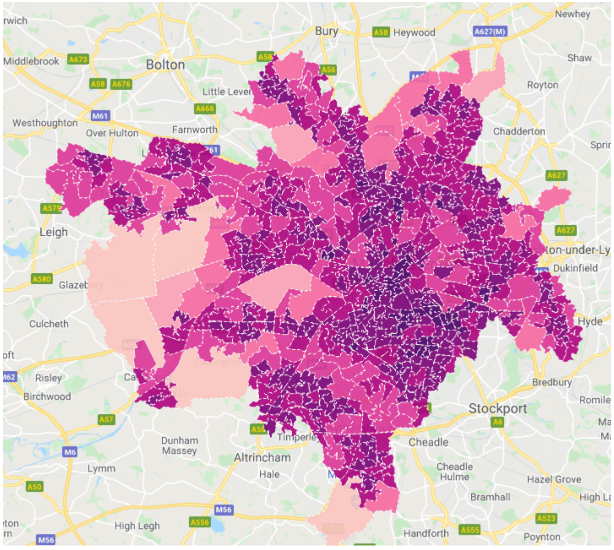


Figure 3.34: Population density of Manchester.

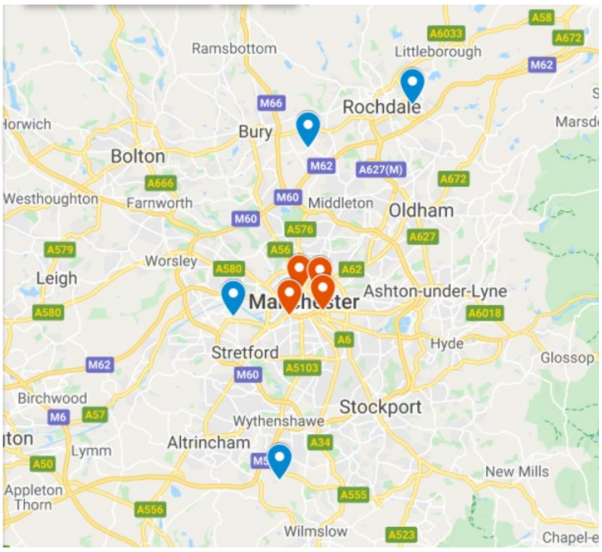


Figure 3.35: Locations of the logistics centers (blue pins) and potential city-hubs (red pins).

3.5.3 Transferability approach

The goal of this study is to address the transferability of the methodology. When considering the primary output to be the total mileage, we want to identify the key factors that influence the output most. These are shown in Figure 3.18, which illustrates a qualitative chart of dependencies.

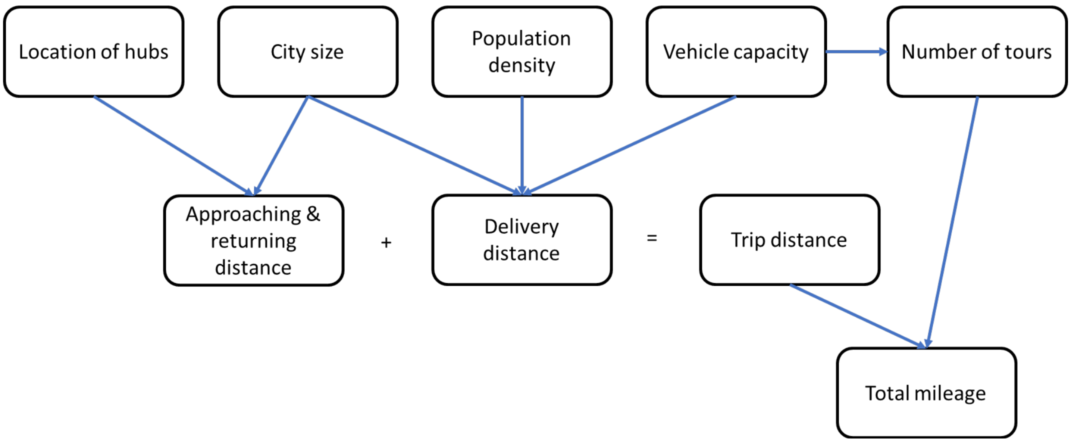


Figure 3.36: Key factors for transferability in automated delivery.

The approaching & returning distance is the route of a delivery vehicle from the origin (distribution center or city hub) to the delivery area and back, which directly depends on the location of the hubs and the city size. The delivery distance is the driven km within the delivery area, from the first parcel to the last one. This primarily depends on the size of the delivery are, the population / parcel density, and the vehicle capacity. Finally, the trip distance of each vehicle is the sum of its approaching & returning distance and the delivery distance. The sum of all trip distances results in the total mileage.

Following the correlations, a simplified transferrable approach can be summarised as the following steps:

1. Estimate the parcel demand
2. Identify the distribution centers and potential city-hub locations
3. Subdivide the city / region into areas (e.g., districts or postal codes)
4. Calculate the average approaching distance to the delivery areas
5. Estimate the average delivery distance w.r.t. population density for each area
6. Multiply average trip lengths with the number of trips for each area

This results in an approximation for the total delivery mileage, without the necessity to apply the tour calculations in detail.

3.5.4 Impacts

For automated delivery and automated consolidation, the primary factors for the impacts are the fleet size and the driven km. They are fundamental for freight operations since other impact indicators are directly based on them, such as annual fleet cost, freight transport cost, CO_2 emissions and congestion.

Fleet size and driven km
Table 4.4 and Table 4.5 show all delivery variants with respect to their fleet composition and driven km per day. The columns show the number of delivery trips, fleet size, average number of stops (parking operations) per trip, average trip length and mileage of all delivery trips. This is followed by the mileage of the consolidation trips by trucks (i.e., trips for delivering to parcels to the city-hubs), and finally the total mileage of all vehicles. As we can see, the results of Vienna and Manchester are similar, except that the total fleet size and mileage for delivery is larger for Vienna since the city is larger. However, the percentage of changes are equal.

We see that on the one hand, the mileage is significantly shortened by the consolidated delivery via the centrally located city-hubs, and on the other hand, mileage increases due to the lower capacities of the robo-vans for automated delivery.

Table 3.24: Results for automated delivery and automated consolidation for Vienna.

	Delivery via van / robo-van				Consolidation trips by trucks	Total driven km
	No of trips	Fleet size	Avg. trip length	Driven km	Driven km	
No consolidation						

Manual delivery	1,799	1.799	44.7 km	80,389 km	-	80,389 km
Automated delivery	2,692	898	39.4 km	10,6177 km	-	106,177 km
Consolidated delivery						
Manual delivery with city-hubs	1,806	1.806	13.7 km	24,675 km	10.445 km	35,120 km
Automated delivery with city-hubs	2,716	906	11.9 km	32,347 km	10.445 km	42,792 km

Table 3.25: Results for automated delivery and automated consolidation for Manchester.

	Delivery via van / robo-van				Consolidation trips by trucks	Total driven km
	No of trips	Fleet size	Avg. trip length	Driven km	Driven km	
No consolidation						
Manual delivery	299	299	32.8 km	9751 km	-	9751 km
Automated delivery	444	148	27.3 km	12087 km	-	12087 km
Consolidated delivery						
Manual delivery with city-hubs	444	148	11.8 km	3579 km	783 km	4362 km
Automated delivery with city-hubs	299	299	9.4 km	4245 km	783 km	5027 km

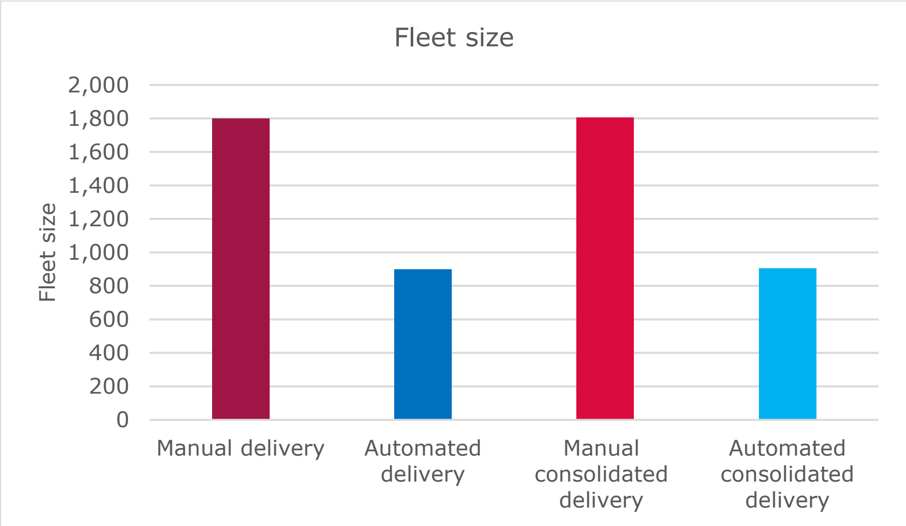


Figure 3.37: Fleet size results for automated delivery and automated consolidation in Vienna.

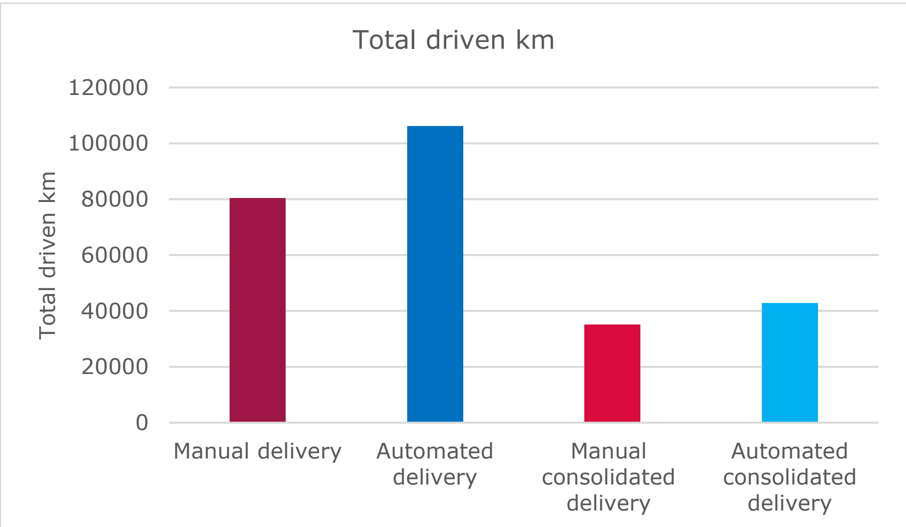


Figure 3.38: Mileage results for automated delivery and automated consolidation in Vienna.

Congestion

Micro-simulation results have shown that the congestion caused by the freight vehicles to the overall traffic is not significant, since their share of the traffic volume is minimal (Hu et al. 2021). However, automated delivery and automated consolidation have the following positive impacts regarding the congestion.

- Automated freight delivery can utilise the off-peak hours and the night-time, therefore giving passenger transport more space during the peak hours and reducing tension in the traffic.
- Following the first point, while the congestion impact of freight transport on the overall traffic is minimal, the impact of the overall traffic on freight transport is substantial. Delivering freight during off-peak hours and night is much more efficient.

Minimising freight mileage via to consolidation contributes to less congestion in overall.

Figure 4.18 shows a breakdown of freight mileage for different time periods of the day. While automated delivery generates more mileage, it is distributed over the full day, and even the rush hours 6am – 9am and 3pm – 6pm can be entirely avoided. The consolidation tours to service the city-hubs via trucks are done at 6am for the manual scenario and between 0am and 6am in the automated scenario.

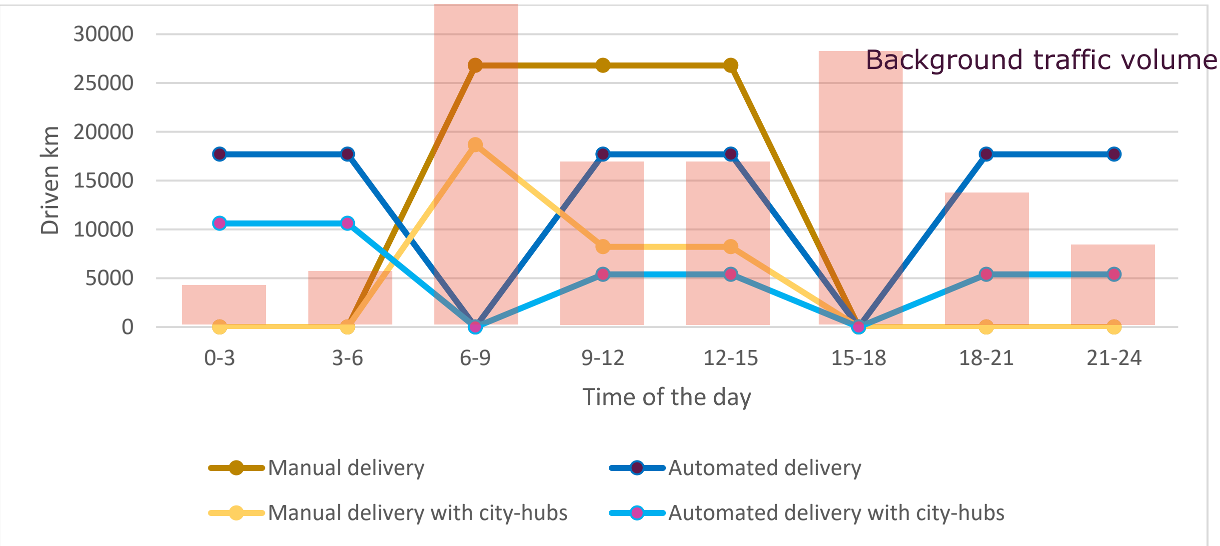


Figure 3.39: Chart for mileage (km) for each delivery scenario and breakdown to time of the day.

3.5.5 Conclusions

For the cities Vienna and Manchester who are partners of the Levitate project, we showed that the robo-van concept for automated urban delivery will increase the mileage of the delivery trips when compared to the current manual delivery situation. The main reason is the assumption that the vehicle capacity will decrease due to the delivery robots and additional equipment. In general, the biggest advantage of automated freight transport is the possibility to deploy these when the demand for road capacity is low or at its lowest, for example at night. Without restrictions on working times, the road infrastructure can be utilised more efficiently by particularly freight transport by avoiding deliveries during peak traffic periods. Looking at automated consolidation, the current delivery system has a high redundancy since multiple delivery companies operate in the same area, thus one delivery address is often approached multiple times by different delivery companies. Therefore, consolidation through city-hubs is in the spotlight, especially white-label concepts where the infrastructure is shared among different logistics provider companies in order to reduce redundancy and therefore the freight mileage (c.f. Schodl et al., 2020). Automated logistics will be a big support for the implementation since servicing the city-hubs can be automated and shifted to the night, when all incoming parcels arrived.

Regarding the methodology, we used for this case study operations research for detailed calculation and a simplified macro approach for quick assessment. While operations research requires a full road network of the city in order to calculate the delivery tours of each vehicle, this step is omitted in the simplified approach. For that we only require a demographic data of the city, estimation of parcel volume, and knowledge on the distribution centers and the potential city hubs. With these data, the simplified macro approach can obtain a good approximation of the delivery performance.

3.6 Platooning on urban highway bridges

In this CS, we address an urban highway section where a large portion consists of bridges. This is typical for urban highways, which experience many crossings. The properties of the bridge models were chosen to include most commonly built bridge types. In this study, the traffic flows are compared to the baseline of current traffic without truck platooning in terms of their effect on resulting internal forces in the investigated bridge models. The main question is whether the bridges can safely fulfil their intended function under the new traffic scenario.

Scenarios of the automation of freight traffic consider forming of truck platoons, which feature certain similarity to trains, in that the distance of vehicles within the platoon is short and in that the vehicles in one platoon follow the driving manoeuvres of the leading vehicle. The sources of concerns with this new traffic composition in regard to bridge safety are:

- Concentration of vertical traffic loads causing higher bridge internal forces,
- Increase of dynamic amplification due to repetitive axle load spacing,
- Increase of braking forces that must be absorbed be the bridge.

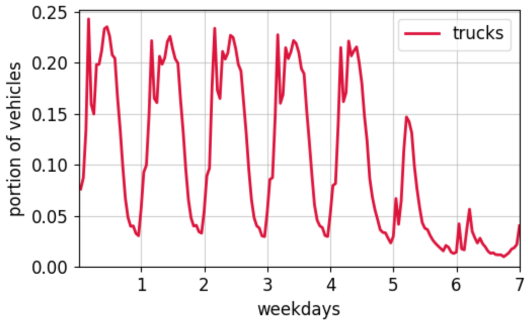
Concentration of vertical traffic loads on the bridge can affect the magnitude of internal forces in the bridge. Since each bridge is designed to a certain level of traffic loads, this may affect the bridge safety. Similarly, to the procedure in the Deliverable D7.3 (Hu et al. 2021), the analysis of bridge safety will focus on evaluation of bending moments and shear forces in bridge main (longitudinal) girders, which are crucial elements of bridge's load-bearing system. The load-bearing capacity of a bridge is evaluated using these main Ultimate Limit States (ULS). It can be expected that an insufficient load-bearing capacity of main girders would cause significant retrofitting cost, or even make a bridge replacement necessary.

Increase of braking forces affects primarily the bridge bearings, which are in most cases responsible for the transfer or horizontal forces from the bridge to the foundations. In other bridge configurations, horizontal forces in bridge's longitudinal direction can be transferred through piers rather than bearings. In that case, the increase could affect safety of the piers. An insufficient capacity of bearings to transfer horizontal loads is considered to be less critical in terms of retrofitting costs, compared to ULS of main girders.

3.6.1 Model and Methodology

Traffic modelling

The properties of traffic composition used here were derived from traffic measurements and Weigh-In-Motion (WIM) data recorded in an urban area. The traffic composition was artificially adjusted to the ratio of freight traffic chosen for the scenarios. All traffic properties shown below depict the adjusted characteristics, which were used in all simulations presented below. Figure 19 shows the variation of the portion of trucks in the traffic flow in the right lane (lane 0) and the left lane (lane 1) from Monday to Sunday. In the right lane, the portion of trucks varied between 1% and 24%; the portion of trucks in the left lane was assumed to be lower (Figure 19 right). In contrast to this urban traffic model, the inter-city traffic model used previously in Deliverable D7.3 featured a constant 100% of trucks in the right lane and 20% of trucks in the left lane, if redistribution between lanes was not necessary due to traffic amount.



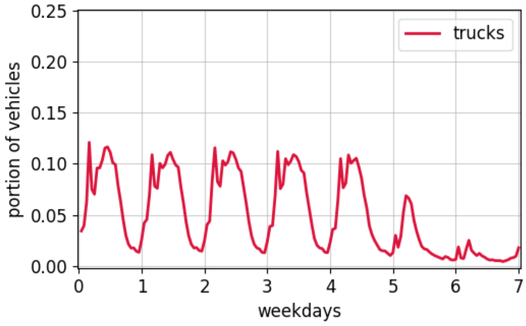


Figure 3.40: Portion of trucks among all vehicles in the traffic flow, depicted for the lane 0 (left) and lane 1 (right).

The vehicle types, properties of each vehicle type and relative number of vehicles of each type in the traffic flow, are essentially based on traffic measurements. This resulted in more than 50 different vehicle types that were used in the traffic simulation for the urban traffic. The inter-city traffic model applied in D7.3 used only 6 vehicle types.
Each vehicle type is defined through deterministic values of axle distances and the distribution of gross vehicle weight to individual axles (i.e., ratio of axle weight / total weight). Additionally, the gross vehicle weight is defined as a probabilistic variable, consisting of a sum of several distributions.
The traffic flow in each lane is defined through the portion of vehicles of each type and the overall amount of passing vehicles per hour. Both of these values change over time in a weekly cycle. The amount of passing vehicles in simulated urban traffic, which includes consideration of future traffic increase, is depicted in Figure 20. The number of vehicles is limited by the lane capacity. In contrast to this, the model of the previously used inter-city traffic applied in D7.3 featured a constant number of vehicles.

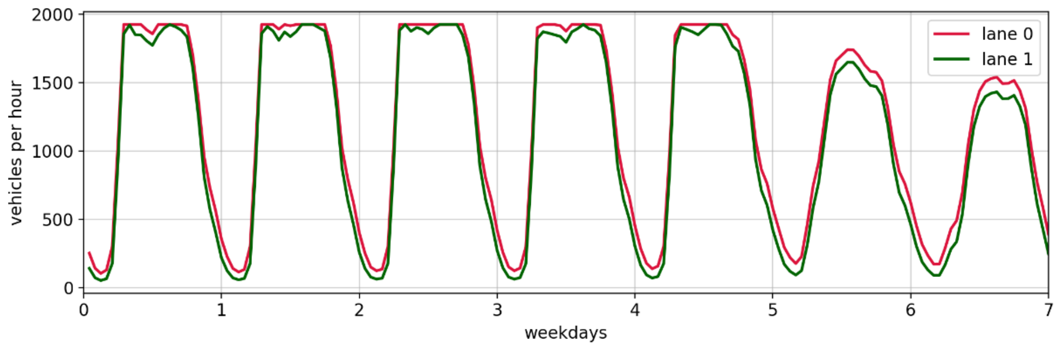


Figure 3.41: Number of vehicles per hour and lane in course of a week.

Combining the traffic composition in each lane with evaluated properties of different vehicle types, it is possible to show a distribution of gross vehicle masses for each lane. Figure 3.24 compares the distributions between the previously used intercity traffic model and the urban traffic model used in this study. It is apparent, that the urban traffic model consists of much larger portion of light vehicles; the difference is particularly distinct for the right lane (lane 0). On the other hand, the occurring maxima of vehicle weights are larger in the urban traffic model. This is caused by different consideration of special vehicles in the two models. The intercity traffic model considered violations of prescribed weight limit (set at 40 t) up to approx. 53 t, but excluded the presence of special vehicles. The urban traffic model used here considers the fact that special vehicles are allowed up to 60 t, as well as it considers small violations of this limit. Although the total amount of such heavy vehicles is very low, they do appear in the regular traffic flow. They can significantly influence the results, because the evaluated quantities are the extremes of bridge internal forces.

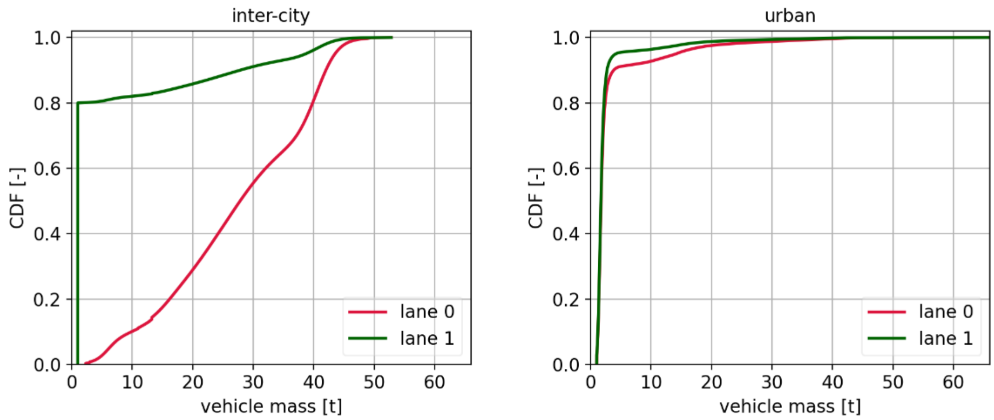


Figure 3.42: Cumulative Density Function of vehicle masses, aggregated lane-wise. Intercity traffic model (left) and urban traffic model (right).

The urban traffic model included vehicle types with up to 9 axles. A detailed description of the properties of all vehicle types is omitted in this report for the sake of compactness.

3.6.2 Bridges in the modelled urban highway section

This case study models an actual section of urban highway. Typically, large portion of urban highways are carried by bridges, since the highway must cross many streets, railway lines and other obstacles without interruption. The bridges modelled in this case study are fictitious, but they are intended to resemble the most widespread structural properties of bridges used in many European cities. Most urban highway bridges are constructed using prestressed concrete, which is mostly used in bridges up to medium spans. An overview of basic properties of the modelled bridges is given in Table 5. The total length of all bridges is 3056 m, which would correspond to an estimated total length of the highway section of approx. 8 – 30 km, depending on how large is the portion of the highway that is carried by the bridges.

Table 3.26: Basic properties of modelled bridges

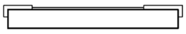
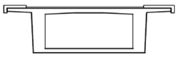
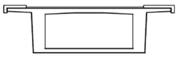
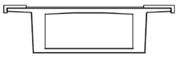
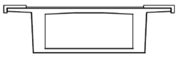
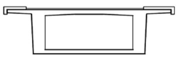
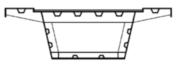
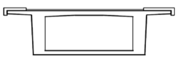
Bridge	Crossed obstacle	Material	Type of cross-section	Number of lanes	Length [m]	Largest span

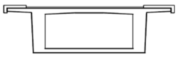
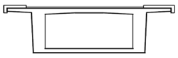
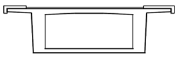
						[m]
1	Railway lines	Prestressed concrete	Box-girder	2	84	21
2	Streets	Prestressed concrete	Slab	3	190	19
3	Streets	Prestressed concrete	Slab	3	79	29
4	Railway lines	Prestressed concrete	Box-girder	3	120	40
5	Streets	Prestressed concrete	T-beam	3	125	25
6	Streets	Prestressed concrete	Box-girder	3	105	35
7	Streets	Prestressed concrete	Box-girder	3	348	36
8	Water channel	Prestressed concrete	Box-girder	3	147	73
9	Streets; park	Composite	Double-box-girder	3	450	23
10	Streets	Prestressed concrete	Box-girder	3	80	40
11	River	Steel	Box-girder	3	450	210
12	Water channel	Prestressed concrete	Box-girder	3	302	51
13	Streets	Prestressed concrete	T-beam	3	173	29
14	Streets	Prestressed concrete	Box-girder	3	89	33
15	Streets; brook	Prestressed concrete	Box-girder	3	210	47
16	Streets	Prestressed concrete	Box-girder	3	104	35

The bridges were modelled with a constant cross-section, which is appropriate for short and medium span bridges. Although variable cross-section is typical in girder bridges with spans above 60 m, the bridge models were assumed as having constant cross-section for reasons of modelling simplicity.
The model for calculating vertical load effects included max. 3 spans, since the results provided by a 3-span model are very similar to multi-span models. The model for calculating horizontal effects of vehicle braking included the whole bridge length, since the horizontal braking forces in longitudinal direction accumulate over its whole length.
The basic cross-section properties are listed in Table 6.

Table 3.27: Cross-section properties of modelled bridges

Bridge	Cross-section sketch	Height [m]	Dimensions
1		1.4	Web thickness = 0.6 m, Deck width = 10 m Thickness of top / bottom slab = 0.25 /

			0.15 m
2		0.9	Deck width = 10.5 m
3		1.3	Deck width = 10.5 m
4		2.0	Web thickness = 0.7 m, Deck width = 10.5 m Thickness of top / bottom slab = 0.3 / 0.2 m
5		1.3	Number of beams = 2, , Deck width = 10.5 m Beam width = 0.65 m, Slab thickness = 0.3 m
6		1.8	Web thickness = 0.7 m, Deck width = 10.5 m Thickness of top / bottom slab = 0.25 / 0.2 m
7		1.8	Web thickness = 0.6 m, Deck width = 10 m Thickness of top / bottom slab = 0.35 / 0.2 m
8		2.7	Web thickness = 0.8 m, Deck width = 10.5 m Thickness of top / bottom slab = 0.35 / 0.2 m
9		1.0	Thickness of top slab = 0.3, Deck width = 10.5 m Box width = 0.8 m, Steel web thickness = 20 mm, Thickness of top / bottom of steel box = 20 / 40 mm
10		2.0	Web thickness = 0.75 m, Deck width = 10.5 m Thickness of top / bottom slab = 0.35 / 0.2 m
11		7.0	Deck width = 10.5 m, Height of stiffenings = 0.27 m Web thickness = 25 mm, Thickness of stiffenings = 10 mm Thickness of top / bottom of steel box = 25 / 40 mm
12		2.5	Web thickness = 0.7 m, Deck width = 10.5 m Thickness of top / bottom slab = 0.3 / 0.2 m
13		1.5	Number of beams = 2, Deck width = 10.5 m Beam width = 0.6 m, Slab thickness = 0.3 m

14		1.6	Web thickness = 0.6 m, Deck width = 10 m Thickness of top / bottom slab = 0.25 / 0.15 m
15		2.3	Web thickness = 0.6 m, Deck width = 10 m Thickness of top / bottom slab = 0.25 / 0.15 m
16		1.75	Web thickness = 0.6 m, Deck width = 10 m Thickness of top / bottom slab = 0.25 / 0.15 m

3.6.3 Traffic modelling

Besides the above-mentioned properties of the urban traffic model, assumptions regarding the congestion properties were applied. The forming and dissolving of congestions was modeled using the same methodology as presented in D7.3. In contrast to D7.3, where the governing parameters P_{cong} and P_{flow} were constant, the model used here allots their values in dependance on the amount of traffic. In low traffic, the probability of the congestion formation is lower, and the probability of congestion dissolving is higher. Figure 22 shows the used values of $1\text{-}P_{flow}$ (left) and $1\text{-}P_{cong}$ (right). In comparison, the model of intercity traffic used in D7.3 used constant values of $1\text{-}P_{flow}=0.001$ and $1\text{-}P_{cong}=0.01$ in most cases.

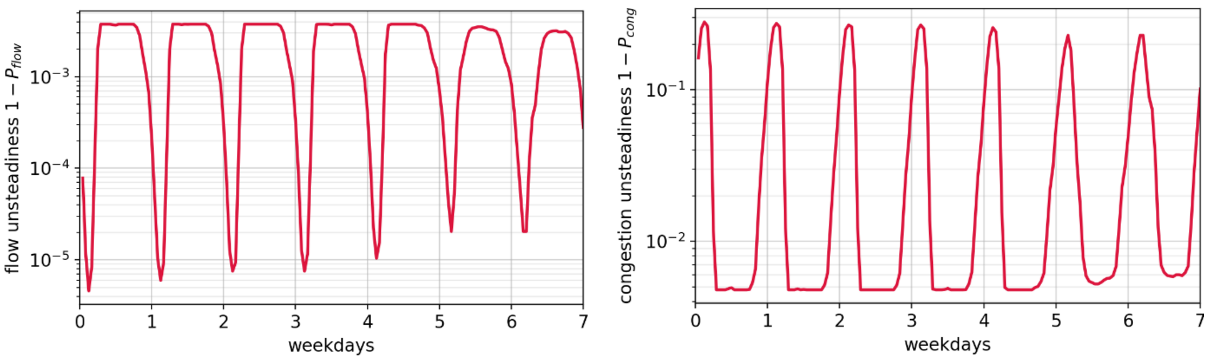


Figure 3.43: Parameters of P_{cong} and P_{flow} that govern the formation and dissolving of congestions.

Additionally, the parameter of vehicle distances in congestion is important. Similarly to the work in D7.3, the axle-to-axle vehicle distance was modelled using a normal distribution $\mathcal{N}(10,5)$ with added boundaries of 3 m and 20 m.

Similarly to the work of D7.3, the assumptions include:

- Constant vehicle speed of flowing traffic; no overtaking
- A platoon consists of vehicles of the same type
- Number of trucks in a platoon is between 3 and 12, randomly generated from a uniform distribution
- Inter-vehicle distances of trucks within platoon are approx. 0.5 m

- Braking manoeuvres that include full braking occur statistically at 1 in every 1000 passing vehicles.

3.6.4 Scenarios

The following traffic scenarios were analysed:

Baseline
The baseline scenario models the traffic with the above-mentioned properties, without any formation of truck platoons.

Platoons
The platoon-scenario models the traffic with the above-mentioned properties, with added formation of truck platoons. The total amount of trucks is the same as is the baseline scenario. It was assumed that 60% of trucks are organized in platoons (penetration rate = 60%). Since the previous investigation shown in D7.3 showed that the penetration rate has almost no effect on the results, its value was not varied.
The inter-vehicle distances were assumed to be very low and following a normal distribution $\mathcal{N}(0.5, 0.1)$ with added boundaries of minimum=0.1 m and maximum=0.9 m. Up to 12 trucks can be included in one platoon.

Intelligent access control
For the intelligent access control, the above-mentioned platoon-scenario was modified using different inter-vehicle distances. The modelling assumptions are listed in Table 4.8. They include four distributions with means of $d_\mu = 2.5\ m, 5\ m, 10\ m$ and $15\ m$.
The implementation did not envisage repeated generation of traffic flows, but rather a modification of the already generated flows in the platoon scenario, by altering the inter-vehicle distances within platoons.

Table 3.28: Modified assumptions of inter-vehicle distances between trucks in platoons

Nr.	Distribution of inter-vehicle distances	Lower boundary	Upper boundary
1	$\mathcal{N}(2.5, 0.225)$	1.825 m	3.175 m
2	$\mathcal{N}(5, 0.35)$	3.95 m	6.05 m
3	$\mathcal{N}(10, 0.6)$	8.2 m	11.8 m
4	$\mathcal{N}(15, 0.85)$	12.45 m	17.55 m

3.6.5 Impacts

This chapter summarizes the simulation results. In the subchapter 0, the results regarding the structural safety in two scenarios (baseline & platoons) are compared. Based on these results, the strengthening needs are described in subchapter 0.
The results from scenarios of intelligent access control are shown in subchapter 0.

Structural safety
Similarly to the study presented in Deliverable D7.3, the evaluation of structural safety with regard to vertical traffic loads was done in probabilistic manner by calculating the probability of exceedance of the characteristic traffic load effects (M_k, V_k) due to Load Model 1 (LM1) that is specified in current EuroCode. The probability of its exceedance

within 50 years should be less than 5%. The calculated probabilities, evaluated using fitted distributions of extreme values, are shown in Figure 23 and Figure 24, for the limit states of bending moment and shear force, respectively.

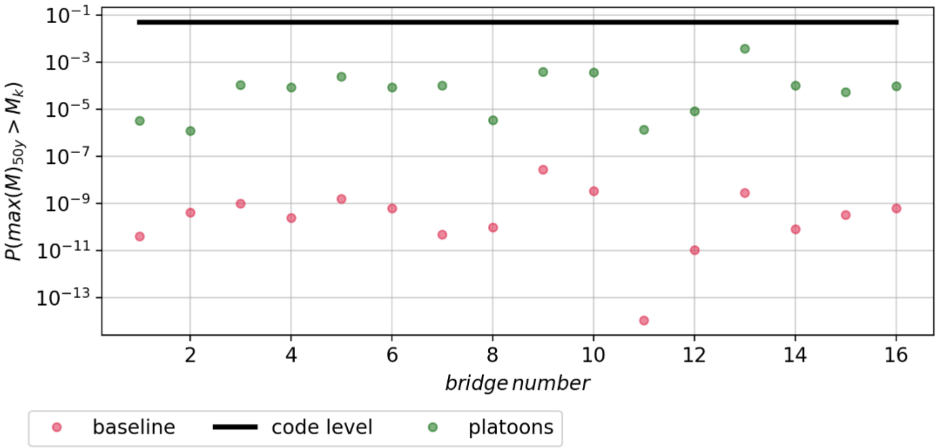


Figure 3.44: Probability that the 50-year-extreme of bending moment exceeds M_k.

In contrast to the results of the previous study shown in D7.3, the exceedance probability remained consistently below the level of 5%. Thus, the bridges analysed in this case study would not have a problem with structural safety, presuming they were built according current EuroCode requirements for the design of new bridges. Although the difference in exceedance probabilities between the baseline and the platoon scenario is apparent, the significantly larger probabilities in the platoon scenario still do not exceed 5%.

The largest increase of exceedance probabilities $P(M > M_k)$, $P(V > V_k)$ between the baseline and the platoon scenario was observed at the bridge nr.11, which is the bridge with the largest span. This is in line with the previous findings in Deliverable D7.3 (Hu et al. 2021), where the span length proved to be a significant factor when assessing the effect of introduction of truck platoons. Structural safety still does not reach the critical point at bridge nr.11 because the exceedance probability in the baseline scenario starts at a very low point.

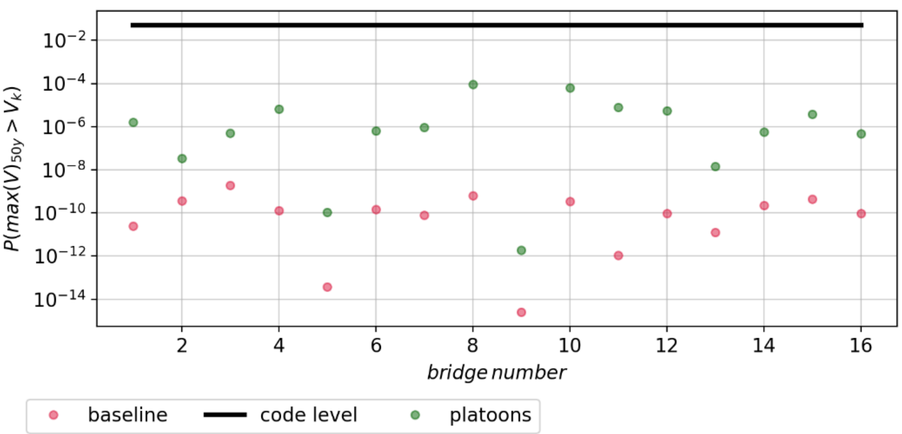


Figure 3.45: Probability that the 50-year-extreme of shear force exceeds V_k.

The cause of the difference in the results between the previous study (D7.3) and this case study lies undoubtedly in the difference of the used traffic models. The intercity traffic model used in D7.3, which had a very large portion of trucks, resulted in significantly higher probabilities of exceeding the characteristic values of traffic load effects, particularly for bridges with larger spans (>60 m). The effect of the introduction of truck platoons was therefore quite pronounced in the intercity traffic scenario. Since the current case study uses an urban traffic model, which has much lower portion of trucks in the traffic flow (particularly in the right lane), the predicted effects of the introduction of truck platooning are hence less pronounced and in overall not critical, as far as the vertical traffic load effect concerns.

The extreme values of the horizontal braking force were very pronounced, similarly to previous findings in D7.3. The very small inter-vehicle distances assumed in platoons (0.5 m) caused the requirement of almost perfectly synchronized braking. The braking scenarios with full braking (deceleration ~0.5g) coupled with platoon lengths of up to 12 trucks resulted in quite large total braking force that must be transferred from the bridge deck to the foundations. In contrast to the analysis in D7.3, which investigated only single-span bridges, the bridges in this study accommodate the braking forces over a larger road length due to their multi-span nature. This contributed to the relatively large extreme values of braking forces in the platoon scenario, shown in Figure 3.28.

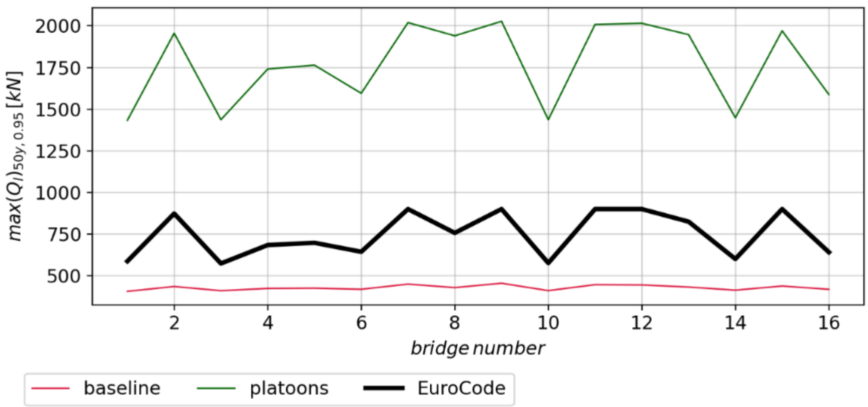


Figure 3.46: 95%-quantiles of 50-year-extremes of horizontal braking force Q_l.

The difference to the study shown in D7.3 is in that the expected braking force extremes in the baseline scenario are well below the EuroCode requirements. Again, this is undoubtedly due to used urban traffic model with much lower truck ratio. The previously used intercity traffic model caused together with other model assumptions an exceedance of the EuroCode requirements even in the baseline scenario for certain range of bridge lengths.

Strengthening needs

As shown above, the extreme values of bridge internal forces are not expected to exceed the characteristic load effects of the Eurocode in the bridge models analyzed here. That means there is no strengthening need for bridges that are built according to the current Eurocode requirements (LM1 load model) for new bridges, as far as it concerns the vertical traffic load effects. However, national regulations can allow the usage of lower requirements especially when assessing existing bridges. The requirement is defined by multiplication of LM1 load model with a coefficient (for example 0.8). Structural safety is then evaluated with regard to reduced traffic loads. Figure 26 shows the values of the LM1-reduction coefficient that would correspond to the expected extremes (95%-quantile of 50-years-extreme distribution) of bridge internal forces in the baseline and platoon traffic scenario. That means for example that with a value of 0.83 for the platoon scenario, the bridge would need to have the load-bearing capacity to carry 83% of LM1 load model to ensure structural safety. Figure 26 combines the limit states of bending moment and shear force by showing the higher of the two for each bridge.

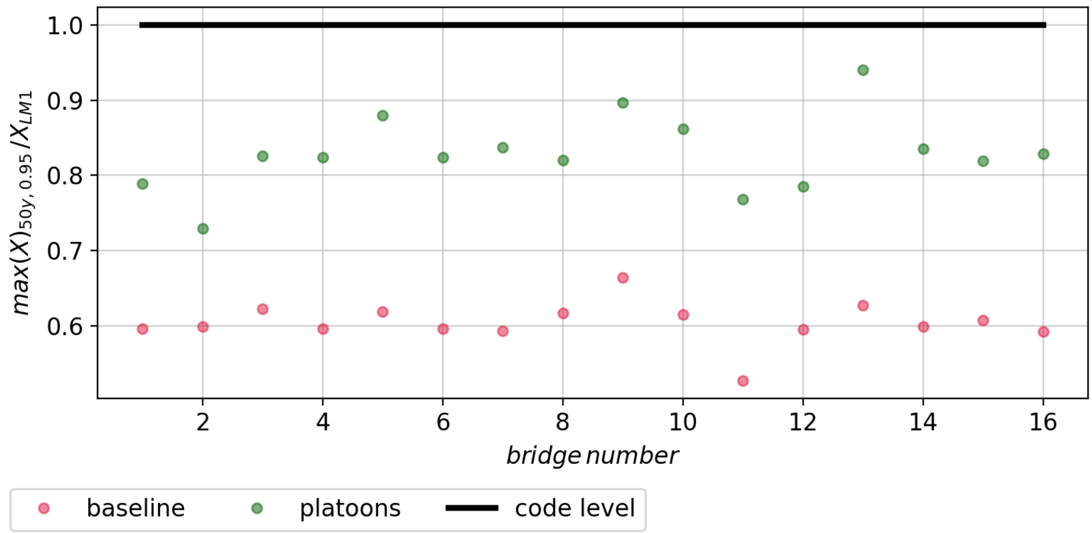


Figure 3.47: Ratio of expected extremes of vertical traffic load effects to the Load Model 1 effects (Eurocode).

There is an apparent difference between the load-carrying requirements of the two traffic scenarios. While the baseline scenario required values of only around 0.6, the platoon scenario required mostly values around 0.83. Depending on the bridge construction and its condition, this requirement may by met, or bridge strengthening may be required.
As an alternative to (very costly) bridge strengthening, intelligent access control may be introduced, which is described in the next subchapter.

Intelligent access control

The concept of intelligent access control mentioned in D7.3 envisages dynamic change of the inter-vehicle distance within platoons based on the requirements of bridges in individual road sections. As shown above, the introduction of some measures would be needed at the investigated road section only if the load-carrying capacity of the bridges would not meet the requirements of the Eurocode for new bridges. In such case, the inter-vehicle distances would need to be modified. This was analysed similarly to the study shown in D7.3; the evaluation was repeated for different values of vehicle distances listed in Table 7.

Figure 27 shows the results for the bending moment limit state in terms of the ratio of expected bending moment extremes to the bending moment due to Load Model 1. Figure 28 shows the same evaluation for the shear force limit state.

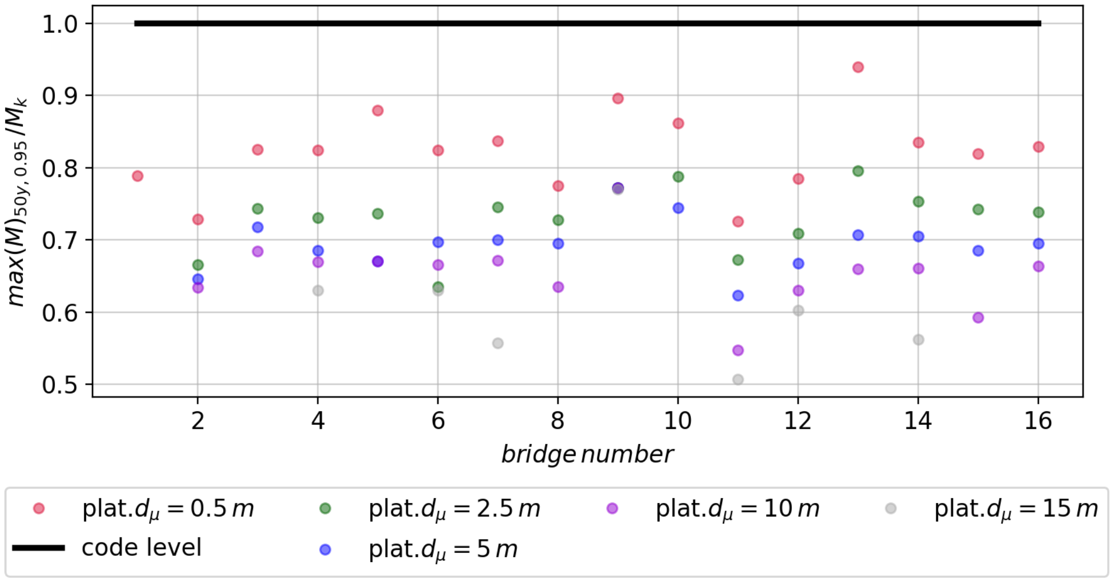


Figure 3.48: Ratio of expected bending moment extremes to the characteristic values of LM1 in different options of access control.

It appears that already an increase of the mean inter-vehicle distance to $d_\mu = 2.5\,m$ would be sufficient to ensure the structural safety of all bridges in this case study, if their load-bearing capacity reaches 80% of the Load Model 1.

Bridges in worse conditions would require higher inter-vehicle distances. For example, if the bridges would be able to carry only 70% of the Load Model 1, the inter-vehicle distances would need to be raised to at least $d_\mu = 10\,m$.

For bridges with load-carrying capacities of only 60% of Load Model 1, no meaningful access control measure could be determined, making truck platooning to be not viable.

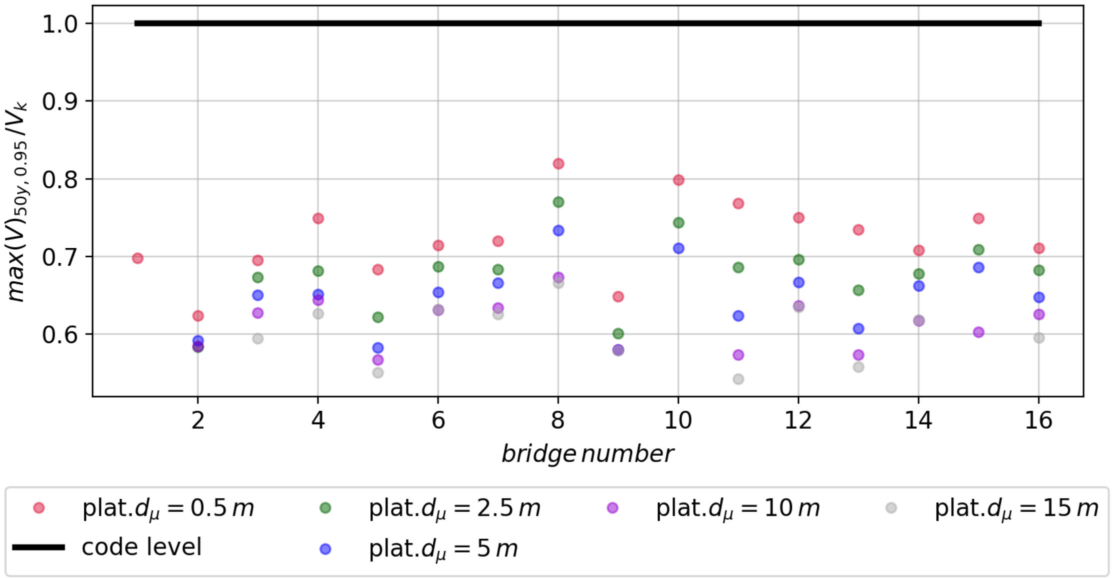


Figure 3.49: Ratio of expected shear force extremes to the characteristic values of LM1 in different options of access control.

As shown in chapter 0, the extremes of the horizontal braking force were substantially increased by the introduction of platoons due to the fact that all trucks in the platoon must brake almost simultaneously. This leads in case of full braking to a very large total braking force. The situation becomes less critical when inter-vehicle distances between trucks in platoons are increased. The larger vehicle distances can be used as braking distance reserves. This lowers the required deceleration of trucks in the platoon. While the first truck must perform full braking (deceleration ~0.5g), the required deceleration of following trucks decreases with its position in the platoon. Figure 29 shows the expected braking force extremes in different scenarios of mean inter-vehicle distance d_{μ}. With the value of $d_{\mu} = 15\,m$, the braking force extremes were approximately equal to the current requirements of the Eurocode.

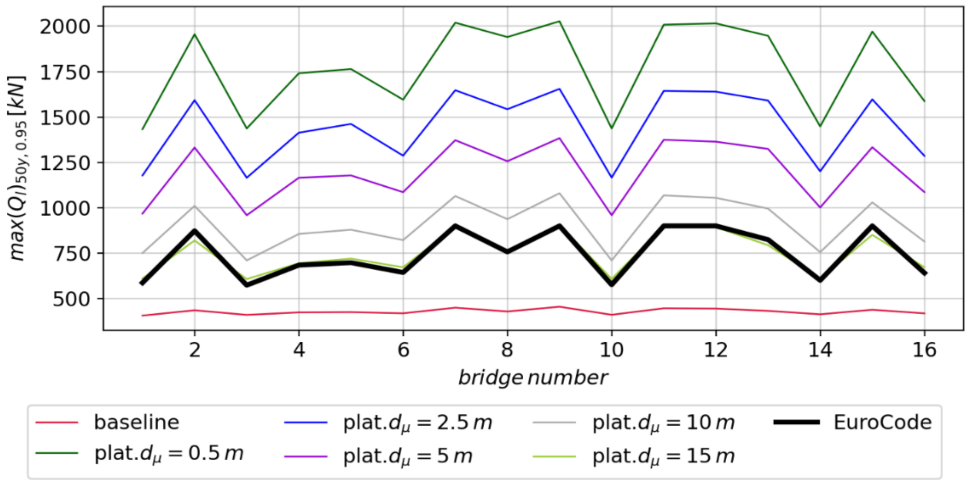


Figure 3.50: 95%-quantiles of 50-year-extremes of horizontal braking force Q_l in different options of access control.

3.6.6 Conclusions

The presented analysis of an urban highway section showed the effects of different traffic scenarios on estimated structural safety of bridges. The simulated traffic flow was adapted to resemble properties of urban traffic, where the portion of trucks is lower compared to intercity traffic. The traffic properties were modelled to vary in a weekly cycle. The portion of trucks in the right lane reached up to 24%. The adopted traffic model had a significant impact on the results of estimated structural safety of bridges, when compared to the previously used intercity traffic model.

The modelled urban highway section had 16 bridges with a total length of ~3 km. The properties of bridge models, although fictitious, were chosen to represent widely used urban highway bridges. To analyse structural safety, vertical traffic load effects as well as the effects of horizontal braking forces were calculated.

The analysis showed that formation of truck platoons can have a significant effect on the expected extremes of bridge internal forces. However, most relevant is their comparison to the load-carrying capacity of the bridges. In contrast to previous analysis, in this case study the bridge force extremes did not exceed the requirements of Load Model 1 of current Eurocode. That means, if the bridges were built to meet current code requirements for new bridges, their structural safety would not be impaired by truck platoons with the urban traffic of the above-mentioned properties. Surprisingly, this included results for a larger bridge with main span over 200 m.

However, existing bridges do not always meet current code requirements for new bridges. In here, intelligent access control could be introduced to ensure the structural safety. If the bridge load-carrying capacity would reach only 80% of Load Model 1, the inter-vehicle distances within platoons should be at least 2.5 m in the analysed scenario. With bridge load-carrying capacities in range 65%-80% of Load Model 1, the inter-vehicle distances should be increased further.

The expected braking forces were substantially higher in the traffic with platoons, compared to the baseline scenario. Again, the inter-vehicle distances were a major factor determining the magnitude of braking force maxima. Although the maximum braking forces is increased significantly, the required strengthening of load-carrying elements seems less problematic than in the case of vertical traffic load effects, which influence the bridge Ultimate Limit States.

When comparing the results of this case study to previous analysis, which modelled intercity traffic, it was obvious that the traffic composition plays a significant role. Therefore, it has to be noted that the results of this case study cannot be generalized. Especially with traffic compositions with higher truck ratios than assumed here, or different bridge structures than modelled in case study, repeated analysis would be required.

References

Alawadhi, M., Almazrouie, J., Kamil, M., & Khalil, K.A. (2020). A systematic literature review of the factors influencing the adoption of autonomous driving. International Journal of System Assurance Engineering and Management 11, 1065–1082. https://doi.org/10.1007/s13198-020-00961-4

Aoyama, Y., & Leon, L.F.A. (2021). Urban governance and autonomous vehicles. Cities, Volume 119, 103410.https://doi.org/10.1016/j.cities.2021.103410

Bertolini, A. & Riccaboni, M. (2021). Grounding the case for a European approach to the regulation of automated driving: the technology-selection effect of liability rules. European Journal of Law and Economics. http://doi.10.1007/s10657-020-09671-5

Bezai, N.E., Medjdoub, B., Al-Habaibeh, A., Chalal, M.L., & Fadli, F. (2021). Future cities and autonomous vehicles: analysis of the barriers to full adoption. Energy and Built Environment, 2(1), 65-81. https://doi.org/10.1016/j.enbenv.2020.05.002.

Boesch, P. M., Ciari, F., & Axhausen, K. W. (2018). Transport policy optimization with autonomous vehicles. Transportation Research Record, 2672(8), 698-707. https://doi.org/10.1177/0361198118791391

Boghani, H.C., Papazikou, E., Zwart, R.d., Roussou, J., Hu, B., Filtness, A., & Papadoulis, A., (2019). Defining the future of passenger car transport, Deliverable D6.1 of the H2020 project LEVITATE.

Burkacky, O., Deichmann, J., Klein, B., Pototzky, K., & Scherf, G. (2020). Cybersecurity in automotive: Mastering the challenge. Munich, McKinsey.

Carsten, O., & Martens, M.H. (2019). How can humans understand their automated cars? HMI principles, problems and solutions. Cognition, Technology & Work, 21, 3–20. https://doi.org/10.1007/s10111-018-0484-0

Chaudhry, A., Sha, H., Haouari R., Zach, M., Boghani, H.C., Singh, M., Gebhard, S., Zwart, R.d., Mons, C., Weijermars, W., Hula, A., Roussou, J., Richter, G., Hu, B., Thomas, P., Quddus, M., & Morris, A. (2021). The long-term impacts of cooperative and automated cars, Deliverable D6.4 of the H2020 project LEVITATE

Chaudhry, A., Papazikou, E., Haouari, R., Sha, H., Singh, M.K., Quigley, C., Quddus, M., Thomas, P., Morris, A., Gebhard, S., Mons, C., Weijermars, W., Roussou, J., (2022) Green Light Optimal Speed Advisory (GLOSA) - passenger cars. Levitate Sub-Use Case Definition and Documentation

Chng, S., Kong, P., Lim, P.Y., Cornet, H., & Cheah, L. (2021). Engaging citizens in driverless mobility: Insights from a global dialogue for research, design and policy, Transportation Research

City of Manchester (2017). The Greater Manchester Transport Strategy 2040. First published February 2017.

City of Vienna (2015). Urban Mobility Plan Vienna. Available at https://www.wien.gv.at/stadtentwicklung/studien/pdf/b008443.pdf.

Correia, G., & van Arem, B. (2016). Solving the user optimum privately owned automated vehicles assignment problem (UO-POAVAP): A model to explore the impacts of self-driving vehicles on urban mobility. Transportation Research Part B, 87, 64–88. https://doi:10.1016/j.trb.2016.03.002

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

Eurorap (2013). Roads that cars can read: A Quality Standard for Road Markings and Traffic Signs on Major Rural Roads - Proposals for consultation. Basingstoke, UK, Eurorap.

Evas, T. (2018). A Common EU Approach to Liability Rules and Insurance for Connected and Autonomous Vehicles: European Added Value Assessment: Accompanying the European Parliament's legislative own-initiative report. Brussels, European Parliamentary Research

Figliozzi, M. and Jennings, D. (2020). Autonomous delivery robots and their potential impacts on urban freight energy consumption and emissions. Transportation Research Procedia, 46, 21-28.

Fraedrich, E., Heinrichs, D., Bahamonde-Birke, F. J., & Cyganski, R. (2019). Autonomous driving, the built environment and policy implications. Transportation Research Part A: Policy

Gebhard, S., Nabavi Niaki, M., Schermers, G , Goldenbeld, C. and Chaudhry, A. (2022). Guidelines and recommendations for future policy of cooperative and automated passenger cars, Deliverable D6.5 of the H2020 project LEVITATE.

Goldenbeld et al., 2021a): Goldenbeld, C., Gebhard, S., Schermers, G, Nabavi Niaki, M., Mons, C. (2021a). Guidelines and recommendations for future policy of automated urban transport, Deliverable D5.5 of the H2020 project LEVITATE.

Goldenbeld, C., Gebhard, S., Schermers, G., Mons, C and Hu, B. (2021b). Guidelines and recommendations for future policy of cooperative and automated freight transport, Deliverable D7.5 of the H2020 project LEVITATE.

Gruyer, D., Orfila, O., Glaser, S., Hedhli, A., Hautiere, N., & Rakotonirainy, A. (2021) Are Connected and Automated Vehicles the Silver Bullet for Future Transportation Challenges? Benefits and Weaknesses on Safety, Consumption, and Traffic Congestion. In Frontiers in Sustainable Cities, 2, p. 63.

Habibzadeh, H., Nussbaum, B.H., Anjomshoa, F., Kantarci, B., Soyata, T. (2019). A survey on cybersecurity, data privacy, and policy issues in cyber-physical system deployments in smart

Hall, 2018: Hall, J. D., Palsson, C., & Price, J. (2018). Is Uber a substitute or complement for public transit? Journal of urban economics, 108, 36-50

Haouari, R., Chaudhry, A., Sha, H., Richter, G., Singh, M., Boghani, H.C., Roussou, J., Hu, B., Thomas, P., Quddus, M., & Morris, A. (2021). The short-term impacts of cooperative, connected, and automated mobility on passenger transport, Deliverable D6.2 of the H2020 project LEVITATE.

Hartveit, K.J.L., & Veisten, K. (2022). Methods for cost-benefit analysis to support decision making. Deliverable D3.4 of the H2020 project LEVITATE.

Hibberd, D., Louw, T., et al. (2018). From research questions to logging requirements. Deliverable D3.1. L3 Pilot Driving Automation. University of Leeds.

Horizon 2020 (2020). Ethics of Connected and Automated Vehicles: recommendations on road safety, privacy, fairness, explainability and responsibility. Luxembourg, Publication Office of the European Union.

Hu, B., Brandstätter, G., Gebhard, S., A., Zwart, R.d., Mons, C., Weijermars, W., Roussou, J., Oikonomou, M., Ziakopoulos, Chaudhry, A., Sha, S., Haouari, R., & Boghani, H.C. (2021c). Long term impacts of CCAM on freight transport, Deliverable D7.4 of the H2020 project LEVITATE.

Hu, B., Brandstätter, G., Ralbovsky, M., Kwapisz, M., Vorwagner, A., Zwart, R.d., Mons, C., Weijermars, W., Roussou, J., Oikonomou, M., Ziakopoulos, Chaudhry, A., Sha, S., Haouari, R., & Boghani, H.C. (2021b). Medium-term impacts of CCAM on freight transport, Deliverable D7.3 of the H2020 project LEVITATE.

Hu, B., Brandstätter, G., Ralbovsky, M., Kwapisz, M., Vorwagner, A., Zwart, R.d., Mons, C., Weijermars, W., Roussou, J., Oikonomou, M., Ziakopoulos, Chaudhry, A., Sha, S., Haouari, R., & Boghani, H.C., (2021a). Short-term impacts of CCAM on freight transport, Deliverable D7.2 of the H2020 project LEVITATE.

Hu, B., Zwart, R.d., Papazikou, E., Boghani, H.C., Filtness, A., & Roussou, J., (2019). Defining the future of freight transport, Deliverable D7.1 of the H2020 project LEVITATE.

Jennings, D., & Figliozzi, M. (2019). Study of Sidewalk Autonomous Delivery Robots and Their Potential Impacts on Freight Efficiency and Travel. Transportation Research Record: Journal of the Transportation Research Board, 2673(6), 317–326.

Khan, S.K., Shiwakoti, N., Stasinopoulos, P. & Chen, Y. (2020). Cyber-attacks in the next-generation cars, mitigation techniques, anticipated readiness and future directions. Accident Analysis & Prevention, 148. https://doi.org/10.1016/j.aap.2020.105837

Kim, K. H., Yook, D. H., Ko, Y. S., & Kim, D. H. (2015a). An analysis of expected effects of the autonomous vehicles on transport and land use in Korea. New York, New York University.

Korse, M.J., Schermers, G., Radewalt, N.M.D., de Hoog, A., Alkim, T. 2004. On track. Results of the trial of LDWA systems. Rotterdam, Th e Netherlands: Transport Research Centre (AVV) of the Dutch Ministry of Transport, Public Works and Water Management. (https://puc.overheid.nl/rijkswaterstaat/doc/PUC_116055_31/)

Kröger, L., Kuhnimhof, T., & Trommer, S. (2018). Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour for Germany and the USA. Transportation research part A: policy and practice, 122, 146-161. https://doi.org/10.1016/j.tra.2018.03.033

Kyriakidis, M., Winter, J.C.F de, Stanton, N., Bellet, T., Arem, B van, et al. (2017). A Human Factors Perspective on Automated Driving. Theoretical Issues in Ergonomics Science, Taylor & Francis, 1-27. https://doi.10.1080/1463922X.2017.1293187

Lee, D., & Hess, D.J (2020). Regulations for on-road testing of connected and automated vehicles: Assessing the potential for global safety harmonization. Transportation Research Part A: Policy and Practice, 136, 85-98. https://doi.org/10.1016/j.tra.2020.03.026

Lim, H.S.M. & Taeihagh, A. (2018). Autonomous Vehicles for Smart and Sustainable Cities: An In-Depth Exploration of Privacy and Cybersecurity Implications. Energies, 11, 1062.

Liu, Y., Tight, M., Sun, Q., & Kang, R. (2019). A systematic review: Road infrastructure requirement for Connected and Autonomous Vehicles (CAVs). Journal of Physics: Conference Series, 1187, 042073.

Lytrivis, A., Manganiaris, S., Reckenzaun, J., Solmaz, S., Protzmann, R., Adaktylos, A.-M., Wimmer, Y., Atasayar, H., Daura, X., & Porcuna, D. (2019). Deliverable. D.5.4 Infrastructure Classification Scheme. INFRAMIX – Road INFRAstructure ready for MIXed vehicle traffic flows

Mahdavian, A., Shojaei, A., Mccormick, S., Papandreou, T., Eluru, N., & Oloufa, A.A. (2021). Drivers and Barriers to Implementation of Connected, Automated, Shared, and Electric Vehicles: An Agenda for Future Research. IEEE Access 9, 22195-22213.

Mardirossian, V. (2020). Will Autonomous Cars Put an End to the Traditional Third-Party Liability Insurance Coverage? In: P. Marano & K. Noussia (Eds.), InInsurTech: A Legal and Regulatory View (pp. 271-290). Switzerland: Springer-Verlag.

Martin, E., & Shaheen, S. (2011) The impact of carsharing on public transit and non-motorized travel: an exploration of North American carsharing survey data.Energies, 4, 2094–2114. https://doi.org/10.3390/en4112094

McAslan, D., Gabriele, M. & Miller, T.R. (2021) Planning and Policy Directions for Autonomous Vehicles in Metropolitan Planning Organizations (MPOs) in the United States, Journal of Urban Technology. https://doi.org/10.1080/10630732.2021.1944751

Medina, A., Maulana, A., Thompson, D., Shandilya N., Almeida, S., Aapaoka A., & Kutila, M. (2017). Public Support Measures for Connected and Automated Driving: Final Report. GROW-SME-15-C-N102. European Commission EC. EU Publications, No. EA-01-17-634-EN-N. https://ec.europa.e

Milakis, D & Müller, S. (2021). The societal dimension of the automated vehicles transition: Towards

Morales-Alvarez, W., Sipele, O., Léberon, R., Tadjine, H.H., & Olaverri-Monreal, C. (2020) Automated Driving: A Literature Review of the Takeover Request in Conditional Automation. Electronics. 9(12):2087. https://doi.org/10.3390/electronics9122087

Mulder, T., Vellinga, N.E. (2021) Exploring data protection challenges of automated driving.In Computer Law & Security Review, 40(105530)

Papazikou, E., Zach, M., Boghani, H.C., Elvik, R., Tympakianaki, A., Nogues, L., Hu, B. (2020a). Detailed list of sub-use cases, applicable forecasting methodologies and necessary output variables, Deliverable D4.4 of the H2020 project LEVITATE.

Rendant, K., & Geelen, van (2020). Connected & Autonomous Vehicles and road infrastructure State of play and outlook. Brussels, Belgian Road Research Centre.

Roussou, J., Oikonomou, M., Mourtakos, V., Müller, J., Vlahogianni, E., Ziakopoulos, A., Hu, B., Chaudhry, A., & Yannis, G., (2021b). Medium-term impacts of CCAM on urban transport, Deliverable D5.3 of the H2020 project LEVITATE.

Roussou, J., Oikonomou, M., Mourtakos, V., Vlahogianni, E., Ziakopoulos, A., Gebhard, S., Mons, C, Zwart, R. de, Weijermars, W., Zach, M., Chaudhry, A., Hu, B., & Yannis, G., (2021c). Long-term impacts of CCAM on urban transport, Deliverable D5.4 of the H2020 project LEVITATE.

Roussou, J., Oikonomou, M., Müller, J., Ziakopoulos, A., & Yannis, G. (2021a). Short- term impacts of CCAM on urban transport, Deliverable D5.2 of the H2020 project LEVITATE

Roussou, J., Papazikou, E., Zwart, R. de, Hu, B., Boghani, H.C., & Yannis, G. (2019). Defining the future of urban transport, Deliverable D5.1 of the H2020 project LEVITATE.

Saeed, T.U., Alabi, B.N.T., & Labi, S. (2020). Preparing Road Infrastructure to Accommodate Connected and Automated Vehicles: System-Level Perspective. Journal of Infrastructure Systems, https://doi.1061/(ASCE)IS.1943-555X.0000593

Seetharaman, A., Patwa, N., Jadhav, V., Saravanan A.S., & Sangeeth D. (2021) Impact of Factors Influencing Cyber Threats on Autonomous Vehicles. Applied Artificial Intelligence, 35:2, 105-132, DOI: 10.1080/08839514.2020.1799149

Sha, H., Chaudhry, A., Haouari R., Zach, M., Richter, G., Singh, M., Boghani, H.C., Roussou, J., Hu, B., Thomas, P., Quddus, M., & Morris, A. (2021). The medium-term impacts of CCAM on passenger transport, Deliverable D6.3 of the H2020 project LEVITATE

Soteropoulos, A., Berger, M., & Ciari, F. (2019). Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies. Transport reviews, 39(1), 29-49.

Stevanovic et al, 2015: Stevanovic, A., D. Randivojevic, J. Stevanovic, M. Ostojic and C. Kergaye. Impact of Green Light Optimized Speed Advisory Systems on Surrogate Safety

Measures of Arterials. Road Safety & Simulation International Conference (RSS), 6-8 October, 2015, Orlando, Florida USA

Taeihagh, A., & Lim, H.S.M. (2019). Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks. Transport Reviews, 39 (1), 103-128.

Vellinga, N.E. (2019) Automated driving and its challenges to international traffic law: which way to go? Law, Innovation and Technology, 11(2), 257-278. https://doi.org/10.1080/17579961.2019.1665798

Vitunskaite, M., He, Y., Brandstetter, T., & Janicke, H. (2019). Smart cities and cyber security: Are we there yet? A comparative study on the role of standards, third party risk management and security ownership. Computers & Security, 83, 313-331.

Weijermars, W. et al. (2021). Road safety related impacts within the Levitate project. Working paper of the road safety working group of the H2020 project LEVITATE.

Zach, M., Sawas, M., Boghani, H.C., & de Zwart, R. (2019). Feasible paths of interventions. Deliverable D4.3 of the H2020 project LEVITATE