SHared automation Operating models for Worldwide adoption

SHOW

Grant Agreement Number: 875530

D10.3: Requirements for AV fleets operation simulation suite and first evidence on pilot results based simulations for impact assessment

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Legal Disclaimer

Executive Summary

The fundamental scope of the current document is to lay the ground for the development of the **Automated Vehicles (AV) fleets operation simulation suite** and provide first evidence of pilot-based simulation results for impact assessment. According to the Grant Agreement, the present deliverable needs to provide all the requirements for developing the SHOW Simulation Suite, a tool that acquires a common pool of simulation data from the different automated mobility use cases resulting in an integrated and holistic simulated AV fleets operation.

After an initial overview of the simulation of automated mobility use cases and scenarios provided by the partners reported in Deliverables 10.1 and 10.2, it is clearly understood that due to the different simulation tools and approaches ideal for each occasion, depending on the different pilot site needs, there is a need of a methodology to acquire a common pool of simulations. Specifically, this method should provide a pool of simulation data from the different scenarios and use cases, to identify the key parameters and possible methodologies on automated driving simulation as well as to synthesize the simulations for all test sites. All these will be accomplished by the development of the **SHOW Simulation Suite**, which will combine the knowledge gained in WP10 of simulating automated mobility and integrate the fundamental aspects of this procedure at its optimal level. The conceptualization of this tool is described in Chapter 3.

The simulation suite will be **a web-based front-end tool** that will give guidelines about simulation of automated driving and will include (i) the followed steps of simulating automated mobility between the different pilot sites, (ii) simulation transferability, (iii) connections between simulation models, and (iv)a library including visualised instructions in the used software and tools. One of the most critical parts of the tool is connecting the different simulation models, in order to enable the upscaling of impacts from microsimulation to macroscopic models and vehicle-level to microscopic scenarios as well. For this reason, different methodologies are proposed by the present deliverable (Section 3.2.4).

The SHOW Simulation Suite, proposed by the present deliverable, will be **useful for every researcher** who is interested in simulating automated mobility. The tool design will offer a great experience to the users by providing information about the possible tools and layers, suitable scenarios, guidelines and by further giving directions about the desired simulation scenario or use case. More mathematical information about modelling AVs will be also given, useful for simulation experts, as the automated mobility is still under investigation and there are significant challenges on simulating automated driving. Through a simulation library provided also by the tool, the simulation suite will be beneficial for city planners and practitioners as well, as the key results will be deposited, and could also guide **interested stakeholders** for future management of cities by using suitable strategies, as transportation systems will be fundamentally affected by the evolution of automated driving.

Furthermore, a detailed overview of the results of the **second run of pilot-based simulations** from all partners is presented in Chapter 4, as follow up of the D10.2 content. The results are linked with the KPIs from WP13 and the next steps for exploiting the real-world pilot data coming from the SHOW test sites operations are also described from each partner.

Finally, the **conclusions** reached from the simulation activities so far, as well as **future plans**, which will be dedicated in collecting all necessary data and in the development of the web-based SHOW Simulation Suite are discussed in Chapter 5.

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2.0	24/01/2023	Final version sent after addressing peer review comments.	All Authors

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Abbreviation List

Abbreviation	Definition
ACC	Adaptive Cruise Control
AD	Automated Driving
AS	Automated Shuttles
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CAV	Connected Automated Vehicle
CCAV	Cooperative Connected Automated Vehicle
CO_2	Carbon Dioxide
COVID	Coronavirus Disease
CV	Conventional Vehicle
D	Deliverable
DRT	Demand Responsive Transport
DVRP	Dynamic Vehicle Routing Problem
Kph Or Km/H	Kilometre Per Hour
KPI	Key Performance Indicator
L	Level (Of Automation)
Lidar	Light Detection And Ranging
M	Meters
MFD	Macroscopic Fundamental Diagram
Min	Minutes
MPR	Market Penetration Rate
MRM	Minimum Risk Maneuvers
NOx	Nitrogen Oxides
O-D/OD	Origin-destination
OSM	Open Street Map
PCU	Passenger Car Units
PM	Particulate Matter
PT	Public Transport
ROS	Robot Operating System
S Or Sec	Seconds
SUMP	Sustainable Urban Mobility Plans
TMC	Traffic Management Center
TOC	Transitions Of Control
VRU	Vulnerable Road Users
VTTS	Value of travel time savings
WP	Work Package

1 Introduction

1.1 Purpose of the document

The scope of the current document fundamentally is to lay the ground for the development of the **Automated Vehicles (AV) fleets operation simulation suite** and provide first evidence of **pilot-based simulation results** for impact assessment.

There are three simulation scenarios that are examined within WP10 simulations efforts, i.e. Street-level, City-level, and local Vulnerable Road Users-VRUs simulations, outlined in Chapter 2, while numerous automated mobility pilot sites, scenarios and use cases were also investigated (as shown in Chapter 4). Moreover as it is reported in previous deliverables D10.1 and D10.2, different simulation tools and approaches ideal for each occasion were used, depending on the different pilot site needs and partner expertise. Therefore, the need of a methodology to acquire a common pool of simulation data from the different scenarios and use cases, to identify the key parameters and possible methodologies on automated driving simulation and to synthesize the simulations for all test sites was highly required. For all these reasons, the development of **the SHOW Simulation Suite** has been incorporated. The main idea of the simulation suite is to combine the knowledge gained in WP10 of simulating automated mobility and integrate the fundamental aspects of this procedure at its optimal level. This will be accomplished by the **development of a web-based front-end tool** that will give guidelines about simulation of automated driving and will include (i) the followed steps of simulating automated mobility between the different pilot sites, (ii) simulation transferability, (iii) connections between simulation models, and (iv) a library including visualised instructions in the used software and tools. In the present deliverable, the fundamental elements and the aim of the integrated simulation suite are structured and discussed in Chapter 3.

In addition, the **simulation efforts by WP10** focus on the three aforementioned distinct simulation scenarios by eleven pilot sites (i.e., Brainport, Graz, Karlsruhe, Klagenfurt - Carinthia, Linköping, Madrid, Monheim am Rhein, Rome[1], Salzburg, Tampere and Trikala) are also presented in the present deliverable. These sites have been the most accessible with regards to data, at this stage, and also more pertinent to partners working in WP10. For all the simulation sites and developed scenarios presented in detail in the previous deliverable 10.2, some **additional second-iteration results** are given in the current document, in order to fulfil the project requirements with regards to the use cases, as well as the KPIs for the safety and impact assessment of automated driving applications. Specifically, this second iteration exploits pilot field data (mainly from the pre-demo phase of the running test sites), so that the simulations are more accurate, aiming finally to support and give guidance for the final large scale field tests of SHOW test sites as well as to conclude their impacts with the support of WP5 & WP13.

The deliverable is structured as follows: after this introductory chapter that provides the purpose, structure, intended audience and the interrelationships of this document with the rest of the project, Chapter 2 presents briefly the three simulation scenarios. Chapter 3 includes the aim and the design of the SHOW Simulation Suite as well as the fundamental components are discussed in detail. Chapter 4 presents the second

[1] For clarification purposes, the city of Rome (Italy) is not part of the SHOW pilot sites and it was used in order for CTLup to develop the necessary tools. Rome was suitable due to the infrastructure availability for the logistics simulations and the extracted results and lesson learned are intended to be transferred and further deployed to the Trikala (Greece) and the Rouen (France) sites.

iteration of eleven SHOW pilot-based simulations which are enriched compared to the previous iteration presented in D10.2 with field data from the pre-demonstration phase of the SHOW pilots. Finally, conclusions are drawn in Chapter 5 and the next steps for the overall work of WP10 are presented.

1.2 Intended Audience

This document is intended for public and open access, and builds upon the work presented in D10.1 & D10.2 (SHOW, 2021 [16]; SHOW, 2020 [15]) which described the first simulation iteration, scenarios, relevant KPIs, and use cases and chosen simulation tools that are going to be utilized in SHOW.

This document serves as a manual for the partners involved in WP10 by providing information on relevant simulation tools and scenarios and showing connections made to real-world pilots and future plans. Similarly, as WP10 works closely with WP13, which aims at assessing the SHOW use cases with regards to the safety and other layers of impact of automated driving services, partners involved in the impact assessment work are anticipated to be closely monitoring the progress of the work described in this document. Also, there is an inevitable connection to WP5, since the Data Management Platform (DMP) developed therein, is hosting the simulation outputs of WP10.

From the "open-access nature of this document" point of view, it serves as an informative document for external stakeholders, as it describes the simulation approaches and efforts as well as the simulation suite developed within SHOW. Thus, stakeholders will be able to understand how SHOW test sites simulations will be/have been held, using field data, and how the results will be combined, integrated and exploited. The current document will be also useful for every future SHOW Simulation Suite user, interested in simulating automated mobility, who will be informed about the tool purpose, elements and structure and gain all supporting details.

1.3 Interrelations

As mentioned in the previous subsection of the intended audience, this deliverable builds upon the results of D10.1 & D10.2 (SHOW, 2021 [16]; SHOW, 2020 [15]) and is related to all ongoing activities of WP10 i.e., 10.2, 10.3 and 10.4 which provide the simulation results with regards to SHOW pilots and the development of the SHOW Simulation Suite. Furthermore, as WP10 is closely cooperating with WP13 by providing inputs to the impact assessment framework. The considered KPIs were developed under the auspices of WP9 and its related activities. Also, WP5 is associated since the simulation suite connects the simulated pilot outputs with the SHOW data management platform and the KPI evaluation.

2 Simulation scenarios

As mentioned in the introduction, the aim of this chapter is to provide insights into the three simulation scenarios that are examined within WP10 simulations efforts, in order to find common ground among them and prepare their integration within the simulation suite.

2.1 Scenarios Overview

This subsection gives an overview of the scenarios of the current simulation sites within the context of SHOW. A more detailed representation of the scenarios can be found in the previous deliverables D10.1 & D10.2 [16]; [15], since the scenarios remain unchanged from the past period. All the partner simulations were split into three dedicated scenarios i.e.:

- Scenario 1: Street level simulations
- Scenario 2: City level simulations
- Scenario 3: Local VRU simulations

This classification took place based on the respective real-life demonstration activities of SHOW and its test sites characteristics. These three simulation scenarios are presented along with matched partners and the relevant simulation tools they are deploying. Table 1 presents the coverage of pilot site scenarios by WP10 partners and simulation tools used.

Table 1: Coverage of simulation scenarios by simulation sites and simulation tools used.

Simulation site	**Simulation tools**	**Scenario 1:** Street level simulations	**Scenario 2:** City level simulations	**Scenario 3:** Local VRU simulations
Brainport (TNO)	VISSIM, New MobilityModeller, Urban Strategy, SIL Simulator		X	
Graz (VIF, AIT)	ROS, Autoware simulator	X		X
Karlsruhe (FZI)	ROS, SUMO, Menge, CARLA, Gazebo	X		X
Klagenfurt - Carinthia (AIT)	SUMO		X	
Linköping (DLR, VTI)	SUMO	X		X
Madrid (NTUA)	AIMSUM, SSAM	X		X
Monheim am Rhein (DLR)	SUMO	X		X
Rome (CTLup)	TBD	X		
Salzburg (AIT)	MATSim, SUMO		X	
Tampere (VTT)	AVSS	X		X
Trikala (CERTH/HIT)	SUMO	X		

2.1.1 Scenario 1: Street level simulations

In this street level simulation scenario, both operation routes and served stops are pre-defined and fixed. In order to consider the interactions between different types of road users and to explore AV-logic and safety issues, microscopic traffic simulation is applied with or without coupling with other simulation-related tools. Furthermore, the respective focus is put rather on the test site level than on the whole city/region level. Accordingly, change in transport mode choice is not the focus here.

2.1.2 Scenario 2: City level simulations

In this scenario, automated shuttles are simulated at city level using demand responsive transport (DRT) applications. The city level scenario includes both DRT on fixed routes as well as station-based DRT services with fixed stations but without fixed routes to door-to-door services. The difference to Scenario 1 is that the simulation level does not only include the microscopic level at different degrees of detail, but the macroscopic level as well, aiming at providing region or city-wide results on the impact of automated vehicles for different implementations of automated DRT-services. The extension from local to city wide simulations enables the DRT simulations to address additional KPIs like the modal split changes and others due to the introduction of automated DRT services, compared with scenarios 1 and 3.

2.1.3 Scenario 3: Local VRU simulations

Scenario 3 covers applications focusing on VRUs and shared spaces. The scope of this scenario is the safety of all VRUs in the vicinity of vehicles such as pedestrians, cyclists, etc. Passengers on board in vehicles are considered out of the scope of the simulations. For most pilots, the bus stop is the situation in which an AV comes close to VRUs consisting mainly of possible passengers. Most partners consider a bus stop as an important element from the point of view of an ego vehicle serving this bus stop. This means a bus stop is an essential part within the simulations of scenario 1 (Street level simulations), where safety and pedestrian aspects need to be included with the focus always on one vehicle. In some cases, the scope is to study the interactions of automated vehicles with pedestrians and not necessarily passengers. This is especially important in bus terminals with a higher number of pedestrians, where automated vehicles need to pass through. In this case, also the focus is more on the environment of the vehicle than the vehicle itself.

2.2 The need of a unified simulation suite

The above three distinct scenarios, offer many possibilities for developing a unified framework for AV fleet simulations. Initially, Scenarios 1 & 3 (i.e. street level and local VRU) can be considered as microscopic, while Scenario 2 concerns a more macroscopic (network-level) simulation environment. For this reason, guidelines of how this kind of scenarios can be simulated are highly required. Through the SHOW Simulation Suite, the specific use cases will be given (as shown in section 3.2.1) among with the scope, used simulation tools, key inputs and outputs, strengths and limitations, followed models and results. More information can be found in sections 3.2.2 and 3.2.3.

Nevertheless, in order to assess the impact of AV fleets, the transferability between microscopic and macroscopic scales needs to be also established. In this respect, the optimal outputs (i.e. indicators) from microsimulation could be expanded to macro simulations as well as from vehicle-level to micro simulations in order to understand the effect that individual vehicle behaviour can have on the entire network. For example, AVs are envisioned to follow shorter headways and, in this respect, enhance traffic efficiency and road safety. Nevertheless, a cross-site comparison of the impact that different headways have simultaneously on a street and network-level has yet to be realised. The vast amount of KPIs in WP13 of the project also require the testing of different behavioural scenarios that can easily be up-scaled from streets to the entire transportation networks and can assure safety, efficiency and limited emissions. A discussion on how this upscaling can be performed is discussed in section 3.2.4 of this deliverable.

The inputs and scope of the simulations and the combination/integration of results are shown in Table 2.

Table 2: Methodological Framework of Simulations as in the SHOW Grant Agreement.

		Vehicle simulation (A10.2)	Traffic Simulation (A10.2)		Driver simulation (A10.3)	Passengers simulation (A10.3)	VRUs simulation (A10.3)	PT simulation (A10.3)	Freight transport simulation (A10.3)	Infrastructure simulation (A10.3)	Combination of simulations (Micro/ Macro/ Driving) (A10.4)	Results integration (Impact) (A10.4)
			micro-simulation	macro-simulation								
Scope	Mega sites	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Satellite sites	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Follower sites	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Data input		Penetration level of (AV levels, CCAV systems)	Road design, traffic volumes, Modal split, OD matrices	Road design, traffic volumes, OD matrices	Driving behavior data w/o automated features	Number of accidents including passengers	Number of incidents including VRUs	PT usage rates	Freight transport rates	Road design, infrastructure characteristics	Inputs from micro, macro and driving simulation	Outputs from all simulations
Involved Beneficiaries		VIF, eGo, VTI	DLR, Vedecom, AIT, CERTH, NTUA, VTT	CERTH-HIT, VTT, VEDECOM, NTUA	NTUA, VTI	Vedecom	AIT	Vedecom	CTLup	TNO	NTUA	NTUA, VIF, AIT, CTLup
Results/ outputs (Impact)	Traffic efficiency	*	***	***	*	***	*	***	***	**	***	Scenarios
	Safety	***	**	**	***	***	***	**	**	***	***	
	Environment	***	***	***	***	**	*	**	**	**	***	
	Energy	***	***	***	***	**	*	**	**	**	***	
	Health	**	**	**	**	**	***	***	*	*	**	
	Quality of life	***	**	**	**	**	***	***	*	*	**	
Innovation contribution		Impact of different penetration levels	AI-based models for micro-simulation of AVs	Network level impacts	Insights into the reaction time alteration	Investigate users' willingness to adopt	Examine CCAVs' level of service to VRUs	Insights into the future PT usage percentages	Identify the freight distribution system of the future	Identify the areas where take-over action is required	Analyze data coming from several CCAV simulation sources, Investigation of TOR/MRM interaction	Integrated tool for CCAV impact assessment
Challenges / Risks		Simulate the exact specifications of each automation level's CCAV	Data from sites delayed - models incompatibilities	Obtain representative and reliable macroscopic data	Limited scenaria	Difficulties in collecting and analyzing passengers' accident data	Pedestrian data - difficult to collect	Data for all transport modes is not always available	Relevant data is not always available	Simulate the infrastructure design in detail	Combine simulate on data	Evaluation and validation of the overall tool created

3 Simulation Suite

3.1 Conceptualization of simulation suite

As analysed in Chapter 2, three main simulation scenarios are within the scope of WP10, namely Street-level, City-level and Local VRU simulations. For the purpose of sketching the layout of the simulation suite tool, its comprehension from external stakeholders (e.g. early researchers, Ph.D. students, OEMs) and in order for it to be more user-friendly a slightly modified term will be used for the categorization of the different simulations within the simulation suite. Thus, the term “levels” will be used instead of the term “scenarios”**.** Apart from these three levels, numerous automated mobility sites, scenarios and use cases were investigated for each level. Moreover as it is reported in previous deliverables D10.1 and D10.2, different simulation tools and approaches ideal for each occasion were used, depending on the different pilot site needs and partner expertise. For all these reasons, it is rational that a framework that will **combine all critical elements of the simulation** approaches followed in each case is highly required, through implementing the tool of an integrated simulation suite.

The **integrated simulation suite** has to be a tool that acquires a common pool of simulation data from the different levels and use cases, identifies the key parameters and possible methodologies to simulate automated driving and attempts to synthesize the simulations for all test sites. For this purpose, critical elements from the implemented simulations such as the followed methodologies, used tools and models should be integrated as well as combination and level transitions to be accomplished. In addition, the co-simulation techniques, such as up-scaling methodologies should be also identified and examples of their application should be provided.

In order for all the above to be accomplished, the suite should take the form of **a web-based front-end tool** that will present all valuable information regarding simulating automated mobility and providing guidelines related to each simulation level by presenting the followed steps, key inputs and outputs, mathematical definitions, feasible transitions between levels, and individual components formed into a library including visualised instructions for the used simulation software and tools. The structure of the simulation suite is illustrated in more detail in Figure 1.

More specifically, the SHOW simulation suite will be designed to compose **three different layers**, as shown in Figure 1, namely 1) Simulating Automated Mobility, 2) Simulations Transferability, 3) Connections between Simulation Levels as well as the SHOW simulation Library, which will be the repository of fundamental information regarding simulating automated mobility of each layer. The layers and the simulation library as well as their components are discussed in more detail in the following sections.

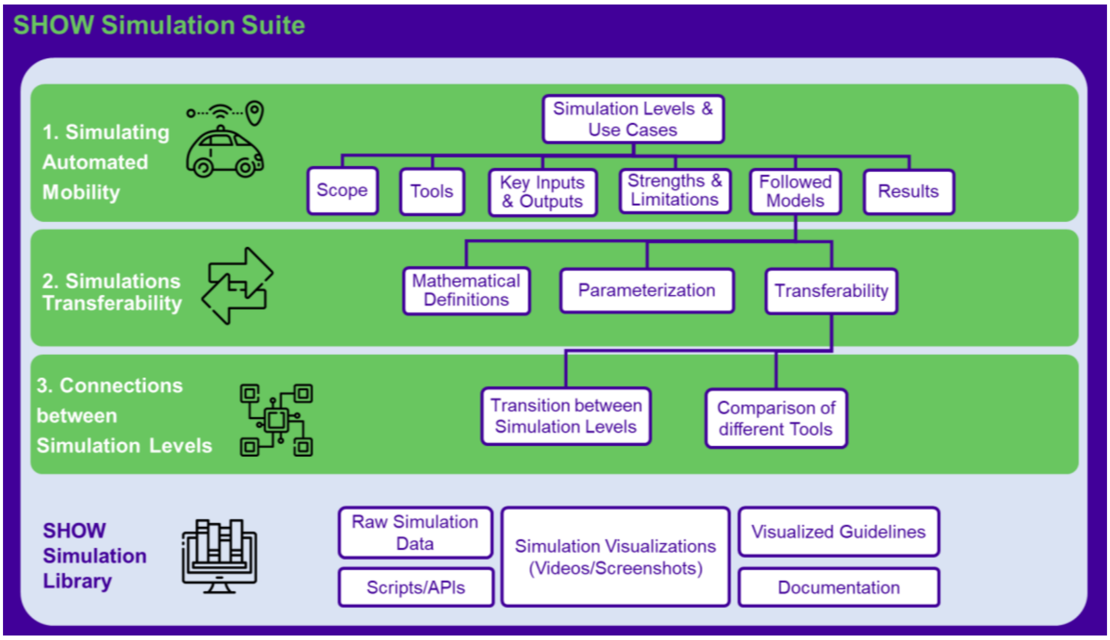

Figure 1: Structure of SHOW Simulation Suite.

3.2 Structure of simulation suite

3.2.1 SHOW simulation levels and cases

The simulation levels and use cases are the first aspects of the first layer (Simulating Automated Mobility) of the simulation suite, as shown in Figure 1. Firstly, these aspect concerns the **three simulation levels** that are examined within WP10 simulations efforts, i.e. Street-level, City-level, and local Vulnerable Road Users-VRUs simulations, which means that possibly as a first step, the SHOW Simulation Suite web-based tool users will be able to choose the level that they are interested in and need the corresponding information. Secondly, the user will be able to choose a more specific study area, namely to choose between the different examined use cases of the eleven pilot sites i.e., Brainport, Graz, Karlsruhe, Klagenfurt - Carinthia, Linköping, Madrid, Monheim am Rhein, Rome, Salzburg, Tampere and Trikala. The three simulation levels matched with the corresponding pilot site are presented in Table 1.

3.2.2 Guidelines for simulating automated mobility

The second aspect of the first layer (Simulating Automated Mobility) of the simulation suite includes **general information on simulating automated driving**. Specifically, the simulation suite user after choosing the desired simulation level and use case will be informed about the scope of the studied use case, the used simulation tool, the key inputs and outputs, strengths and limitations of the followed methodology, the used models and results of the simulation. It is envisioned that a step-by-step tutorial layout will be incorporated for each scenario and use case, so as to accelerate comprehension by third parties and early researchers.

Along with the **scope** of the studied use case, the most important information will be given to the user regarding the importance of this use case investigation, the detailed description of the respective pilot site implementation (i.e. network specifications, automated vehicles parametrization, etc.) as well as the selection of the simulated scenarios (i.e. which are the scenarios, why these scenarios were selected for this kind of investigation, etc.). Moreover, the used **simulation tool** will be mentioned and the relevant technical specifications regarding the reasoning for selecting it will be also provided and discussed. Regarding the tool, the required **inputs and outputs** of simulating the respective automated mobility use case, meaning the data received by the tool and the data extracted from it, will be presented in detail. In addition, the user will be able to receive the **strengths and limitations** of the followed steps in the conducted simulation, e.g. the integration of real-traffic data and not taking into account pedestrian traffic, respectively. Furthermore, the **models followed** in each use case will be mentioned as well, for instance which car-following or lane-changing model was used. Finally, the key findings of each use case will be presented and discussed, as well.

3.2.3 Mathematical models in automated driving simulations

In this layer of the Simulation Suite, which is the third layer as shown in Figure 1, more technical information will be given to the user, i.e. **specifications of the followed models**. Specifically, the mathematical definitions as well as parametrization and the possibility of transferability will be discussed for the models used in the simulation procedure. This will be helpful by giving insights and capabilities regarding traffic simulation in general as well as about automated driving in specific. There are many differences between modelling human-driven vehicles and automated driving vehicles and therefore by these specifications, an in-depth understanding of modelling auotmated vehicles will be accomplished. The transferability capabilities in more detail will be included in the fourth and last layer of the Simulation Suite tool which is presented in the following sections.

3.2.4 Connections between simulation levels

It is also fundamental to investigate and present how the different simulations of each simulated pilot site and their **outputs could be combined**, as well as how the followed methodologies and indicators could be transferred. As it is known, traffic flow models can be classified as macroscopic, microscopic or mesoscopic. The macroscopic models (and mesoscopic models as well) employ aggregated parameters on velocity, density and flow, while microscopic models consider individual vehicle behavior. Within SHOW, microscopic, macroscopic as well as mesoscopic modelling was conducted. The pilot simulations divided by each of these three models along with the used simulation tool are shown in Figure 2. The vehicle-level simulations are illustrated in Figure 2 as a separate category, as the approach in order to be combined with the rest simulation models will be difference from the one that depicts micro-macro (or micro-meso) simulations combination.

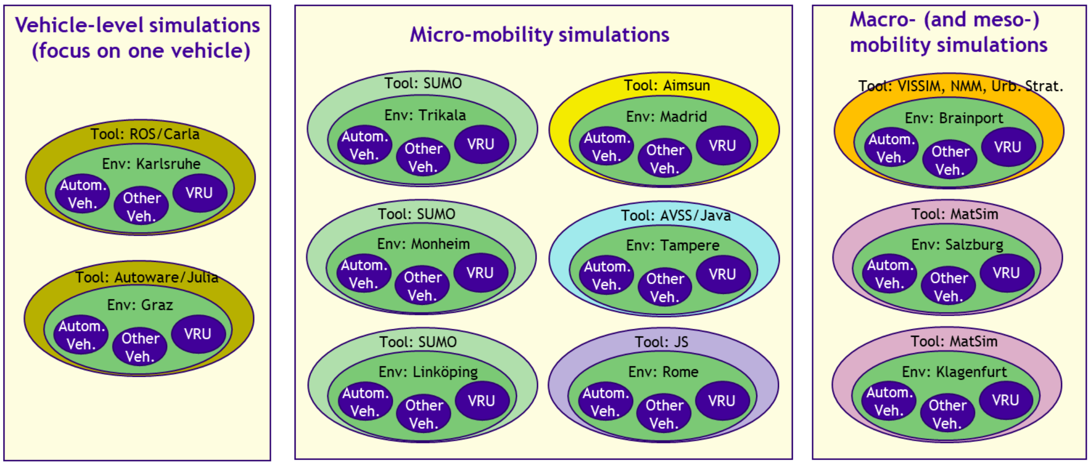

Figure 2: Simulation modelling within SHOW.

The combination of simulations requires an upscaling from microscopic simulations to macroscopic ones as well as from vehicle-level simulations to microscopic simulations in order for a holistic impact assessment of automated fleets to be realized. This upscaling procedure, can be realized either through strict mathematical transformations (e.g. Cardaliaguet and Forcadel, 2019 [3]; Forcadel and Zaydan, 2016 [6]; Helbing, 1998 [7]) or by identifying traffic flow parameters or indicators that could be transferrable from microscopic simulations to macroscopic ones using the Macroscopic Fundamental Diagram (MFD). Such indicators include Passenger Car Units - (PCUs; Tympakianaki et al., 2022 [17]), speeds (Zheng et al., 2017 [19]) and headways (Li and Chen, 2017 [9]). More information and details are described in the following subsections.

3.2.4.1 Up-scaling from micro to macro simulation using PCUs

This methodological approach is based on the integration of microscopic simulation outputs into the macroscopic models. This will also be able to give guidelines about simulation of automated vehicles demonstrating directions and policies for simulation needs and limits.

Within SHOW project, both macroscopic and microscopic (or mesoscopic) simulations were conducted. For this reason, an up-scaling methodology is necessarily to be applied in order the generalisation as well as the transferability of the results to be succeed. A similar methodology of up-scaling automated driving simulation outputs, was conducted by Tympakianaki et al. (2022 [19]) and used in the LEVITATE EU project (LEVITATE EU, 2022 [8]). The main difference between simulations conducted within the LEVITATE and the SHOW project, is that in LEVITATE the simulation concerned microscopic city-scaled networks while in SHOW there are vehicle-level and VRU-level simulations as well. Therefore, this methodology can be explored and extended in order to give insights of how the simulation results of SHOW project could be up-scaled as well. More information about this conducted methodology follows.

In this methodology, the impacts of CAVs were assessed with respect to network performance. In Figure 2, the considered steps of the up-scaling method are illustrated.

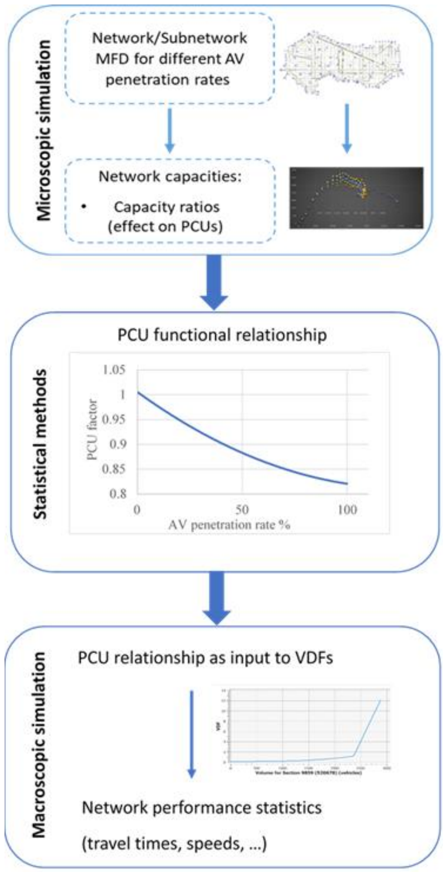

Figure 3: Aimsun approach by Tympakianaki et al. (2022).

The considered steps of the up-scaling method are explained:

1. Firstly, the network capacity should be derived through the microscopic simulation. By network capacity we define the maximum number of vehicles exiting the simulation network between simulation time intervals (e.g. 2 minutes). A suitable and easily transferable approach for observing the network capacities is through the Macroscopic Fundamental Diagram (MFD). The MFD is the basis of traffic flow theory and demonstrates a functional relationship between the network characteristics, i.e., traffic flow (throughput), vehicle density and speed.
2. The second step includes a statistical analysis that identifies the effects on the Passenger Car Units (PCUs)[2] as a relative change of capacities. Based on the microscopic simulation results, a fitted function (i.e. linear, polynomial, etc.) can be used to derive the PCUs given the capacities obtained from the network MFD. The PCUs are derived by the capacity ratio of conventional vehicles (CV) and AVs using the following formula:

$$PCU_{AV} = PCU_{CV} \times \frac{\text{Network Capacity}_{CV}}{\text{Network Capacity}_{AV}}$$

3. The last step is to provide the PCU relationship as an input to the Volume Delay Functions (VDFs) of macroscopic models to forecast the potential macroscopic implications on the network performance. The VDFs are functions that model travel time among different parameters such as volume and capacity. For this reason,

[2] Passenger Car Unit (PCU) measures the impact of a transport mode (passenger cars, heavy vehicles, buses, etc.), as a function of vehicle dimensions and operating capabilities, on the traffic flow efficiency compared to a standard unit of passenger car. Hence, a PCU factor of 1 is used as the unit for conventional cars.

the macroscopic models apply VDFs in order for **travel time** values to be calculated. VDFs represent the relationship between flows and delays of each road segment. A function defining travel time was developed by US Bureau Public Roads (1964) [29] and is the following:

$$t=t_{ff}\left(1+a \left(\frac{v}{c}\right)^{b} \right)$$

where t_{ff} is the free-flow travel time, v/c is the volume-to-capacity ratio, and a, b two parameters.

This proposed methodology is intended to be holistic and used between different networks and CAV modelling parameters. The involved partners would be those who conduct micro and/or macro simulation.

This methodological approach is essential as **the small-scale simulated networks would be up-scaled to city-level networks**. In addition, the transferability of the simulation outputs to other networks or/and regions would be applicable. If a microscopic simulation model of a city is not available, the generalized PCU functional relationship estimated from a different network could be used as input into a travel demand model to forecast the macroscopic impacts. Furthermore, more robust simulations with validated AV parameters (limiting the assumptions related to AV parameters) will be executed and consequently, more concrete results will be extracted. Finally, the aligned simulations will create a common background for collaboration among the WP10 partners by setting common research questions.

A comprehensive example (not based on actual results of SHOW project simulations) of the proposed methodology in terms of up-scaling from micro to macro simulation follows:

For instance, there are three distinct micro simulation scenarios that the WP10 partner focuses on for analysis purposes:

- Manual-driven bus line
- Automated bus line (short headways)
- Automated bus line (long headways)

<u>1st step – Micro Simulation</u>

The first step of this example is to run the above microscopic simulation scenarios. Then, the WP10 partner is able to derive the network capacities for each scenario as the number of vehicles that exiting the network is one of the outputs of microscopic simulation. As mentioned again, the network capacities for each scenario are defined as “the maximum number of vehicles exiting the network between simulation time intervals (e.g., 2 min)”

Therefore, the following capacities have been extracted for the three simulated scenarios:

- Manual-driven bus line → 1100 vehicles/2 min
- Automated bus line (short headways) → 1250 vehicles/2 min
- Automated bus line (long headways) → 1200 vehicles/2 min

<u>2nd step – Micro Simulation</u>

Then, using the aforementioned capacities and the PCU formula (PCU_{AV} = PCU_{CV} * ($Network\ capacity_{CV}$ / $Network\ capacity_{AV}$)) the PCU for the AVs can be calculated. The PCU factor of the manual bus is considered as 1.50 (for buses with less than 30 seats) according to (AASHTO, 2011 [1]). Therefore, the PCU factors of the automated shuttles are calculated as follows:

- PCU of Automated bus (short headways) = 1.50 * (1100/1250) = 1.32
- PCU of Automated bus (long headways) = 1.50 * (1100/1200) = 1.38

<u>3rd Step – Macro Simulation (linkage step)</u>

This step connects the micro with the macro simulation. The WP10 partners that run macro simulation scenarios could exploit the PCU factor of the AV that the micro simulation extracted and run the following macroscopic simulation scenarios:

- Manual-driven bus lines – current conditions
- Convert manual-driven buses to Automated buses with a 1.32 PCU factor
- Convert manual-driven buses to Automated buses with a 1.38 PCU factor

Then, the **total network travel times** can be derived with the macro simulation models that applying VDFs and the up-scaling from micro to macro can be accomplished:

- Manual-driven bus lines → 3,303,740 min
- Automated bus lines (short headways) → 3,087,630 min → 7% reduction of travel time
- Automated bus lines (long headways) → 3,207,980 min → 3% reduction of travel time

This methodology requires the combination of micro with macro simulations. The main benefit of this methodology is that the results of microscopic simulation can be evaluated if are significantly similar to those derived from macroscopic simulation (essentially to be up-scaled) in order to see if they can be generalized as well as are transferable to different regions or cities. Therefore, the fundamental expected outcomes by applying this methodology are that up-scaled to city-level network results can be derived and this does not restrain the results only to micro and macro as well as this method gives the ability to the simulation outputs to be transferable to other networks/regions.

At the moment, only three partners (Trikala-CERTH/HIT, Brainport-TNO and Madrid-NTUA) are able to support the PCU-based upscaling. The difficulties of applying the methodology by the rest of the partners were mainly based on the fact that their simulations were on vehicle-level or VRU-level and the deriving of network capacity was not applicable. Nevertheless, efforts of the aforementioned methodology extension are on-going so that more partners are able in near-future to demonstrate upscaling capabilities.

3.2.4.2 Up-scaling from micro to macro simulation using extensions of driver models and additional MFD specifications

Building upon the PCU method and recent advances in the literature with regards to traffic flow theory and AVs, the MFD could be further exploited for the upscaling. One alternative is proposed by Shi and Li (2021) [13], where an MFD for AV traffic flows is proposed along with macroscopic and microscopic measurement proposals. For example, using vehicle travel time and distance travelled inside a simulation area, an FD can be created and up-scaled in the macro scale, in order to be fitted into a macroscopic simulation. Furthermore, recently developed models such as the cell transmission model (CTM) by Adacher and Tiriolo, (2018) [2], headway modelling as described in Li and Chen, (2017) and the Flexible Traffic Stream Model (FTSM) by (Zheng et al., 2017 [19]), that have been shown to be easily transferrable from the micro to the macro scale could be used to obtain MFDs using the methodology described in Lu et al., (2020) [10]. In Lu et al., (2020) [10], an MFD is drawn based on measurements from SUMO inputs and a macroscopic speed-density function is obtained through a Generalised Additive Model (GAM) regression for specific AV penetration rates.

As it can be understood, apart from network capacity and the PCU method, even with limited AV trajectories (as in Shi and Li, 2021 [13]) or with the exploitation of headways (Zheng et al., 2017 [19]) and speeds of vehicles (Lu et al. 2020 [10]) the transferability of microscopic simulation outputs can be achieved through the construction of MFDs to the macroscopic level and further impact assessment results can be obtained.

More specifically, upscaling using MFDs and new driver models will be based on mathematically correlating the microscopic speed/spacing relationship with the flow rate/density fundamental relationship.

3.2.4.3 Up-scaling from vehicle-level to micro simulation using physics-based sensor simulations and APIs

Within that layer, the user of the suite will be informed on available physics-bases sensor simulations (e.g. PreScan[3]) and how to program a co-simulation with a specific microsimulation platform (e.g. Aimsun, Vissim). Alternatives to programming languages and API tools is going to be provided and the most useful inputs from a simulated sensor platform will be recommended for each use case. In that way, inputs from a vehicle-level (sensor readings) will be inserted into different microsimulation setups in order to identify the impact that each sensor system has on the automated fleet performance. For example, the steps to be followed would be given as:

- Create a detailed road network model in the microsimulation software, including the geometric layout of the roadways, traffic signals, and other infrastructure.
- Import the vehicle trajectory data from the vehicle-based simulation into the microsimulation software. This data can be used to initialize the positions and velocities of vehicles in the microsimulation.
- Calibrate the microsimulation model by adjusting various parameters such as vehicle speed-flow relationships, traffic signal timings, and lane changing behavior, to match the traffic conditions observed in the vehicle-based simulation.
- Validate the microsimulation model by comparing its output to the vehicle-based simulation data. This can be done by comparing key performance metrics such as average travel time, vehicle delay, and queue lengths.
- Once the microsimulation model is calibrated and validated, it can be used to simulate a variety of traffic scenarios and analyze the impact of different design or operational changes on traffic flow.

3.2.5 Library of SHOW simulations

The SHOW simulation Library will be the **static repository of fundamental information** regarding simulating automated mobility of each Simulation Suite layer. More specifically, will include all these important data that will be in an appropriate format in order to be easily downloaded and used by the user.

This kind of data will be for instance the raw results extracted from the traffic simulation tool, which can be useful in order to be filtered and processed in a different way than

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[3] https://www.plm.automation.siemens.com/global/en/products/simcenter/prescan.html

the one presented in the results aspect. Another type of data that will be also included in the library is the scripts and/or APIs used in the respective simulation. With these data, the user will be able to directly use the relevant scripts in case of a similar case or using the same simulation tool. In addition, relevant documentation with the automated mobility use cases will be also included in the library, such as useful research papers, traffic simulation instructions or tutorials, theoretical background documentation of behavioral models and algorithms, etc.

Furthermore, the SHOW simulation library will also consist of visualized instructions for simulating automated mobility. Specifically, there will be recorded videos as well as screenshots from the simulation procedure in the respective simulation software in order the user to be familiarized with it. Finally, visualized guidelines across the different use cases and software will be also given in order to increase understanding of the information and create a memorable experience for the user.

3.3 Value added and roadmap towards SHOW integrated AV fleets operation simulation suite

The **main idea behind the SHOW Simulation Suite** is to combine the knowledge gained in WP10 of simulating automated mobility and integrate the fundamental aspects of this procedure at its optimal level. This will be accomplished by the development of the web-tool that is proposed and presented in this deliverable, which is also considered to form the simulation suite scope.

With regards to the **added value on the project level**, the simulation suite tool will lead to the exploitation and dissemination of WP10 findings at the maximum possible degree. Furthermore, great gains will be also succeeded as in the proposed tool all possible data and information will be collected, enhancing in this way the data availability for each site. Specifically, this process can give deeper insights into the pilots with indicators that cannot be directly measured in real-life pilots as well as make comparisons between real and simulation data. Another gain and advantage of the integrated simulation suite is that by providing fully-detailed information, the WP13 could easily assess the desired impacts in a unified manner using all data that will be collected there and not directly by the WP10 partners. In addition, by manipulating critical aspects of the simulation in a similar manner for all pilot sites, comparisons among scenarios, networks, models, methodologies and tools could be easier generated. Last but not least, with the proposed up-scaling capabilities, there are many benefits for the project. A fundamental benefit is that by connecting different simulation levels, connected simulation will be resulted and not independent or simulations that addressing a different objective. Another fundamental benefit is that by up-scaling data, in many cases there will be the possibility to generate more KPIs and possibly detailed data for WP5/ WP4 and further WP13.

From the **user side aspect**, the proposed SHOW Simulation Suite will be useful for every researcher who is interested in simulating automated mobility, and who is not necessarily an expert on traffic simulation. For this reason, the tool will be designed in order to provide information about the possible tools and layers, suitable scenarios, guidelines and to further give directions about the user's desired simulation scenario or use case or study area. Moreover, as it is already mentioned in the previous sections, more mathematical information will be given by using the tool as well. This means that simulation experts will also gain knowledge through the documentation provided by the tool, as the automated mobility is under investigation and hence there are significant challenges on simulating automated driving. Finally, the included SHOW simulation library could set the tool also beneficial for city planners as well as practitioners, as the key results for each studied use case and level will be deposited. Therefore, the simulation suite could also guide interested stakeholders for future management of cities by using suitable strategies, as transportation systems will be fundamentally affected by the evolution of automated driving.

At present, as discussed in the previous sections the initial layers and elements of the SHOW simulation suite were defined. For **future plans** in developing the tool, specifications of how the relative elements will be collected as well as the format of each type of data that is required (e.g. simulation results, followed models, use case description, etc.) should be specified and given to all simulation partners. This is considered as a critical step due to the fact that the informative representation of all critical aspects of the conducted simulations within SHOW project has to be as concise as possible and should not lacks consistency between the different pilot site simulations. This will result in eliminating misunderstandings and confusion of the tool user. Afterwards, all the required information and data will be collected and feed up the components of the tool. This work along with the development of the web-based tool as the final step, is ongoing and will be included in the next deliverables of WP10.

4 Second iteration of SHOW Pilot-based simulations

The aim of this chapter is to report the second pool of simulation results. This second iteration compared to the first one was fed by data generated by the pre-demonstration phase from SHOW test sites during real-life demo activities. This deliverable gives an overview of pre-demo simulation results on calibrated networks for eleven simulated pilot sites (i.e., Brainport, Graz, Karlsruhe, Klagenfurt - Carinthia, Linköping, Madrid, Monheim am Rhein, Rome, Salzburg, Tampere and Trikala) and regarding the three simulation scenarios presented in section 2.1.

First of all, the pilot description and the current progress are outlined for each pilot site. In this context, the pilot general description along with pilot pre-demo progress are given as well as what has been accomplished since the previous deliverable with regard to the simulation and by the exploitation of pre-demonstration data. Then, the simulation specifications are given i.e., simulation parameters, simulation network, simulation scenarios and the pre-demo field data used. In turn, the results are outlined for each pilot and it is attempted to be relevant to the KPIs and the scope of the SHOW project. Finally, the next steps are given by considering the simulation overall progress and what has been accomplished since the very beginning of the project and combining them with simulation future plans.

4.1 Aachen (Scenarios 1 & 3)

The simulations in Aachen performed and presented in D10.2 will be discontinued due to the exit of the partner e.GO MOOVE from the SHOW project. As a replacement, simulations for the site of Monheim will be carried out (see section **Error! Reference source not found.**).

4.2 Brainport (Scenario 2)

4.2.1 Pilot description & progress

4.2.1.1 Pilot general description

In the Brainport area, Eindhoven, the Netherlands, a joint effort between a pilot and two simulation tools is made as shown in Figure 4**Error! Reference source not found.**. An automated DRT passenger vehicle on the pilot site will deliver input which is used – via a software-in-the-loop vehicle simulation – to the microsimulation environment. The DRT vehicles are confronted in the microsimulation environment with various demand intensities and conditions that are not possible to perform on the pilot site itself. The resulting delays for various scenarios (for both DRT and conventional cars) will then provide the input to the macrosimulation tooling. In this macrosimulation environment we re-estimate the mode choice for several scenarios to estimate how many people will use the DRT system (incorporating delays outputs from the microsimulation), and compute impacts such as **modal split**, **congestion** and **emissions**.

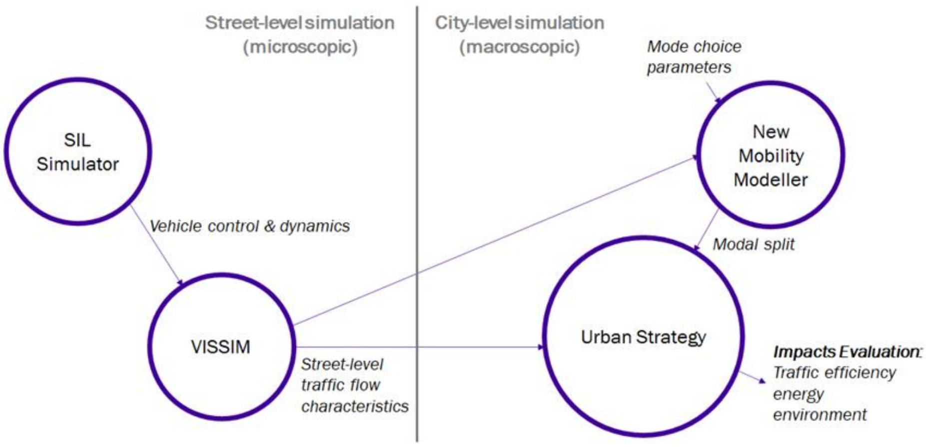


Figure 4: Brainport Simulation model architecture.

4.2.1.2 Pilot pre-demo progress

The pre-demo pilot runs have been completed during two tests: at the test track in Lelystad in April 2021, and at the test track of Aldenhoven in November 2021. The first test focused on interaction with Vulnerable Road Users (and has been reported in D10.2), the second test focused on GLOSA. The pre-demo phase of the pilot vehicle is thereby completed.

4.2.1.3 Simulation pre-demo progress

The pre-demo data was used to validate the driver model in the microsimulation software VISSIM. The validation of the first pilot runs have been reported in D10.2. In this deliverable, the validation of the second pilot runs are reported. This activity thereby has been finished.

As a next step, the DRT driver model is used in VISSIM for several intersection types and penetration rates to compute the impact of DRTs on street-level. These are reported in this deliverable.

In the next deliverable, D10.4 the impact on city-level will be reported, where the junction delay results of VISSIM are used in the macroscopic simulation software to assess the impact of DRT introduction on the modal split.

4.2.2 Validation tests

Prior to running the simulations a series of validation tests were carried out. These focused specifically on the data from the pilots executed at Aldenhofen which included two different use cases namely, GLOSA and VRU, for three and two different subcases for each: for GLOSA the varied parameter was distance at which the traffic light was switching to amber and it varied among values in 20, 50, and 120 m. The approaching speed was the same for all cases, 40 km/h. For VRU it was the persistence of the message, in one case the message was held until the vehicle reached full stop and in the other case the persistence of the message was until the vehicle was 10 m from the crossing line.

For all the 5 cases, 20 simulation runs were executed with the same vehicle model implemented in VISSIM. The validation consists of qualitatively comparing the results of the field data and the simulation data. In order to do so, the speed profiles for both the simulation and the field pilot were averaged and plotted vis-à-vis with their respective confidence intervals of one standard deviation.

4.2.2.1 GLOSA

In Figure 5, Figure 6, and Figure 7 the GLOSA results are shown. Red and blue depict the field pilot and simulation speed profiles. In all cases, for the speed and the acceleration also the dispersion is shown as a lighter region around the mean values (solid lines). In all cases it is observed that **the signal states change earlier** (for a larger distance between the vehicle and the crossing) **for the pilot cases**. We will discuss the consequences and potential explanation of this, but it is important to notice from the bottom panels of all in Figure 5, Figure 6, and Figure 7 that there seem to be a global shift in the signal status' between the pilot and the simulation.

For the first case, GLOSA 20, where the light turns amber when the vehicle is 20 m away from it; in both cases (the pilot and the simulation) the model does not decelerate because it is determined that the vehicle has crossed the so called point of no return. In both cases the acceleration and the speed remain stable throughout the signalized intersection crossing.

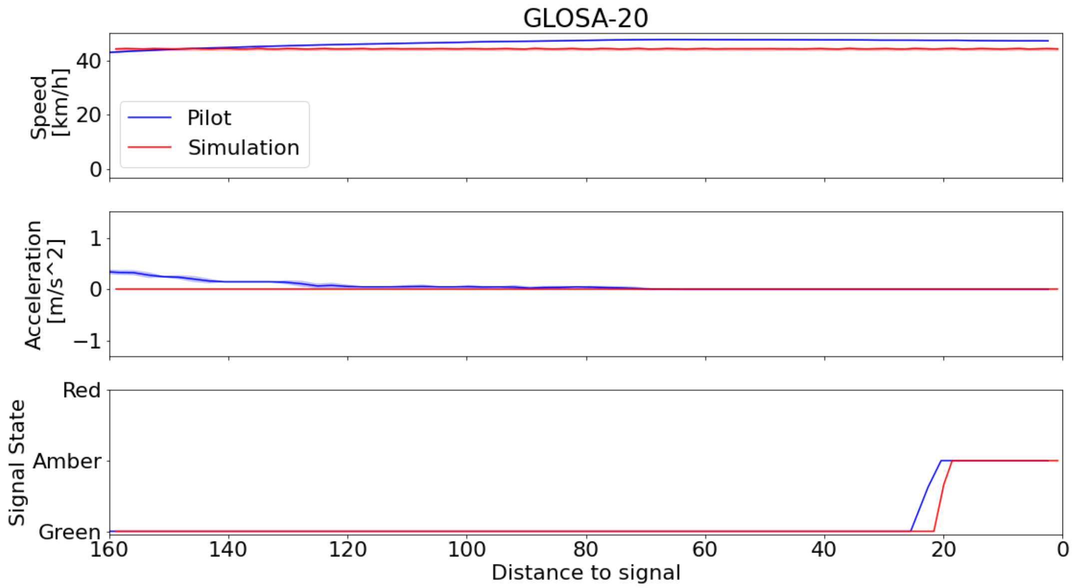


Figure 5: Comparison between the model in the pilot and in the simulation for the GLOSA case when the switch traffic light switch happens when the vehicle is 20 m apart from the intersection. From top to bottom, the speed, acceleration and signal state of the traffic light. Solid lines represent the mean over trials for the speed and the acceleration and the shaded area is one standard deviation interval. In all cases blue represents the data from the field pilot and red the data from the simulation.

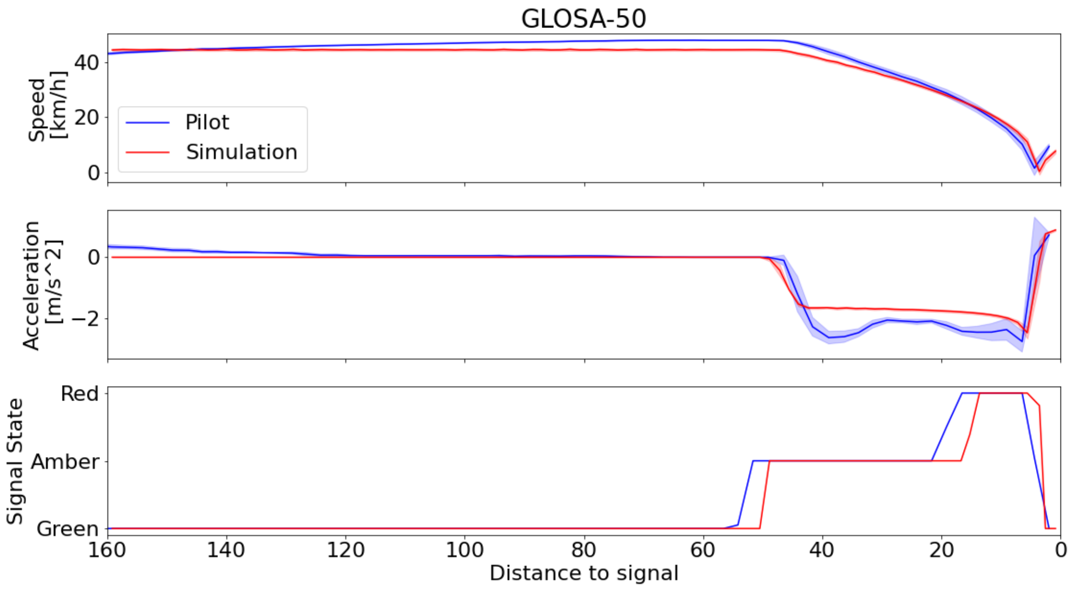


Figure 6: Comparison between the model in the pilot and in the simulation for the GLOSA case when the switch traffic light switch happens when the vehicle is 50 m apart from the intersection. From top to bottom, the speed, acceleration and signal state of the traffic light. Solid lines represent the mean over trials for the speed and the acceleration and the shaded area is one standard deviation interval. In all cases blue represents the data from the field pilot and red the data from the simulation.

In the second case the signal switches when the vehicle is 50 m apart. In both cases the approaching speed is the same, and overall the kinematics seem to be almost a perfect match between the models with respect to the timing of the changes. The noticeable discrepancy between the accelearation patterns can be attributed to the fact that the simulation does not incluse a vehicle model, hence, the smoothness of the simulation deceleration profile compared to that one of the pilot.

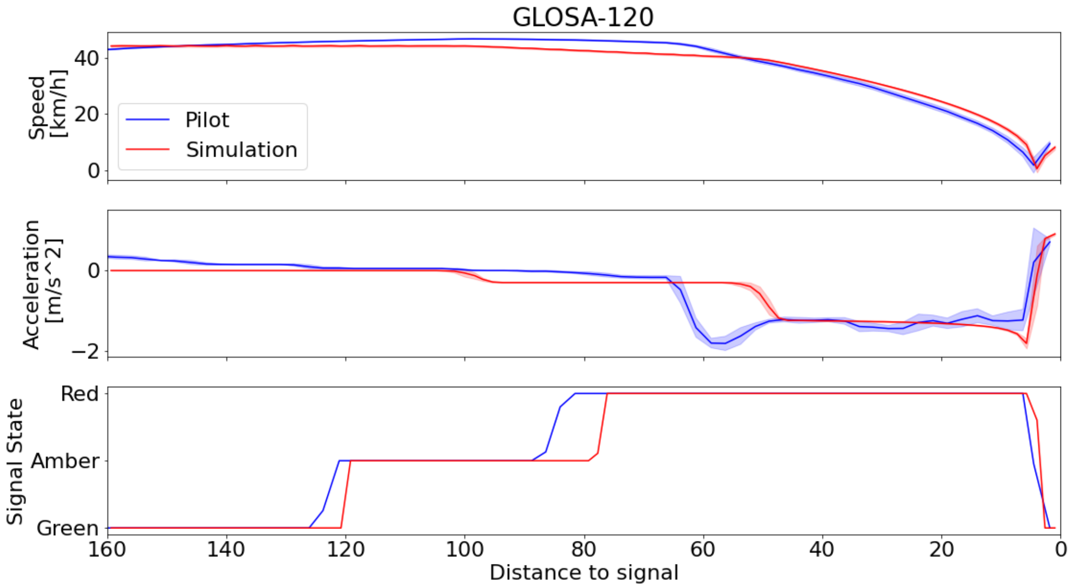


Figure 7: Comparison between the model in the pilot and in the simulation for the GLOSA case when the switch traffic light switch happens when the vehicle is 120 m apart from the intersection. From top to bottom, the speed, acceleration and signal state of the traffic light. Solid lines represent the mean over trials for the speed and the

acceleration and the shaded area is one standard deviation interval. In all cases blue represents the data from the field pilot and red the data from the simulation.

In the third case the signal switches when the vehicle is 120 m apart. In both cases the approaching speed is the same, and the speed matches very well throughout the crossing. The acceleration pattern shows some discrepancies, mainly that the deceleration onset is further away from the traffic signal (earlier) in the pilot. Nevertheless, this seems to be in accordance with the spatial shift observed in the signal status switch that is larger than in the previous cases (20 and 50 m). This is most likely explained as a measurement inacurance and provided that is a global shift does not have further consequences.

4.2.2.2 VRU

The same validation was made for the VRU use case. The variation in this case was the VRU message persistence, i.e., how long was the message held. In one case the message was held until the vehicle was 10 m away from the crossing line (I.e., the message was discarded before the vehicle actually reached a full stop) whereas in the otherone was held until the vehicle was reaching a full stop.

In the two variations of this use case, the acceleration profiles seem to slightly differ between the pilot and the simulation, but the difference is explained by the longer duration of the state 5 of the VRU status in the simulation. Specifically, for the first case (shown in Figure 8) in which the message is held until the vehicle reaches the full stop, the speed profile is almost identical. In the case in which the message holds until the vehicle is 10 m after the crossing line (Figure 9).

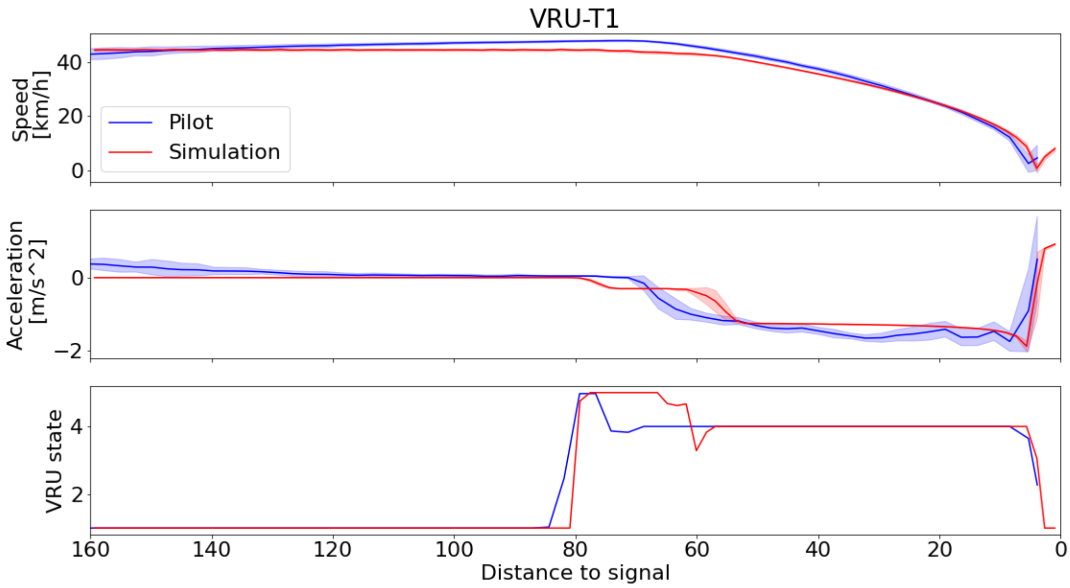


Figure 8: Comparison between the model in the pilot and in the simulation for the VRU case. The VRU message is held in this case until the vehicle stops completely. From top to bottom, the speed, acceleration and signal state of the traffic light. Solid lines represent the mean over trials for the speed and the acceleration and the shaded area is one standard deviation interval. In all cases blue represents the data from the pilot and red the data from the simulation.

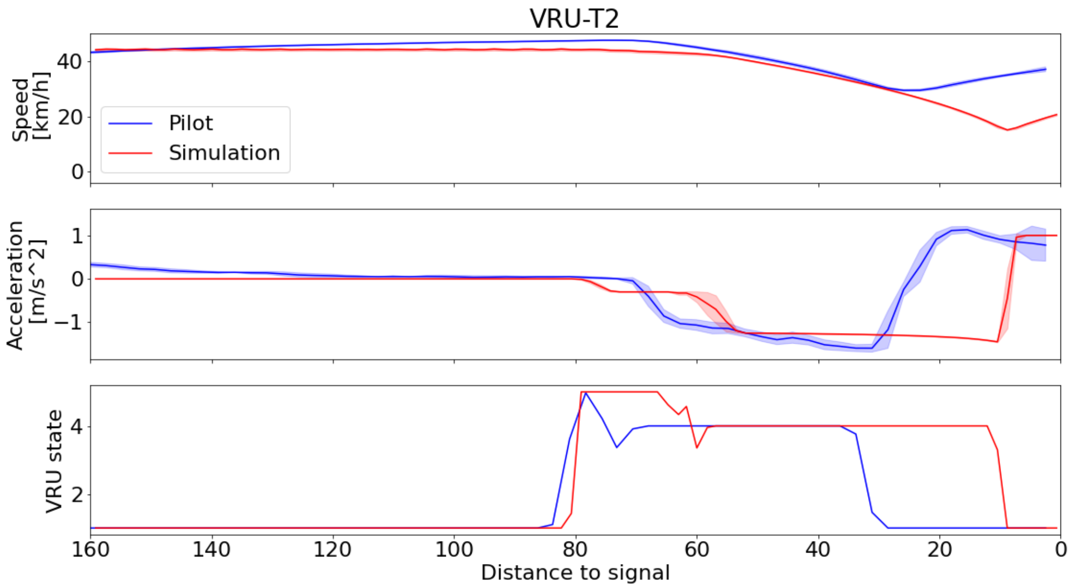


Figure 9: Comparison between the model in the pilot and in the simulation for the VRU case. The VRU message is held until the vehicle is 10 m apart from the stop line. From top to bottom, the speed, acceleration and signal state of the traffic light. Solid lines represent the mean over trials for the speed and the acceleration and the shaded area is one standard deviation interval. In all cases blue represents the data from the pilot and red the data from the simulation.

4.2.3 Simulation specifications

A set of street-level simulations with VISSIM have been performed in order to assess the effects of CACC DRT vehicles in mixed traffic on turn delay in three different intersection types. These results are used as an input for the next step, where the junction delays are used in a city-level simulation to compute the number of people that would like to use the DRT system.

4.2.3.1 Simulation parameters

In this iteration of street-level simulations, several parameters are varied, these are:

- The time of day (peak-hour / off-peak)
- The availability of DRTs (penetration rate)
- Intersection type (by changing the network layout)

For the time of day, the main input that changes in the simulations is the total demand. This demand is derived from the macroscopic model, specifically the turn loads are used. These turn loads represent the amount of vehicles that pass an intersection and make a specific turn. The sum of these can be used as the vehicle input, and the distribution of traffic over turns of the same ingress can be used as route fractions for each of the turns.

The demand of the morning peak (7.00 – 9.00) is used as the peak-hour demand. It is translated to a one-hour period for VISSIM. In order to represent an off-peak demand, this demand is multiplied with 0.9, i.e. 90% of the peak-hour demand is used as off-peak demand. It is chosen to reduce the demand proportionally (i.e. the same reduction in each ingress and turn), since demand in specific intersection ingresses and turns varies a lot during the day. This means that, even though the total demand is less, it is spread very differently over the turns in different time periods. This would make comparison between peak-hour and off-peak periods difficult. For the off-peak period a multiplication factor of 0.9 is derived from the difference in total demand in the macroscopic model between morning peak and the rest-of-day (off-peak) period for selected intersections.

For the availability of DRTs, three different penetration rates are used: 0%, 5% and 20%. This means that in the 20% penetration rate case, 20% of cars are replaced by DRT vehicles that have a CACC function. All DRT vehicles are programmed to follow the same route, this is always the turn with the highest flow rate. The routes of other (conventional) cars are adjusted such that every route is taken equally often in the 0% DRT case compared to the 5% and 20% DRT scenarios.

Three different intersection types are studied, an intersection with 3 arms where each ingress has 2 lanes (3 arm 2 lanes intersection), an intersection with 3 arms where each ingress has 3 lanes (3 arm 3 lanes intersection), and an intersection with 4 arms where each ingress has at least 3 lanes (4 arm 3 lanes intersection). The networks are described in more detail in the next section.

4.2.3.2 Simulation network

Three different junction lay-outs with traffic lights are used in this set of street-level simulations. These are the intersections that are most common in macroscopic (city-level) network of Eindhoven. Each VISSIM network contains one intersection type with extended ingresses. The networks are all set up in a similar way. The three networks are:

- A 3-armed junction with 2 lanes per arm (see Figure 10). This junction type is used in 13% of the signalized intersections in Eindhoven.
- A 3-armed junction with 3 lanes per arm (see Figure 11). This junction type is used in 19% of the signalized intersections in Eindhoven.
- A 4-armed junction with 3 lanes per arm (see Figure 12). This junction type is used in 10% of the signalized intersections in Eindhoven.

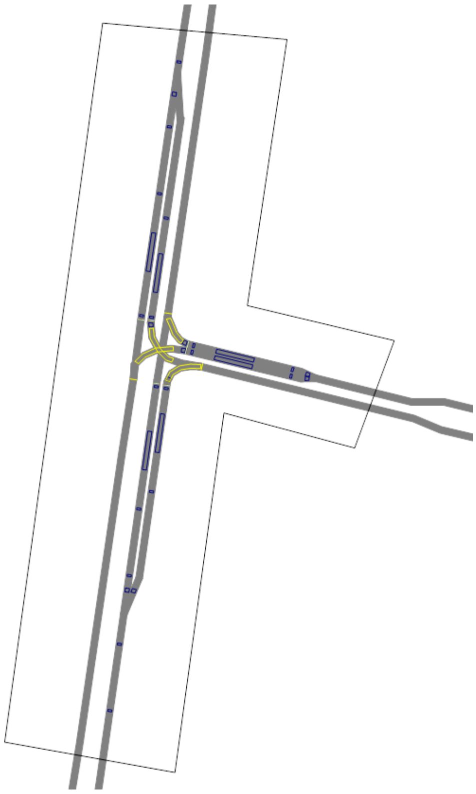


Figure 10: 3 Arm – 2 lanes intersection in VISSIM.

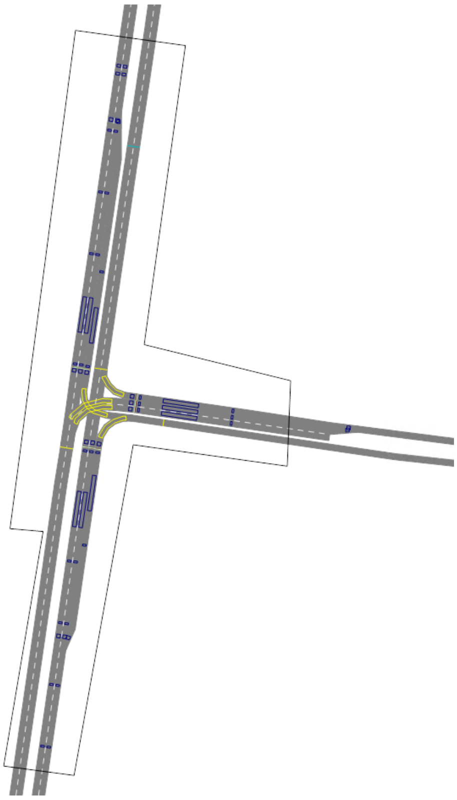


Figure 11: 3 Arm – 3 lanes intersection in VISSIM.

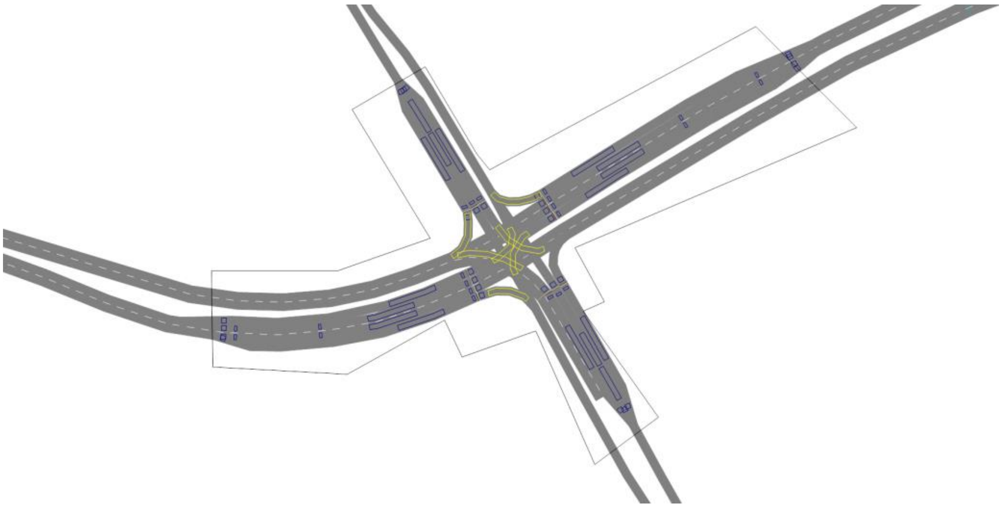


Figure 12: 4 Arm – 3 lanes intersection in VISSIM.

Each network is equipped with a simple signal controller, which is optimised based on the demand in the peak-hour, with 0% penetration rate of DRTs.

The desired speed is set at 50 km/h for all parts of all three intersections.

In order to measure the delay in each of the different turns, travel time measurements are set up for each turn. These start at 10m from the start of the network ingresses, and end at the traffic signal head. The travel time measurements are used for analysis of the delay, travel time, and average speed in each of the turns. Delay is defined as the loss of time by driving the actual speed instead of the desired speed of the vehicle.

4.2.3.3 Simulation scenarios

In this set of street-level simulations, 18 scenarios are studied. For each of these scenarios, 10 simulation runs are performed. The scenarios vary in intersection type (network), peak-hour/off-peak time, and three penetration rates for DRT vehicles (0%, 5% and 20%). This results in 18 scenarios, as shown in Table 3.

Table 3: Scenario overview Brainport.

Scenario number	Intersection type	Demand	Penetration rate DRT
1	3 Arm 2 Lanes	Peak-hour	0%
2	3 Arm 2 Lanes	Peak-hour	5%
3	3 Arm 2 Lanes	Peak-hour	20%
4	3 Arm 2 Lanes	Off-peak	0%
5	3 Arm 2 Lanes	Off-peak	5%
6	3 Arm 2 Lanes	Off-peak	20%
7	3 Arm 3 Lanes	Peak-hour	0%
8	3 Arm 3 Lanes	Peak-hour	5%
9	3 Arm 3 Lanes	Peak-hour	20%
10	3 Arm 3 Lanes	Off-peak	0%
11	3 Arm 3 Lanes	Off-peak	5%
12	3 Arm 3 Lanes	Off-peak	20%
13	4 Arm 3 Lanes	Peak-hour	0%
14	4 Arm 3 Lanes	Peak-hour	5%
15	4 Arm 3 Lanes	Peak-hour	20%
16	4 Arm 3 Lanes	Off-peak	0%
17	4 Arm 3 Lanes	Off-peak	5%
18	4 Arm 3 Lanes	Off-peak	20%

4.2.4 Simulation results

For each of the scenarios, the simulation has been run 10 times. The following results present the averages of these 10 runs for each of the simulation scenarios. The presented results per scenario are: **average delay per turn** and **average speed per turn**. Each turn is measured from 10m from the start of the ingress until the stop line of the traffic signal.

Table 4 shows the average delay per vehicle in each of the 18 simulation scenarios. It can be seen that the average delay increases with a higher demand, i.e. the delay in the peak-hour is higher than in the similar scenarios off-peak. Due to the larger amount of vehicles in the network, vehicles have to wait longer and are more often slowed down by leading vehicles, causing more delay. It can also be seen that the average delay is larger in the scenarios with higher DRT penetration rates. This can be explained by the behaviour in these vehicles. The DRT vehicles are equipped with CACC, which causes larger following distances (headways) compared to conventional cars. This is true both at standstill (at a traffic light) and when driving. Additionally, the acceleration of the DRT vehicles when resuming driving from standstill is slower, causing extra delay for these vehicles as well as the following vehicles. It is important to realise that, in this case, the DRT vehicles do not receive acknowledgement about the state of the traffic light.

Table 4: Average delay in seconds per vehicle for all turns of an intersection.

	3 Arm 2 Lanes		3 Arm 3 Lanes		4 Arm 3 Lanes	
	Peak-hour	Off-peak	Peak-hour	Off-peak	Peak-hour	Off-peak
0% DRT	10.71	10.60	11.51	11.30	16.79	16.84
5% DRT	11.16	10.95	11.62	11.44	16.87	16.80
20% DRT	13.81	12.07	11.89	11.68	17.78	17.27

In Table 5, Table 6, and Table 7 the delay per turn are presented for the 3 arm 2 lanes, 3 arm 3 lanes and 4 arm 3 lanes intersections, respectively. The DRT vehicles are instructed to follow a single route, and therefore they are all driving via the same turn. For the 3 arm intersections (both 2 lane and 3 lane), DRT vehicles are in turn numbers 2, 4 and 5. For the 4 arm 3 lanes intersection, the DRT vehicles are in turn numbers 3, 5, 9 and 11. These turns are marked grey in each of the tables.

In these numbers, it can again be seen that the higher demand causes higher delays, and that especially in the turns with the DRT vehicles, the delay increases with higher penetration rates of DRT vehicles.

Table 5: Delay in seconds per vehicle per turn for 3 Arm 2 Lane intersection. Turns where DRTs are driving are marked grey.

		Peak-hour			Off-peak		
Turn number	Description	0% DRT	5% DRT	20% DRT	0% DRT	5% DRT	20% DRT
1	South To East	7.2	7.3	7.2	7.1	7.2	7.3
2	South To North	7.8	7.9	8.6	7.9	8.0	8.5
3	East To North	13.4	13.2	14.1	13.8	14.2	15.8
4	East To South	15.9	16.2	17.3	15.7	15.7	16.5
5	North To South	10.6	11.4	16.3	10.3	10.9	12.8
6	North To East	22.7	23.8	24.8	24.5	25.1	24.2

Table 6: Delay in seconds per vehicle per turn for 3 Arm 3 Lane intersection. Turns where DRTs are driving are marked grey.

		Peak-hour			Off-peak		
Turn number	Description	0% DRT	5% DRT	20% DRT	0% DRT	5% DRT	20% DRT
1	South To East	8.8	8.9	9.0	8.9	8.8	9.6
2	South To North	9.0	9.0	9.0	9.0	9.1	9.0
3	East To North	13.6	13.7	13.5	13.0	13.8	12.6
4	East To South	14.5	14.7	15.5	13.9	13.7	14.8
5	North To South	8.8	9.0	9.3	8.9	9.2	9.2
6	North To East	19.4	19.0	19.4	19.3	19.4	20.8

Table 7: Delay in seconds per vehicle per turn for 4 Arm 3 Lane intersection. Turns where DRTs are driving are marked grey.

		Peak-hour			Off-peak		
Turn number	Description	0% DRT	5% DRT	20% DRT	0% DRT	5% DRT	20% DRT
1	South To East	16.2	16.5	16.8	19.1	19.1	18.1
2	South To North	22.0	20.9	19.9	14.6	17.3	14.1
3	South To West	23.0	28.2	29.9	22.2	25.2	21.3
4	East To North	12.7	12.1	12.1	13.4	12.5	13.2
5	East To West	12.5	12.7	13.2	12.6	12.7	13.0
6	East To South	23.1	22.6	21.9	22.2	21.4	20.9

		Peak-hour			Off-peak		
Turn number	**Description**	**0% DRT**	**5% DRT**	**20% DRT**	**0% DRT**	**5% DRT**	**20% DRT**
7	North To West	18.6	17.4	15.8	18.6	18.6	19.0
8	North To South	11.4	14.0	17.5	21.7	21.6	15.0
9	North To East	26.8	28.9	37.3	27.1	28.2	33.6
10	West To South	11.1	12.6	10.9	12.4	8.6	10.7
11	West To East	14.0	14.0	14.6	13.9	14.1	14.7
12	West To North	18.5	17.7	19.5	18.6	19.3	18.0

In addition to the delay, also the average speed can be studied. Generally, an increase in delay is accompanied by a decrease of average speed in the same turn. Therefore, the figures of speed do not give much additional insights. They are presented for the 4 arm 3 lane intersection in Figure 13 and Figure 14.

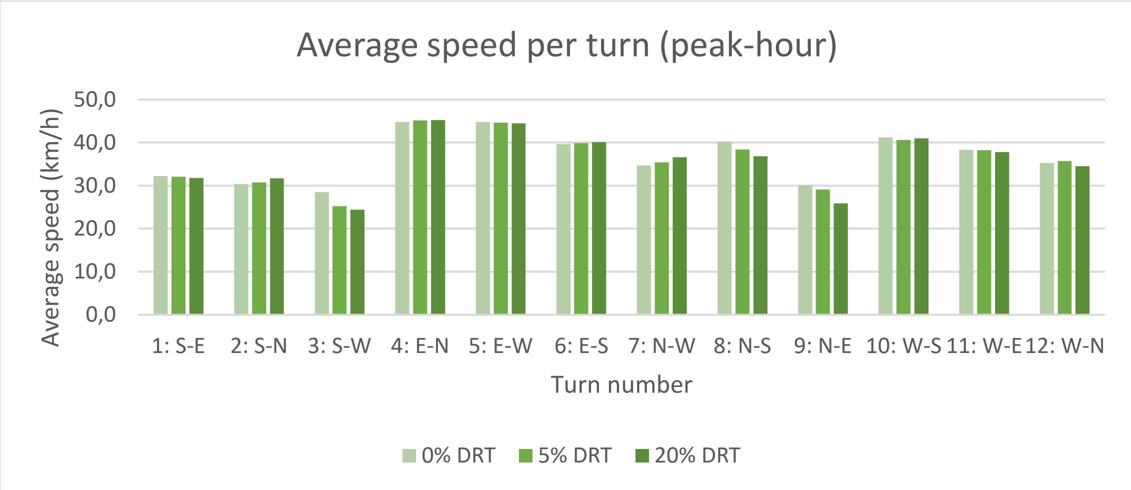


Figure 13: Average speed per vehicle per turn of the 4 arm 3 lane intersection, for the three different penetration rates at peak-hour demand.

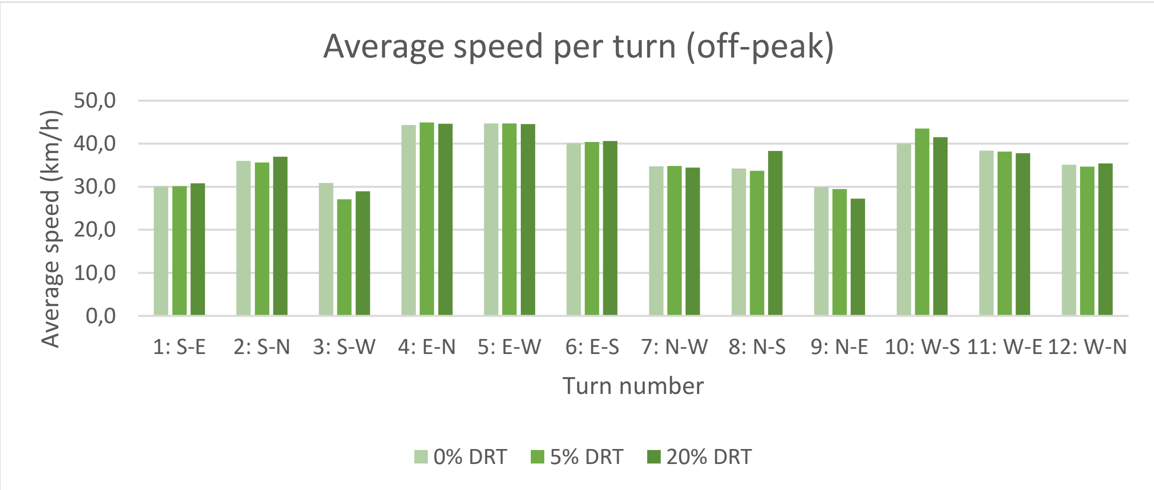


Figure 14: Average speed per vehicle per turn of the 4 arm 3 lane intersection, for the three different penetration rates at off-peak demand.

It is good to note that, although the delay is higher in scenarios with more DRTs, this is largely due to the fact that the CACC vehicles are keeping larger following distances for safety reasons. With (very) high market penetration rates of CACC vehicles, these safety margins may be decreased, since (almost) all vehicles can communicate.

Additionally, it must be remarked that the occupancy rate of DRT vehicles can be higher than for conventional vehicles. When a higher occupancy rate is achieved, less vehicles are required to perform all trips. With a lower demand (even lower than off-peak), the increase in travel time due to large following distance may be compensated by a decrease due to lesser demand. This aspect will be investigated during the city-level simulations.

4.2.5 Next steps

4.2.5.1 Simulation overall progress

The validation of the software-in-the-loop driver model using test data of the pre-demo's has been finalized and reported in this deliverable. This driver model has been used in VISSIM to simulate several scenarios with different intersection lay-outs, with different penetration rates and demand levels. This provided insights to the street-level impacts of DRTs, that (for low penetration rates) mainly cause additional delays.

For the city-level simulations, progress has been made on forming a methodology on modelling (microscopic) DRT vehicles including vehicle dispatching within a macroscopic traffic model. The methodology and a first use case has been described in the TRA 2022-paper "Vehicle dispatching in macroscopic transport models: modelling Demand Responsive Transit" (authors van der Tuin, Spruijtenburg and Zhou).

4.2.5.2 Simulation future plans

The microscopic street-level simulations in VISSIM will be extended by one other scenario, where a bus lane is introduced. On this bus lane - besides buses – DRTs are allowed to drive. More specifically, a DRT driving on this bus lane will get priority over all other traffic. We expect that this results in a large decrease of intersection delays for DRTs, whereas other conventional cars will have to wait longer than in the current non-DRT situation.

Next, the city-level impact of introduction of DRTs in the city of Eindhoven is being estimated using macroscopic simulation. This will involve the earlier developed methodology on modelling DRT vehicles as well as mode choice re-estimation. Also, the junction delays following the VISSIM street-level simulations will be incorporated in the macroscopic simulation.

Both activities will be reported in D10.4.

4.3 Graz (Scenarios 1 & 3)

4.3.1 Pilot description & progress

4.3.1.1 Pilot general description

Automated shuttles have the potential to offer safe transportation with ecological impact. For end-user acceptance, these shuttles must drive safely and efficiently in complex environments with other road users. This section focuses on automated shuttle services at a bus terminal in Graz, Austria, in the presence of buses and pedestrians. Driving situations in intersections, gas stations, and parking slots might lead to similar problems. It would be convenient for the passengers if the shuttle service could find the fastest way to the target. Road users might block some pathways, leading to deadlocks and untypical scenarios where the shuttle service should react and adapt adequately. The task is difficult because the vehicle itself does not observe the whole environment by the onboard sensors and the lack of knowledge to predict the future intention of other road users. This section analyses a navigation approach for microenvironments like bus terminals, gas stations, and similar environments finding optimal pathways with simulations (co-simulation between ROS and Julia). A virtual agent tries to find a suitable policy in the presence of buses and pedestrians, where only unlabeled LiDAR data is available. The perception and predictability of objects lead to uncertainty and make the problem challenging.

4.3.1.2 Pilot pre-demo progress

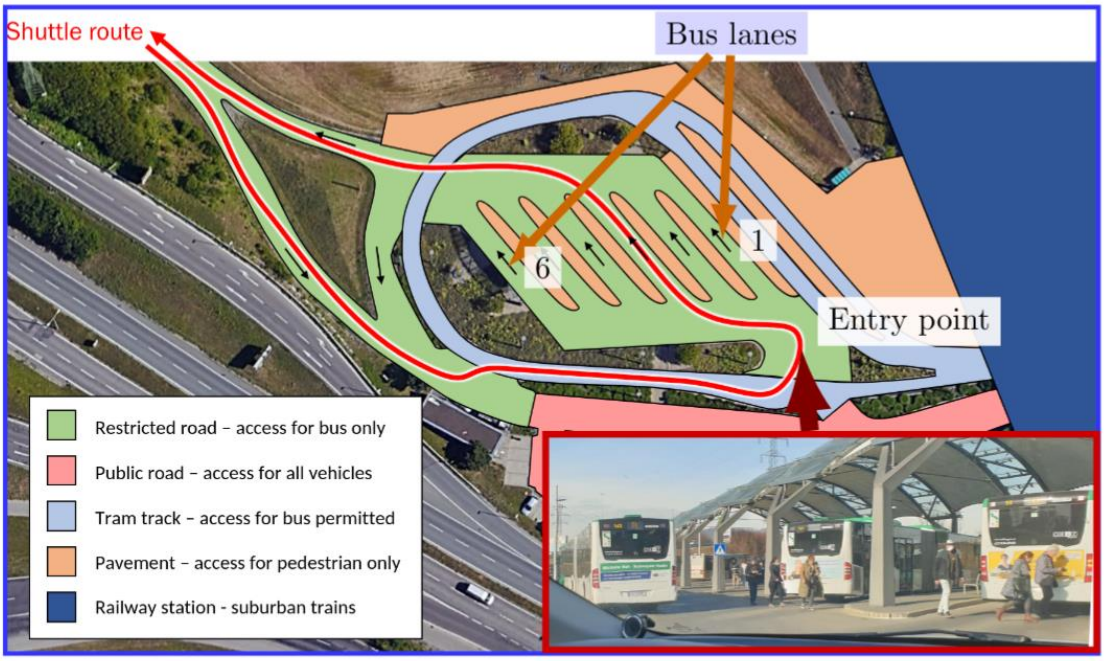


Figure 15: Map of the bus terminal in Graz.

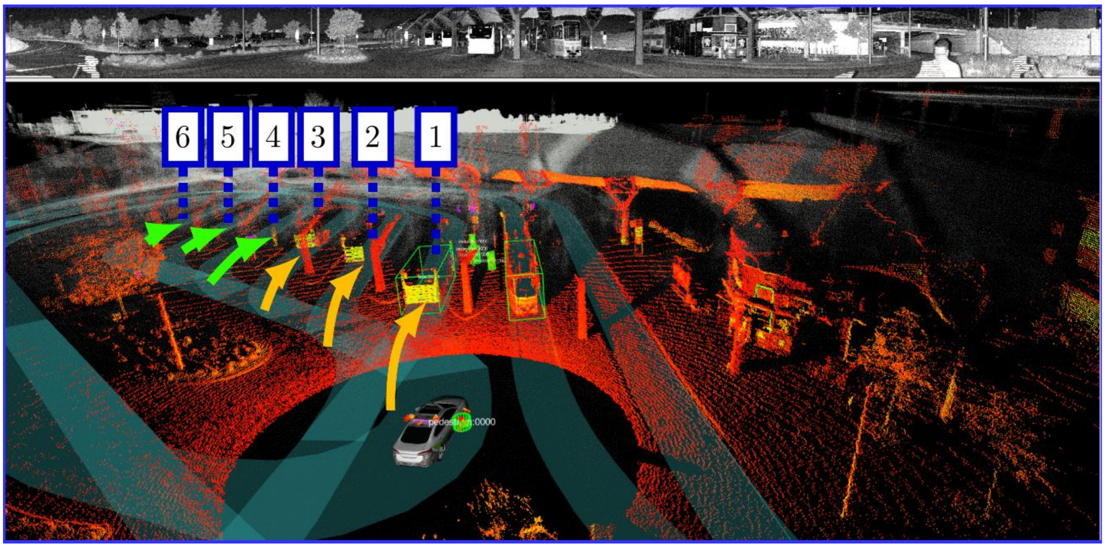


Figure 16: Which lane to choose (1 to 6)? Automated vehicle at a bus terminal in Graz, Austria.

4.3.1.3 Simulation pre-demo progress

Automated driving technology could be implemented in shuttle services and buses. There are already driverless trains, subway stations in some cities, and many driverless bus research projects, but often with a few buses. Driverless buses make sense for significant events or, in general, for transporting large crowds. This section addresses the challenges and development of this new technology in the presence of higher numbers of buses. Automated shuttle services might provide a pivotal solution to future questions of handling the environmental crisis and reducing traffic jams. Automated buses could have a better CO_2 balance than conventional automated vehicles (transportation of a higher number of persons). Nowadays, automated shuttle services often drive on a fixed route and observe the environment by on-board sensors. Some tasks in urban environments are difficult to be automated. The challenge of current approaches is how to drive intelligently in complex urban environments and the presence of other buses without blocking each other's movements. How can an automated vehicle reach its target by operating efficiently?

Use-case: Transportation in Graz Austria from Bus-terminal to shopping mall:

This section focuses on a bus station in Graz, Austria, with the presence of buses and pedestrians. Figure 15 shows a 2D map and an image section with standing buses and walking pedestrians. Therefore, the automated shuttle service should perceive environmental information and choose a specific bus lane in the presence of buses and pedestrians. The map of the bus station in Graz, Austria (blue border) shows a green area for restricted roads to access the buses and the research vehicle. Due to the operating buses and research purposes, the entry point for passengers for the automated vehicle is not directly on the bus lanes but directly before. Buses and pedestrians (actual image with red border) might block the shuttle route (red curved arrow). Figure 16 shows a simulation example with sensor data. The simulation 3D model of an ego-vehicle is in the middle of the picture. The vehicle perceives information about the environment with LiDAR sensors, which produce point cloud data (red dots) in the Robot Operating Simulation (ROS). In this section, the vehicle has to find a way to pass six different bus lanes (marked with the numbers 1 to 6), which buses, cars, and pedestrians could block. On the right lane is a tram station, and it is forbidden to pass this lane. The ego vehicle will be stopped by standing buses (see orange arrows) and could pass lane-6 (green arrows) directly. The two cuboids represented with green lines show that the vehicle's software detected the tram station and the bus as objects. The buses on lanes 2 and 3 were not recognized as standing due to the distance and static obstacles. This research project aims to find an optimal policy to traverse the bus station (six bus lanes).

Figure 16 and Figure 20 show Light Detection and Ranging (LiDAR) data and the problem of detecting buses, vehicles, and pedestrians with absolute certainty. The future movements of buses and pedestrians are unknown in advance, and the decision dilemma exists that the intention of the road users is unknown. A bottleneck of an automated vehicle is that the computing system with the perception system cannot observe all environmental factors. This lack of knowledge might lead to inefficient behaviour. In fatal situations, it might lead to collisions with other road users. There are difficult situations, especially in intersections, parking stations, bus terminals, bus stops, toll booths, and gas stations.

The automated vehicle is driving to the entry point (EP) Figure 15**Error! Reference source not found.**, Figure 16**Error! Reference source not found.**, Figure 18**Error! Reference source not found.** coming to a stop and waiting for a passenger. If the passenger is ready to go, the vehicle has to decide which lane to take. In the current system, the safety driver chooses the lane to drive the passenger to the shopping mall. Automation might help transport the passengers without a safety driver, which is the section's aim, which analyses the possibilities of automating the procedure. Some buses might come to one of the six bus lanes within a specific time, maybe with delays.

Buses and pedestrians might block the future movements of an automated vehicle of the virtual vehicle research centre, which might be replaced by an automated bus.

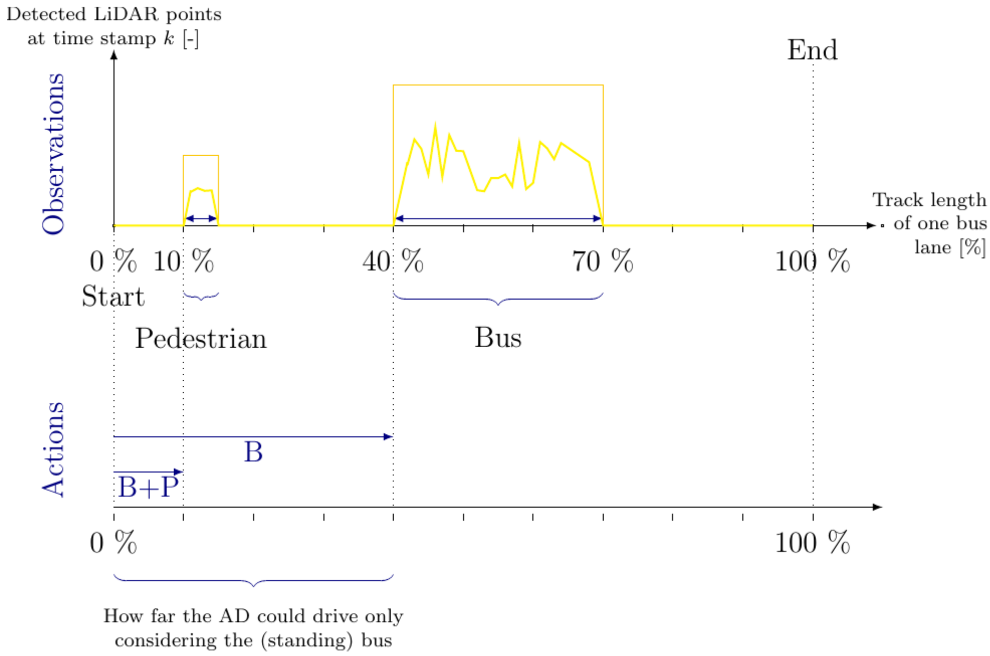


Figure 17: Idealized analysis of one bus lane.

Figure 17 presents a simplified view on observations near to one bus lane with track length normalized from 0% to 100 %. Pedestrian(s) and a bus might block a single bus lane. On the LiDAR data profile for a bus lane one can define a policy how far the automated vehicle might drive (Actions). In this idealized example the pedestrian(s) stand and also the bus does not drive (40% to 70%). The blue arrow in the bottom might signalize how far the automated vehicle might drive only considering the bus or the bus and the pedestrian(s) (B+P).

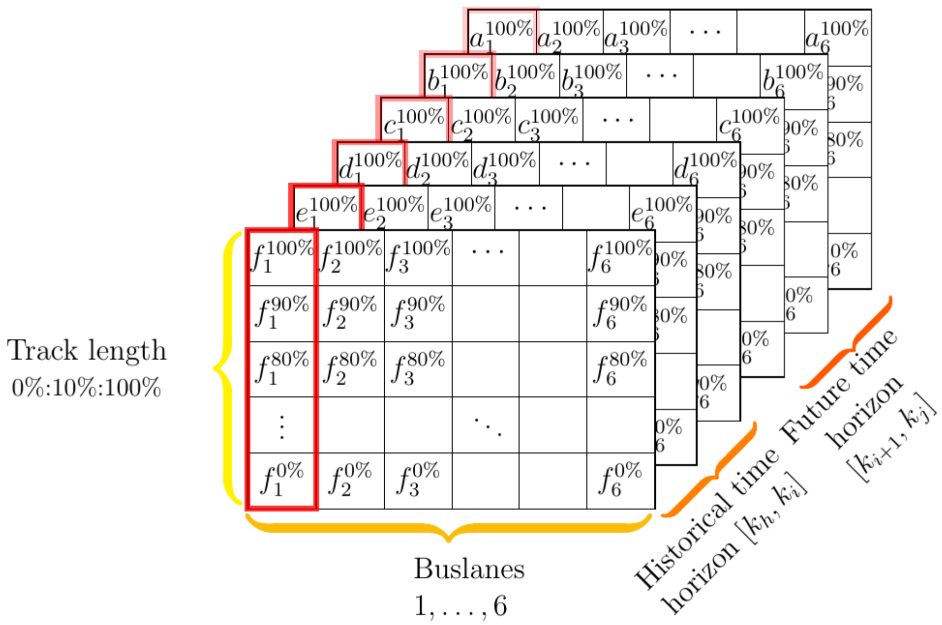


Figure 18: Tensor to tensor prediction for the six bus lanes.

Figure 18 shows six staggered matrices for different consecutive timestamps. The figure should illustrate the theory of a tensor-to-tensor prediction approach. Each cell of the tensors shows how many observations lie inside the bus lane section. How many reflections of LiDAR technology are on each sequence of one of the six bus lanes? Due to static objects, there might be some noise, which has to be filtered to count only the points from dynamic objects. In Figure 20 we can also see that on the right side, a pedestrian or bus is disturbing the parts of other areas, like this is visualized in Figure 19**Error! Reference source not found.**.

4.3.2 Simulation specifications

4.3.2.1 Simulation parameters

The vehicle parameters are not the main focus of the parameter representation. The grid point representation and parameter for the data representation are the focus of interest.

4.3.2.2 Simulation network

The co-simulation framework consists mainly of JuliaLanguage Scripts and ROS. The simulation in Julia is hearing the data of the point cloud near the bus terminal.

4.3.2.3 Simulation scenarios

Different constellations of the buses and pedestrians from the rosbag files were analysed. The idea of the simulation is pattern recognition, prediction and decision making for finding optimal bus lanes with complex LiDAR data.

4.3.2.4 Pre-demo data used

The rosbag files from the measurements were used and analysed in the simulation.

4.3.3 Simulation results

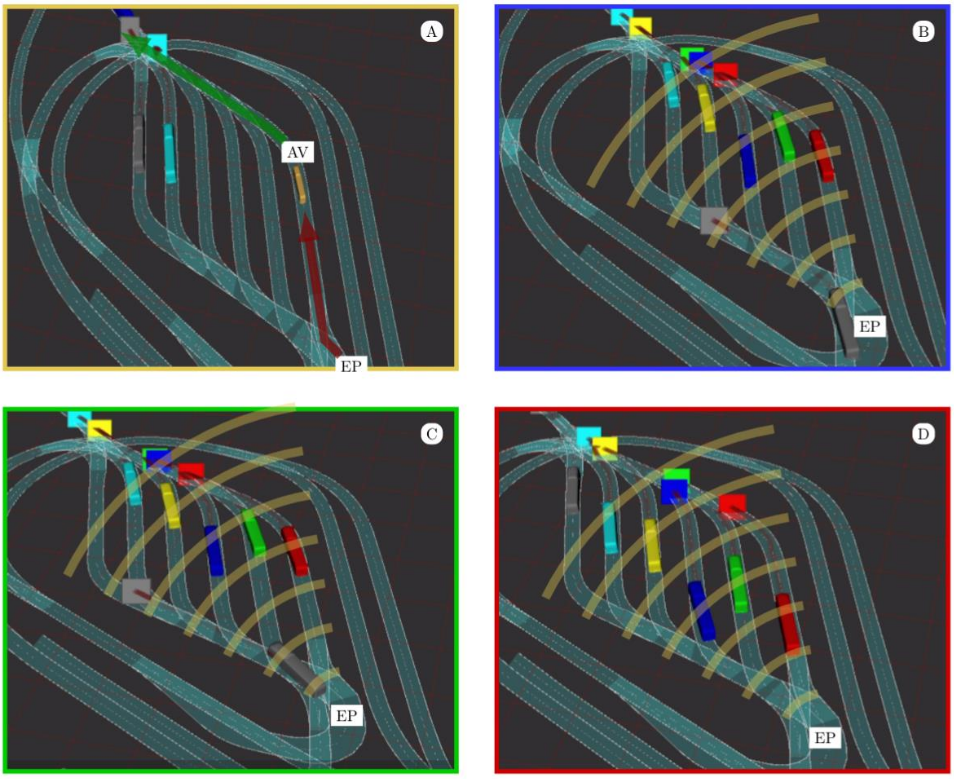


Figure 19: Co-simulation results of Julia Programming and ROS.

Figure 19 shows the Julia-ROS simulation framework. This project aims to traverse the bus station without a collision. Therefore, this Julia/ROS Simulator has different buses (golden automated vehicle AV and grey and cyan buses in subfigure A and red, green, blue, yellow, cyan, and grey buses in all others B to D) shows how the golden automated vehicle takes the first lane. The optimal policy is evident in subfigure A (with full observability and without uncertainty). One would take one of the first four lanes as an apparent policy, maybe with further selection criteria (total distance or curvature).

This section discusses different frameworks for analyzing the raw data and its use for decision-making. Also, different data pipelines will be compared. Each data pipeline might have different (dis-)advantages for further processing and decision-making. The questions about this section might be which data is relevant for the decision making. Which data could be filtered, and which data is irrelevant due to occlusions?

The spatial data over time could be represented in different ways. For larger datasets not every representation might be useful for storage and prediction. To find a suitable representation for the data is a prevalent engineering problem. We might represent the spatial environment with grid points or only consider data-points near to the manifold structure of the route.

The size of the LiDAR data is not small. In the use case for Graz, Austria we have more than 40k LiDAR points for one timestamp, where some LiDAR points were prefiltered for different height profiles. The representation for the different algorithmic representations is essential for real-time performance, data storage and further prediction. The data was represented in the "Pointcloud2" format in ROS and the JuliaProgram subscribes on the LiDAR messages. Each coordinate of each data point is coded as UInt8 variables (instead of Int64 this might lead to significant reduction of data storage).

The vehicle gets the raw-data observations. We might ask which representation might help us to represent a situation with multiple buses and pedestrians. Maybe we might have different state set representations. A simple representation of the environment by a manifold. We could filter the raw-data by a certain distance.

Figure 20 shows two different point clouds on the same route. The histograms are for each of the six lanes (bus lanes) and one access lane (lane number 7). In comparison, the left histogram in Figure 20 shows a different profile. These different profiles might be caused by obstruction when buses and pedestrians obstruct the view. These kinds of patterns are not very intuitive to read by humans because different obstructions, static and dynamic objects, and correlations between each lane section exist. However, a virtual agent might learn the data through intelligent algorithms. Therefore, this paper shows some approaches to learning from these datasets. In the current approach, the "rosbag" files (datasets in ROS) do not have valid labels for each object (unsupervised learning). The location of pedestrians and buses is unknown, making representation learning for the raw data necessary. Two situations for different timestamps are highlighted in Figure 20, where the point cloud near each bus lane is plotted on the two-dimensional plane with corresponding histograms. The LIDAR data on the route is on lane 1 with blue dots, lane 2 with yellow dots, lane 3 with red dots, lane 4 with orange, lane 5 with pink dots, and lane 6 with green dots. Lane 7 is the entrance lane in front of all other lanes 1-6 with cyan lidar points.

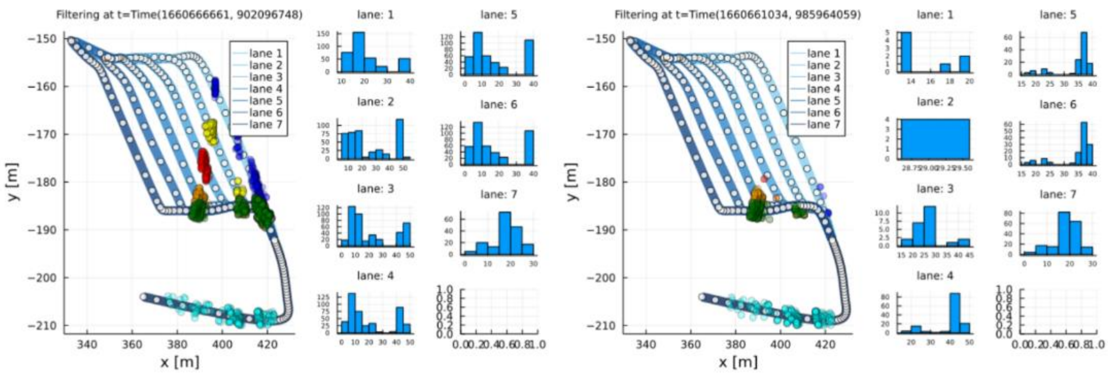


Figure 20: Point cloud filtered near to the bus lanes for two different timestamps.

The time evolution of the detected LiDAR on each bus lane is of interest, but also the correct interpretation (perception, prediction). Comparing predicted values to updated values due to measurements is of vital interest for the later selection of actions. There might be some one-to-one prediction and measurement updates like in (The Bayesian filter, with Gaussian dynamics in the Kalman filter, or particle filter). However, as shown in figure VIF4, there is a kind of tensor-to-tensor prediction. The following section analyses the computational complexity of different filtering and prediction techniques. If we divide the track length of each bus lane into N support points, we will get a matrix with 6 * N elements if we have M timestamps for the historical time sequence from k_h to k_i. We have a N x 6 x M tensor, which we map to a future N x 6 x M tensor by formulating a function f mapping the historical elements to the future elements.

Instead of doing the complex tensor to tensor prediction, one could focus on the time evolution of a single bus lane or every element. There might be pros and cons to this approach. Prediction of single elements might be easier to understand and evaluate with less complexity, but the computational complexity in total might be higher.

Figure 21 shows three situations for one bus lane where LiDAR data were represented on each track section. It is also not obvious for a single bus lane to decide which section might be driven by the vehicle. The blue and orange arrows represent the movements of pedestrians and a bus. From the LiDAR points, the number of pedestrians may be hidden, and occlusions might corrupt the detection of each object.

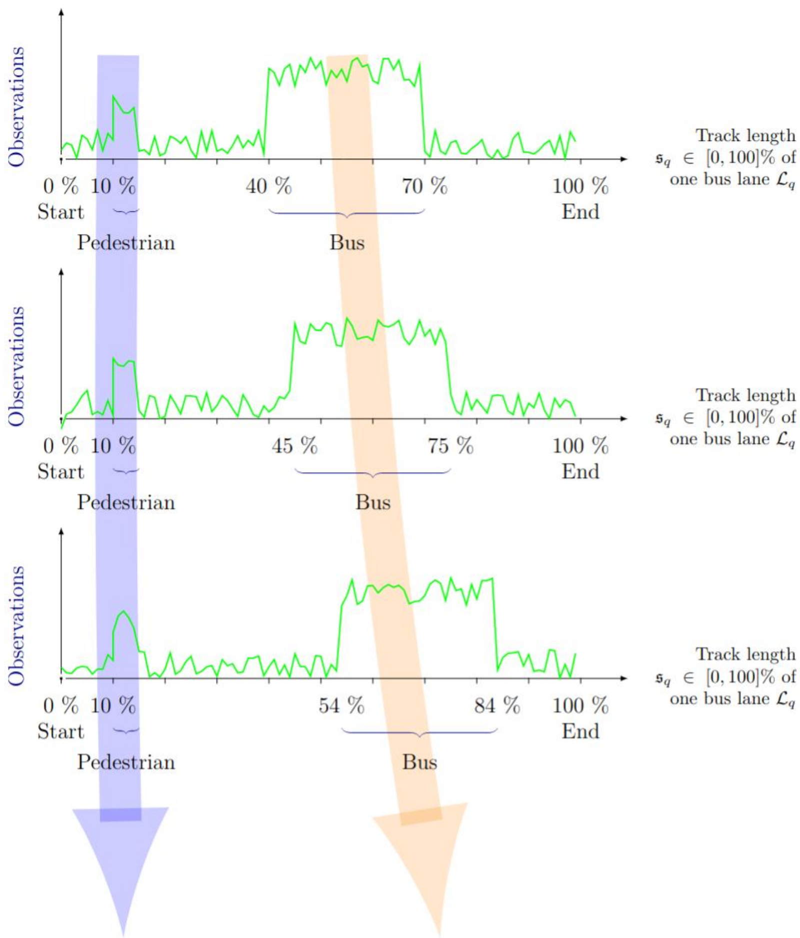


Figure 21: Simplified example of LiDAR data for one bus lane over time.

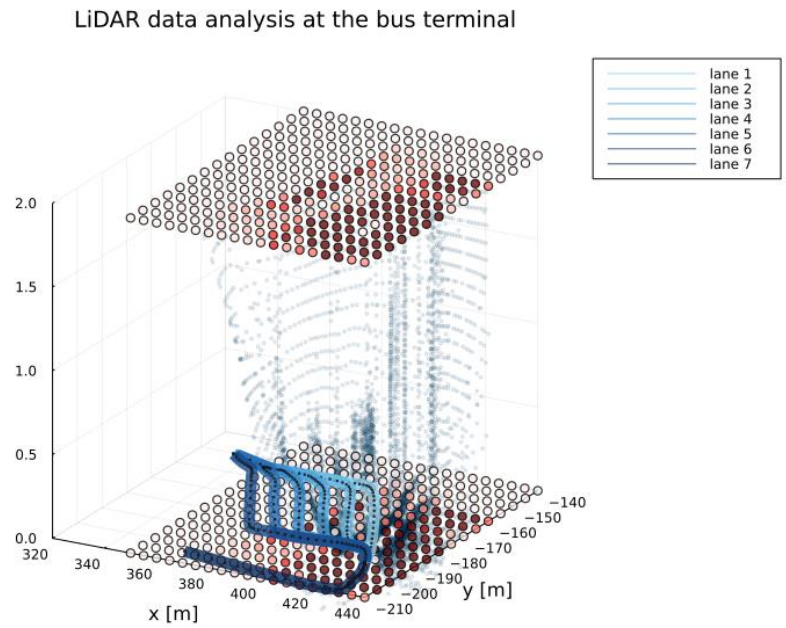


Figure 22: Point cloud (grey points) represented with two matrices.

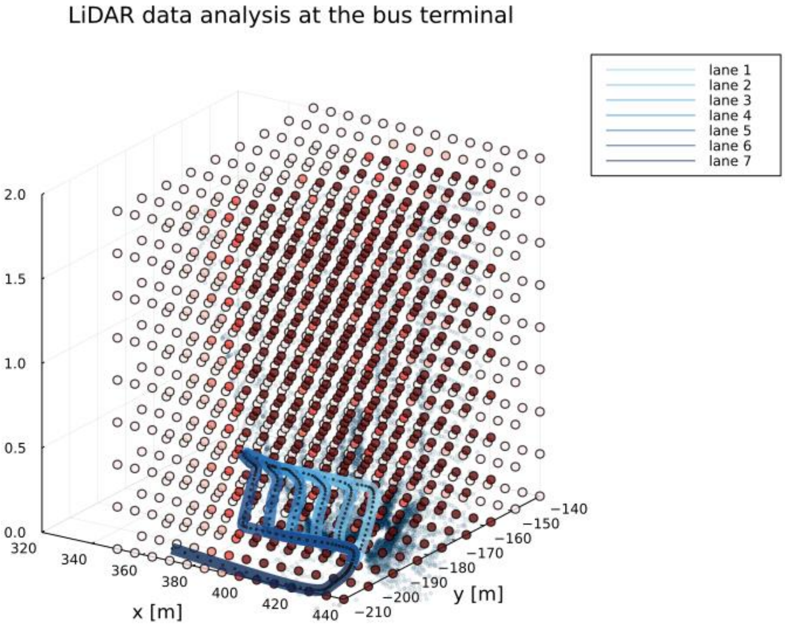


Figure 23: Point cloud (grey points) represented with dense matrices representation (9 height layers).

Figure 22 and Figure 23 show two different representations of grid representations, where the size of the grid differs a lot. In Figure 22 two matrices (layers) represent 4k LiDAR points. In the second picture Figure 23, the same data were represented by nine matrices (layers). The grid points are coded with different levels of red colours representing the density.

4.3.4 Next steps

4.3.4.1 Simulation overall progress

The statistical analysis of the rosbag files can be evaluated in the new Julia/ROS co-simulation. The import and selection of point clouds with approximation in the bus lane sequences work. Due to the complexity of finding the optimal bus lane, many research efforts are in progress. The mathematical results will be presented in a scientific publication. The research question is to find excellent and robust prediction results and an optimal policy for lane selection. The results of the statistical analysis and the invention by using the new co-simulation platform and the statistical analysis of ROS measurement data are written in detail in the submitted paper Hartmann et al., 2023 [30]. This conference is relevant for SHOW. The approach also helps researchers and practitioners with skills in statistical learning on big datasets to use new and innovative data analysis. The paper also discusses solutions by detecting incoming buses with statistical learning like Principal Component Analysis.

4.3.4.2 Simulation future plans

This section proposes predicting data with Long short-term memory (LSTMs) networks. Depending on the different representation forms and time intervals mentioned in the previous sections, we might have different prediction results. In the future, we will evaluate research prediction quality, practicality, and the inference possibilities for taking the correct route.

4.4 Karlsruhe (Scenarios 1 & 3)

4.4.1 Pilot description & progress

4.4.1.1 Pilot general description

The Karlsruhe Test Site consists of two subsites, namely the subsite “Campus-Ost” and the subsite “Weiherfeld-Dammerstock”. While the “Campus-Ost” subsite consists of a restricted area, the subsite “Weiherfeld-Dammerstock” is located in a suburb of Karlsruhe, thereby providing many challenges in real traffic like narrow streets and interaction with Vulnerable Road Users (VRUs). The “Campus-Ost” subsite is primarily used to test new Highly Automated Driving (HAD) functions before these functions are deployed in real life traffic. The test sites can be seen in Figure 24.

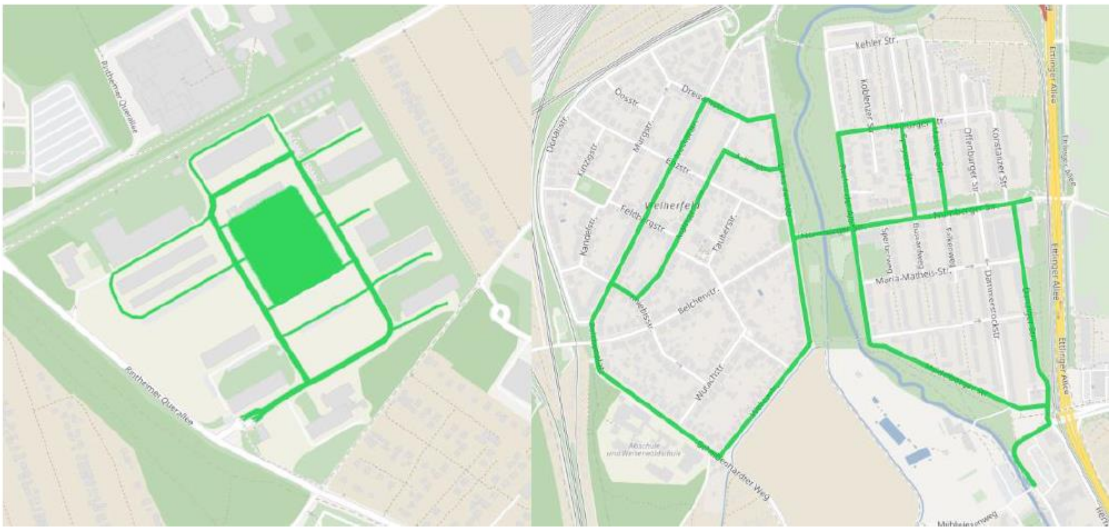


Figure 24: The Test Site Karlsruhe (Graphhopper, 2021 [25]).

4.4.1.2 Pilot pre-demo progress

The Pre-Demo Phase has successfully taken place for the Use Cases UC1.1, UC1.2 and UC1.6 between 27.01.2022 and the 15.07.2022, which is in alignment with the completion of the verification and validation process for these Use Cases. The verification and validation process has been conducted for the FZI shuttles, which are based on EasyMile Shuttles EZGen2 shuttles but with heavily modified hard- and software. These modifications allow the FZI shuttles to operate without the need of a “virtual rail”, meaning that the concrete path within the driving lane is planned during operation. This allows the FZI shuttle to navigate around obstacles and to drive through narrow streets with blocked lanes, e.g., due to parking vehicles. The FZI shuttle can be seen in Figure 25, the results of the verification and validation process can be found in D11.2.

Figure 25: The FZI shuttles.

4.4.1.3 Simulation pre-demo progress

Former work and the results of D10.2 have been combined for the simulation of selected parts of the verification and validation process; thereby serving as a preparation for the Pre-Demo Phase. The validation process covers various safety critical scenarios, which shall ensure a safe operation of the AVs during the Pre-Demo and Demo Phase. The main purpose of the work provided here has been to identify and simulate scenarios of the validation process, as defined in D11.2, that are either

- especially safety-critical during the operation; or
- hard to measure in an accurate way during real life operation.

Since the localization system of an AV plays a crucial role in terms of safe operation, additional scenarios have been tested in simulation. The goal of this work is to ensure the functionality of the probabilistic diagnosis system as defined in D7.4. The diagnosis system is used to warn safety operators about potential malfunctions regarding the localization system.

4.4.2 Simulation specifications

4.4.2.1 Simulation parameters

The simulation heavily depends on the specific scenarios, which describe the path of simulated VRUs as well as the start and target point of the AV, annotated speed limits and errors in the localization system. Furthermore, the specific planning software version of the AV influences the outcome of the simulation, e.g., due to a more aggressive or more comfort orientated set up of the controlling software.

4.4.2.2 Simulation network

The simulation network are the digital twins of the subsite “Weiherfeld-Dammerstock” and Campus Ost”. The street network can be seen in Figure 24.

4.4.2.3 Simulation scenarios

Regarding the verification and validation process this work focuses on the Test Cases “STS02 - Dynamic and static objects detection”, and “PTS04 – Speed adaption” as defined in D11.1. Each Test Case is defined by a sequence of Actions that have to be verified. All Actions have been verified in real world scenarios, but it turned out, that some actions are more traceable in a controlled environment, e.g., provided by simulation. In order to test the AV's diagnosis system small positioning errors have artificially been induced into recordings of real automated drives in such a way, that the shuttle slowly drifts away from the lane centerline, thereby simulating a critical error in the localization system.

4.4.2.3.1 Simulation of STS02

Table 8 shows the formal Definition of STS02. Since the simulation of Step 4 is only informative for this Use Case if the sensors and the environment of the AV are perfectly modelled, the FZI decided to focus on step 5.

Table 8: Formal Definition of STS02.

Step	Type	Description
0	Action	Ensure that there are no obstacles around the route, including intersections with incoming traffic, that are not part of the test.
1	Action	Ensure that there are no static and dynamic obstacles that are not anticipated to be on the route.
2	Action	Attend to the vegetation maintenance on the side road and cleaning of the road.
3	Action	Ensure that all the parked cars are correctly parked and have pre-defined parking lot zones.
4	Verify	The AV is able to detect the dynamic and static objects anticipated to be on the route.
5	Verify	The AV is able to avoid collisions with obstacles that could lead to a dangerous situation.

To do so, a VRU was placed after a poorly visible corner. Figure 26 shows the scenario in CARLA and from a more abstract top down view. The start of the sequence can be seen on the right. The AV starts to accelerate and drives through the corner. At the same time the VRU starts to walk over the street in such a way that would cause a collision if the AV does not slow down. The AV's path planning utilizes a HD-Map and the same HAD software that is used during the Demo Phases. The presence of the obstacle is provided via ROS to the planning software of the AV.

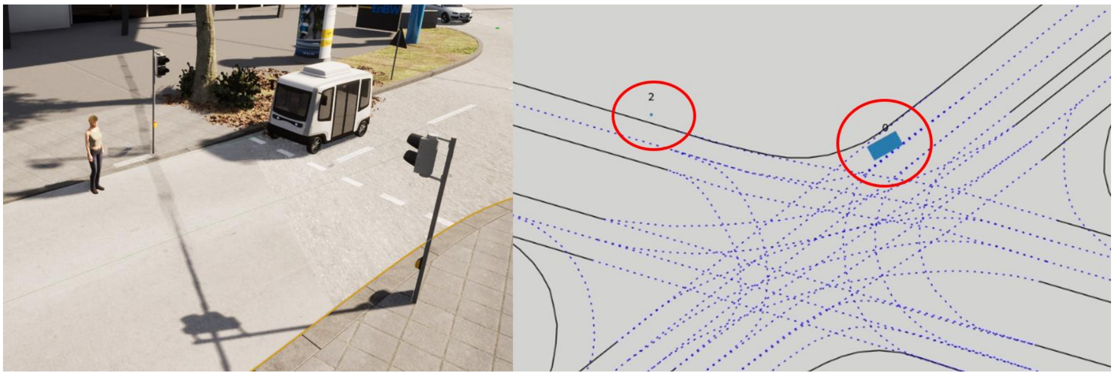


Figure 26: Carla model of STS02.

4.4.2.3.2 Simulation of PTS04

Table 9 shows the formal Definition of PTS04. The crucial Action is Step 3. Therefore, a defined speed has been annotated into the HD-Map of the subsite "Weiherfeld-Dammerstock", which is used during simulation as well as during the Demo-Phase. During the simulation the AV changes from a section with no annotated speed limit into a section with annotated speed limit. The main goal of this simulation is to verify that the correct speed limit is recognized and reached in an appropriate way without the occurrence of critical side effects e.g., due to the characteristic of the control software.

Table 9: Formal Definition of PTS04.

Step	Type	Description
0	Verify	Verify with the FAV's OEM, integrator, or constructor which technology is chosen for speed adaptation: - Predefined speed zone in path And / or - Adaptive Cruise Control and traffic sign reading - Other…
1	Verify	If in the pre-defined speed zone in path, verify that the information is shared with the site authorities during the mapping of the site according to the risk analysis that is done by OEMs (items considered: ODD, traffic density, visibility, localization, etc.).
2	Verify	Verify that the vehicle can adapt its speed depending on the environment conditions on specific sections on the path, (the ACC shall be tested apart from this requirement).
3	Action	This will be checked during the deployment on site.

4.4.2.3.3 Simulation of a malfunctioning Localization System

As reported in D7.4 and in (Stefan Orf, 2022 [26]) the FZI introduced probabilistic diagnosis system for AVs, which relies on parametric modelling of random variables, that describe the performance of the localization system. An especially safety-related random variable is the "smallest distance to the nearest centreline". To model this, various test drives have been conducted in the subsite CO. Figure 27 shows a visualization of the training trajectories, as well as the SLAM map and a grid map representing the number of data points per grid cell.

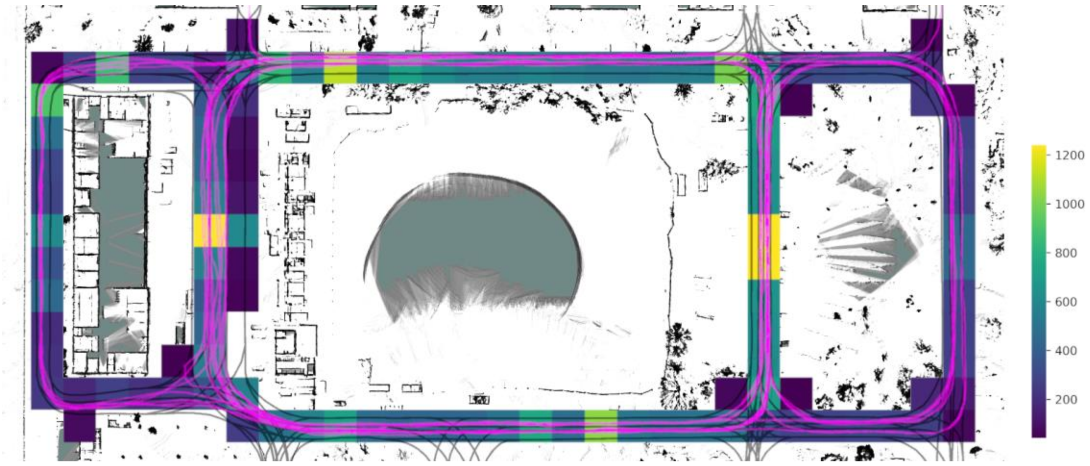


Figure 27: Training data aggregated in the subsite Campus-Ost.

For each cell a predefined set of parametric distributions has been fitted, and the parameters of the best suited distributions have been stored. During operation, the "smallest distance to nearest centerline" is computed with live data. The outcome of this computation is then compared to the probability of such a value given the learned distribution parameters. Since a malfunctioning localization system is hard to test in real life operation recorded data was manipulated in such a way, that ROS messages that describe the current position of the AV have been manipulated with a linear increasing offset. A similar approach was taken for the random variable "timing discrepancy", which describes the time difference between consecutive localization updates. In this case, recorded ROS messages were replayed during the simulation with varying speed for short amounts of time.

4.4.2.4 Pre-demo data used

The utilized data was part of the verification and validation process, not the pre-demo.

4.4.3 Simulation results

4.4.3.1 Simulation of STS02

Figure 28 shows the velocity of the AV during a run of the STS02 simulation. The AV accelerates to a maximum speed of about 4.25 m/s before decelerating due the upcoming turn. After reaching the middle of the turn, the AV starts to accelerate again until the VRU is detected, which results in deceleration. Although the deceleration starts very early the AV does not reach a standstill but continues to drive slowly towards the obstacle. Once the VRU has left the area in front of the AV, the AV starts accelerating again. The smoothed character of the curve is heavily influenced by the AVs controlling software, which can be seen in the continuously decreasing braking acceleration and the noisy velocity signal during low speed. Although the AV's behavior is heavily influenced by the controlling software, the AV's behavior is in line with the requirements of D11.1. Nevertheless, this test should be repeated for every software update that influences the controlling software.

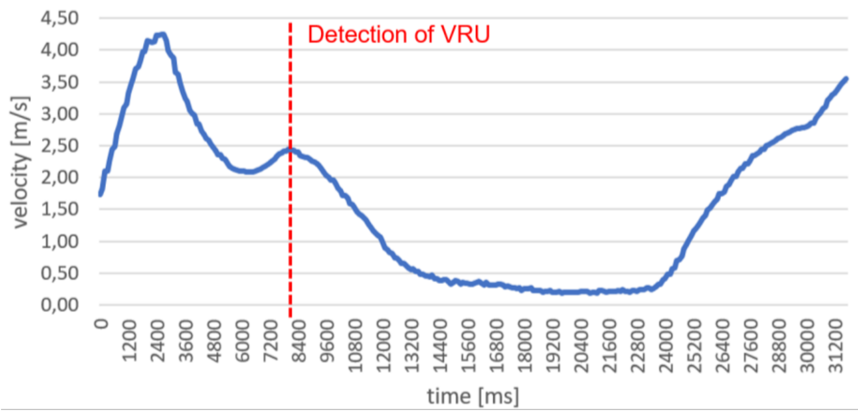


Figure 28: The AV's speed during the simulation of STS02.

4.4.3.2 Simulation of PTS04

Figure 29 shows the velocity of the AV during the simulation of PTS04. Similar to the simulation of STS02, the AV accelerates to its maximum speed followed by a phase deceleration due to an upcoming corner. After reaching the midpoint of the corner the shuttle starts to accelerate again until the speed restricted area is reached. The following deceleration phase follows an undulating form, which is also due to the character of the controlling software. It is worth noting that this behaviour leads to velocities that exceed the speed limit of 2 m/s. Although this speed excess is negligible, it shows that the controlling software plays a major factor in the safety of an automated vehicle at that updates regarding this software should be carefully tested.

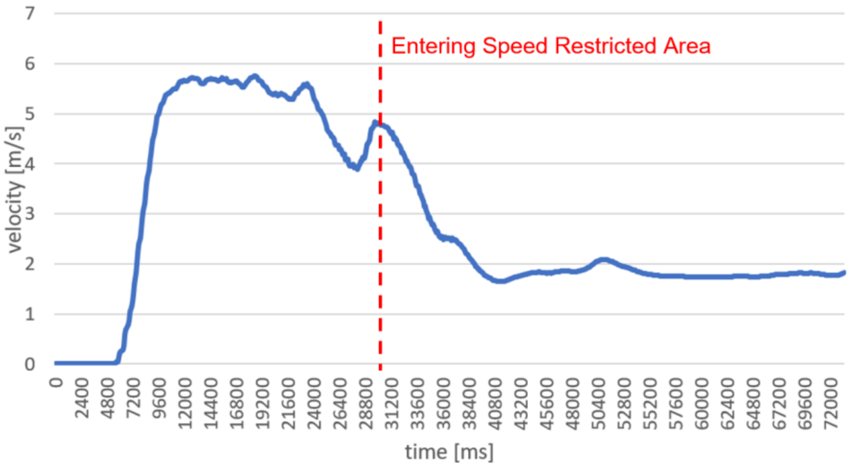


Figure 29: The AV's speed during the simulation of PTS04.

4.4.3.3 Simulation of a malfunctioning Localization System

Figure 30 shows the probabilities for each possible position within the displayed map section as well as a record of an error free trajectory and a simulated erroneous trajectory, leading to the AV leaving the lane. The displayed map is created by the computation of the distance to nearest centerline for every pixel, which is then used as an input for the probability computation given the fitted distributions parameters. Since the AV only has one pose for each timestep, the computation in the diagnosis system gets much more lightweight. Details for this computation can be found in (Stefan Orf, 2022 [26]). One can clearly see, that the probabilities for localization positions outside of the lane are extremely low. Even Poses near the border can be detected as erroneous, depending on the probability threshold of the diagnosis system. An advantage of this method over strictly forbidding the AV to leave its lane, is that the method allows different margins for different sections of the map.

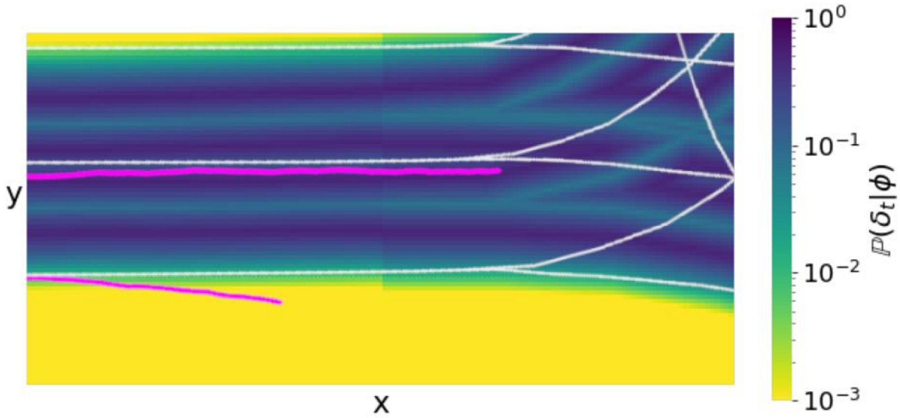


Figure 30: Heatmap representing the probabilities for the distance to closets lane centerline (Stefan Orf, 2022 [26]).

The upper half of Figure 31 shows a record of typical time differences between consecutive localization systems, which was modified in such a way, that for a short amount of time the corresponding ROS messages were replayed faster or slower than normally, thereby simulating a malfunction regarding the update rate of the localization algorithms. The lower half of Figure 31 shows the corresponding probabilities for the measurements above. One can clearly see, that the erroneous measurements corresponds with low probabilities, which leads to warnings from the diagnosis system.

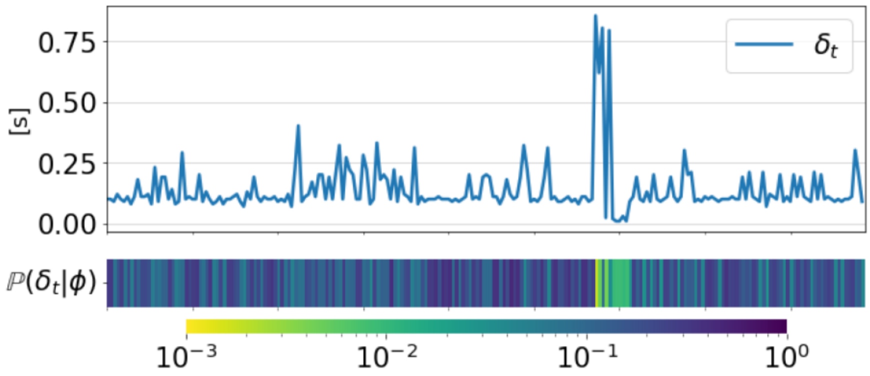


Figure 31: Time different between consecutive measurements and their corresponding probabilities (Stefan Orf, 2022 [26]).

4.4.4 Next steps

4.4.4.1 Simulation overall progress

Based on the Simulation tools identified in D10.1 a suitable subset was selected and used for street level simulation of AVs and other traffic participants in D10.2. The results of D10.2 as well as work from other projects was used in D10.3 to verify safety critical HAD functions including street level and VRU simulation.

4.4.4.2 Simulation future plans

Since the implementation of “UC1.7: Connection to Operation Centre for tele-operation and remote supervision" will be V2X-based, future simulation plans will cope with modelling RoadSide Units and their range limitations. The simulated V2X messages e.g., CAM and CPM, will be passed to the driving stack.

4.5 Klagenfurt – Carinthia (Scenario 1)

4.5.1 Pilot description & progress

Within the area of Seaside Park, Europapark and Alpen-Adria university located at the western border of the City of Klagenfurt (Carinthia) a shuttle service operated by SURAAA with three Navya Shuttle will be established. The pilot will operate three lines with three shuttles in total. The simulations goal is to pre-identify the impacts on common road traffic within the planned shuttle routes. The results show that the automated shuttles have no significant impact on regular traffic. Hence, no improvements of the routes and the physical environment need to be taken to accommodate the automated shuttles.

4.5.2 Simulation specifications

The simulation is utilized with the open-source traffic simulator SUMO. On top of the simulator, a demand generation algorithm, based on the common four-step- demand generation model is placed. This model is used to provide realistic, demographic data-based movements within the transportation network.

As foundation, traffic assignment zones (TAZ), as shown in Figure 32 are used to match official demographic datasets for calculations within the four-step model and connect demand to the microscopic simulation network.

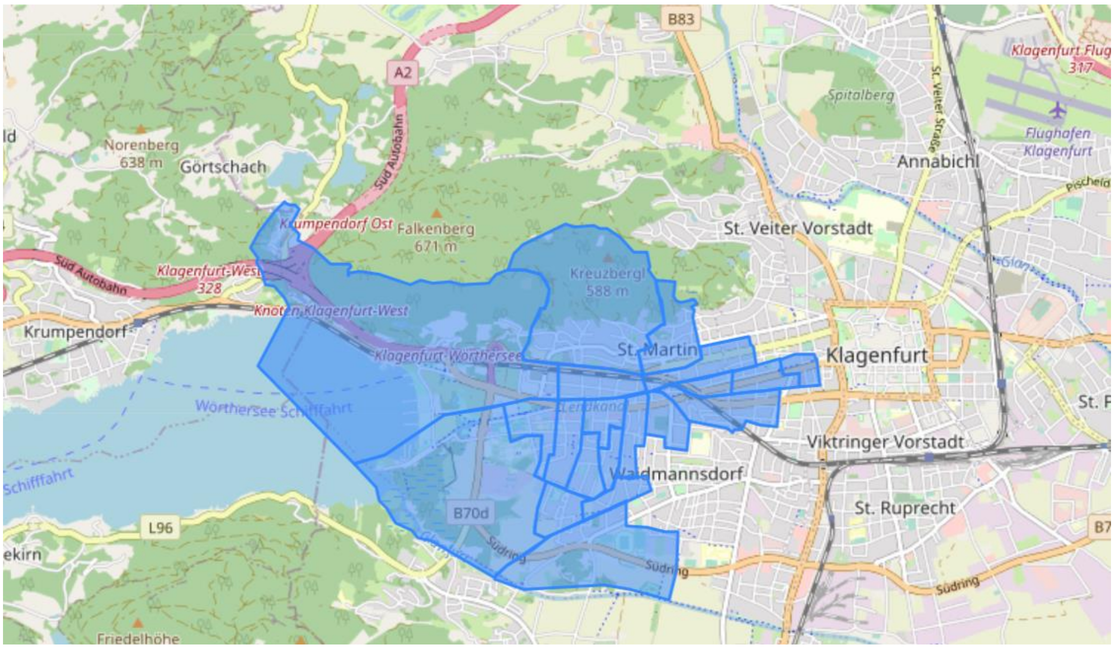


Figure 32: Traffic Assignment Zones (TAZ) Klagenfurt.

The four step model relates not only on demographic data, but also on data of land use coverage. In this model specific demand generation values for each demand generating entity are used, that can be found in each TAZ. With this approach each TAZ generates a specific amount of demand. To define certain demand streams between TAZ, a skim matrix based approach is used to identify boundaries between TAZ in terms of travel distance and travel time. Figure 33 shows the generation of these skim matrices based on routing between five points in each TAZ to all other TAZ.

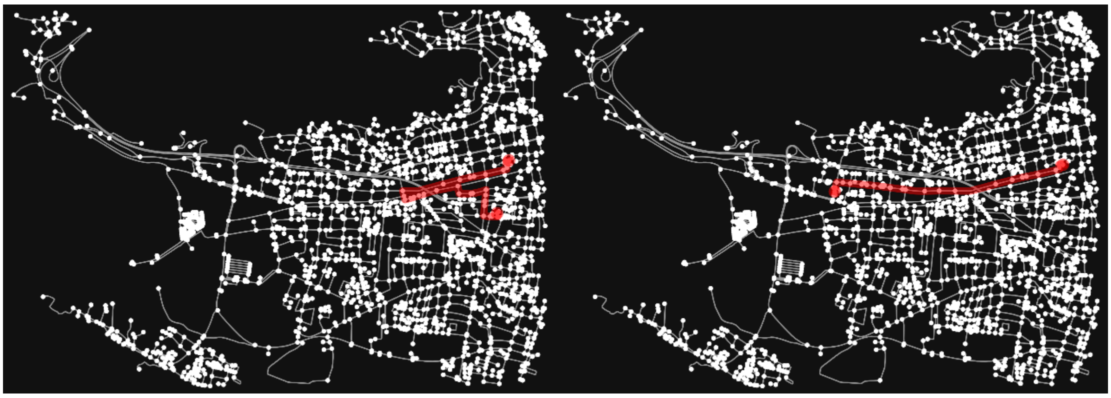


Figure 33: Routing approach for estimation of skim matrices.

The final step is to generate a transport mode specific matrix for each TAZ-relation and based on the routing results. With this demand TAZ-relations are routed within the microscopic simulation.

4.5.2.1 Simulation network

AIT generated a mesoscopic approach with the mesoscopic package implemented in SUMO for laying a foundation in terms of traffic assignments towards large-to-small modelling tools. With this package, a complete microscopic network including person plans could be generated in a single step. After execution, the following network was available.

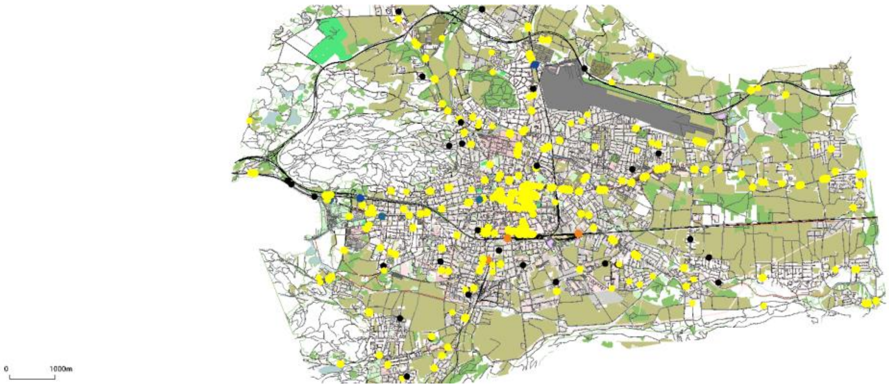


Figure 34: Mesoscopic SUMO network for Klagenfurt (yellow taxis, orange PT).

A mesoscopic simulation sized as shown above is not feasible for a detailed pilot-study, as the impacts are locally expectable, and a more practicable computing time was also a target. The network itself was resized to provide a simulation interface to all planned routes within the pilot at Klagenfurt, as show in Figure 35.

Figure 35: Detailed simulation network SUMO.

The shuttle itself was implemented as already used within two projects, namely auto.bus seestadt and Drive2theFuture, where AIT contributed microscopic simulations and pilot support to the overall project results. No ODD-breakdown is simulated, the setup of the shuttle(s) were not altered during each simulation run and were not changed throughout each scenario.

Table 10: Navya shuttle SUMO vehicle model values Klagenfurt pilot.

Shuttle name	Max. speed [m/s]	sigma	Tau	acceleration [m/s]	deceleration [m/s]	Actionstep length [s]	vClass	carFollowModel
"Navya_neu"	13.8	0.6	1.0	1.2	5	0.1	evehicle	ACC

4.5.2.2 Simulation scenarios

The simulation consists of five scenarios in total, as shown in the list below. The shuttle is operated with a scheduled cycle time accordingly to the length of the route. The main advantage of this approach is that the vehicle is kept in the simulation, so delays are simulated in a better and more precise way. Using a standard public transport vehicle operated under a schedule means, that the used shuttle would be terminated at the end of its scheduled journey along each planned route and a new shuttle will be placed on the starting point of the route within the next scheduled round-trip. Statistics covering complete operational phases, such as overall-travel time or overall-stops, are not possible.

Scenario B – Baseline Scenario

This scenario specifies the baseline situation with demand generated from 2019 demographic data and calibrated with traffic count data acquired from macroscopic transport models and counting data from traffic light signals. Also the baseline public transport service is integrated and used in the simulation.

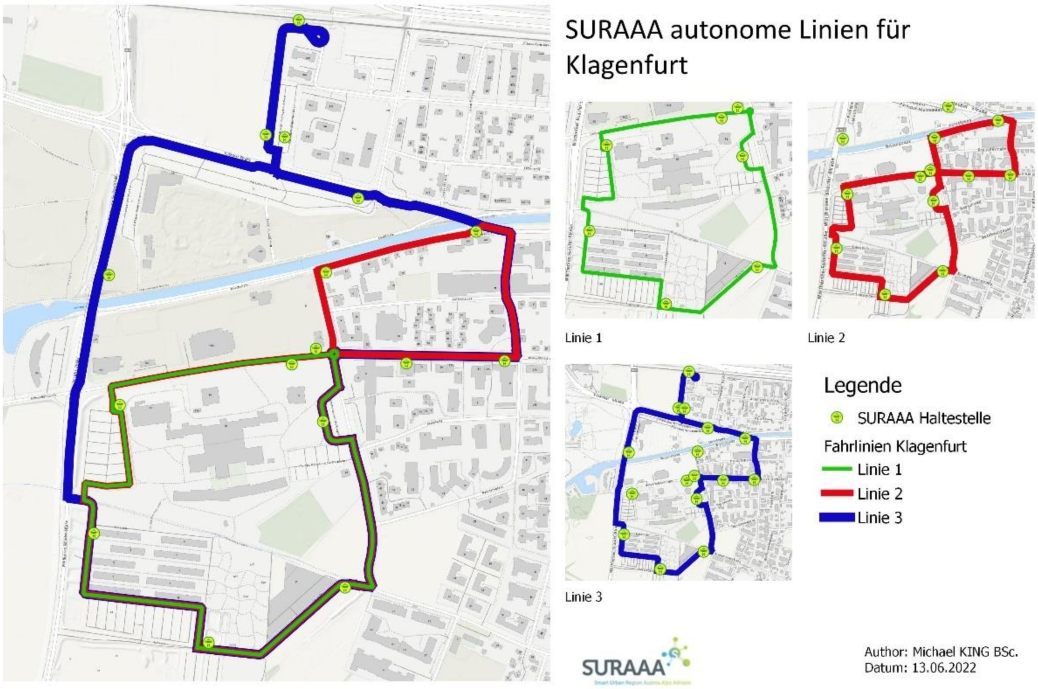


Figure 36: Three lines of Klagenfurt pilot (source: SURAAA).

Scenario 1 – Baseline Scenario + Route 1 SURAAA

Describes the simulation of the route in light green, shown in Figure 36, connecting the university of Klagenfurt (AAU) with parking lots in the south-western part of the demo area. This route is 4000 meters long and consists of seven stops in total.

Scenario 2 – Baseline Scenario + Route 2 SURAAA

The baseline traffic is added to the simulation of route 2, shown in red. This route, eight-shaped, connects bus lines on the main road between the train station and the demo area. Within this route, also route 2 is embedded.

Scenario 3 – Baseline Scenario + Route 3 SURAAA

Within R3, the train station near Minimundus, a well-known touristic venue, is equipped with automated shuttle transport, additionally to the local public transport service. This route shares parts with both other routes, but is more planned as an outer ring-route to connect each bus- and train-service feeding the demo area.

Scenario 4– Baseline Scenario + Route1 + Route 2 + Route 3

This simulation approach allows to identify impacts if all three routes are operated at the same time during a normal workday.

4.5.2.3 Pre-demo data used

The main input to the baseline scenario was an openstreetmap file for the region Klagenfurt City including the next motorway nodes. The openstreetmap file was put into the SUMO Activity Gen (SAG) [27], a tool for automated activity-based scenario generation based on demographic statistic files and openstreetmap-data only. The generated network was broken down to the detailed network as shown in the chapter above. With this network, a more precise view was created by adding the following data sets offered by Land Kärnten and the pilot operator SURAAA:

- GTFS data by ARGE ÖÖV for baseline public transport coverage within the area of interest
- Traffic Signal programs for each of the four traffic lights in the area of pilot operations
- New traffic light added to the pilot routes for safe crossing of the main road connecting the motorway with Klagenfurt and the south-eastern area of Wörthersee
- Pilot routes by SURAAA
- Pilot specification taken from Navya-shuttle operations conducted at seestadt-aspern (projects auto.bus and Drive2TheFuture, both with AIT contributions) and adapted to new settings within Klagenfurt pilot.

With this data a baseline scenario was generated, the pilot routes were added as provided by SURAAA to scenarios one to four.

4.5.3 Simulation results

Overall, the simulations show that there is no significant influence of the automated shuttles on all routes on the overall traffic performance. This is the result of the setting with only one shuttle in peak-load environments on a two lane infrastructure and up to three shuttle on single lane infrastructure in low-traffic environment. As a result there is always ample chance to overtake the slow automated shuttles.

Results in Figure 37 show that there is very limited reactions on the shuttles. While the graph of the overall network travel times seems to show large differences, the actual travel time changes by only about 100 minutes which is about 0,12%. The travel times actually decrease very slightly which might be because the automated shuttles are overtaken with slightly higher speeds on the four lane roads, as shown in Figure 37 below.

Overall, the pre-demo simulations show that no actions are necessary to ensure traffic flow on the shuttle routes. However, the simulation shows a steady-state, where road users react to shuttle traffic like they would to common vehicles. In the initial phase of pilot operations (2-4 weeks from first use) there might be reactions of road users to the new mode of transport, attracting attention, e.g., the shuttle might be an eye catcher and an attraction leading to a slight slowdown in traffic in the vicinity of the shuttle.

Figure 37: Results of the SUMO simulations for the different scenario with overall network travel times in blue, average speeds in orange and average time loss in green.

It must be stated, that all situations, the shuttle operates in parts of the cities road network with higher traffic loads based on the function of the network (connecting industrial and retail areas) two lanes are available. Overtaking is possible and within the inner area of lakeside park small congestions occur that are dissolving within minutes.

As the simulation is not able to provide road traffic behaviour within changed traffic situations based on new and improved technology through onlookers, road traffic participants testing the autonomous functions of the shuttle, there might be diverging results during the first weeks of operation. With ongoing operation and habituation effects the traffic situation should be normalized again.

4.5.4 Next steps

4.5.4.1 Simulation overall progress

All scenarios were simulated with 12 simulation runs each, resulting in a total of 70 simulation runs. The main goal of all simulation work carried out within this work package is to generate knowledge about the impact of all possible routes operated within the Klagenfurt pilot on everyday road traffic. For this, analysed KPIs are as follows:

- Average Travel times of both network traffic and shuttles
- Average Speeds of both network traffic and shuttles
- Average Time Loss of both network traffic and shuttles

4.5.4.2 Simulation future plans

Once the shuttle operation has started, real data from the shuttle will be used to better calibrate the shuttle variables and compare output to real live scenarios. In addition, VRU will be included in the simulation to check if they will influence the performance of the shuttle. In addition, the pilot shuttles are modelled with an attached battery model by using SUMO-internal battery-device [28] implemented by TU Braunschweig and available within the SUMO simulator package. With this model, battery consumption will be simulated, nevertheless also recharging during non-operation hours. This can be compared to real data from the Klagenfurt site to improve models for future use.

4.6 Linköping (Scenarios 1 & 3)

4.6.1 Pilot description & progress

4.6.1.1 Pilot general description

The test site Linköping has extended its AS service from the campus to the neighboring residential area named Vallastaden as planned since the middle of 2022. The main purpose for the extension is to improve the elderly's and children's travel qualities, accessibility and experiences. Apart from the 8 stops on the campus, there are now totally 12 stops on the whole AS route (around 4 km long), illustrated in Figure 38. Currently, 3 AS, one Navya DL4 and 2 EasyMile EZ10 Gen2, are in operation and the maximum speed remains 13 km/h due to the legal regulation, while the general road speed limit varies between 30-40 km/h. In addition, a local dashboard, based on the SAFE platform, that is developed by the Saab Group, is continuously under implementation to support the preparation toward vehicle remote monitoring and tele-operation, executed by a traffic management center (TMC). The orders issued by TMC will be carried out by safety operator onboard.

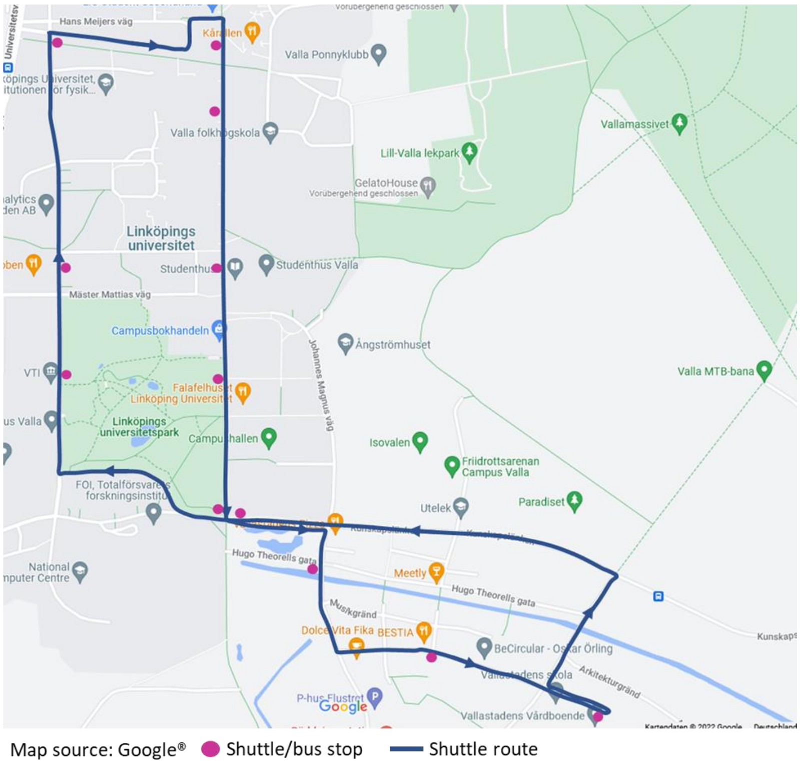


Figure 38: The complete AS route and the stops at the test site Linköping.

4.6.1.2 Pilot pre-demo progress

The pre-demo successfully took place in November and December 2021, and the AS has run around 1800 km in total and carried around 400 passengers (only during the pre-demo phase). Several lessons were learned regarding e.g. weather conditions, road works and onboard working conditions for the safety drivers. For instance, problems with hard braking occurred due to external conditions, e.g. snow and leaves, which influence the degree of friction between AS and road pavement. More pre-demo results are documented in D11.3: Pre-Demo evaluation activities.

4.6.1.3 Simulation pre-demo progress

The simulation scope in this progress is to adjust, improve and extend the established simulation environment and the applied models in D10.2 due to the changes in the real pilot activities and the 2nd demonstration phase in the residential area. The AS route covers both normal roads and a shared space, where bikes share the bike path with AS and pedestrians may cross the bike path from time to time, if necessary. The major task of the work was to improve the representation of shared spaces within the simulation, with a focus on the interaction of autonomous vehicles with VRU. For this purpose, the used microscopic traffic flow simulation SUMO was extended by the representation of road sections that may be used in both directions (bi-directional edges) and methods for representing the interaction between vehicles, pedestrians and bicyclists.

Furthermore, to enhance the simulation modeling and the parameter setting, two Telraam devices were installed at the main road and in the shared space in the period between the 22nd of September to the middle of December 2021 for collecting traffic flow and speed data respectively. Moreover, a Viscando OTUS3D video camera system was installed at the place where the Telraam device located, in the shared space from the 20th of September to the 26th of September for capturing the interactions between AS, bicycles, and pedestrians. Since all devices use cameras to detect/count objects, measurement errors are expected due to weather conditions, situations where objects are hidden by AS, and wrong classification, e.g. due to two objects being close to each other. Nevertheless, this data can help to find out the peak hour, the rough amount of the involved traffic participants and potential critical conflicts/issues. The locations of the deployed devices are indicated Figure 39.

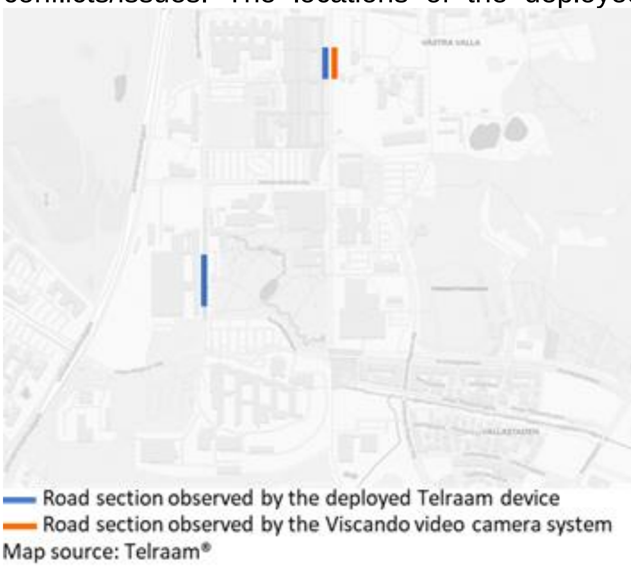
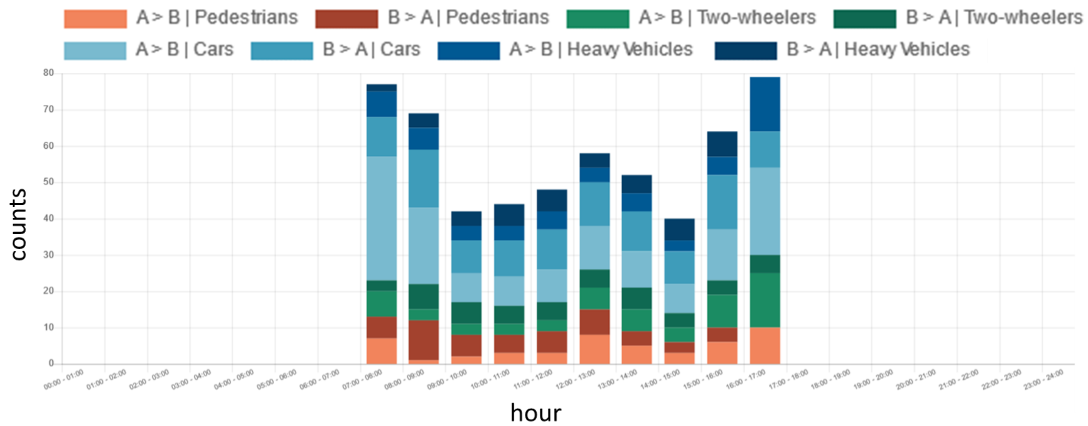


Figure 39: Locations of the deployed sensors at the test site Linköping.

- Olaus Magnus väg (normal road)

Figure 40 illustrates the hourly flow averages per road user and per direction. There was more traffic between 7-9 and 15-17 o'clock. No traffic appeared before 07:00 and after 17:00 which is mainly due to campus character and the COVID-19 situation. The maximum number of road users was around 80 per hour. The peak period was between 16:00 and 17:00.

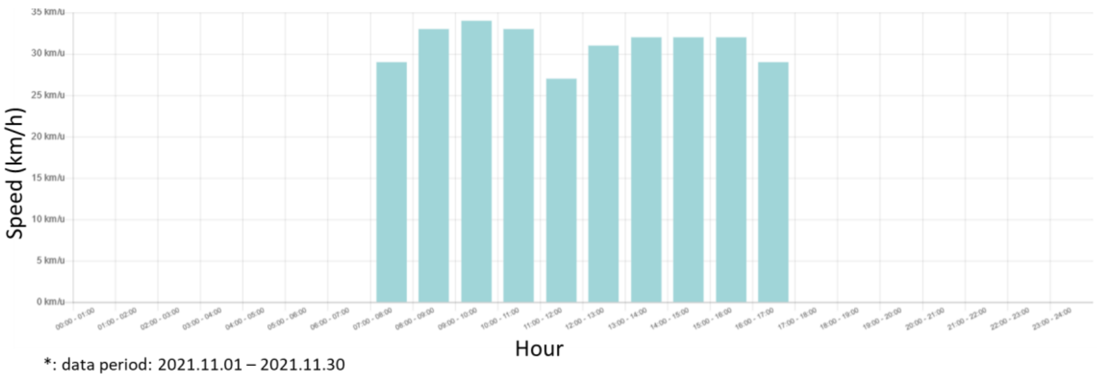


*: A > B: northbound; B < A: southbound; heavy vehicles were mainly buses; data period: 2021.11.01 – 2021.11.30
Source: Telraam

Figure 40: Hourly flow averages at the data collection location on Olaus Magnus väg.

Regarding car speed, the 85th percentile speed (V85), i.e. the speed that 85% of drivers do not exceed, and 15% of drivers exceed, is used to give an indication of the typical driving speed.

Figure 41 shows that there was no speed data before 07:00 and after 17:00, which corresponds to the traffic flow data. During the daytime, hourly V85 was around the road maximum speed, 30 km/h, and the speed deviation was about 10%.

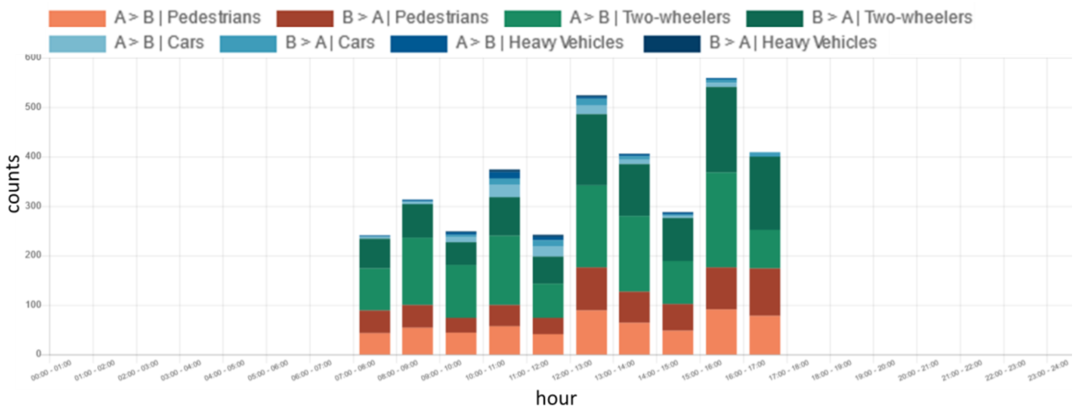


*: data period: 2021.11.01 – 2021.11.30
Source: Telraam

Figure 41: Hourly 85th percentile speed average (V85) of passenger cars.

- Campus Valla (shared space)

Figure 42 shows that the main road users are pedestrians and bicycles as expected. The peak period was between 15:00 and 16:00 and the maximum number of road users were around 550 per hour. It has to be noted that road users in this area can move in all directions, i.e. not only northbound or southbound, and AS's running speed is sometimes similar to bike's running speed, while they share the bike path together. So, larger measurement error is expected here. But the total amount of road participants and the time series pattern can still be considered as reference for simulation parameter setting.

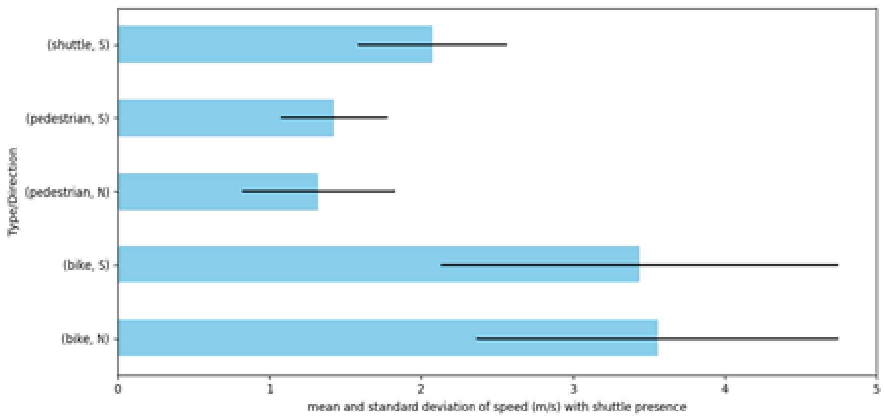


*: A > B: northbound; B < A: southbound; data period: 2021.11.01 – 2021.11.30
Source: Telraam

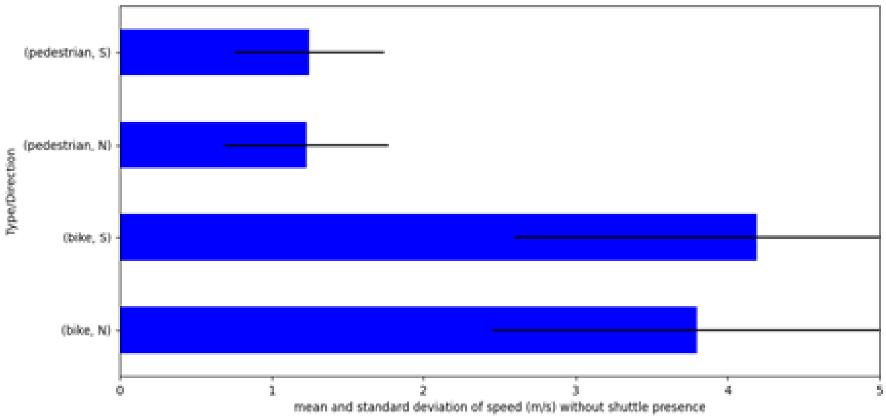
Figure 42: Hourly flow averages at the data collection location on Campus Valla.

Furthermore, road users' speeds and accelerations were analysed with use of the data from the Viscando OTUS3D video camera system. According to Figure 43 the mean speed of AS was around 8 km/h and there was a small tendency for pedestrians to walk slightly faster when the shuttle was present. It could potentially mean that pedestrians got a sense of urgency when the shuttle was present and therefore walked slightly faster. Moreover, there were substantially fewer crossings while the shuttle was present. Thus, another possible reason could be that speeds during straight walking are faster than those during crossing. Deeper investigations would be needed for finding out the reason. In addition, bikes tended to slow down in both directions when the shuttles were present. However, such slow-down with larger standard deviation is not statistically significant according to the t-test result with a significance level of 0.05.

Figure 44 shows the speed and acceleration distribution of the objects in the shared space. AS's and pedestrians' speed-acceleration distributions overlapped with each other greatly. AS's running speed was less than 10 km/h and the acceleration was mostly between -1 and 1 m/s2, fulfilled the comfort riding requirement. Bicycles had higher running speed than AS and their acceleration was also between -1 and 1 m/s2 in both directions.



(a) with shuttle presence



(b) without shuttle presence

Figure 43: Mean speed and standard deviation of the objects in the shared space at the test site Linköping.

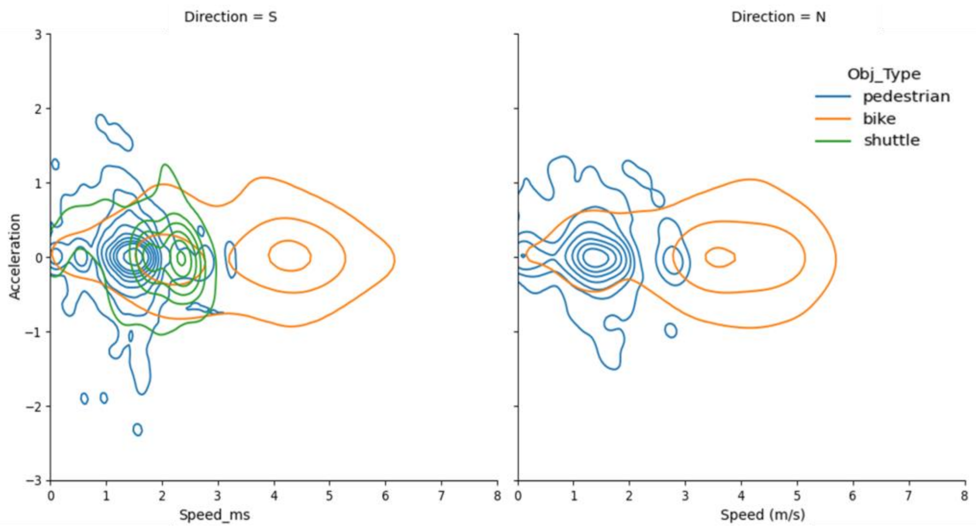
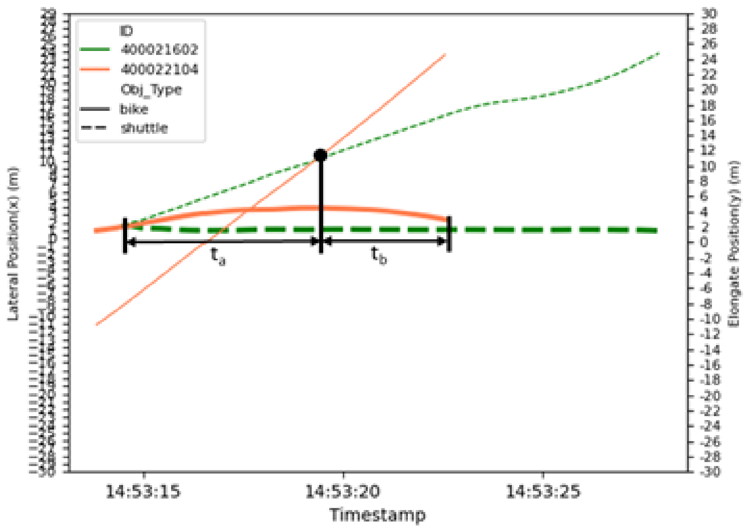


Figure 44: Speed-acceleration distribution of the objects in the shared space at the test site Linköping.

- Interactions between AS, bicycles and pedestrians

From video data it is not possible to observe the road users' intentions or reasons for their actions and the respective times spent. Thus, interactions between objects and shuttles cannot be completely observed from extracted trajectory data, and only the manoeuvres resulting from cyclists/pedestrians intending to take. Accordingly, only the corresponding action points, not decision points, can be discovered. Some interactive manoeuvres, compatible with yielding, following, and overtaking, were observed according to the respective time-space diagrams. A corresponding example is shown in Figure 45 where the duration for overtaking ta + tb can be derived from the trajectory data. However, such behaviours appeared quite rarely and uncritically in the study area during the whole data collection period. Most of them were between bikes and shuttles, since pedestrians mainly used sidewalks, that can be observed in Figure 46 and the result in Table 11. The derived durations for overtaking and conflict avoiding are not representative mainly due to the rare appearance of the corresponding behaviours. More analysis results can be found in [12] and [18].



*: fat dash line: shuttle's x positions; thin dash line: shuttle's y positions; fat solid line: bike's x positions; thin solid line: bike's y positions; ; t_a time from overtaking start to side-by-side; t_a time from side-by-side to end of overtaking.

Figure 45: Time-space diagram of an exemplary object with overtaking manoeuvre.

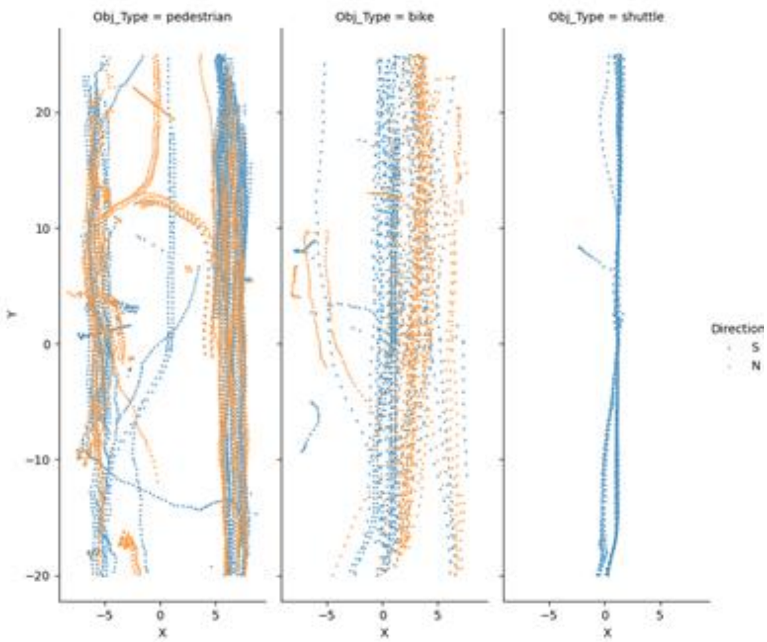


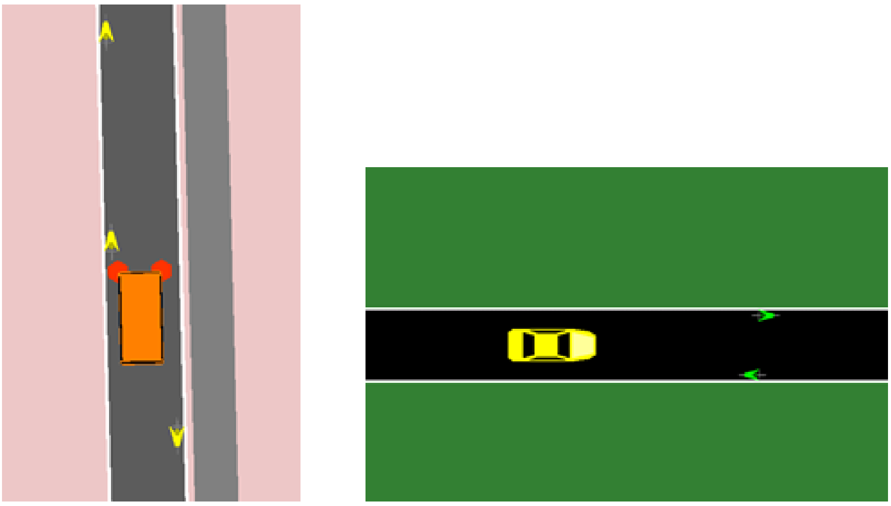
Figure 46: Object trajectories when shuttle was present.

Table 11: Changes in space usage with and without shuttle presence.

X position (m)	Type	With shuttle presence	Without shuttle presence
-2 <= x <= 2 (with in bike path)	AS	99.5%	-
	pedestrian	5.3%	7.2%
	bike	47.0%	68.2%

The simulation network is based on OpenStreetMap, where pedestrian paths are separated from the bi-directional shared corridor. According to the data analysis result, the interactions between pedestrians and AS and between pedestrians and cyclists within this corridor were quite limited. Therefore, the focus will be put on the interactions between cyclists and AS, and no further network structure adjustment in the shared corridor was made. The derived parameters, related to speed and acceleration, and the revealed phenomenon, i.e., less overtaking and conflict-avoiding situations, are used for improving the parameter setting.

In addition, the model enhancement work in SUMO has been also continuously carried out with the main focus on more logical overtaking behavior, made by bikes, and road users' interactions in shared space. Road users in a shared space interact with each other when they are approaching each other also when they are in opposite direction. Such situation is normally not considered in traffic simulation, which commonly only consider one directional roads/traffic, i.e., road users do not take other road users in the opposite direction into consideration. In order to simulate such interactions, the concept of bi-directional edges in SUMO, used for railway simulation, was adopted and extended, so that simulated pedestrians, vehicles and bicycles on bidi-edges can interact with each other in both directions. Bidi-edge is modelled by two edges that have their geometries exactly reversed so that lane geometries are overlaid exactly. Objects on such edges can, if necessary, adapt their behaviours when they approach each other. An example is illustrated in Figure 47. The resultant model enhancement and extension can bring the simulation work much closer to the real situation and benefit the evaluation work in WP13.



(a) (b)

Figure 47: Illustration of exemplary situations where objects meet in the shared space with use of bidi-edges in SUMO.

4.6.2 Simulation specifications

According to the aforementioned data analysis result it is foreseen that critical situations caused by AS would possibly occur between bicycles and AS in the shared space and between vehicles and AS on the shuttle route, especially close to parking entrances and exits. In addition, buses, which also drive on the shuttle route, will also be influenced due to AS's lower travelling speed. Accordingly, the related aspects have been considered in the simulation environment.

The simulation environment has been extended due to the change in AS route. Moreover, the information about the local public transport in OSM was considered, and the corresponding bus flows were generated with an average running period 16 minutes. The entrances and exits of some car parks are connected to the roads where the AS run. Thus, these parking lots are considered in the simulation with synthetic parking demand in order to be able to analyze possible influence, caused by the AS operation, in WP13.

4.6.2.1 Simulation parameters

According to the aforementioned data analysis result, speed deviation, maximum acceleration and deceleration and maximum speed are adjusted for passenger cars, pedestrians, bicycles and AS. The IDM-model is chosen as the car-following model for AS. The driver's imperfection is set to 0 and the minimal gap is set to 2 m. The ac- and decelerations are set to 0.45 and 0.48 m/s2 correspondingly in addition to the adjustment of the shuttle physical size. Furthermore, lane-changing is not allowed since the AS follow a pre-defined virtual rail track. Although overtaking and conflict-avoiding situations were not significantly observed in the collected data, such manoeuvres could still happen. Thus, SUMO's sublane model is continuously adopted so that overtaking or yielding behaviour could happen when one or several of the speed difference related thresholds are reached. Due to the observed low appearance of overtaking manoeuvres the parameters related to overtaking speed factor and speed gain are set to lower than the default values in SUMO. Accordingly, bikes do not actively tend to make overtaking, and could make overtaking on the right-hand side, observed in the real situation. The simulation runs with step length 0.1 second.

4.6.2.2 Simulation network

The adapted simulation network with the consideration of the extended AS route, the relevant car parks and local bus stops is shown in Figure 48. The edges in the shared space are adjusted to bidi-edges for enabling road users to interact with each other regardless of running direction. In addition, shuttle and local buses shared the bus lanes in the extension area (Vallastaden).

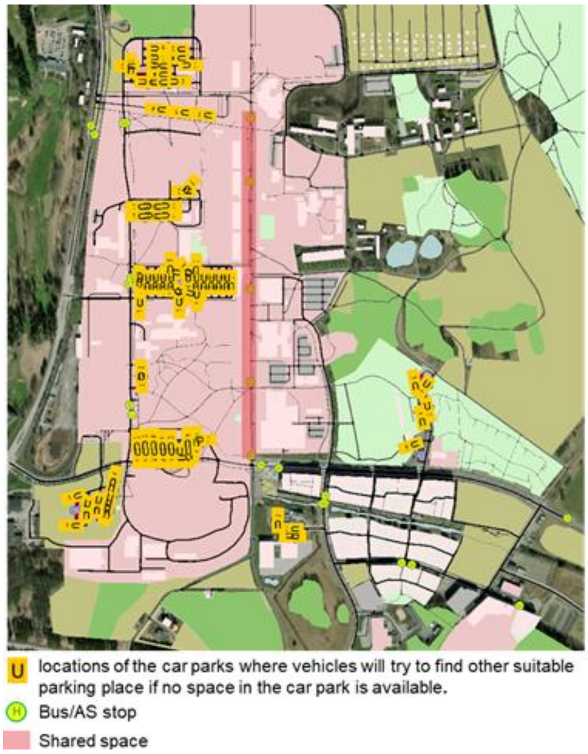


Figure 48: Layout of the extended simulation network for the test site Linköping.

4.6.2.3 Simulation scenarios

The precise research-questions oriented scenarios and the related impact assessment of the AS introduction will be developed and carried out in WP13. Therefore, the scenarios considered here are to provide an insight into the extended simulation environment and possible AS's influences on the network performance. There is a well-built walking path infrastructure, separated from the vehicular roads, at the test site and pedestrians mainly use the sidewalks in the shared space. Thus, the analysis made here is with the focus on vehicles, bicycles and local buses.

The scenarios focus on a general situation when there are vehicles leaving the parking lots. The total simulation duration is 2 hours, where the first hour is for the warming-up purpose, so that the simulation does not begin with an empty network and there are already vehicles in the parking lots. The considered demand includes 532 vehicles (96 buses, 66 cars, 381 cars leaving from parking lots), 330 pedestrians and 394 bicycles. AS runs every 20 minutes and local buses lines operate with an average period of 15 minutes.

4.6.2.4 Pre-demo data used

The vehicular trajectory, flow and video data was used for parameter setting and simulation environment improvement (see section 4.6.1.3).

4.6.3 Simulation results

Figure 49 shows different road users' travel time comparison before and after the AS operation at the whole network level. Although the given traffic demand is not high and the AS only run every twenty minutes, differences in travel time for each road user type can be revealed. The main reason for that is due to AS's low travelling speed. When bikes, buses and vehicles happen to run behind AS, the respective travel duration will then increase. More simulation runs regarding different scenarios will be carried out in WP13, resulting in further results.

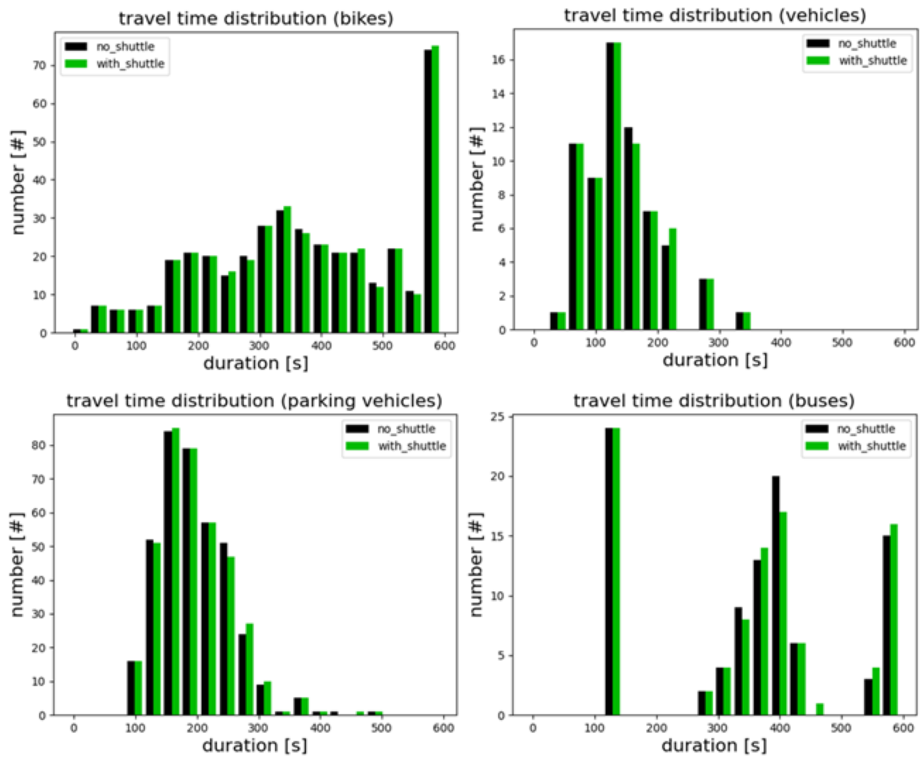


Figure 49: initial analysis of the travel time with and without AS operation at the test site Linköping.

4.6.4 Next steps

4.6.4.1 Simulation overall progress

The OSM-based simulation network for the campus area was set up with network correction in the beginning. In order to better understand how AS operate and what kind of issues they have faced, the respective trajectory data was collected and analyzed. The AS related parameters are calibrated in simulation accordingly. An initial analysis about the impact, brought by AS, in the network were carried out. Afterward, the simulation network has been extended due to the change in AS's service area. Parking traffic and local public transport are considered in the simulation as well. Moreover, the models especially regard to bicycle overtaking and the interaction between bicycle and pedestrian have been enhanced, and the basic modelling for object interactions in shared space has been implemented. Video data in the shared space and flow data within the test site were collected and evaluated for adapting simulation environment and the relevant parameters. The current simulation will be used as base scenario for the oncoming evaluation work in WP13.

4.6.4.2 Simulation future plans

According to the research questions in D9.3 it is needed to develop and set up simulation scenarios for quantitative evaluation in WP13. Moreover, interactions between bicycle, pedestrian and AS in shared space/paths are complex and vary when the composition of arrival time, speed, acceleration, road geometry, etc. changes. Accordingly, further enhancement on the modelling of travellers in shared space/paths will be continuously carried out during the impact evaluation work in WP13. At the test site Monheim, the work to evaluate possibilities to implement an easily transferable demand model is carried out (see section 4.8). If the required data is available for test site Linköping within this project, the resultant demand model would facilitate to consider relatively realistic traffic demand in simulation.

4.7 Madrid (Scenario 1 & 3)

4.7.1 Pilot description & progress

4.7.1.1 Pilot general description

The NTUA simulations within WP10 are carried out for two different demonstration sites or pilots in Madrid, Spain. The first site is in Villaverde, including a circular automated transit service route within an urban environment. The second site is in Carabanchel; a parking area; a bus terminal for Madrid public buses operated by EMT Madrid. The microsimulation scenarios aim to investigate and support critical aspects for the operation of the Madrid site (both Villaverde and Carabanchel). Within the microsimulation scenarios, several use cases were and will be examined for both sites. This subsection is a continuation of the previous two deliverables, which act as a basis for this document as well. In this deliverable, efforts were made to include real-data from the conducted pilots in the microsimulation.

4.7.1.2 Pilot pre-demo progress

Firstly, the Villaverde site consists of a circular bus route from "Villaverde Bajo-Cruce" point to "La Nave"; a subway station. The operating AD vehicles within this bus route are three. Specifically, the bus fleet consists of an Irizar (12m) bus and a Gulliver mini-bus, as well as an automated light-weighted passenger vehicle named Renault Twizy, which will be part of the fleet to support the capacity of the Gulliver shuttle. Currently (September 2022), the real-pilot operations and the pre-demonstration phase have not yet initialized in Villaverde. On the contrary, for the Carabanchel site, all vehicles have been tested and the pre-demonstration phase is currently on-going. Carabanchel site is a bus parking area and specifically the main bus terminal for Madrid public buses operated by EMT Madrid. The three SHOW vehicles (Irizar, Gulliver and Twizy) were tested inside the parking depot in a circular route and simultaneously the parking depot was working normally with daily traffic volumes in terms of parking/unparking buses, passenger vehicles as well as pedestrians. More details about the simulation efforts are described below.

4.7.1.3 Simulation pre-demo progress

As it is logical, simulation efforts align and follow the pilot progress. All efforts along with the results are discussed below. In summary, since the previous deliverable D10.2, some additional scenarios were simulated in the Villaverde site with regards to the operational speed of the electric AD Irizar bus. Furthermore, with regards to the Carabanchel simulations, the total network was set up and in a later stage, field data from SHOW vehicles were considered in the simulation network. From both sites, noteworthy results can be extracted, however, the Carabanchel results are more accurate (without assumptions) since they include real-data for the piloted SHOW vehicles.

4.7.2 Villaverde Site

4.7.2.1 Simulation network

The Villaverde network is illustrated in Figure 50 and the detailed network features and parameters can be found in D10.2 [16] and are not repeated herein, in order to avoid repetitions since are simulation efforts from previous period. More specifically, an automated shuttle bus service has been integrated into the study network of the “Aimsun Next” software and has been modelled to run concurrently with the current public transportation. Its line connects the "Villaverde Bajo Cruce" metro station with "La Nave," a public building that houses a variety of activities, as seen in Figure 50. There is a single automated shuttle bus that runs at a fixed 15-minutes interval; as a result, there are four departures every hour. There are two bus stops along the 1.6 km long service circular route. The shuttle bus is fully electric and runs in AD throughout the route. It has been constructed by Irizar and has a total capacity of around 58-61 passengers with a 25 seating capacity. Its dimensions are 12m in length and 2.55m in width.

Figure 50: Villaverde network in Aimsun Software and the circular route of the shuttle service.

4.7.2.2 Simulation scenarios

Three additional sets of simulation scenarios have been investigated since the previous deliverables: i) various CAV market penetration rates (MPRs) within the current traffic demand (0%-100% increasing by 10%) applied to passenger cars and trucks, ii) with or without the operation of the Irizar (i.e., automated shuttle bus service), and iii) different operational speeds for the Irizar bus service. Overall, the following scenarios for the operation of shuttle services were developed:

- Baseline (no Irizar bus operation)
- Irizar bus service driving at 15 km/h operational speed
- Irizar bus service driving at 30 km/h operational speed
- Irizar bus service driving at 45 km/h operational speed

Different CAV market penetration rate scenarios were also simulated for each of the aforementioned situations, ranging from 0% to 100% increasing by 10%. The introduction of CAVs specifically replaced the corresponding percentage of conventional vehicles. Traffic demand and characteristics were held constant throughout all shuttle service scenarios and MPRs for comparative analysis purposes. Since the primary goal of the current study is to look into different operational speeds for bus services, future traffic demand was not taken into account or forecasted. In total, 44 scenarios were simulated (11 MPR scenarios for each of the 4 shuttle service operation scenarios).

Additionally, 10 distinct replications of each scenario using random seeds (numbers used to initialize a pseudorandom number generator) were also simulated. Each scenario's simulation lasted an hour during a peak hour. The automated shuttle bus service and the simulated CAVs were assumed to be fully electric. Furthermore, the change in CAV MPRs only applied to passenger cars and trucks; did not apply to public transportation buses, which continued to operate as usual in all of the scenarios considered. The modeling of the simulated parameterization of CAVs is based on upcoming publications and deliverables of the LEVITATE project that NTUA had been involved in the past, background material may be found at the following website (https://levitate-project.eu/downloads/).

4.7.2.3 Simulation results

The SHOW project developed an impact assessment framework, in which the several KPIs were classified into groups including "Road safety", "Traffic efficiency," and "Environment and energy efficiency" and other categories that cannot be extracted by the simulation tools. Multiple metrics assessing the impacts of CAVs in different traffic conditions were derived through the microscopic simulation. The following measurements can be transformed into KPIs fulfilling the impact assessment of WP13. To that end, the KPI Number (or KPI ID as in Table 18), as mentioned in updated D9.3, is indicated next to each measurement in the following list. It should be mentioned that many additional and detailed measurements can be extracted using the microsimulation model but only the most important are reported in the current document. The definition of the plotted measurements along with the corresponding related KPI follow:

Road Safety

- Conflicts: the number of conflicts with other road users and infrastructure during the operation of the AV (count) – [KPI B2 from D9.3]

Traffic efficiency

- Delay Time: mean delay time (sec/km) – [KPI X from D9.3]

- Speed: mean speed (km/h) – [KPI B7 or B14 from D9.3 and depends on vehicle or network level, respectively]
- Total Distance Travelled: total distance travelled of the vehicles that exited the network (km) – [KPI B13 or B21 from D9.3 and depends on vehicle or network level, respectively]
- Travel Time: mean travel time (sec/km) – [KPI B19 & B22 from D9.3]

Environment and energy efficiency

- CO_2 Emissions: total carbon dioxide emissions (g) – [KPI B26 from D9.3]
- NO_x Emissions: total nitrogen oxides emissions (g) – [KPI B26 from D9.3]
- PM Emissions: total particulate matter emissions (g) – [KPI B26 from D9.3]

The automated shuttle bus service results on Irizar level are illustrated in Figure 51. By increasing the CAV MPR, Irizar mean speed was slightly increased, while travel time was decreased, as can be concluded by Figure 51. As would be expected, 45 km/h consistently recorded a higher speed and shorter travel time than the other speed services across all MPR scenarios. In all three MPR conditions, the service operating at 15 km/h records disproportionately lower speed and travel time than the other two speed services. When the shuttle bus travels at 45 or 30 km/h as opposed to 15 km/h, the conflicts decrease in higher CAV MPRs, with the 45 km/h speed exhibiting the greatest decrease. This result could have been caused by the fact that the higher operational speed shuttles adapt more to the average traffic speed, which makes them better synchronized with the traffic flow, especially at higher MPRs. This would prevent the higher-speed shuttle buses from having more risky interactions with other vehicles.

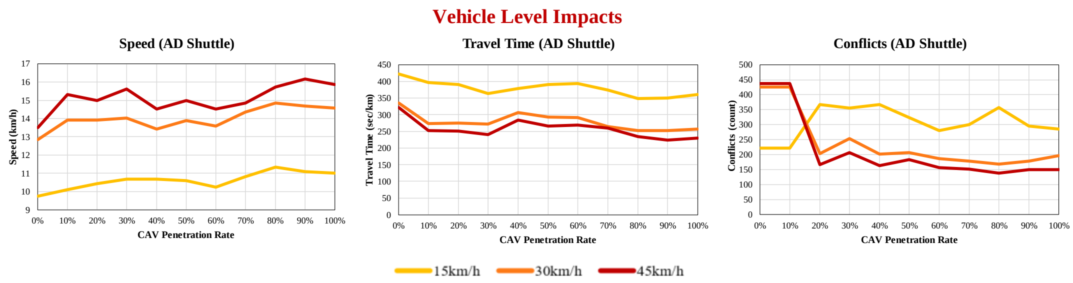


Figure 51: **Automated shuttle bus service level results.**

In addition, more measurements (i.e., automated shuttle service delay time, speed and travel time) are revealed for the entire traffic within the network. Figure 52 and Figure 53 show the network-level traffic and environmental measurements, such as delay time, speed, total distance travelled, and CO_2, NO_x, and PM_{10} traffic emissions, that were revealed from microscopic simulation.

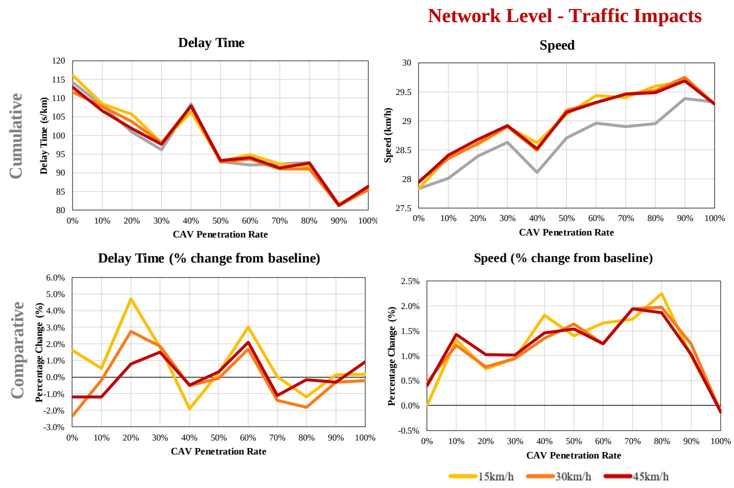


Figure 52: Network level traffic impacts.

Investigating the general trend reflected in Figure 52, by increasing the CAV MPR the traffic conditions were improved. More specifically, distance travelled and delay time were reduced while speed was raised. Additional comparative plots were made in the second row of Figure 52, to compare the various operational speeds for the shuttle bus service with regards to the baseline scenario (without the existence of the Irizar AD shuttle service) because no significant variations between them on network level can be observed. It can be concluded that lower delay time was experienced with the higher operational speed services (30 and 45 km/h). The mean speed for all CAV MPRs displayed a similar trend, with a little increase indicated in comparison to the baseline situation. In addition, the majority of the MPR conditions had little effect on the overall distance travelled. Overall, it was shown that the three services' effects stabilized at higher MPRs whereas the lowest operational speed service showed more fluctuations at early MPRs compared to the other two services.

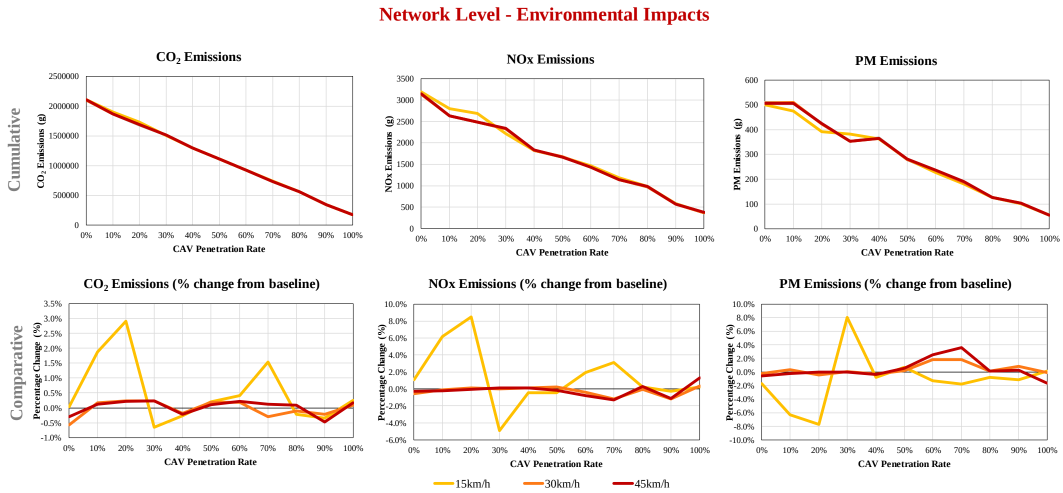


Figure 53: Network level environmental impacts.

By examining the overall trend, it is possible to draw the conclusion that the electrification of CAV fleet significantly improved the environmental conditions at network level. More particular, linear and significant reductions in CO_2, NO_x, and PM emissions resulted from raising the MPR. As a general conclusion, it can be drawn from Figure 53; the second row of comparative plots, that the operational speed services of 30 and 45 km/h were relatively consistent and close to the baseline across the MPR scenarios, while the operational speed service of 15 km/h fluctuated significantly below 70% MPR. Particularly, in lower MPRs (below 30%), the lowest operational speed service resulted in higher CO_2 and NO_x traffic emissions and lower PM emissions. The increase in CO_2 and NO_x is correlated to the respective increase in delays as shown in Figure 52. On the other hand, the PM levels for the respective CAV MPRs were lower due to the fact that fewer miles were driven as a result of the traffic (Figure 52), tire and brake wear, and vehicle-induced resuspension of road dust, which all cause PM emissions. For greater MPRs, no appreciable differences between the different services were found.

4.7.3 Carabanchel Site

The aim of this simulation was to use field pilot data of the automated vehicles in order to derive as realistic results as possible and provide impacts through microscopic simulation (e.g. delay time, emissions, conflicts, etc.) that cannot be measure in reality and can be also useful to the pilot sites. The followed steps in order the Carabanchel site to be simulated are mentioned below.

4.7.3.1 Simulation network

Firstly, the Carabanchel site in the city of Madrid, Spain was designed in the "Aimsun Next" mobility software. The simulated network, as shown in Figure 54 consists of 30 nodes and 40 sections. The prevailing movements were considered in the model: the vehicle OD matrices consisted of 11×11 centroids and a total number of 34 cars and 126 buses for a morning hour. The pedestrian OD matrix consisted of 6 entrances and 7 exits and a total number of 211 pedestrians for a morning hour. Parking lots were simulated as centroids since the parking maneuver is not feasible in the simulation software and hence the effect on the network will be the same due to the network calibration.

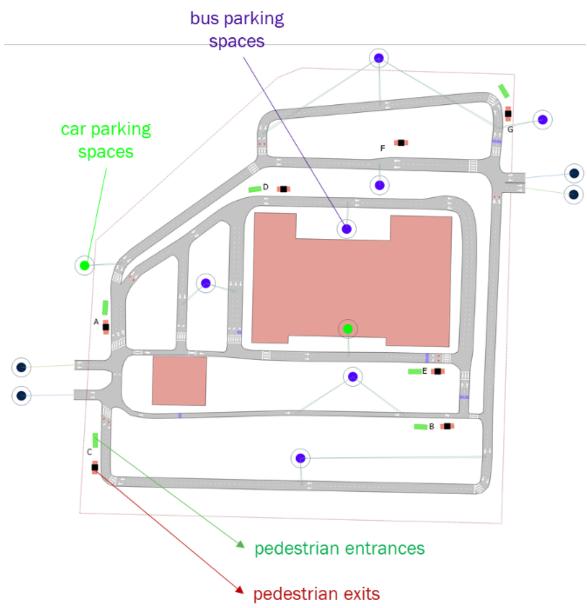


Figure 54: **Carabanchel network in Aimsun Software.**

4.7.3.2 Simulation specifications

The Carabanchel model was simulated for a morning hour taking into account the prevailing traffic conditions (vehicle and pedestrian flows), as provided by TEC & EMT. TEC & EMT provided relevant data in order to create the OD matrix for buses, cars, and pedestrians. Specifically, the moving buses, cars and pedestrians inside the parking depot within a timeframe were considered during the simulation network development. After that, the network calibration took place in order to create more realistic results.

After the initiation of the pre-demonstration phase that SHOW vehicles were tested on-site, TEC & EMT provided the trajectory data as extracted from all three SHOW automated vehicles (Gulliver, Irizar and Twizy) operation with the aim of inserting naturalistic data into the simulation model and several impacts to be extracted. The real-data were inserted in the simulation in the following way. The AD vehicles route included 19 different sections in the Aimsun model. The main idea was to set a speed limit for each AD vehicle (Gulliver, Irizar and Twizy) for each of the 19 sections according to the provided field data in order to have the most realistic results possible. Based on vehicles trajectories, the real speeds of each vehicle (Gulliver, Irizar and Twizy), as well as the X and Y coordinates, were used in order to estimate the maximum speed for each section (per vehicle).

Also, from trajectory data, the bus stops were found and located in the simulation model as well as the average waiting time, which was 14 seconds. The bus stops as well as the route can be found in Figure 55. Nevertheless, Twizy which is a light-weighted passenger vehicle drives the entire round without stops.

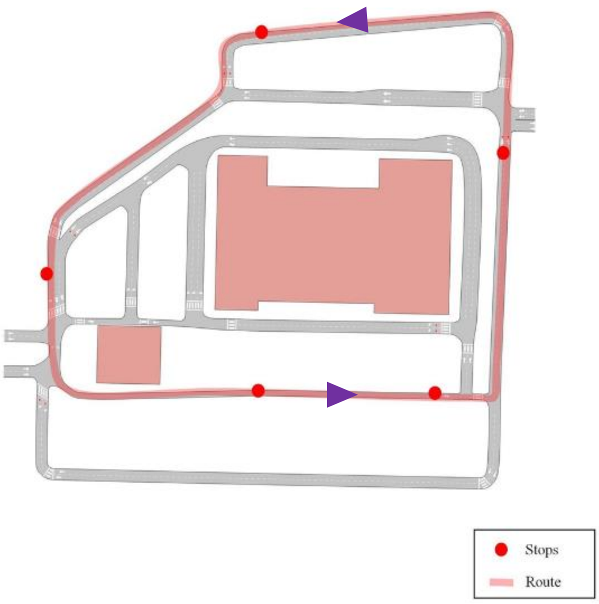


Figure 55: **Carabanchel circular route and bus stops.**

Then, the parameters of each vehicle are inserted into the simulation. Specifically, the Irizar shuttle bus dimensions were 12 m in length and 2.55 m in width and had a total capacity of 60 passengers with 25 passengers seating. Its maximum desired speed was 60 km/h, maximum acceleration 1.36 m/s^2, maximum deceleration 10 m/s^2 and weight 15,845 kg. Similarly, Twizy dimensions were 2.4 m in length and 1.4 m in width. Its maximum desired speed was 80 km/h, maximum acceleration 1.00 m/s^2, maximum deceleration 1.00 m/s^2 and weight 480kg + ~120kg. Additionally, the Gulliver mini-bus has a length of 5.32 m, and a width of 2.116 m. Regarding the maximum desired speed, is 32 km/h and weighs 3.000 kg. Its maximum acceleration is 2 m/s^2, maximum deceleration is 6 m/s^2 and the normal is 4 m/s^2. Also, it has a total capacity of 25 passengers and 7 who are seated.

4.7.3.3 Simulation scenarios

Four scenarios were considered in the simulations taking into account the field data from the pilot operations. Three scenarios were created for each of the three AD vehicles operation (Gulliver, Irizar and Twizy) as well as a baseline scenario consisting of the existing network without Gulliver, Irizar and Twizy operations. The simulation time for all scenarios was 1 hour (morning peak hour). For the Gulliver, Irizar and Twizy scenarios, only one route/round of each one was completed during the 1 hour slot. In the next subsection, comparative plots are presented and the results are discussed.

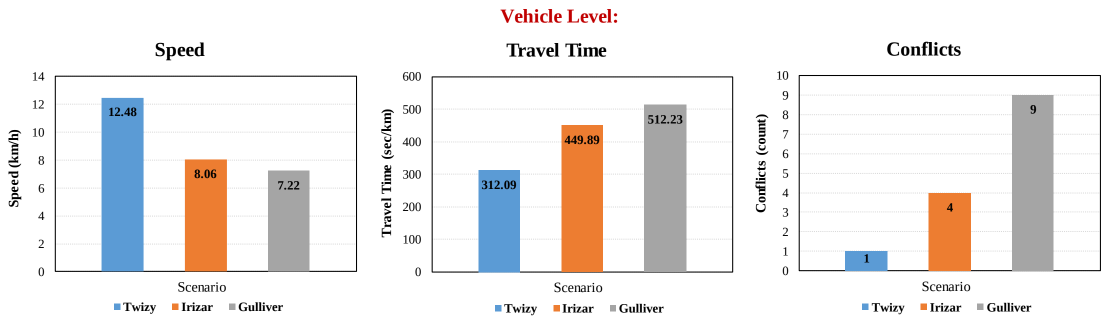
4.7.3.4 Pre-demo data used

TEC & EMT provided the trajectory data from the three SHOW automated vehicles (Gulliver, Irizar, and Twizy) inside the parking depot intending to incorporate real-world data from the automated vehicles into the simulation model and extract the relevant impacts. The file of the trajectories included measurements per 250 ms and the following measurements were recorded: time [s], auto mode, bus stopped, num obstacles advice area, num obstacles emergency area, num obstacles warning area stopped, angular error deg, brake 0_1, lateral error m, speed profile kph, speed profile ms, speed set point kph, speed set point ms, steering -1_1, throttle 0_1, traj x, traj y, veh speed kph ,veh speed ms, gnss fixed:x, gnss fixed:y, gnss fixed:vx, gnss fixed:vy, gnss fixed:ax, gnss fixed:ay, gnss fixed:yaw, and gnss fixed:yaw_rate.

4.7.3.5 Simulation results

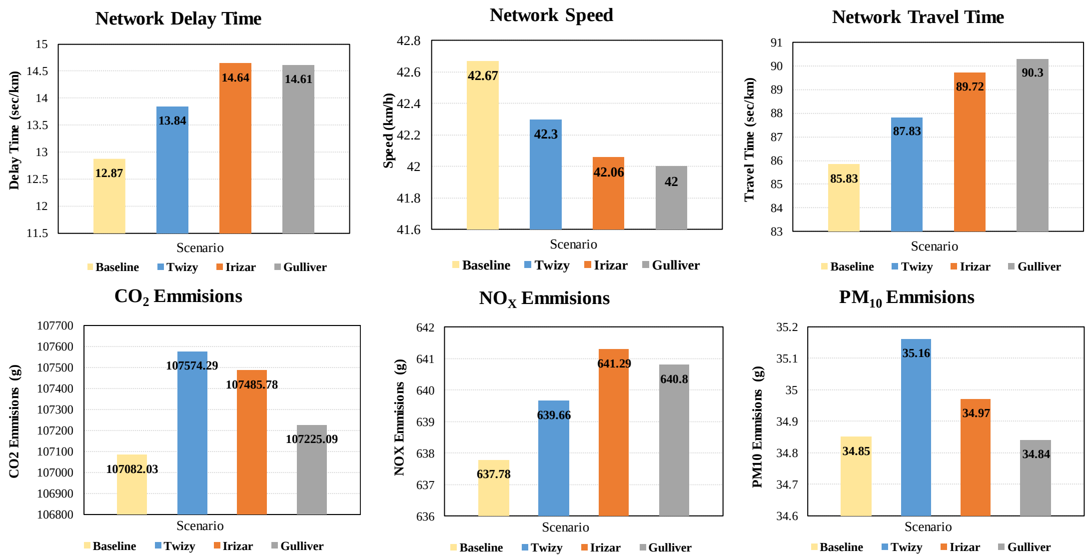
Following the same logic as the results of the Villaverde site, comparative plots were created based on the extracted values from the simulation. Specifically, three groups of plots were created:

- Vehicle Level
- Network Level
- Pedestrian Level



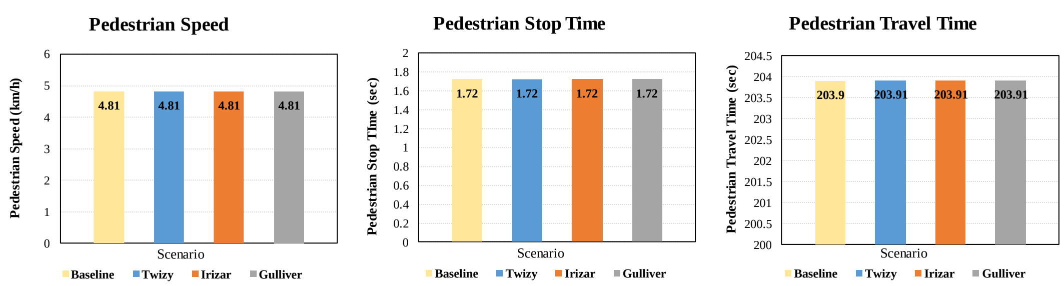
(a)

Network Level:



(b)

Pedestrian Level:



(c)

Figure 56: Comparative plots for the investigated impacts at a: (a) vehicle level, (b) network level, (c) pedestrian level.

Considering the extracted values from the microsimulation in Figure 56**Error! Reference source not found.**, Twizy seems to have a higher speed throughout the entire route since it is a light-weighted passenger vehicle compared to the others which are characterized as buses. The speed trend is also reflected to travel time, meaning that with lower speeds, higher travel times are recorded. Additionally, conflicts, that the SHOW vehicles were involved in, seem to have the exact opposite trend compared to speed. Probably due to the fact that a vehicle operating with a higher speed results a shorter trip duration with lower interactions with other vehicles inside the bus depot. With regards to the network level and more specifically the traffic impacts, all three vehicles seem to increase network delay time and travel time as well as decrease network speeds since all SHOW vehicles are slower than the manually driven vehicles that coexist in the network. The trends of the aforementioned measurements follow the opposite trend of speed as it is rational. With regards to the environmental impacts, all three vehicles seem to increase environmental emissions more than the current baseline conditions. However, the following trend needs further research to understand the different patterns observed within the vehicles and emissions. Finally, on pedestrian level, pedestrians' speed, stop time and travel time seems to remain unaffected by the operations of the different vehicles, probably due to the fact that there were several crossings in the depot.

Also, for each scenario, vehicle-level results (i.e., the trajectory of the SHOW vehicles) for each vehicle were extracted. With the aim that the simulation data of this file to be in the right format and be uploaded on the data collection platform (https://show-data-portal.eu/) in the future, for accomplishing the simulation suite creation.

4.7.4 Next steps

4.7.4.1 Simulation overall progress

A number of simulations were carried out since the previous iteration for both Villiaverde and Carabanchel sites. More specifically, additional scenarios testing different operational speeds for the Irizar bus in the Villaverde site along with different CAV MPRs were simulated. Furthermore, the Carabanchel site network was designed and calibrated based on real-traffic data. In this parking depot network, naturalistic driving data of three AD vehicles operation was inserted in the simulation model, as well. For each AD vehicle, the corresponding scenario was simulated in order to investigate its impact on traffic, the environment and road safety. All the results of the above simulations are considered to be a guide for pilots as the simulation scenarios included fundamental aspects for future traffic conditions, such as CAV market penetration rates and different AD shuttle bus service operations.

4.7.4.2 Simulation future plans

From both sites, noteworthy results were extracted, however, the Carabanchel results are more accurate (without assumptions) since they included field data for the piloted SHOW vehicles. Therefore, a future plan is to simulate the three different AD vehicles operation in the Villaverde site based on naturalistic data as well. Moreover, different vehicle parameters significant for CAV functionality (except for the operational speed) can be also investigated for both sites, based on desired scenarios that could be able to support the site operations.

4.8 Monheim am Rhein (Scenario 1 & 3)

4.8.1 Pilot description & progress

4.8.1.1 Pilot general description

The city Monheim am Rhein (Monheim) hast joined the project SHOW as test site since mid-2022. There have been automated shuttles in Monheim am Rhein (Monheim) since the beginning of 2020, and 5 EasyMile AS (EZ10 Gen2 with SAE level 4) are in service. Due to the current regulation a safety driver is on board. The whole AS operation, i.e., Line A01, is fully integrated into the regular public transport service and provide service between the bus terminal and the old town at 15-minute intervals from 7 a.m. to 11 p.m. everyday. The originally planned shuttle route, shown in Figure 57 (a) is not used yet due to the related road construction work. Currently, the AS operate on the pre-defined detour route with a maximum speed of 20 km/h and stop at 6 pre-defined places. The shuttle route with the length of 2.7 km is shown in Figure 57(b).

(a) planned AS route

(b) current AS route

Figure 57: AS route in Monheim am Rhein. Source: [4]

Moreover, just like a typical old town, the road infrastructure in the old town area is quite compact and includes a shared area where bikes and pedestrians are the main users and that can be also used by delivery vehicles occasionally. Most streets have only one lane. The AS route consists of one-way streets, two-way streets and shared space. In the latter area, AS have more interactions with bikes and pedestrians.Figure 58 gives an idea about the AS running in the shared space. In addition, AS run to and leave from the bus terminal. The respective intersections between AS and buses are expected during operation. More information about the test site can be found in [14].

Figure 58: A view to show a AS running in the shared space of the old town in Monheim am Rhein [source: City Monheim].

4.8.1.2 Pilot pre-demo progress

As mentioned before, the AS service in Monheim have been already integrated in the regular public transport system before SHOW. Therefore, no pre-demo phase was needed here.

4.8.1.3 Simulation pre-demo progress

Although no pre-demo activity was needed at this test site, a simulation environment has been set up with limited field data, where no data related to flows, traffic demand and shuttle trajectories is available. Within the scope of representing the current situation, a demand model would deliver more realistic background traffic for the test site. As the current test lines of AS are relatively short in comparison to the overall city, no major changes in mode choice should be expected. For simulating the effects of changes in AS offer, one though needs a demand model that represents the mode choice of the population. Such models exist for many years and are used in transport planning and when examining the effects of introducing new mobility offers. Yet, such models usually need lots of data about population, infrastructure, and people's mobility behaviors in the investigated region. So, the effort was made to evaluate possibilities to implement an easily transferable demand model with use of freely available data. The model requirements are identified. Briefly, such model should have the following characteristics:

- It must deliver the mobility of the inhabitants of a regarded area (origin/destination matrix and mode choice).
- It shall work with freely available data only (data availability may depend on region).
- It shall be applicable for the complete European area (data availability may depend on region).
- It may deliver the mobility of commuters (it may be necessary to extend the area, so that commuters are located within the regarded area).
- It may be sensitive to changes in infrastructure, mobility offers and prices, and other measures (this is hardly achievable).

Currently, using European data, we are capable to compute a valid synthetic population and allocate it within the area on the level of buildings. The statistics about sex and employment are available on NUTS 2 level [5], age distribution on NUTS 3 level. This data comes from the 2011 census, so it is outdated. New census data will be released in 2023. Information about population density is available for a 1km×1km grid. When comparing the results against our simulation of the city of Berlin, we observe that the share of unemployed persons is too high. In our internal model, about 37% of the total population is employed, while the currently implemented model delivers only 19%. The best ways to resemble the mobility behavior are tried to be determined presently. Unfortunately, two import data sets are missing: (a) places of activities and (b) empirical data on mobility behavior. OpenStreetMap data may be used to solve issue (a), yet only partially, as important information about work places and their capacities is not included. It may be possible to get statistics about the number of work places on NUTS 2 and combine them with information from OSM, yet this will inaccurate. Pan-European data on mobility behavior (b) is lacking as well. Needed are daily activity plans and information about mode choice. We currently assume that we may be capable to obtain information about daily activity plans on national scale from some countries what is assumed to be sufficient. Modal splits but would be needed on a higher spatial resolution as within the countries, city differ in public transport options as well as, e.g., the topology what determines the share of using a bike.

4.8.2 Simulation specifications

To assist the evaluation work in WP13, i.e., to evaluate the AS impacts regarding the respective research questions defined in WP9, the basic simulation environment is set up. The data related to traffic demand and traffic flows within the test site and the AS trajectory data is not available. Therefore, traffic demands are synthetically generated with use of SUMO's tool randomTrips.py as the base scenario. The mainly considered road users include bikes, pedestrians, passenger cars and buses. These demands may be further adjusted for different scenarios in WP13 if necessary.

4.8.2.1 Simulation parameters

Regarding missing vehicular trajectory data, the corresponding results from the test Linköping are applied in the simulation here. It is because the test site Linköping also adopts EZ10 Gen2 and the respective trajectory data was used for calibrating the simulated shuttle parameters [16]. The other parameters related to bikes and pedestrians will also be corresponding to those used in the simulation of the test site Linköping. Only the bike parameters related to the distance to be hold from intersection are adjusted due to the site character (not campus area). Such parameter consistence can facilitate the analysis work in WP13 in case of that cross comparison will be executed between test sites Linköping and Monheim am Rhein.

4.8.2.2 Simulation network

The network is based on OSM and generated with use of SUMO's tool osmWebWizard.py. The respective public transport data in OSM is also imported and the related bus routes and stops are considered in the simulation. Bus flows were generated synthetically. The implemented bi-directional edges for modelling the interactions between road users on both directions (see also the description of the Linköping simulations) are used for setting up the shared space in the simulation. Figure 59 gives an overview about the network layout and the shuttle route.

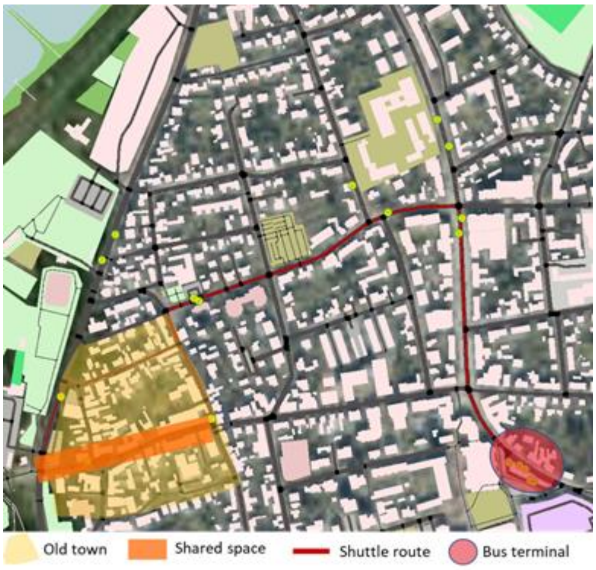


Figure 59: Layout of the simulation network for the test site Monheim am Rhein.

4.8.2.3 Simulation scenarios

With the aim to help to identify critical issues with regard to the research questions, pointed out in D9.3 [6], and to shape the corresponding analyses the aspects related to vehicles, parking lots, bicycles, pedestrians and local buses are considered. To provide an overview about the built simulation environment, two scenarios, with and without AS operation respectively, are established. The local bus lines and the AS run every 15 minutes. The simulation period is set to 1 hour and the considered traffic demand include 590 vehicles, 253 people, 175 bicycles, 104 buses.

4.8.2.4 Pre-demo data used

4.8.3 Simulation results

According to the initial simulation result, shown in Figure 60, AS has certain impact on the overall network performance and road users' travel time, especially due to the lower allowed maximum speed and the limitation of road infrastructure, i.e., most roads have only one lane.

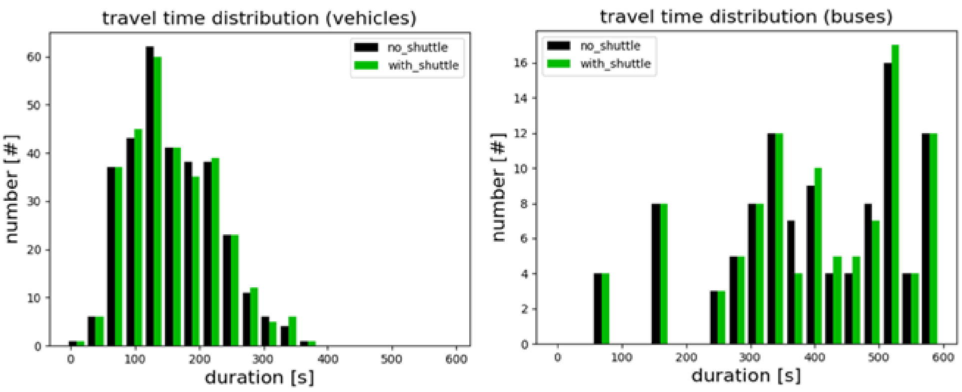


Figure 60: Initial comparison of the travel durations spent by vehicles and buses with and without the AS service at the test site Monheim am Rhein.

4.8.4 Next steps

4.8.4.1 Simulation overall progress

This test site has joined the project since several months. The availability of field data for setting up a relatively realistic simulation environment is very limited. According to the field visit result a simulation is set up and most of the respective parameters correspond to those applied at the Linköping test site. The main concern for that is that both test sites adopt the same type of the AS and have shared space for bikes, pedestrians and AS. Furthermore, possibilities to implement an easily transferable demand model are evaluated.

4.8.4.2 Simulation future plans

The established simulation environment is used as the base scenario and will be further adapted according to the scenarios developed in WP13. More focus will be put on the enhancement of the shared space modelling, due to the complex interactions between pedestrians, bicycles and AS, and the respective analysis. The possibility and the extent to implement the aforementioned demand model will be further investigated and examined with the consideration of the developed scenarios in WP13. In addition, the availability of some critical input data, e.g., places of activities and empirical data on mobility behavior, is unsure, and effort will be put on to find out if alternative data is available and to which extent it can be applied.

4.9 Rome (Scenario 1)

4.9.1 Pilot description & progress

The Italian logistics simulation scenario is located in Rome, Italy. With available data from the logistics operator, this site can be planned for both micro-macro simulation levels along with implementation similarities determined within some of the SHOW logistics site implementation plans in order to similarly cover the requirements of the SHOW objectives and evaluation approaches. As the scenarios, citizen perspectives and logistics distribution methods are quite similar between the simulation site and the SHOW logistics pilot sites, solid links for validation can be created through the number of deliveries and distribution area similarities.

In this scenario, the conventional (for the baseline scenario) and electric logistics vehicles (which might be even automated and electrified vehicle option to simulate for comparison with/without automation) operates on a fixed route comprising two determined cases, as summarized below:

- between two hubs (from main storage-hub to secondary-hubs) in the Rome metropolitan area
- from secondary hubs, where located in optimized positions with respect to distribution routes, to final customers

The objective is to create simulation scenarios that form a virtual twin site for similar real-world demonstration sites within the SHOW project. This logistics simulation plan is intended to be a transferable implementation of the Rome pilot-based simulation to any pilot site within the SHOW project. This serves to have similar Italian logistics data that will ideally be useful for the objectives of the SHOW project’s logistics scenarios.

The logistics simulation scenario examines the effects of transfer points and automated vehicles on traffic congestion, routing, distance traveled and time before the real-world scenarios take place during the SHOW demonstrations. Driving behaviors will be analyzed and the various stakeholders will be integrated into the simulation tool as in the SHOW pilot sites. Different parameters and logistical variants within the simulation scenarios will be used and tested involving speed, automated vehicle option, and transfer points.

The logistics simulation plan is designed to evaluate the effects of logistics services in terms of environmental impact and efficiency. To this end, the collection of the necessary data for the logistics simulation is also carried out to fulfil the requirements of the SHOW; therefore, this logistics simulation plan is based on the "Rome Logistics Case Study". On this basis, the data required for the simulation is collected from the case study of “Santa Palomba, Rome” (Smart Packaging project, 2019) within the framework of the objectives of SHOW and the defined simulation scenario. The characteristics of this collected study site are quite similar to the pilot logistics sites of the SHOW program in terms of study area and characteristics of logistics services.

Based on this information, the logistics simulation scenario, with respect to the mentioned case study (Smart Packaging, 2019), was defined in terms of objectives, data availability and scenario characteristics, as summarized in further subsections. In this logistic simulation scenario, the route, the road network and the predefined areas of influence are modelled and validated within the objectives of the SHOW project. Furthermore, the virtual representation of the real-world road network for the simulation can have several geographical errors that will be detected and corrected during the bilateral connections with the Italian site and the SHOW pilot sites as satellite sites. This is due to the similarities between the implementation and simulation site characteristics, the features of the distribution and citizens both for simulation and

SHOW logistics sites, as well as the deployment methods. Subsequently, the logistical simulation will examine energy consumption, travel times, delays, interchanges, effects on other road users and driving behaviors.

The purpose of the data collected is to deepen some analysis on the distribution of e-commerce materials in the province and/or city of Rome. It is thereby a matter of providing a service to intermediate distribution centres from the permanent distribution centres to save distance and time for the same deliveries. This approach is also likely to have a point-to-point distribution analysis, similar to the pilot implementations of SHOW logistics. To this end, the main distribution hub (Santa Palomba - Pomezia) transfers products to the intermediate distribution hubs that will deliver the materials to the final customers. On this basis, the secondary hubs, which will be transit points, will be located as different intermediate hubs in the territory of the Municipality of Rome (or the Province of Rome). These transit points will deliver products/materials to final customers according to the on-time delivery approach.

As already mentioned, logistics simulation implementation concentrates on environmental impact and efficient approaches to logistics services in terms of optimization and timely delivery to end customers.

Regarding data requirements, geometric road networks and relevant inputs will be collected from the Santa Palomba case study for real-time traffic and logistics services data. The expected results of Logistics Simulation Scenario 1 are highlighted below:

- Errors in automated logistics as a service processing
- Identification of potential difficulties and barriers
- Routing-related tests
- Impact assessment parameters such as (reduced) time-spent during operation, reduced travel distance with same amount of deliveries, etc.

Consequently, the possible data fields to be exported from the logistical simulation tool can be highlighted below:

- Data Sources: Static, Dynamic, Event-based, Service, Booking, Optimization, etc.
- Variables Name: Pickup Time, Dropoff Time, Actual Ride Duration, Actual Distance, Emission, Braking, Delay, etc.
- Data Types: Integer, Float, String, Time, Location, etc.
- Data Types Description:
- For which UC: Logistics UCs
  Optimization Algorithms: TSP, VRP, BinPacking.

4.9.2 Simulation specifications

4.9.2.1 Simulation parameters

For the automated logistics simulation, several data are needed for routing and optimization to arrange such as time windows at the stopping points, timing of routes, and the user's request to receive the delivery at a certain time (and on a certain day). Delivery details are available, but the booking details' part is not mentioned (it refers that it is not known when the user made the delivery request).

The order requests are apparently illustrated by rows. Thus, each order symbolizes a row; rows of orders that may be part of the same shipment. Several rows would be part of the same shipment because there is the possibility of ordering three different things that arrive at the same destination; thus, one row describes three shipments as one delivery - a composed shipment for things that are delivered from the same area, the shipment will consist of several rows of the order. The scenario variants have been are summarized in Table 12 and listed below:

- **Baseline:** Cargo Transport in conventional traffic without designed transfer points and automated vehicles
- **Variant 1:** Cargo Transport with designed transfer points via non-automated vehicles whereas maximum speed cannot exceed 25km/h.
- **Variant 2:** Cargo Transport with designed transfer points via automated vehicles whereas maximum speed cannot exceed 25km/h.
- **Variant 3:** Cargo Transport with designed transfer points via non-automated vehicles whereas maximum speed can exceed 25km/h.
- **Variant 4:** Cargo Transport with designed transfer points via automated vehicles whereas maximum speed can exceed 25km/h.
- **Variant 5:** Cargo Transport without designed transfer points via automated vehicles whereas maximum speed cannot exceed 25km/h.
- **Variant 6:** Cargo Transport without designed transfer points via automated vehicles whereas maximum speed can exceed 25km/h.
- **Variant 7:** Cargo Transport with designed transfer points via automated vehicles whereas maximum speed can exceed 25km/h and minimum risk maneuvers.
- **Variant 8:** Cargo Transport without designed transfer points via automated vehicles whereas maximum speed can exceed 25km/h and minimum risk maneuvers.

The following table represents the details of the simulation scenario and variants as follows:

Table 12: Logistics simulation scenario baseline and variants (Rome Scenario)

Scenario Name	Scenario Variant	Scenario Description
Baseline	-	• Cargo Transport in conventional traffic without designed transfer points and automated vehicles
Logistics Simulation Scenario	Variant 1 (non-automated + transfer points + low speed)	• Non-Automated logistics vehicles • Operated with designed transfer points • Maximum speed cannot exceed 25km/h
	Variant 2 (automated + transfer points + low speed)	• Automated logistics vehicles • Operated with designed transfer points • Maximum speed cannot exceed 25km/h
	Variant 3 (non-automated + transfer points + high speed)	• Non-Automated logistics vehicles • Operated with designed transfer points • Maximum speed can exceed 25km/h
	Variant 4 (automated + transfer points + high speed)	• Automated logistics vehicles • Operated with designed transfer points • Maximum speed can exceed 25km/h
	Variant 5 (automated + without transfer points + low speed)	• Automated logistics vehicles • Operated without designed transfer points • Maximum speed cannot exceed 25km/h

Scenario Name	Scenario Variant	Scenario Description
	Variant 6 (automated + without transfer points + high speed)	• Automated logistics vehicles • Operated without designed transfer points • Maximum speed can exceed 25km/h
	Variant 7 (automated + transfer points + high speed + min risk)	• Automated logistics vehicles • Operated with designed transfer points • Maximum speed can exceed 25km/h • Minimum risk maneuvers are allowed
	Variant 8 (automated + without transfer points + high speed + min risk)	• Automated logistics vehicles • Operated without designed transfer points • Maximum speed can exceed 25km/h • Minimum risk maneuvers are allowed

4.9.2.2 Simulation network

The scenario is defined on the basis of distribution zones; in particular, deliveries that are being currently made directly to the final customer (main hub to secondary hub, secondary hub to end customer). For the simulation, the logistics scenario is that the main distribution zone delivers to the secondary hubs (in an area close to the end customer); then there will be another service (with smaller vehicles, perhaps simulating electric or environmentally friendly vehicles) that departs from these secondary hubs and operates in the relevant area to deliver to the end customer.

As already mentioned, the automated logistics service scenario involves two phases. The first part of the scenario is the delivery from the main-hub to the secondary-hub (also called transit or transfer points) to serve certain areas according to the delivery shipping postcodes. Subsequently, the second phase will consist of time-responsive deliveries related to customer requests to transfer materials, which will be delivered, from the transit points to the final customers. In summary, the simulation scenario envisages two approaches: the first works on deliveries to the transfer points; the second transfers shipments from the transfer points to the final customers. Apparently, the conception is about timing (when the customer places the request-order, how the company-organization handles the delivery) and the simulation predicts these process times.

Scenario data relating to these shipping situations and data on where deliveries are made will be taken into account. Shipments to final customers may be even delivered on a different day. Perhaps, if it is organized with transit points, this means that deliveries will be transferred a few days earlier than the requested day from the main hub to these transit points. After that, the shipment will be ready to be delivered to final customers in the preferred day.

4.9.2.3 Simulation scenarios

The positioning of the transit points (e.g., they would be positioned east-west-north-south of Rome) is based on simulation projections that also depend on numerous parameters. A centroid, respecting an area to be served, would very reasonably be positioned in the center of the communication network between the commercial-business area and the distribution hubs.

From the central hub (main-hub) in Pomezia to the transit points, the simulation scenario also analyses the service variables with respect to the delivery flow to final customers - which means - from main-hub to transit points (to locate these points efficiently) and then from there to final customers with respect to the booked delivery time. The routing optimization works on these transit points positioned as the first routing from the main hub to them; subsequently, the routing will consider the optimization of the final deliveries with respect to the time from the transit points to the final customers. The logistics simulation can even include a hub-to-hub case and a hub-to-customer case related to previously defined cases.

4.9.2.4 Pre-demo data used

Data are available for approximately 34788 different products, with product delivery codes, transferred during the observed time period between 2 March 2017 and 5 December 2018. However, the deliveries (in total) are about 1.380 million for the orders that were placed; obviously, this is a study that was done throughout Italy. It is therefore necessary to filter only those recipients that are in the province (or city) of Rome.

For this objective, a clustering of the postcodes of the city/province of Rome is necessary; therefore, the postcodes of the province of Rome distinguish 138 sets of clusters. For concentration, the analysis must work on the city of Rome (or the province of Rome) for further clustering based on postcodes.

With the Rome postcodes, one should emphasize those areas to designate essentially a secondary distribution pole. Furthermore, each postcode can have an intermediate distribution hub; otherwise, there would be many secondary hubs that would not make sense for the distribution of materials to final customers on time. Consequently, more in-depth grouping according to certain postcodes is required; for example, grouping by a dozen postcodes or postcode meaning zones (one secondary hub per municipality, from the main one to this secondary one, then to the end customer via distribution hubs).

4.9.3 Simulation results

4.9.4 Next steps

4.9.4.1 Simulation overall progress

Based on the previously mentioned data fields, several expected key performance indicators will be addressed, by collecting required input data, both from simulation site and linked SHOW pilot site(s), from logistics simulation scenarios, as listed below:

- Travel time
- Distance
- Average speed
- Fuel consumption
- Avoided conflicts
- Flow
- Duration and Length saving thanks to routing- optimization
- Frequency
- Number of deliveries
- Failures of processing
- O-D relations (matrix)

4.9.4.2 Simulation future plans

The logistics simulation will be implemented immediately after the deadline of the deliverable. The case study of the automated logistics simulation will require further data gathering and categorisation due to the erroneous collection of operator data. This is due to the fact that the available data covers the entire Italian distribution area and all areas of Rome. This data will have to be further processed according to the requirements of the SHOW automated logistics simulation. In the meantime, the automated logistics site in Rome should cover similar areas as the SHOW site in Trikala. To this regard, data will be accumulated according to such specifications. As part of this approach, the deployment will be examined to have a solid connection with the SHOW logistics pilot sites; in particular, a link to the Trikala site. It is most likely that the Trikala site will have similar distribution characteristics to the Rome case study, such as the Trikala site will only have a logistics implementation like the Rome simulation, and the Trikala site will cover a shopping street and attraction points like the Rome simulation site. A further point is that the Trikala site was subjected to similar logistical distribution studies as the Rome site, due to the similar perspectives of citizens, logistics distributions and regulative concerns.

Subsequently, the data will be analyzed and used to work and calibrate appropriate models, sufficient to reflect real-world logistics services and the possible inclusion of automated logistics vehicles. In this way, the tests will ensure that the microscopic logistics simulation model is developed. As the data available from the Rome site (both micro-macro levels) are similar to those available from the Trikala site (as micro level), microscopic simulation models will be guaranteed. A further step forward, the assembled data would also enable a macroscopic level of simulation through the classified data from the Rome site. This simulation will make it possible to more accurately predict the impacts expected from the introduction of transit points and automated logistics vehicles along optimized routes. This will allow the evaluation of different routes and the management of logistical transit points to facilitate and improve logistical operations, the location of transit points and automated logistical vehicles.

4.10 Salzburg (Scenario 2)

4.10.1 Pilot description & progress

4.10.1.1 Pilot general description

For the Salzburg Site, a mesoscopic simulation was set in MATSim. The MATSim model for DOMINO Salzburg includes the city of Salzburg, large parts of the state of Salzburg, the German Corner (road network only) and small parts of Upper Austria (see Figure 61). From the national transport survey of Austria, Österreich Unterwegs 2013/14, a population was created that includes socio-demographic characteristics as well as the activity chain of the individuals. Currently, a population with around 33% of the total mobile population is simulated. The modes of transport available in the MATSim model are walking, cycling, public transport and car. In addition, the automated shuttle running in Koppl is simulated and, for more advanced scenarios, a DRT service in the current region around Koppl that picks up passengers at the stops of the automated shuttle.

Figure 61: Simulation scenario including the area around Koppl as well as the city of Salzburg.

4.10.1.2 Simulation pre-demo progress

In the pre-demo phase, simulations are concentrated on the Koppl and the automated Shuttle servicing the bus line 152 that connects the city of Salzburg with St. Gilgen am Wolfgangsee. Due to the small catchment area of the automated shuttle, there is little difference for the region wide traffic in the pre-demo simulations. To test if a larger roll-out of automated services in the area could have a more significant effect on city- and region wide traffic and emissions, several scenarios were simulated in this period ranging from an additional 6 automated shuttles on fixed routes to area-based automated demand responsive transit in several areas.

The simulation setup of the simulations stays the same as in D10.2. The simulations will be run in the open-source tool. The basic setup of the model will be similar to the one described in Müller et al. 2022 [11] & [20].

For public transport, information from a General Transit Feed Specification file is used. This GTFS-file is also adapted for the scenario that includes the automated shuttle on a fixed route. The timetable was designed such that the shuttles (both the existing shuttle in Koppl and the newly introduced 6 shuttles) would reach the main bus line in time to drop off and pick up passengers.

Initial daily schedules of the simulated mobility population will be created by cleaning, geo-constraining and resampling data of the Austrian national mobility-survey Österreich unterwegs for the described region.

The agents will be assigned potential activity locations based on land use categories and points of interest (both derived from OpenStreetMap) as well as open data for population density and workforce.

Since MATSim's internal default router is not well designed for multi-modal routing, the AIT intermodal routing framework Ariadne [21] is integrated in the iterative replanning of trips in the simulation.

4.10.2 Simulation specifications

4.10.2.1 Simulation parameters

An important parameter for the simulation is to set the attraction of the new shuttle service. Since there have been no SP surveys conducted in the simulation area, we refer to literature. In line with several studies, we assume that the VTTS associated with riding a shared automated electric vehicles is similar to the VTTS of car passenger: whereas Lu et al. (2018) [22] found no differences in the VTTS between drivers and passengers of a car, Fosgerau (2019) [23] and Ho et al. (2015) [24] come to the conclusion 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. Since the VTTS of pt is about 50% of the VTTS of cars in our mode choice model, the VTTS of the new drt service is around 150% of the VTTS of pt.

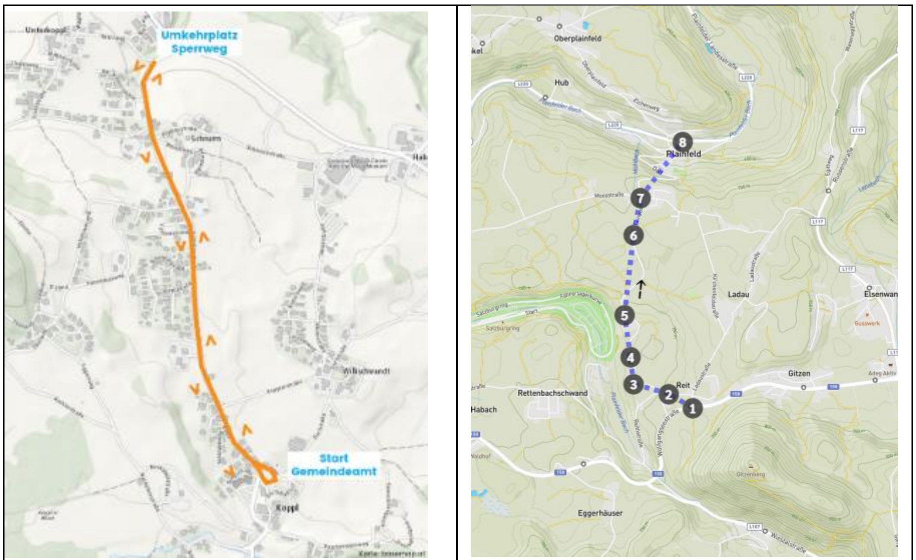
The parameters are all listed in detail in Müller et al. (2021) [20]. A late arrival at the facility is penalized with 1.9 times of the in-vehicle time, whereas waiting is set to 1.83 of the VTTS of pt. If the agent needs to switch to another public transport line, an additional disutility of about 15% of the VTTS of pt is added. Waiting for public transportation has a disutility of 1.77 times of the VTTS of pt.

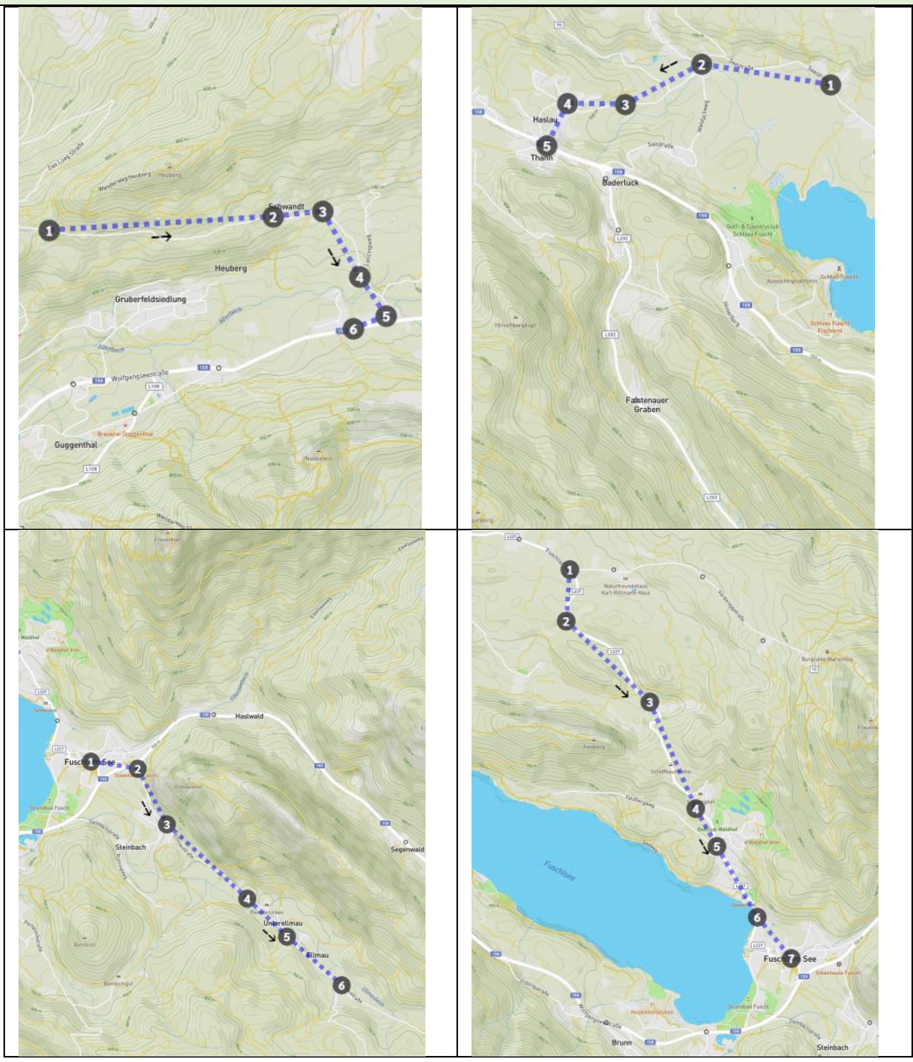
4.10.2.2 Simulation scenarios

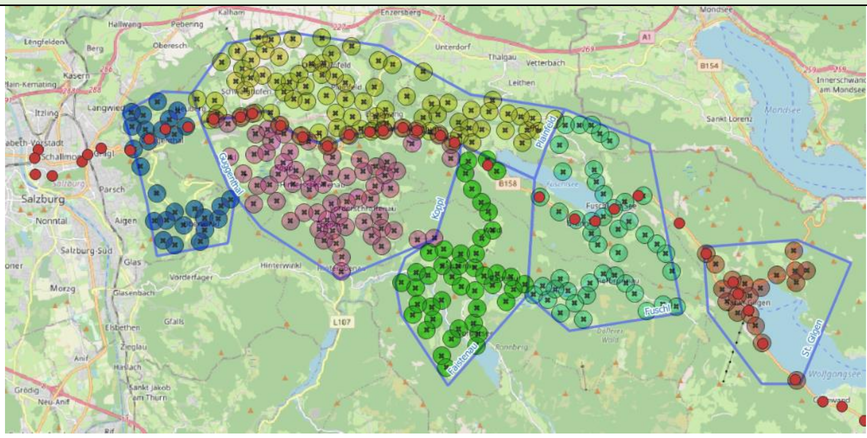
Several scenarios were simulated. The first scenario used for calibration of the model is a baseline scenario that does not include the automated shuttles. This scenario is applied to calibrate the MATSim model to the modal split in the region and serves as a comparison for the other four scenarios.

In addition the following scenarios were run:

Table 13: Simulation scenarios run for Salzburg.

Simulation Scenario	Scenario Description
Scenario A	Set-up of baseline scenario with additional 6 automated shuttles connecting remote areas to bus 152. The lines for the automated shuttles can be seen in Figure 62. 

Simulation Scenario	Scenario Description
	 **Figure 62: The Koppl automated Shuttle (upper left, running within SHOW) and the 5 additional automated shuttles in the simulation.**
Scenario B	Service area based DRT services for 6 service areas, one DRT vehicle per service area. The DRT vehicles should mostly serve as a last mile service and trips need to start and end within one of these service areas. The service areas can be seen in Figure 63.

Simulation Scenario	Scenario Description
	 **Figure 63: DRT service areas for the area based services. The colored points are starting locations for the DRT vehivles, the red points the stops of bus line 152.**
Scenario C	Setup like in Scenario B within this scenario all stops are active but only 5% of stops in the area have a DRT vehicle stationed there at the beginning of the day for all service areas with a DRT vehicle
Scenario D	Setup like in Scenario C with 10% of stops per service area have a DRT vehicle stationed there at the beginning of the day.
Scenario E	Setup like in Scenario B with 15 % of stops per service area have a DRT vehicle stationed there at the beginning of the day
Scenario F	Setup like in Scenario B with 20 % of stops per service area have a DRT vehicle stationed there at the beginning of the day
Scenario G	Area based DRT service with all stops in all service areas of scenario B have a DRT vehicle stationed there at the beginning of the day

4.10.3 Simulation results

Results about modal split changes (KPI B20) Scenarios B-F show are a progression of scenarios with a growing number of DRT vehicles in each area. In Scenarios B there is just one vehicle in each area. In Scenarios C-E the number of DRT stops stays the same, but there is a growing percentage of stations initially equipped with a DRT vehicle at the beginning of the simulation, ranging from 5% of stations in each area to 20% of stations in each area. Finally in scenario F all stations are initially equipped with a DRT vehicle at the start of the simulation. The idea of these scenarios is to see limits in the uptake of DRTs with a growing saturation of DRT vehicles in the area. This helps to see the overall potential of introducing DRT services in a rural setting without adding push measures to limit car commuting into the city of Salzburg. In Figure 64 one can see that for all areas, the number of DRT trips is rising with the saturation in DRT vehicles. Once running the simulation agents switch between different modes, trying to optimise their daily mobility plans until an equilibrium is reached and agents do not change their modes or routes any longer. Comparing the different scenarios, one can see that the largest modal shifts come with higher numbers of DRT vehicles. In addition, one can also see in Figure 67 that these variation trips from all modes are replaced by the DRT service with the largest switches from car to DRT vehicles. The largest switches come from car and walking trips.

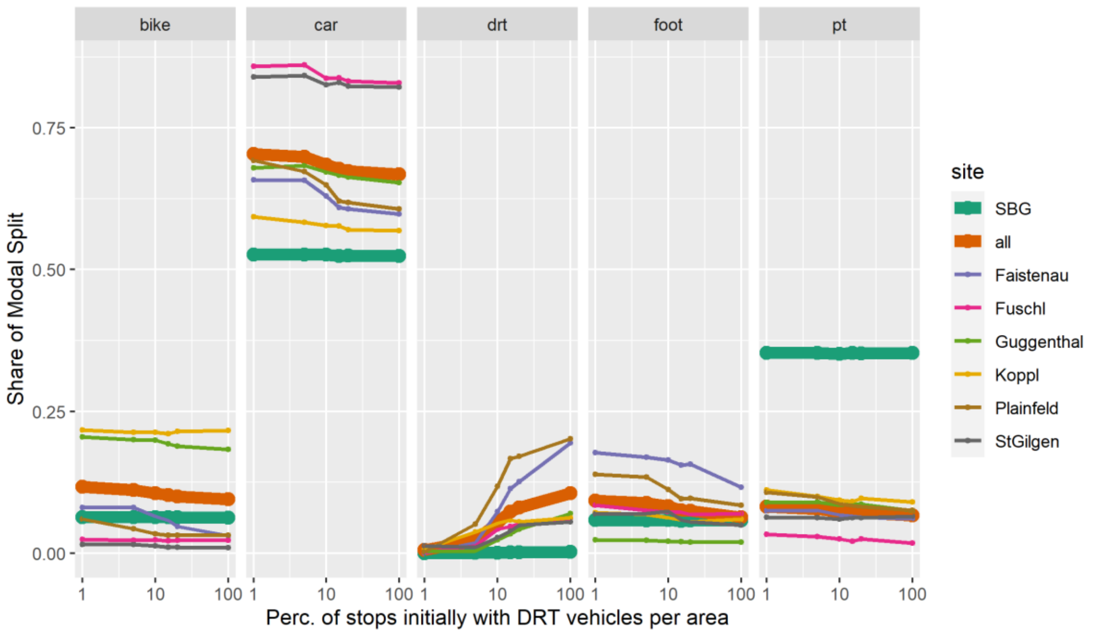


Figure 64: Modal splits in the different DRT areas, the combined area (all) and for trips starting or ending in the city of Salzburg.

While there is a sizeable number of DRT trips starting or ending in the different DRT areas, not surprisingly of the trips starting or ending in the city of Salzburg the share of trips containing a DRT leg is very small. Since the trips would need to start or end in the DRT areas east of Salzburg, this is not surprising. However, Figure 65 shows that even the absolute number of trips containing a DRT leg starting or ending in Salzburg is quite small compared to the number of trips containing a DRT leg starting or ending in one of the DRT areas. This suggests that the trips replaced with trips including DRT legs happens rather for shorter trips, where the replacement trips have only a small number or no changes, i.e., trips within the DRT areas are replaced by trips taken completely in the DRT service. This is partly due to the relatively hard penalty for waiting times at public transit stops which has 1.77 times the disutility of travelling by PT and an additional penalty for switching pt line which is about 15% of the VTT of PT. If there are no other changes to the transport system making car travel less attractive it is hard to convince travellers to switch form a faster mode (car) to a slower one with changeovers, even though travel time is penalised less for pt than for car journeys in the mode choice model within MATSim [11]. Considering, that the total number of about 1000 trips added to the public transport and DRT modes, and these trips will be mostly served by the bus line 152 this is a significant addition to the number of passengers of this bus.

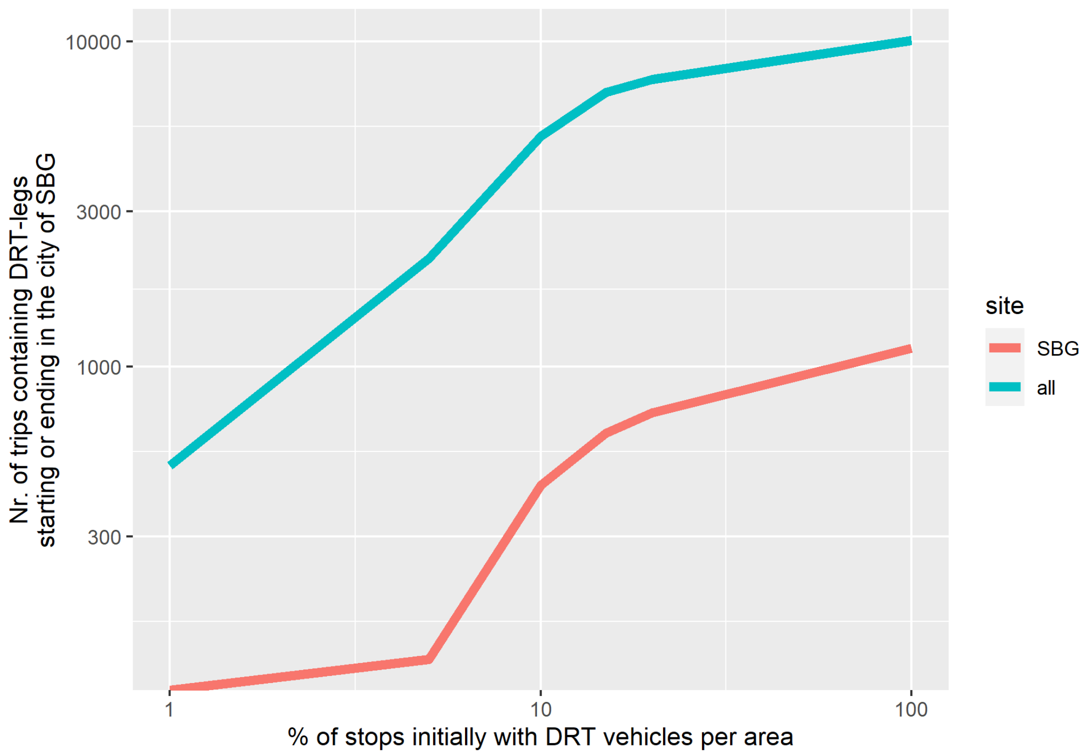


Figure 65: Number of trips containing at least a DRT leg starting or ending in any of the DRT areas (all, blue) or starting or ending in Salzburg (red).

Looking at the modal shifts in Scenario F where we all stations have a DRT vehicle stationed there at the beginning of the simulation, one can see that DRT substitutes all modes almost equally. Out of the around 6250 trips shifted compared to the base scenario, from which 5353 have been shifted towards DRT trips. 34.0% of these DRT trips have been done in the base scenario by car, 30.7 % by foot, 19.4 % by bike, and 15.9 % by public transport.

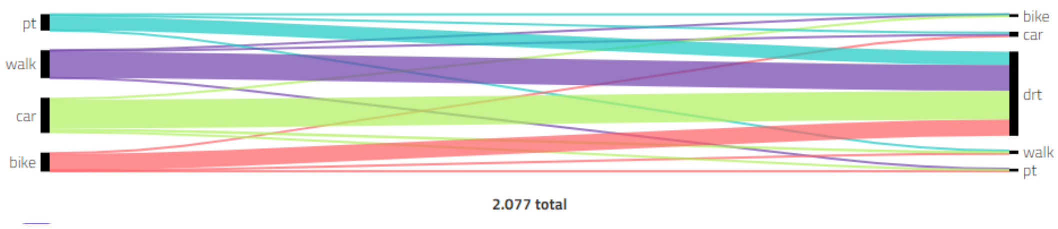


Figure 66: Modal shifts between modes in scenario F where all DRT stops are initially equipped with a DRT vehicle.

Results about shared mobility rates and vehicle utilisation (KPIs B30 and B31): The agent-based simulation allows precise information about the shuttle vehicle usage because their implementation in the simulation comes with an optimization algorithm. This dynamic vehicle routing problem (dvrp) module matches agents that want to go from one region to another at about the same time. These regions are defined in our case as the DRT zones, but could also be set to a grid with a given edge length. The maximum waiting time for an agent is set to 10 minutes.

The output of the simulation runs provide detailed information on how the shuttle vehicles are used such as the passengers' kilometers travelled and empty kilometers. These data allow the calculation of the occupancy rate of vehicles.

Table 14 provides details of the scenarios for the total distance traveled (in km), the total empty distance (in km), and the resulting share of kilometers traveled when the vehicle was empty.

The occupancy rate o refers to the occupancy of the DRT vehicles by distance travelled. It is defined as

$$o = \frac{total\ passenger\ distance\ traveled}{vehicle\ total\ distance - vehicle\ total\ empty\ distance}$$

It is apparent that the occupancy rate increases with the number of vehicles. Already with a provision of 5% vehicles (scenario C) at the stops, the occupancy rate is more than the estimated average occupancy rate in Austria (1.3). The higher occupancy rate in scenarios with more DRT vehicles might appear counter-intuitive, but results from the optimization algorithm. For finding matches of passengers, the MATSim dvrp module (dynamic vehicle routing problem) uses a grid with a configurable edge size (in all scenarios 400m) to determine the origin and destination cells for each agent that makes a request. Only agents with the same start and destination cell will be matched. If a ride with a passenger is ongoing, the destination cell of the agent that makes the request and the one that is already in the vehicle needs to be identical. It is preferred to match passengers instead of requesting a new, unoccupied vehicle for the ride. The increasing occupation rate tells that in scenarios with a small vehicle fleet that there are not enough rides to match agents but instead a new vehicle will be taken.

As a result, the stop based system results in a comparably high mean occupancy rate of almost 2 passengers (1.97, not mentioned in the table) per shuttle vehicle. In the same way the occupancy rate increases, the empty ratio decreases with the number of shuttle vehicles. The minimum of around 16.5% is reached for one vehicle per stop and is assumed to not decrease much further with a higher provision of vehicles.

Table 14: Automated vehicle distances, empty ratios and occupancy rates of the DRT vehicles in the Scenarios.

	Total_distance_km	**Total_empty_km**	**Empty_ratio**	**Occupancy rate**
Scenario B	576.26	243.97	0.350000	1.028333
Scenario C	2381.66	1034.17	0.411667	1.356667
Scenario D	5215.16	2126.41	0.37666	1.468333
Scenario E	6573.19	2543.43	0.348333	1.486667
Scenario F	6778.34	2507.97	0.330000	1.481667
Scenario G	6423.80	1323.05	0.165000	1.548333

Since no economic variables for the implementation and operation of automated DRT services, no cost-benefit analysis is possible at this stage. However, in Figure 65 and Table 14 it can be seen, that the rise in benefits from the number of automated DRT vehicles is diminishing with a growing number of vehicles. While there is a sharp rise in the number of DRT trips and the occupancy rate of DRT vehicles up to a number of vehicles corresponding to 10% of the number of DRT stops in an area. Afterwards the rise in gains drops quickly. Hence, the optimal number of vehicles can be estimated around to be around this number when it comes to changes in modal split and occupancy rates of vehicles compared to the expected costs.

4.10.4 Next steps

4.10.4.1 Simulation overall progress

For the site of Salzburg a MATSim Model was set up to compare the influence of different scenarios of automated shuttle and DRT services for the area serving bus nr 152 connecting St. Gilgen to the city of Salzburg.

While in the initial scenarios run for D10.2 the simulations concentrated on the area of Koppl, where an automated shuttle will run within the SHOW project, the scenarios run for D10.3 are more geared to show what could be achieved once automated shuttles become commonplace and are able to run freely as DRT services. To ensure that the shuttles are not taking away passengers from PT, the services are restricted run in service areas and hence, serve as first and last mile services for PT.

4.10.4.2 Simulation future plans

Once data from the Salzburg site becomes available, the models will be revisited and in particular, parameters concerning automated shuttles on fixed routes will be recalibrated to better fit the models to real SHOW scenarios. Afterwards, the models will be rerun to ensure the results fitting to the real world results. In addition, in the simulation scenarios, mostly the number of DRT vehicles was changed. To give even better recommendations to decision makers, DRT areas will be changed in size and number of areas to allow a sensitivity analysis of set-ups to find the most environmentally friendly outcome, with most car trips being replaced by DRT and PT trips. In addition, since the simulation results show that there is a clear substitution of trips from environmentally friendly modes (bike and walking) especially for short trips, in future scenarios, it will be tested if incentive schemes that support the combination of DRT with PT (e.g. reduced DRT prices) and inhibit motorized individual transport to enter the city of Salzburg will be tested to see if higher rates of Shuttle & Ride trips can be achieved.

4.11 Tampere (Scenarios 1 & 3)

The simulations in Tampere have been concluded with the results presented in deliverable D10.2. A further simulation iteration is not foreseen in Tampere due to the limited partner effort (total of 1 person month available for all simulations).

4.12 Trikala (Scenario 1)

4.12.1 Pilot description & progress

The microsimulation scenarios analysed in the context of this work aim to investigate critical aspects regarding the operation of automated shuttles along a fixed route in the city of Trikala, Greece. Simulations examine the automated shuttles' driving behaviour based on different use cases in order to assess the expected traffic flow impacts from the introduction of the automated shuttles before the real-world scenarios take place. Pedestrians, different types of vehicles and conventional buses are also integrated within the simulation tool as in the real site. Hence, the focus is not only on examining the driving behaviour of automated shuttles, but also on the interaction with other road users, in order to investigate under which conditions automated driving is feasible in a crowded environment and with what consequences.

The following microscopic traffic simulation analysis did not consider empirical evidence for the pilot site at Trikala, since the commencement of the pilot operation of the automated shuttles at Trikala has been transferred to the 4th quarter of 2022. Moreover, the simulated route in Deliverable D10.3 is different from the one simulated in Deliverable D10.2, since the location of the pilot site has been moved to a new route after the submission of Deliverable D10.2. Thus, the simulation model presented in Deliverable D10.3 was developed from the beginning based on all the currently available data (network topology, traffic demand, traffic signal plans, public transport schedules etc.) that has been provided by the city of Trikala.

4.12.2 Simulation specifications

The operation of two automated shuttles along a fixed route in the Trikala site is examined with the use of the open-source microscopic traffic simulator SUMO. The simulation network topology is initially retrieved from OpenStreetMap (OSM) and adapted to accurately reflect real world infrastructure elements and characteristics. Specifically, an adjustment was made at Evripidou and Pylis intersection where the junction has been recently replaced by a roundabout, but the OpenSteetMap database has not been updated accordingly yet. The simulated route connects the Train Station with the Department of Physical Education and Sports Science and serves passenger cars, buses, and trucks. Traffic flow data were assumed based on similar data from previous studies for the same area such as the Trikala's Sustainable Urban Mobility Plan (SUMP) and AVINT project. The assumed data were used to synthesize an Origin-Destination (OD) Matrix. The existing bus lines which serve the test route are also simulated in SUMO, but the schedules of the bus lines are assumed, and the bus stops' locations are collected through Google Maps Street View. Existing traffic signs (e.g., yield or stop sign) were also taken into consideration while the traffic signal plans are automatically generated by SUMO. Moreover, SUMO's tool "randomTrips.py" was used in order to generate person trips that encompass walking between random locations whereas SUMO's tool "intermodal routing" was also used in order to define a trip of a person including mode changes. The parking area outside the Department of Physical Education and Sports Science is also simulated in SUMO. The number of parked cars and the parking duration were stochastically determined. Finally, the railway line is simulated in Sumo based on a hypothetical schedule as well.

The automated shuttles, with a capacity of 12 passengers each, interact with other vehicles on the road and with VRUs at bus stations and intersections. Their allowed maximum operational speed is 25 km/h and they are expected to serve the same bus stops as existing public transport means. Since pilot operation of the automated shuttles in Trikala will not commence prior to finalization of preliminary simulation activities, other shuttle characteristics will be selected based on literature review and experience gained from other pilot sites, but they will be revised when empirical evidence from the Trikala pilot site becomes available. Car-following behaviour of automated shuttles will be initially based on an Adaptive Cruise Control (ACC) algorithm but may be revised according to the analysis of pilot operation data collected at later project stages. The circular route followed by the automated shuttles has a length of about 9 km and includes 14 bus stations in total. The fixed circular route and the 12 predefined bus stops served by the automated shuttles are depicted in Figure 67.

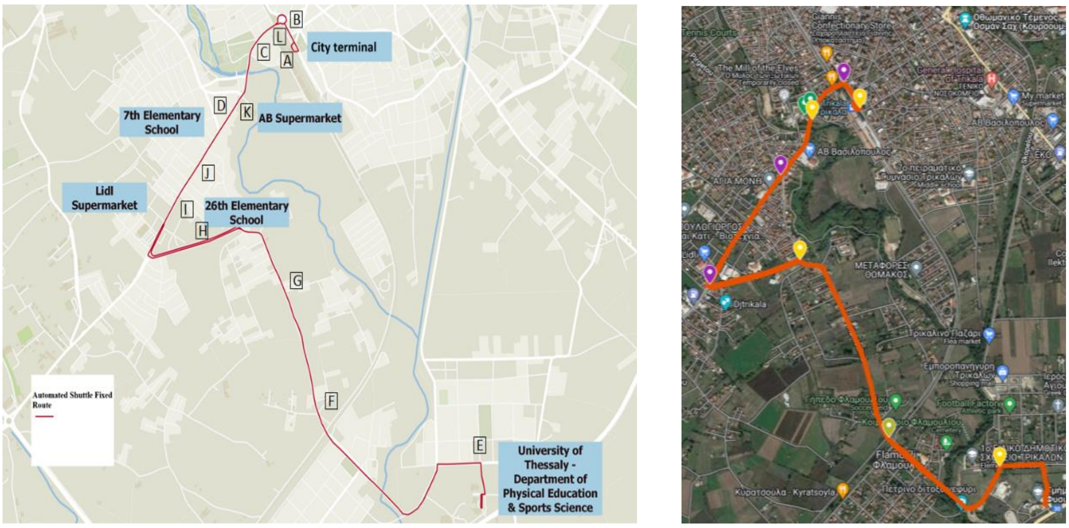


Figure 67: Overview of the Automated Shuttle fixed route at Trikala site.

The simulation environment, as illustrated in Figure 68 and Figure 69, will be used as a base for impact assessment with the introduction of the automated shuttles along the selected route. Impact assessment is conducted for different manoeuvring capabilities of the automated shuttles including different maximum operating speeds. Additionally, the deployment of green priority for the automated shuttles at signalized intersections is evaluated. In more detail, one baseline and six different variants (baseline, variant 1-6) of scenario 1 (Table 15) were studied:

- **Baseline**: Conventional traffic without automated shuttles
- **Variant 1**: Two automated shuttles are teleoperated via AV fleet Control Centre whereas their maximum driving speed cannot exceed 25 km/h.
- **Variant 2**: Two automated shuttles are teleoperated via AV fleet Control Centre whereas their maximum driving speed cannot exceed 50 km/h.
- **Variant 3**: Two automated shuttles operate in automated driving with maximum driving speed of 25 km/h whereas transitions of control (ToCs) and minimum risk maneuvers (MRMs) are possible, see Figure 69.
- **Variant 4**: Two automated shuttles operate in automated driving with maximum driving speed of 50 km/h whereas transitions of control (ToCs) and minimum risk maneuvers (MRMs) are possible, see Figure 69.
- **Variant 5**: Two automated shuttles are teleoperated via AV fleet Control Centre with maximum driving speed of 25 km/h and they receive green priority at signalized intersections.
- **Variant 6**: Two automated shuttles are teleoperated via AV fleet Control Centre with a maximum speed of 50 km/h and they receive green priority at signalized intersections.

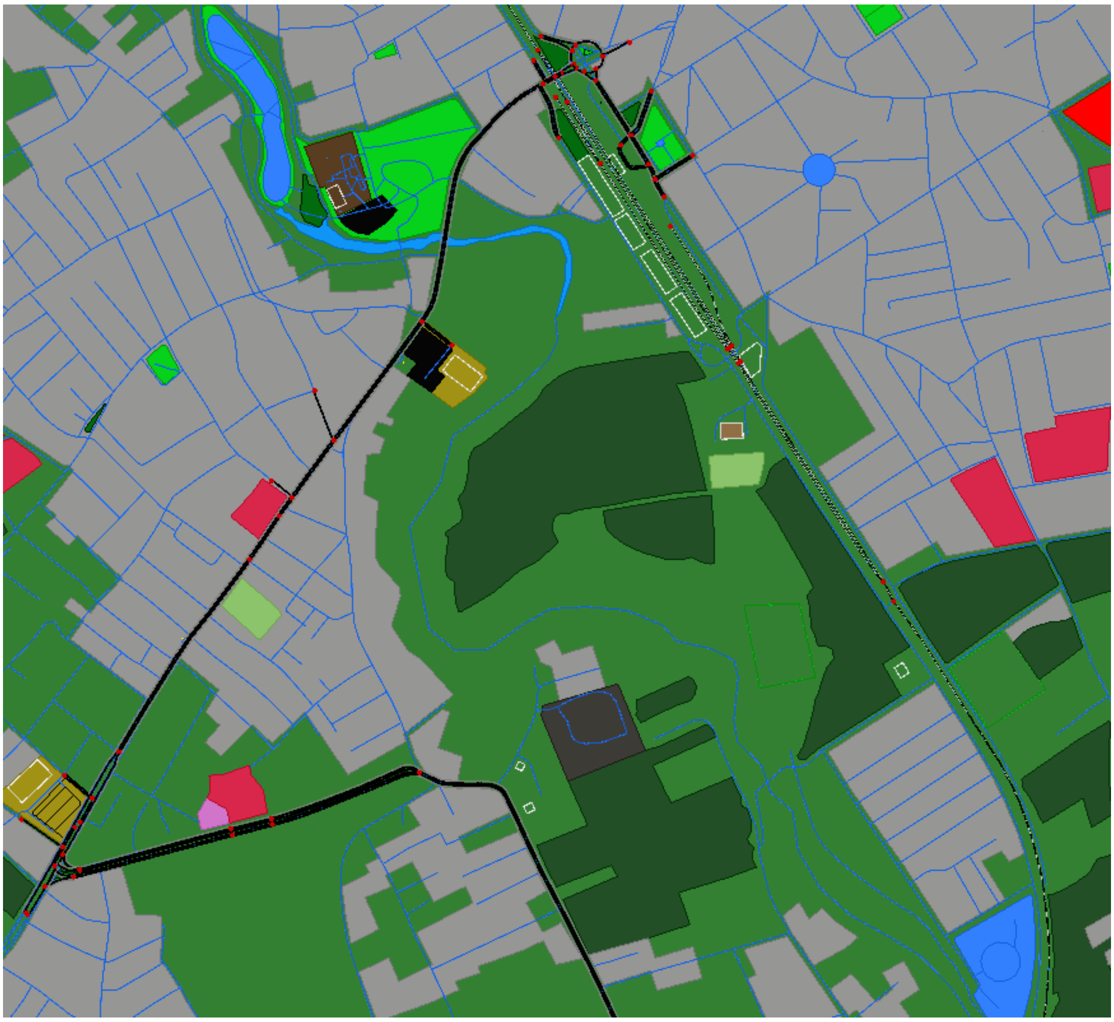


Figure 68: Representation of the simulated network.

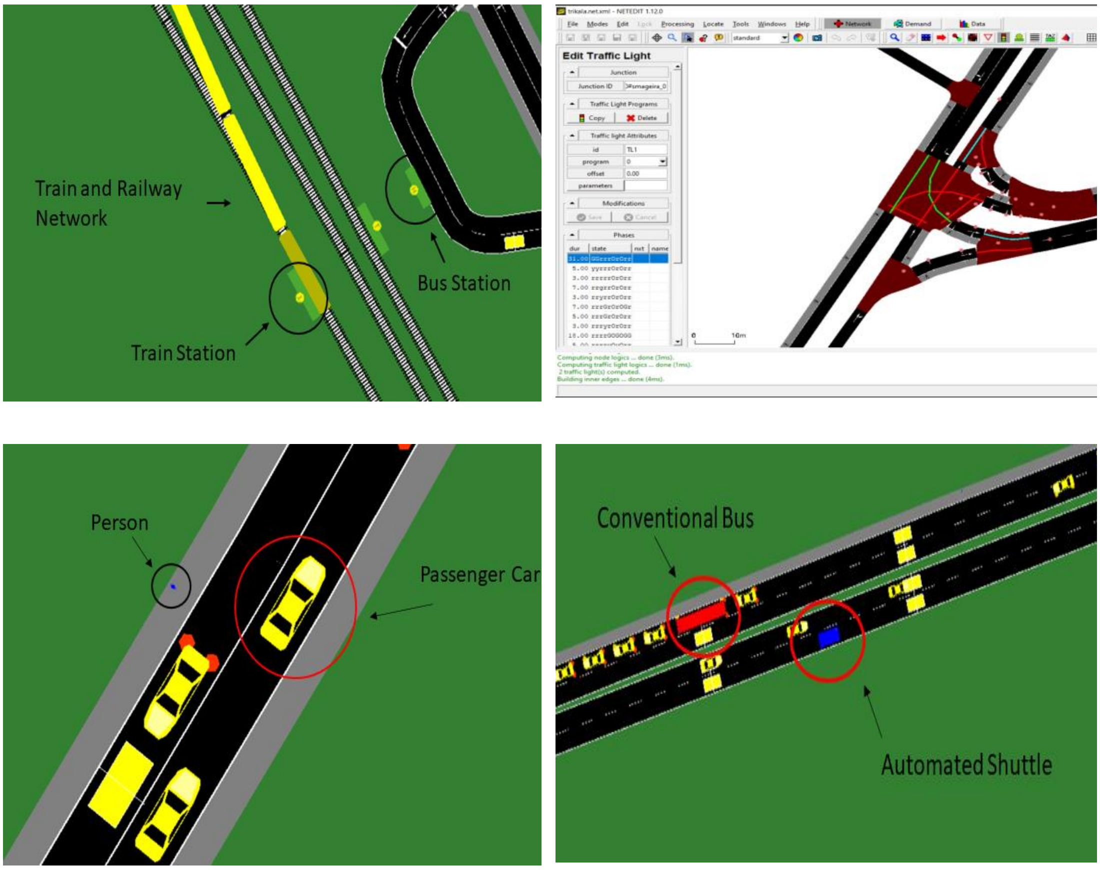


Figure 69: Simulation environment of scenario 1 variants in SUMO.

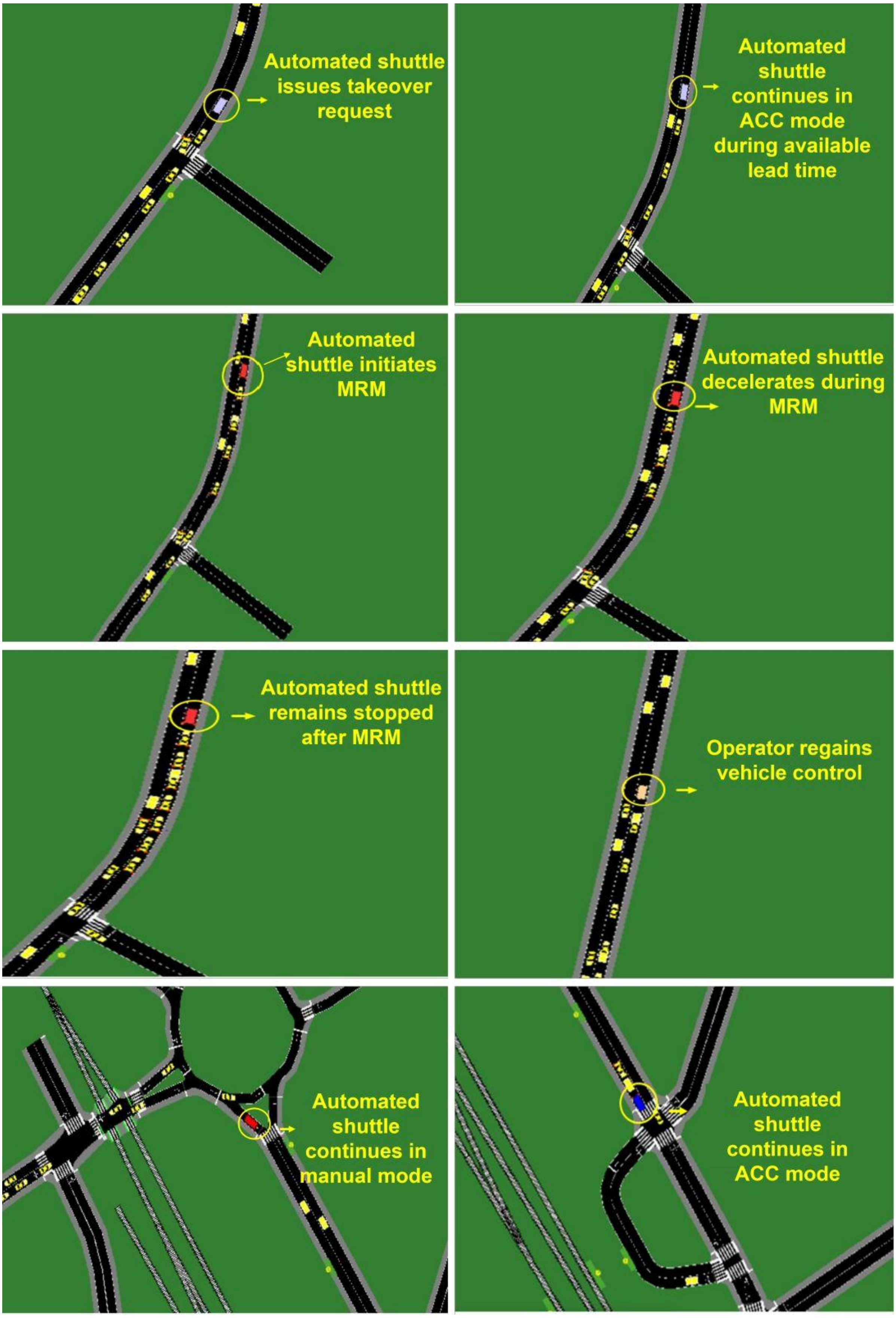


Figure 70: Snapshots of variant 3 in SUMO.

Table 15 presents more detailed information for the baseline scenario and the variants of scenario 1. Parameters values for the automated shuttles' driving behaviour are provided in Table 16 whereas for more details regarding definition of model parameters one may instruct "SUMO "Definition of Vehicles, Vehicle Types, and Routes" wiki page.

Table 15: Simulated variants of scenario 1.

Scenario Name	Scenario Variant	Scenario Description
Baseline	-	• Conventional traffic without automated shuttles
Scenario 1	Variant 1 (Teleoperation + Low speed)	• Automated shuttles teleoperated via Fleet Management Centre. • Automated shuttle speed cannot exceed 25 km/h.
	Variant 2 (Teleoperation + High speed)	• Automated shuttles teleoperated via Fleet Management Centre. • Automated shuttle speed cannot exceed 50 km/h.
	Variant 3 (AV mode + Low speed)	• Automated shuttles operate in automated driving mode. • Control transitions and minimum risk manoeuvres are possible. • Automated shuttle speed cannot exceed 25 km/h.
	Variant 4 (AV mode + High speed)	• Automated shuttles operate in automated driving mode. • Control transitions and minimum risk manoeuvres are possible. • Automated shuttle speed cannot exceed 50 km/h.
	Variant 5 (Variant 1 + Green priority)	• Automated shuttles teleoperated via Fleet Management Centre . • Automated shuttle speed cannot exceed 25 km/h. • Automated shuttles receive priority at signalized intersections.
	Variant 6 (Variant 2 + Green priority)	• Automated shuttles teleoperated via Fleet Management Centre. • Automated shuttle speed cannot exceed 50 km/h. • Automated shuttles receive priority at signalized intersections.

Table 16: Model parameter values for automated shuttles.

Parameter name	Variant 1 (Teleoperation + Low speed)	Variant 2 (Teleoperation + High speed)	Variant 3 (AV mode + Low speed)
sigma	0	0	0
tau (s)	1.5	1.5	1.5
decel (m/s^2)	3.5	3.5	2
accel (m/s^2)	1.5	1.5	1.5
emergencyDecel (m/s^2)	9.0	9.0	9.0
maxSpeed (m/s^2)	6.95	13.8	6.95
speedFactor	1.0	1.0	1.0

Parameter name	Variant 1 (Teleoperation + Low speed)	Variant 2 (Teleoperation + High speed)	Variant 3 (AV mode + Low speed)
actionStepLength (s)	0.1	0.1	0.1
responseTime (s)	-	-	90
initialAwareness	-	-	0.87
recoveryRate	-	-	0.015
mrmDecel (m/s^2)	-	-	3

4.12.3 Simulation results

Ten simulation runs pertaining to different random seed numbers have been executed for the aforementioned simulation scenarios. Moreover, traffic data are collected through simulated detectors that are placed at specific locations of the circular route at every 50m. In the following, simulation results are analysed and discussed in terms of traffic efficiency. The reported simulation results encompass performance measurements such as the average vehicle speed and the average automated shuttle travel time, which are necessary for the quantitative assessment tasks in WP13.

The length of the fixed circular route is about 9 km and the average speed limit is 50 km/h except for the road segments belonging to school zones where the speed limit decreases to 30 km/h based on imposed traffic regulations. Figure 71 depicts the average vehicle speed for each simulated scenario variant (1-6) except for the baseline. According to Figure 71 the average vehicle speed observed in the three high-speed variants (variants 2, 4 and 6) is slightly higher than the observed speed of the low-speed variants (variants 1, 3 and 5). The lowest speed is observed in the low-speed scenario including ToC (variant 3) due to traffic disruption caused by ToCs and MRMs. On the other hand, in the case of **green priority for automated shuttles at signalized intersections** the figure depicts that speed is slightly higher for high-speed scenario.

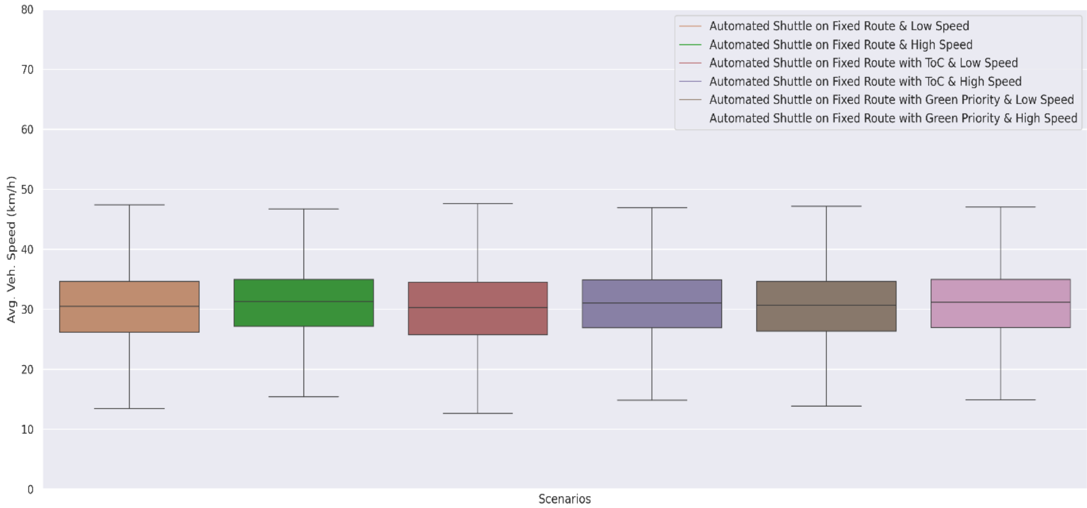


Figure 71: Average vehicle speed pes simulation scenario.

Average throughput is also used as a performance measurement to assess traffic efficiency. Figure 72 shows the number of vehicles that were serviced (exited the network) within an hour of simulation per tested scenario variant. It can be observed that throughput differences among the six variants and the baseline scenario are insignificant. Considering that traffic demand is 1316 vehicles it is clear that vehicular demand can be sufficiently serviced for all simulated scenarios.

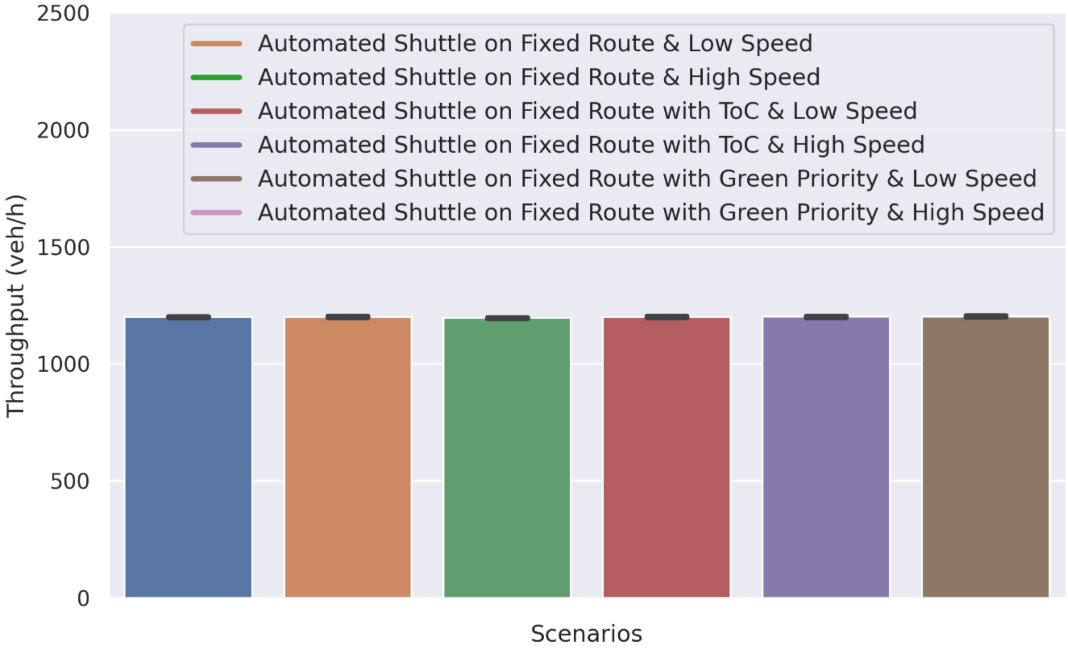


Figure 72: Throughput per simulation scenario.

Speed tempo-spatial plots (generated from simulated detector data) are also presented in order to analyse the traffic flow efficiency on the local scale. Figure 72 shows speed oscillation in space and time for all the simulated scenarios, whereas each plot features the aggregated results of ten simulation seeds. As it can be observed, a speed decrease occurs at the half of the circular route and specifically when vehicles arrive at the Department of Physical Education and Sports Science due to network geometry and the consecutive vehicle stops. Plots also depict the higher average vehicle speed at high-speed scenarios variants compared to the low-speed variants. The introduction of automated shuttles increases consecutive stops and incurs higher traffic disruption, especially in ToC related scenario variants (variants 3, 4). On the other hand, green priority for automated shuttles at signalised intersections reduces slightly queues that are formed upstream of traffic lights, allowing the automated shuttles to cross the intersections either faster or without stopping at all. This result is expected to be more significant for higher demand inputs.

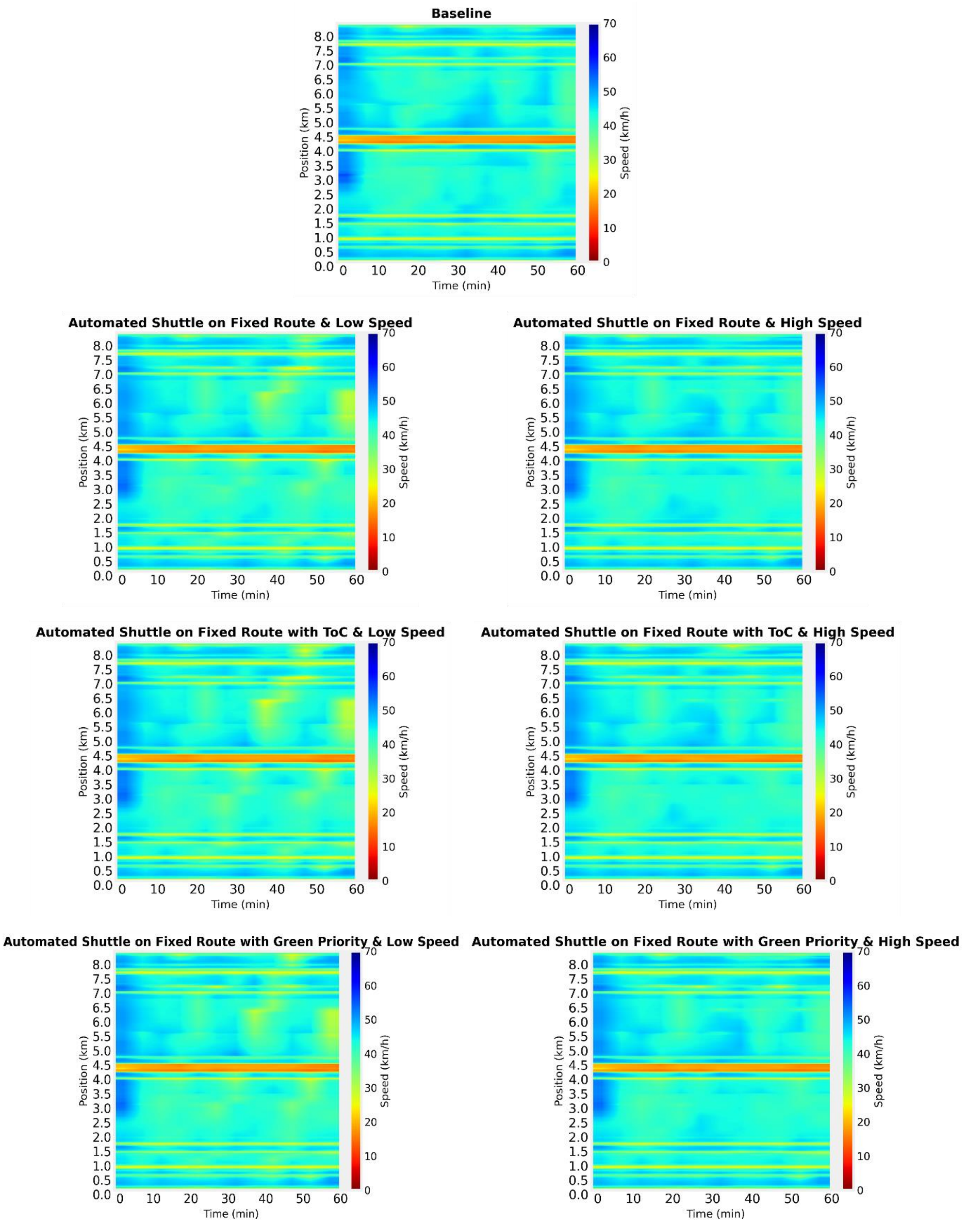


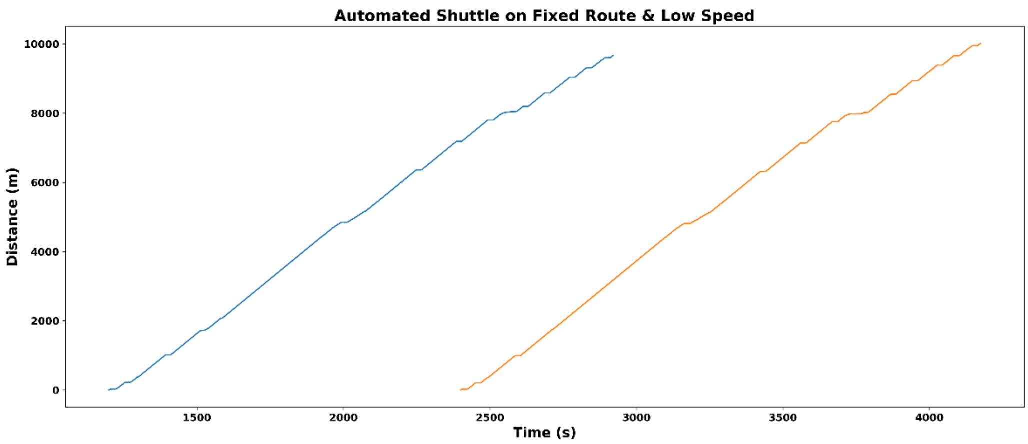
Figure 73: Speed tempo spatial diagrams pes simulation scenario variant.

Table 17 presents the required travel time for an automated shuttle to cross the predefined fixed route for each tested scenario. It is clear that green priority for automated shuttles reduces their travel time by approximately 8% whereas **the green priority combined with high operational speed** reduces the travel time of automated shuttles by 37%.

Table 17: Travel time of automated shuttle per simulation scenario.

Scenario Name	Scenario Variant	Automated Shuttle - Travel time (sec)
Scenario 1	Variant 1 (Teleoperation + Low speed)	1812
	Variant 2 (Teleoperation + High speed)	1116
	Variant 3 (AV mode + Low speed)	1808
	Variant 4 (AV mode + High speed)	1276
	Variant 5 (Variant 1 + Green priority)	1669
	Variant 6 (Variant 2 + Green priority)	1140

Finally, Figure 74, Figure 75 and Figure 76 illustrate the trajectories of the automated shuttles for each simulated scenario. It is clearly shown in Figure 76 that in variants 5 and 6 automated shuttles drive along the fixed route without stopping at the signalized intersections due to green priority. As a result, the automated shuttles arrive faster at their stops and complete the route faster. In case of variant 6 (high speed and green priority) Figure 76 shows the multiple speed adjustments since shuttles exhibit more oscillatory driving behaviour. Scenario variants that encompass ToCs (variants 3 and 4 in Figure 75) result in automated shuttles stop after MRM.



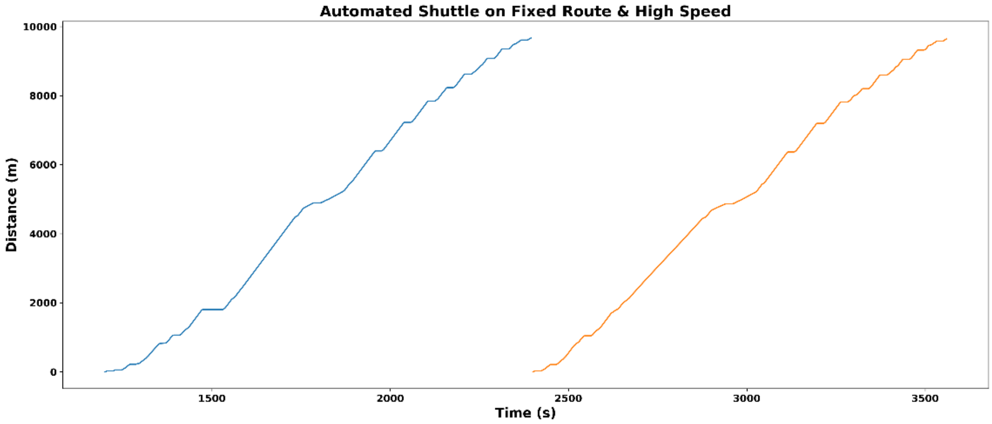


Figure 74: Trajectories of automated shuttles for scenario variants 1 (upper) and 2 (lower).

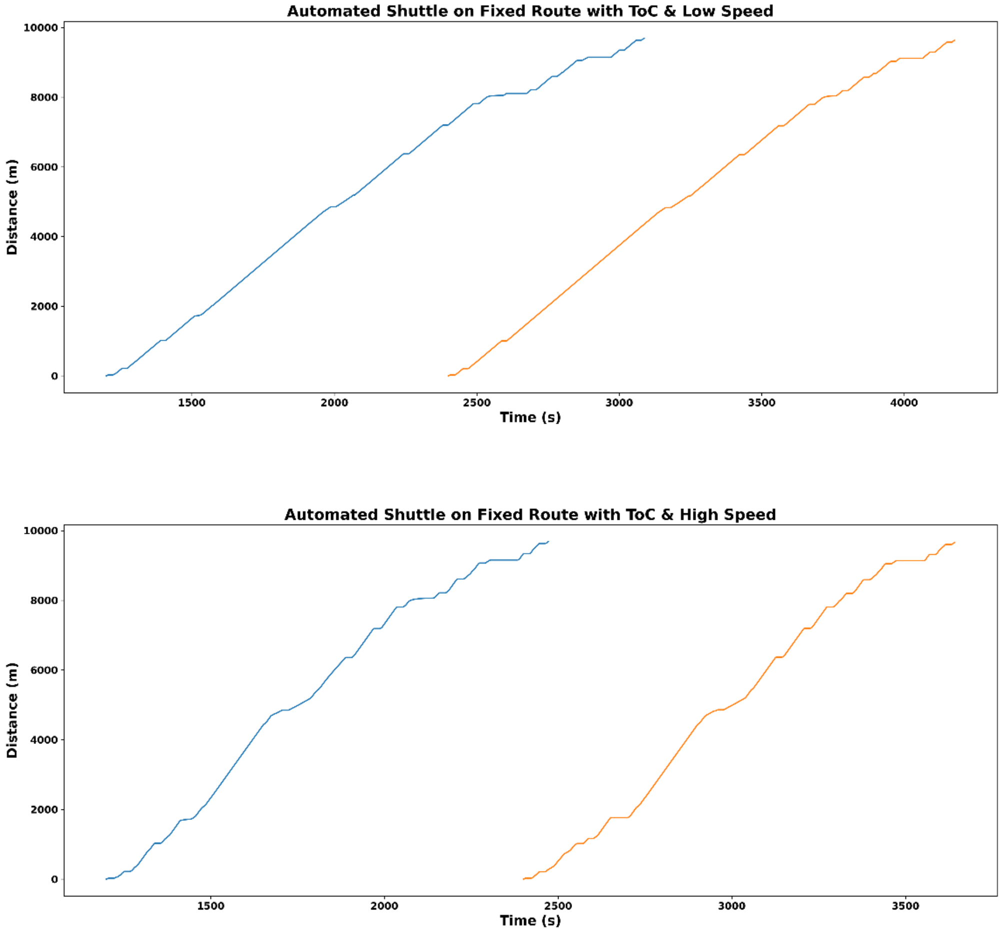
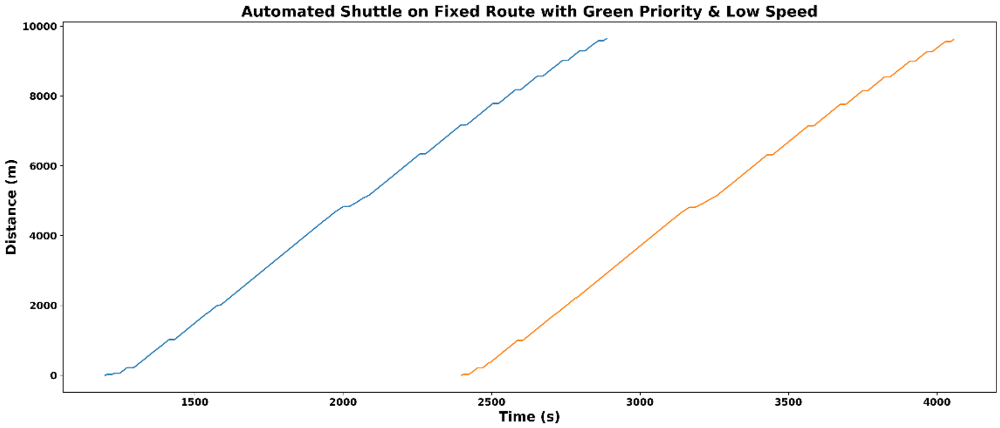


Figure 75: Trajectories of automated shuttles for scenario variants 3 (upper) and 4 (lower).



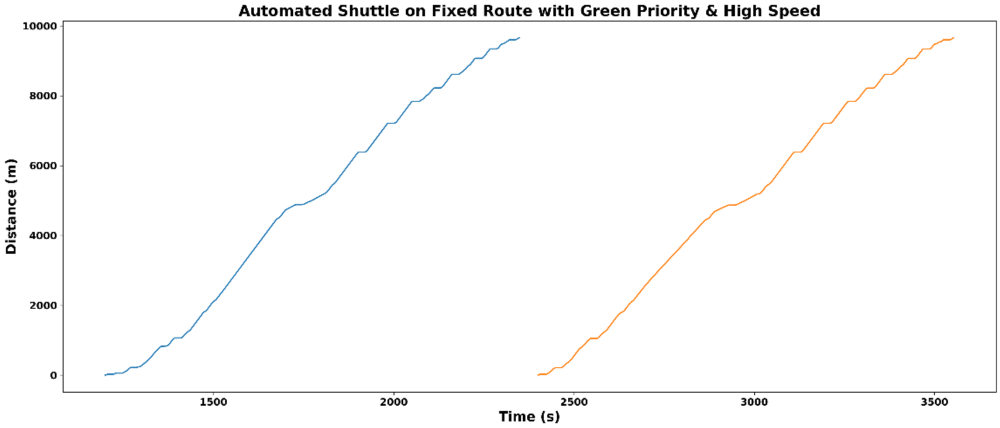


Figure 76: Trajectories of automated shuttles for scenario variants 5 (upper) and 6 (lower).

Summarizing, the objective of the simulations in Trikala is to examine and analyse the operation and the driving behaviour of two automated shuttles that serve the circular route between City terminal and Department of Physical Education and Sports Science. Automated shuttles interact with vehicles, conventional buses, pedestrians, two rail crossings and a parking area. Analysing the produced figures and tables, it is clear that low speed travelling scenario variants or scenario variants which include ToCs/MRMs increase delays. Green priority variants seem to be an efficient solution which reduce the automated shuttles travel time by 37%. Regarding the high-speed variant without ToCs/MRMs or green priority for automated shuttles, a performance similar to green priority variants with respect to travel time is shown.

4.12.4 Next steps

The pilot operation of the AV shuttles along a fixed route in the city of Trikala is expected to provide empirical evidence with respect to their generic driving behaviour. Data collection during pilot operation is expected to encompass AV shuttle position, speed and acceleration during free-flow driving, car-following or hard braking episodes. The latter data will be analysed and used in order to select and calibrate the appropriate car-following models in SUMO that will best reflect the actual AV shuttle operation. If data from the interactions among AV shuttles and surrounding vehicles become available as well, they will be also used in order to appropriately parameterize the behaviour of other vehicle types in the simulation. High-fidelity models are of paramount importance for accurately replicating vehicle behaviour in microscopic traffic simulators and assessing traffic operations with increased reliability. Thus, empirical evidence will ensure that the aforementioned microscopic traffic simulation model developed in SUMO will predict with high accuracy the expected traffic impacts from the introduction of AV shuttles along the fixed route and it will enable a sound evaluation of different traffic management measures that will be tailored to facilitate and enhance the operation of the AV shuttles. The latter information will be of significant value for decision making from the local authorities' side with respect to the robust operation of the AV shuttles and their expected impacts on traffic and the environment. Information pertinent to the improvements in AV shuttle modelling and simulation fidelity based on real world data from the pilot operation will be presented in Deliverable 10.4.

5 Conclusions

The scope of the current document was mainly the definition of the requirements for the Simulation Suite but also the provision of the first evidence of pilot-based simulation results for impact assessment.

Within that scope, the simulation suite, a tool that acquires a common pool of simulation data from the different automated mobility use cases resulting in an integrated and holistic simulated AV fleets operation, was conceptualised as a web-based front-end tool that will provide guidelines about simulation of automated driving and will include (i) a step-by-step guide of simulating automated mobility for different sites and layouts, (ii) the settings for simulation transferability, (iii) potential connections between different levels of simulation models (e.g. vehicle-level, microsimulations, network-level simulations), and (iv) a library including visualised instructions in the used software and tools. The key parameters and possible methodologies to simulate automated driving and attempts to synthesize the simulations for all test sites will also be included. The different options (as discussed in Section 3.2.4) for upscaling impacts from microsimulation to macroscopic models and vehicle-level to microscopic scenarios were also discussed and will be included in the suite. Finally, the suite will be designed in a user-friendly so that even early researchers, Ph.D. students and external stakeholders to the project can follow the provided guidelines.

The concrete milestones concerning the work of WP10 and until the next deliverable include:

- The thorough supply of content to the web-based tool and the beginning of web-designing it.
- The exploitation of the SHOW dashboard with regards to demo site data and the continuation of simulation runs with real demo data
- The demonstration of upscaling simulation impacts from microsimulation to macrosimulation (e.g. for the Madrid simulations)
- The tailoring of simulations towards the impact assessment and the collaboration with WP13 in order to estimate the indicated KPIs.

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Appendix I

Table 18: KPI description and research questions.

KPI # D9.3 - Updated	Impact	Description	Target/RQ
B2	Conflicts	Total number of conflicts with other road users (including VRUs) and infrastructure. Categories of the conflicting road users would need to be developed. *A conflict is a critical traffic situation in which two (or more) road users approach each other in such a manner that a collision is imminent and a realistic probability of personal injury or material damage is present if their course and speed remain unchanged.	What is the number of number of conflicts with other road users and infrastructure during the operation of the AV?
A1	Safety enhancement	% of expected safety enhancement (from WP10 simulations)	What is the safety enhancement induced by AV services when compared to the existing (public) transport services? In terms of accidents, conflicts, harsh events and illegal overtaking frequency. Target is >10% (as PT/ DRT urban accidents are scarce)
B7	Average speed	Average speed of pilot vehicles	What is the average speed of pilot vehicles on the pilot route?
B8	Acceleration variance	Variance of pilot vehicle acceleration	How does the acceleration of pilot vehicle vary on the pilot route?
B10	Non-scheduled number of stops per kilometre	The number of non-scheduled vehicle stops per kilometre. A non-scheduled stop is recorded is a stop during a trip, e.g. stop for red light, congestion or avoid collision.	How often does a pilot vehicle have to make a non-scheduled stop?
B12	Service reliability	Punctuality for vehicles and passengers	How often did the pilot vehicle arrive/depart as scheduled?
B14	Speed per vehicle type	Average vehicle speed per vehicle types	How does the introduction of pilot vehicles impact the average speed for all vehicle types?
B15	Average vehicle delay	Average travel time delay per vehicle types	How does the introduction of pilot vehicles impact the average vehicle delay for all vehicle types?
B16	Vehicle stops	Number of vehicle stops per vehicle for all vehicle types	How does the introduction of pilot vehicles impact the number of stop in traffic?
B17	Hard braking events in traffic	The number of decelerations larger than X m/s^2 for all vehicle types in traffic	How does the introduction of pilot vehicles impact the number of hard braking event in traffic?
B18	Total intersection delay	Total vehicle delays in an intersection	How does the introduction of pilot vehicles impact the vehicle delay on intersection?
B19	Total network travel time per vehicle type	Total travel time in network per vehicle type	How does the introduction of the new mobility system affect the total network travel time?
B21	Total mileage	Total number of kilometres travelled in a network, per mode of transport and/or trip purpose	How does the introduction of the new mobility system affect the

KPI # D9.3 - Updated	Impact	Description	Target/RQ
			vehicle kilometres travelled per mode?
B22	Total network delay	Average travel time delay over the entire network	How does the introduction of the new mobility system affect the total network delay?
B23	Average network speed	Average vehicle speed in a network	How does the introduction of the new mobility system affect the average network speed?
B13	Kilometres travelled	km's travelled by a pilot vehicle	How many kilometres did the pilot vehicle travel?
B20	Modal split	The share of each mode choice (in number of trips or distance travelled)	How does the introduction of the new mobility system affect the modal split ?
B24	Number of trips	Number of trips in the network, per mode and/or trip purpose	How does the introduction of the new mobility system affect the number of trips performed? (e.g. caused by induced demand)
B25	Energy use	Energy use per kilometre of a vehicle	How does the introduction of the new mobility system change energy consumption of vehicles?
B26	CO_2, PM, NOx Emissions	Emissions of a vehicle (CO2, PM, NOx)	How does the introduction of the new mobility system change the amount of vehicle emissions related to transport in the area of interest?
B27	Concentrations (air quality)	Concentrations of pollutants (e.g. NOx) along roads	How does the introduction of the new mobility system affect the air quality in the area of interest?
B28	Noise	Noise levels along roads	How does the introduction of the new mobility system affect the traffic noise in the area of interest?
B29	Amount of travel	Person kilometres of travel per year in an area	How would kilometres travelled by people in an area with shared AV services change?
B30	Shared mobility rate	% of trips made sharing a vehicle with other	What is the proportion of trips where the vehicle is shared between passengers not travelling together?
B31	Vehicle utilisation rate	% of time a vehicle is in motion (not parked)	What is the proportion of time that the AV is not parked and how was the vehicle being used when in motion?