SHared automation Operating models for Worldwide adoption

SHOW

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D10.1: Simulation scenarios and tools

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Executive Summary

This document identifies all simulation tools which are used by all partners participating in Work Package 10 of the SHOW project. Their applications range from vehicle level of shared CCAVs up to mobility level, and they are used to enrich all field experiment results of the SHOW pilots. In addition, a relation of tools to application areas and to SHOW pilots is presented. Furthermore, multiple simulation scenarios are introduced, which define the used tools to evaluate the scenario, their expected results as well as the addressed KPIs from A9.4. After a short presentation of the SHOW sites that are investigated in simulation in this WP, the simulation plans of all participating partners are presented and linked to at least one of the pilot sites. Additionally, data inputs that are required from the SHOW sites are stated.

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Abbreviation List

Abbreviation	Definition
AD	Automated Driving
AV	Autonomous Vehicle
DCP	Distributed Co-Simulation Protocol
DRAC	Deceleration Rate to avoid a Crash
DRT	Demand Responsive Transport
HAD	Highly Automated Driving
KPI	Key Performance Indicator
MaaS	Mobility as a Service
ODD	Operational Design Domain
OBU	Onboard Unit
OSS	Open Source Software
PET	Post Encroachment Time
PT	Public Transport
RSU	Roadside Unit
ROS	Robot Operating System
SUMO	Simulation of Urban MObility
TraCI	Traffic Control Interface (for SUMO)
TTC	Time to Collision
VRU	Vulnerable Road User
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle

Abbreviation	Definition
V2X	Vehicle to Everything
WP	Work Package

1 Introduction

1.1 Purpose of the document

The purpose of the simulation scenarios and tools is to identify simulation tools supporting and enriching field experiments results of the real-world SHOW pilots. In addition, this document provides a description of the simulation scenarios that are investigated and relates them to the addressed KPIs from Activity A9.4. Furthermore, the simulation plans of all partners participating in WP10 are described and related to the SHOW sites.

1.2 Intended Audience

On the one hand, this document serves as a manual for the partners involved in WP10 by providing information on relevant simulation tools and scenarios and showing connections to the real-world pilots, especially the required inputs. On the other hand, it serves as an informative document describing the simulation approaches within SHOW for external stakeholders, and they will be able to understand how these simulations are integrated into the SHOW sites.

1.3 Interrelations

This document was developed in WP10: Operations simulation models platform and tools, which started in M1 with Activity A10.1: Simulation framework for extension of SHOW test sites. All other activities within WP10 are also closely related to the simulation scenarios and tools as they contribute to the simulation tools being used and the scenarios being evaluated.

As a starting point, the defined KPIs and the impact assessment framework from A9.4 is used as a starting point for the simulations. Therefore, the simulation scenarios are defined considering the impact areas that will be assessed as part of WP13.

Finally, this document identifies the contribution of the Pilot sites regarding the necessary inputs to the simulation partners.

2 Identification of Simulation Tools

Due to the high number of participating partners in Work Package 10, the focus of simulation might vary strongly amongst the partners. As a result, numerous simulation tools are used within SHOW. This chapter aims at identifying these tools which are used by the participating partners of WP10 for all aspects of simulation purposes.

All of these tools are presented with a short description and the area of application within SHOW. Figure 1 provides an overview of all simulation tools, linked to the partners that use them within the WP.

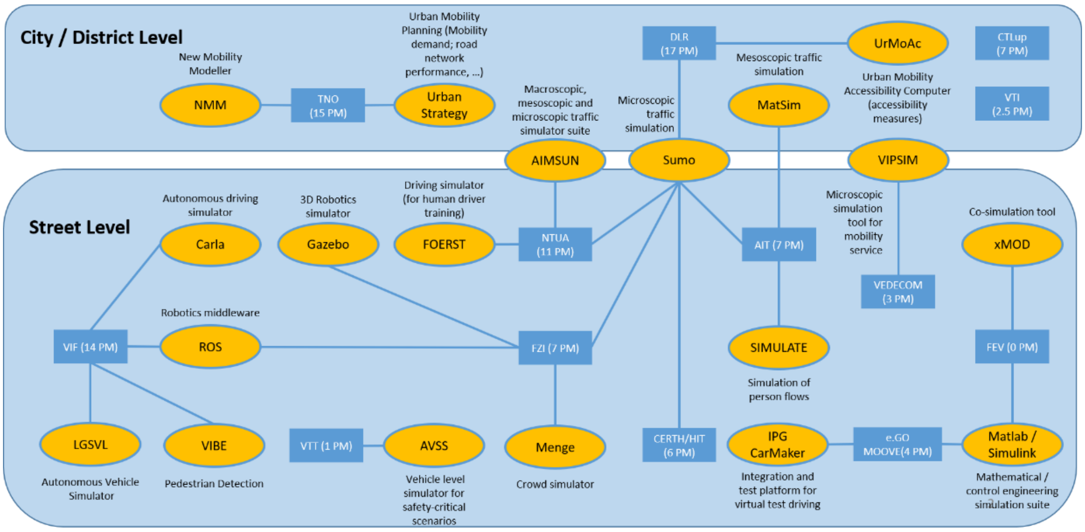

Figure 1: Overview of Simulation Tools as used by Partners.

Moreover, the tools are grouped into three categories: simulation environment, framework and model. Here, simulation environments are simulators which supply an extensive virtual world composed of 3D actor models such as vehicles or pedestrians, streets, buildings and more. In addition, the simulation environments support sensors such as cameras for perceiving the state of this virtual environment, including positions of actors, their speed and acceleration. Frameworks are software libraries and provide drivers, hardware abstraction or inter-process communication. In contrast to simulation environments, models focus on one aspect for simulation, e.g. there are models for the simulation of one special sensor or models for pedestrian crowd simulation.

In the following, all simulation tools provided in Figure 1 are listed in detail with a description, type, area of application, sharing (i.e. whether tool is only used internally or publicly available), usage license, implementation, website and reference.

2.1 Simulation Environments

2.1.1 Gazebo

Field Name	Field Content
Description	Gazebo offers the ability to accurately and efficiently simulate populations of robots in complex indoor and outdoor environments. At your fingertips is a robust physics engine, high-quality graphics, and convenient programmatic and graphical interfaces. Best of all, Gazebo is free with a vibrant community.
Type	Simulation Environment
Area of Application	Vehicle Dynamics, Environment
Sharing	External (Open Source)
License	Apache License 2.0
Implementation	C++
Website	http://gazebosim.org/
Reference	-

2.1.2 CARLA

Field Name	Field Content
Description	CARLA has been developed from the ground up to support development, training, and validation of autonomous driving systems. In addition to open-source code and protocols, CARLA provides open digital assets (urban layouts, buildings, vehicles) that were created for this purpose and can be used freely. The simulation platform supports flexible specification of sensor suites, environmental conditions, full control of all static and dynamic actors, maps generation and much more.
Type	Simulation Environment
Area of Application	Vehicle Dynamics, Environment
Sharing	External (Open Source)
License	MIT License
Implementation	C++, Python
Website	http://carla.org/
Reference	[1]

2.1.3 FOERST Driving Simulator

Field Name	Field Content
Description	The driving simulator consists of 3 LCD wide screens 40'' (full HD: 1920x1080pixels), driving position and support motion base. The dimensions at a full development is 230x180cm., while the base width is 78cm and the total field of view is 170 degrees. It features adjustable driver seat, steering wheel 27cm diameter, pedals (throttle, brake, clutch), dashboard (tachograph, tachometer) and two external and one central mirror that appear on the side and on the main screen, and display in real time objects and events that are happening behind the 'vehicle'. The controls available to the driver are: 5 gears plus reverse gear, flash, wipers, lights, horn, brake and starter. The virtual - animated road environment is generated by computer programming tool and displays the road environment. Users can drive along the road under realistic conditions. It is highlighted that driving conditions in the simulator cannot be absolutely identical to those perceived by the driver in real driving, but the change of the driver behaviour does not necessarily affect the relative influence of various parameters.
Type	Simulation Environment
Area of Application	Environment, Unexpected events
Sharing	Internal
License	-
Implementation	-
Website	https://www.fahrsimulatoren.eu/de/
Reference	-

2.1.4 Automated Vehicle Scenario Simulator (AVSS)

Field Name	Field Content
Description	The Automated Vehicle Scenario Simulator (AVSS) is VTT's in-house software that is used for analysing and developing AV logic for different traffic scenarios. It can simulate the decisions and movement of several automated passenger cars and buses at a time, including pre-programmed movement of other road users such as other cars, roadworks, traffic lights, pedestrians etc. The simulation uses real AV algorithms – although, there are several optional algorithms. It can be used to study safety-critical scenarios and related logic and safety margins.
Type	Simulation Environment
Area of Application	Vehicle Dynamics, Environment
Sharing	Internal
License	-
Implementation	Java
Website	-
Reference	-

2.1.5 MATSim

Field Name	Field Content
Description	MATSim provides a framework to implement large-scale agent-based transport simulations. The framework consists of several modules which can be combined or used stand-alone. Modules can be replaced by custom implementations to test single aspects of your own work. Currently, MATSim offers a framework for demand-modelling, agent-based mobility-simulation (traffic flow simulation), re-planning, a controller to iteratively run simulations as well as methods to analyse the output generated by the modules.
Type	Simulation Environment
Area of Application	Agent Based Transport Simulation
Sharing	External (Open Source)
License	GPL v3.0
Implementation	Java
Website	https://www.matsim.org/
Reference	[2]

2.1.6 SIMULATE

Field Name	Field Content
Description	SIMULATE is AIT's in-house software that is built on a scalable and flexible system architecture to develop and apply pedestrian simulation models from the microscopic to the macroscopic level. SIMULATE includes a range of pedestrian models (e.g. Social Force approaches, Cellular Automaton, Optimal Reciprocal Collision Avoidance model, Optimal Steps Model, Queuing Model, Graph-based Model) as well as models for movement behaviour of bikes and cars particularly used in shared spaces analysis. SIMULATE provides APIs to different programming languages and simulation frameworks (e.g. ROS).
Type	Simulation Environment
Area of Application	Agent Based Simulation; Pedestrian Models; Shared Space (Pedestrian, Bike, Cars)
Sharing	Internal
License	-
Implementation	Java, C++, Matlab
Website	https://www.ait.ac.at/SIMULATE
Reference	[3]

2.1.7 Urban Strategy

Field Name	Field Content
Description	Urban Strategy is an interactive tool for spatial planning, providing detailed insight into the effects of modifications to the surroundings. It assigns traffic to the network (for example the activity schedules resulting from the New Mobility Modeller) and immediately computes resulting delays, mileage as well as the environmental impact. Besides that, modifications such as road closures, parking place availability and changes in speed limits can be applied and within a few minutes the impact can be visualized.
Type	Framework + Simulation environment
Area of Application	Traffic assignment; Environmental impact (air, noise, etc.)
Sharing	Internal
License	-
Implementation	C++, CUDA
Website	https://www.tno.nl/en/focus-areas/traffic-transport/roadmaps/smart-and-safe-traffic-and-transport/societal-impact-for-accessibility-and-liveability/big-data-ecosystems-collaborating-on-data-controlled-cities/urban-strategy-brings-planning-effects-into-clear-focus/
Reference	-

2.1.8 LGSVL Simulator | An Autonomous Vehicle Simulator

Field Name	Field Content
Description	The LGSVL Simulator is a simulator that facilitates testing and development of autonomous driving software systems and is under active development on Github. The simulator is fully integrated with the popular open source platforms Apollo and Autoware and has a ROS/ROS2 and Python interface. It provides real-time outputs from sensors including camera, LiDAR, RADAR, GPS, and IMU. Environmental parameters can also be changed, including map, weather, traffic, and pedestrian. The simulation platform supports flexible specification of sensor suites, environmental conditions, full control of all static and dynamic actors and maps generation (road editor or point cloud importation).
Type	Simulation Environment
Area of Application	Vehicle Dynamics, Environment
Sharing	Internal
License	Apache License 2.0
Implementation	C++, Python, Unity
Website	https://www.lgsvlsimulator.com/
Reference	[4]

2.1.9 VISUM/VISSIM

Field Name	Field Content
Description	PTV Vissim is the world's most advanced and flexible traffic simulation software Simulate complex vehicle interactions realistically on a microscopic level Model demand, supply, and behaviour in detail Simulate new forms of mobility such as CAV and MaaS Seamless integration with PTV Visum, the world's leading traffic planning tool VISUM: PTV Visum is the world's leading traffic planning software designed for transport planners to empower cities Conduct traffic analyses, forecasts and GIS-based data management Model all road users and their interactions Plan public transport services Develop advanced and future-proofed transport strategies and solutions.
Type	Simulation Environment
Area of Application	Macroscopic and Microscopic Traffic Simulation
Sharing	External
License	commercial
Implementation	Proprietary
Website	https://www.ptvgroup.com/de/loesungenprodukte/ptv-visum/; https://www.ptvgroup.com/en/solutions/products/ptv-vissim/
Reference	-

2.2 Frameworks

2.2.1 Robot Operating System (ROS)

Field Name	Field Content
Description	The Robot Operating System (ROS) is a set of software libraries and tools that help you build robot applications. From drivers to state-of-the-art algorithms, and with powerful developer tools, ROS has what you need for your next robotics project. And it's all open source.
Type	Framework
Area of Application	Intercommunication, HW abstraction
Sharing	External (Open Source)
License	BSD-3-Clause
Implementation	Python, C++, Lisp
Website	https://www.ros.org/
Reference	[5]

2.3 Models

2.3.1 Simulation of Urban MObility (SUMO)

Field Name	Field Content
Description	"Simulation of Urban MObility" (Eclipse SUMO) is an open source, highly portable, microscopic and continuous road traffic simulation package designed to handle large road networks. It allows for intermodal simulation including pedestrians and comes with a large set of tools for scenario creation.
Type	Model
Area of Application	Traffic Simulation + simulation environment
Sharing	External (Open Source)
License	EPLv2
Implementation	C++, additional tools in Python
Website	https://sumo.dlr.de/docs/index.html
Reference	[6]

2.3.2 Menge

Field Name	Field Content
Description	Menge is a powerful, cross-platform, modular framework for crowd simulation developed at the University of North Carolina - Chapel Hill. Crowd simulation is a large, complex domain. Developing an effective simulator requires developing many interlocking components. Menge provides basic implementations of many of these components. As such, Menge provides an extensible common platform to facilitate crowd simulation research and development. It provides a basis for performing independent research in motion planning, collision-avoidance, spatial acceleration, behavioural modelling, and more. Its plug-in architecture allows researchers to focus on individual aspects of crowd simulation, relying on built-in functionality for the other components.
Type	Model
Area of Application	Pedestrian Crowd Simulation
Sharing	External (Open Source)
License	Apache License 2.0
Implementation	C++
Website	http://gamma.cs.unc.edu/Menge/
Reference	[7]

2.3.3 AIMSUN

Field Name	Field Content
Description	Aimsun Next software allows you to model transportation networks small and large: from a single intersection to an entire region. Static and dynamic (equilibrium) traffic assignment, mesoscopic, microscopic and hybrid mesoscopic-microscopic simulation along with OD matrix manipulation tools
Type	Model
Area of Application	Traffic Simulation
Sharing	Internal
License	AIMSUN Next Advanced Edition
Implementation	Python
Website	https://www.aimsun.com/aimsun-next/
Reference	-

2.3.4 UrMoAc

Field Name	Field Content
Description	UrMoAC is a tool for computing accessibility measures. The tool works on the fine-grained level of single buildings and computes the fastest routes between a set of origins and a set of destinations. UrMoAC supports different limits for computing the accessibility measures as well as the possibility to load aggregation areas both for sources and for destinations. Different output options are available. The tool supports the modes walking, bicycling, motorised individual transport and public transport.
Type	Model
Area of Application	Accessibility Measures
Sharing	External (Open Source)
License	GPL v3.0
Implementation	Java, additional tools in Python
Website	https://github.com/DLR-VF/UrMoAC
Reference	[8]

2.3.5 CarMaker

Field Name	Field Content
Description	Complete solution for virtual test driving. Comes with interfaces to Matlab/Simulink and C, among others.
Type	Model
Area of Application	Vehicle dynamics
Sharing	External
License	Proprietary
Implementation	Matlab, C
Website	https://ipg-automotive.com/products-services/simulation-software/carmaker/
Reference	-

2.3.6 Matlab/Simulink

Field Name	Field Content
Description	Model-based designer.
Type	Model
Area of Application	Pre- and Postprocessing
Sharing	External
License	Proprietary
Implementation	Matlab, C
Website	https://de.mathworks.com/products/simulink.html
Reference	[9]

2.3.7 New Mobility Modeller (NMM)

Field Name	Field Content
Description	New Mobility Modeller is an explorative model for destination choice and mode choice developed for joint impacts of emerging and traditional mobility concepts. Combing the choice model with a network fundamental diagram, NMM can be used to assess impacts on mileage, delays and vehicle number in a city or region, with a large number of traffic conditions.
Type	Model
Area of Application	Activity Based Simulation
Sharing	Internal
License	-
Implementation	C++
Website	-
Reference	[10]

2.3.8 VIBE

Field Name	Field Content
Description	VIBE: Video Inference for Human Body Pose and Shape Estimation [CVPR-2020]
Type	Model
Area of Application	Pedestrian Detection
Sharing	External (Open Source)
License	non-commercial scientific research purposes
Implementation	Python
Website	https://github.com/mkocabas/VIBE
Reference	-

2.4 Summary

In summary, Table 1 lists all of the tools mentioned above and summarizes the usage conditions, the area of application within SHOW as well as the partners using it.

Table 1: Summary of Simulation Tools.

Tool	Area of Application
Simulation Environments	
Gazebo	Vehicle Dynamics, Environment
Carla	Vehicle Dynamics, Environment
FOERST	Environment, Unexpected Events
AVSS	Vehicle Dynamics, Environment
MATSim	Agent Based Transport Simulation
SIMULATE	Agent Based Simulation, Shared Space
Urban Strategy	Traffic Assignment, Environment Impact
LGSVL Simulator	Vehicle Dynamics, Environment
VISUM/VISSIM	Traffic Simulation
Frameworks	
ROS	Intercommunication, HW abstraction
Models	
SUMO	Traffic Simulation, Simulation Environment
Menge	Pedestrian Crowd Simulation
AIMSUN	Traffic Simulation
UrMoAc	Accessibility Measures
CarMaker	Vehicle Dynamics
Matlab/Simulink	Pre- and Postprocessing
NMM	Activity Based Simulation
VIBE	Pedestrian Detection

3 Simulation Scenarios

This chapter aims at describing the generalized scenarios which are investigated by the participating partners of WP10 for their simulations. As the focus between the partners might vary, multiple scenarios are defined. All of the identified simulation scenarios are presented with a description and furthermore, they are linked to relevant simulation tools from chapter 2. In addition, expected results from the scenarios are identified and their addressed KPIs are listed.

3.1 Overview of Simulation Focuses

As mentioned above, the focus of the simulations conducted in WP10 of the project varies between the partners. On the one hand, some partners focus on the simulation of vehicles and/or pedestrians at street level. On the other hand, some others focus on simulation at city or district level. Figure 2 provides an overview these simulation focuses by mentioning all relevant aspects.

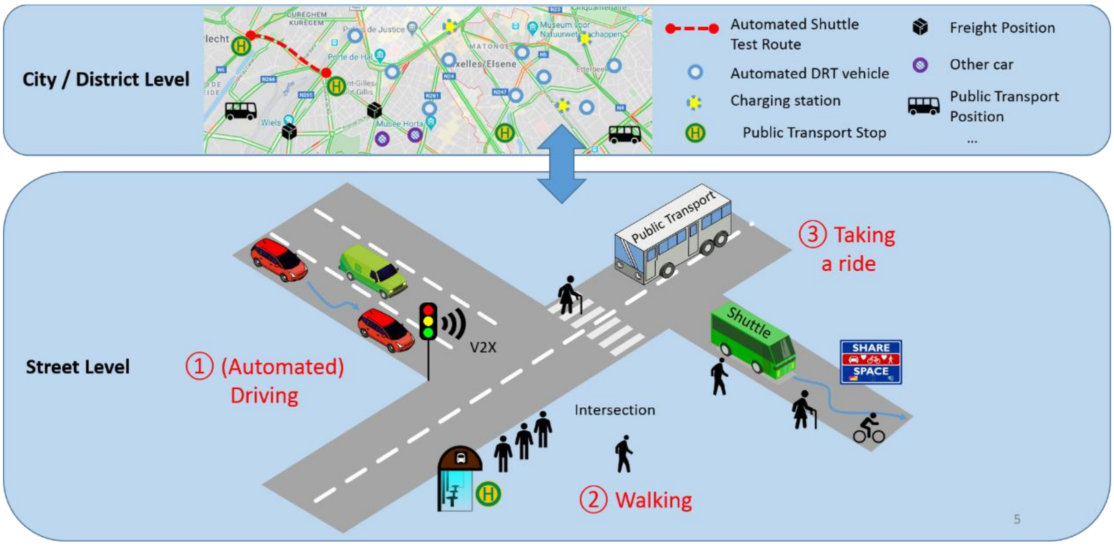

Figure 2: Overview of Simulation Focuses within WP10.

Starting from the simulation focuses, multiple generic simulation scenarios are introduced in the following. These scenarios are meant to cover all simulations which are done by the partners involved in WP10. In addition, the scenarios are linked to the simulation tools described in chapter 2, as well as the addressed KPIs from Activity A9.4.

3.2 Scenario 1: Simulation of Automated Shuttles on Fixed Route

3.2.1 Scenario Description

In this scenario, automated shuttles driving on a fixed route, mostly in an urban development area, are simulated. Thereby, the aim is to set up or continue the simulation of a virtual twin of the shuttle route of a real-world pilot within SHOW. One Example is the fixed shuttle route in Trikala, Greece as part of the Trikala satellite site, which is described in section 4.8.

In the fixed route scenarios, the automated shuttles follow a given route and stop at predefined stops in order to allow passengers to get in or out. In simulation, the geometric environment, for example the road network, is modelled and/or validated. Consequently, errors in the geometric representation of the route can be detected and the required adjustments can be communicated to the corresponding real-world pilot site. Moreover, the shuttles are tested on existing lanes and also in mixed traffic, so that possible bottlenecks and critical areas can be identified before starting service in real-world. In particular, mixed traffic includes vulnerable road users (VRUs) such as pedestrians, so that the vehicle behaviour can be tested in relation to them.

More extended simulations of the fixed route scenario might include the simulation of intelligent simulation and the interaction of its interaction with automated vehicles. Furthermore, the simulation scenario can be used to test one or multiple C-ITS Use Cases (5G) in a defined part of the simulated pilot area.

3.2.2 Used Tools

In the fixed route scenario, the used simulation tools from chapter 2 are the simulation environments, as they are used to model the geometric representation of the route, ROS for the simulation of the automated driving stack of the shuttles as well as SUMO and Menge in order to model additional traffic participants.

3.2.3 Expected Results

As already mentioned above, expected results from the scenario are:

- The identification of errors in the high definition map that is used by the automated driving stack.
- The identification of bottlenecks and critical areas on the route.

The validation of the automated driving stack in mixed traffic, especially regarding VRUs, before testing in real-world.

The addressed KPIs of the fixed route simulation scenario are:

- conflicts (time to collision (TTC),
- deceleration rate to avoid a crash (DRAC),
- post encroachment time (PET), optional usage of SSAM-tool for visualization),
- conflicts with VRUs (usage of SSAM-tool[1]),
- comfort,
- occupancy,
- travel time for pedestrians and vehicles,
- average speed of pedestrians and vehicles,
- waiting times for passengers,
- emissions (CO2, NOx, PMx, noise).

3.3 Scenario 2: Simulation of Demand Responsive Transport (DRT)

3.3.1 Scenario Description

This scenario deals with the simulation of Demand Responsive Transport (DRT). Its concept is to allow a fleet of vehicles to serve customer requests based on a central

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[1] https://highways.dot.gov/research/safety/ssam/surrogate-safety-assessment-model-overview

dispatcher. Sub-scenarios can include different numbers of vehicles, different zones of operation or different cost structures. Related issues are, for example, customers with special needs such as extra capacity for rides, variable boarding duration for each person and routing efficiency.

The dispatcher communicates with all equipped vehicles of the fleet and its actions comprise the drop-off and pick-up of passengers as well as the intermodal routing support for person-trips. In particular, the routing has to start and end within a pedestrian network, whereby pick-up and drop-off locations might be restricted.

The dispatch algorithms have to cope with multiple inputs: first, the assignment order has to be specified, for example first come, first served with the consideration of the reservation date. Second, a single reservation can include either one person or multiple people. Third, the dispatcher has to be able to pick up additional passengers while delivering the customers which already got on.

3.3.2 Used Tools

In the DRT scenario, the used simulation tools from chapter 2 are mainly four tools: SUMO, MATSim, New Mobility Modeller and Urban Strategy. SUMO is utilized for the actual simulation of DRT, whereas MATSim is used for impact assessment of automated vehicles in mobility systems using the MATSim DRT-module. Additionally, the New Mobility Modeller and Urban Strategy will be used for an impact assessment of the introduction of DRTs on a city or district level. This will specifically focus on changes in mode choice and the impact on the whole mobility system including traffic efficiency, energy usage, air quality and noise.

3.3.3 Expected Results

Expected results from the DRT simulation scenario are:

- The development/extension of SUMO's DRT algorithm. This includes, amongst others, the extension of the dispatch algorithms, the integrating of a flexible pick-up and drop-off as well as the extension of the route planning algorithm.
- The examination of the AV-functions according to the shuttles‘ characteristics and the use of those functions in macrosimulation tools.
- The examination/extension of the features and functions related to public transit, e.g. busses or trams.
- The development/extension of TraCI functions, for example regarding tele-operations.
- Deduction of mode choice decisions and modal split under different scenarios including both soft measures, e.g. congestion charges or changes in ticket prices for public transport as well as hard measures, e.g. new automated public transport lines, urban development projects and implementation of new transport services such as autonomous vehicles.
- Impact assessment and impact forecasting of transport measures and their impact on traffic conditions, emissions and noise.
- An interactive platform to be used by infrastructure managers or governmental organizations where one can adjust and add the availability of DRTs such that the impacts on traffic conditions, emissions and noise will automatically be computed and visualized.

The addressed KPIs of the DRT simulation scenario are:

- Travel time,

- Distance,
- Average Speed,
- Occupancy rate,
- Amount of travel,
- Shared mobility rate,
- Vehicle utilisation rate,
- Inequality in transport,
- Willingness to pay,
- Willingness to share a ride,
- Reduction in CO_2 and noise levels,
- Reduction in energy consumption and
- Empty vehicle kms.

3.4 Scenario 3: Simulation of Public Transport Stops

3.4.1 Scenario Description

In this scenario, the complex environment at public transport stops consisting of both bus and railway stations is simulated. This includes the simulation of already existing real-world public transport stops and the integration of AV operation into the simulation. Hereby, especially very busy stations are handled. An example is given in Figure 3, showing a public transport stop in Graz, Austria as part of the Austrian Mega Site.

Figure 3 Public Transport Stop in Graz, Austria

Furthermore, boarding and alighting behaviour at stops of the autonomous bus and the interaction of AVs and other road users, in particular VRUs, are simulated. This is done by means of connecting different simulation tools (e.g. SIMULATE and SUMO) in order to integrate road user behaviour in a more realistic fashion.

Another interest is the prediction and simulation of pedestrian movement at the transport stop, also considering pedestrian activity recognition such as walking or waiting. This prediction will then be used for the navigation and motion planning of the autonomous vehicle.

Different sub-scenarios can be defined: first, the peak hour with a high number of pedestrians and busses will be investigated. Second, extended intervals due to problems on a bus line cause large groups of waiting passengers, partially blocking the lane of the AV, are simulated. Third, by reducing the intervals of the bus and tram lines, reduced waiting times are simulated. Here, the increased traffic of public transport vehicles will eventually affect the AV operations. Furthermore, a failure of railway operations will be simulated, resulting in large pedestrian flows from the railway station to the bus and tram stops. The sub-scenarios are created by varying the origin-destination relations, the share of public transport usage (bus lines, tram, train), the number of passengers and the frequency of bus and tram services.

More extended simulations of the public transport stop scenario might include the simulation of intelligent infrastructure and the integration of V2X communication. Thereby, pedestrians can be detected offboard in order to support measurements of the automated vehicle. In addition, creating a photorealistic simulation of the environment will also be considered.

3.4.2 Used Tools

In the public transport stop scenario, the used simulation tools from chapter 2 are the simulation environments such as LGSVL, Carla or Microsoft AirSim as they are used to model the public transport stop. In addition, SIMULATE and Menge are used to integrate VRUs such as pedestrians or bicycles. They are also used to simulate boarding and alighting in connection with SUMO for the complete simulation of AVs. Again, ROS/Autoware are used for the simulation of the automated driving stack. Regarding measurements, several own programmed software is used.

3.4.3 Expected Results

Expected results from the scenario are:

- Interfaces between different simulation tools, for example between SIMULATE, SUMO and ROS, will be developed in order to create a more realistic simulation of the public transport stop.
- The simulated shuttle should not block bus operation at the bus stop by reacting efficiently to arriving busses. Consequently, it should move away quickly and stop at another place when a bus arrives.
- An adequate movement prediction of the VRUs and the busses.
- The derivation of interaction information between AVs and VRUs.
- The derivation of information on optimization of station/shuttle designs to support smaller passenger exchange times.

The addressed KPIs of the public transport stop simulation scenario are:

- Collision avoidance,
- conflicts with VRUs,
- Time headway,
- Proportion of stopping,
- Manual take-over count,
- Hard breaking,
- Travel time,
- Distance,
- Average speed,
- Duration and length of trips,
- Low speed due to VRU,
- User quality perception,
- User trust,
- User safety perception,
- Perceived usefulness,
- Passenger exchange times and
- Average waiting times of the passengers at the station.

4 Link to SHOW Sites and Data Requirements

All simulations done within the WP are related to the SHOW sites, which are shown in Figure 4.

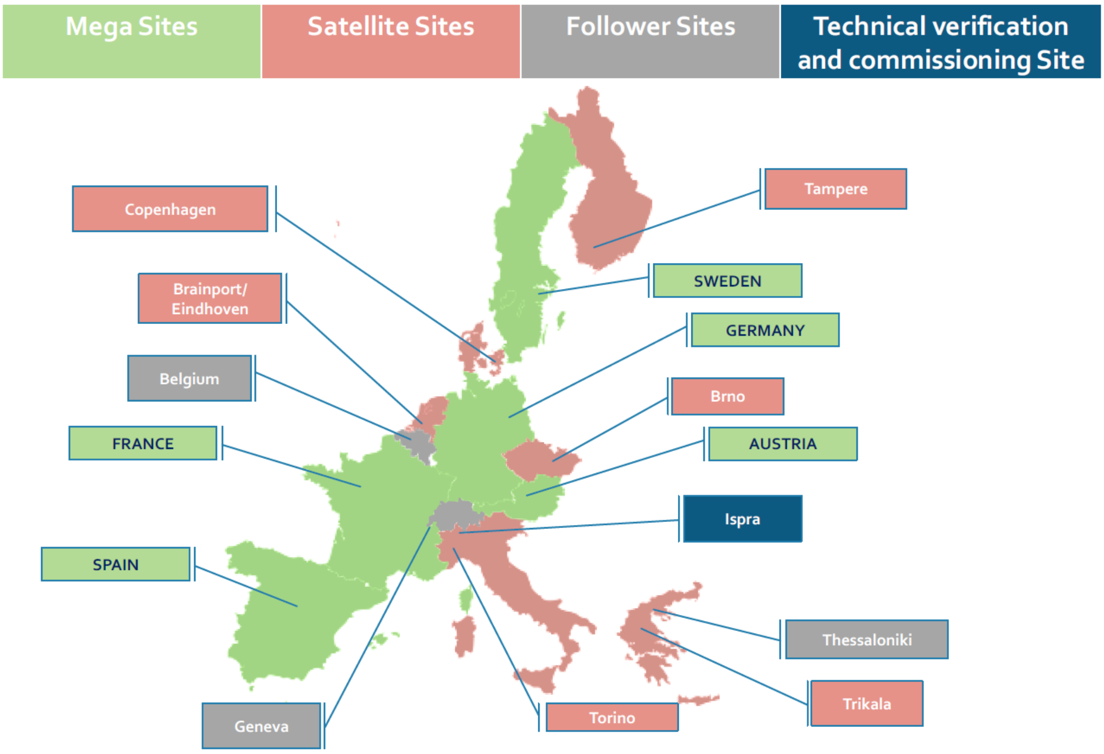


Figure 4 SHOW demonstration sites.

The partners involved in the WP are closely linked to specific SHOW sites. This results from the nature of the project. For that reason, not all SHOW sites, but only a subset of them are considered for the first iteration of site-specific simulations.

The SHOW sites which have been chosen for the first simulation iteration are shown in Table 2. Other sites, such as the French mega site (see section 4.5), will be considered at a later stage. An update including descriptions of the missing sites will be given in D10.2.

Table 2: Relation of partner to SHOW sites.

	Aachen	Karlsruhe	Braunschweig	Vienna*	Graz	Linköping	Brainport Eindhoven	Tampere	Trikala	Copenhagen*
DLR			x			x				
TNO							C			
VIF					C					
NTUA										TBD
AIT				C						
FZI		C								
CERTH/HIT									C	
e.Go Moove	x									
VTI						x				
VTT								x		

Note: x within a cell states that the partner's simulation is linked to the specific SHOW sites, whereas **C** states that the partner's simulation is essential for the development of the specific SHOW sites. Please also note that first Vienna is not a SHOW site anymore (see also section 4.2.1) and second NTUA's link to the Copenhagen site is still under consideration at the time of writing (see also section 5.10). Therefore, these initial simulation plans will be updated in D10.2.

In the following, each SHOW site which is simulated in the first simulation iteration and which is linked to at least one of the scenarios defined in chapter 3 is presented shortly.

4.1 The German twin Mega Pilot

4.1.1 Aachen

The test site Campus Melaten Nord in Aachen is shown in Figure 5. It is a peri-urban environment located close to the borders of both Netherlands and Belgium, easily accessible and fully connected to public transport. The Campus Melaten primarily hosts RWTH institutes. The road network consists of mixed lanes for both public transport (PT) and regular traffic. There are bicycle lanes on all roads separated from the road through lane markings as defined in the road traffic regulations. The traffic density is low to medium, consisting of PT, industrial and private vehicles, pedestrians and bicycles.

Up to two automated e.GO People Mover will be operating in a ring feeder mode partially as on-demand service and partially to extent and complement the regular PT system within the test site area. The People Movers will be interfacing PT and interfacing to connected intelligent DRT and MaaS applications in Aachen established by the public transport service provider ASEAG.

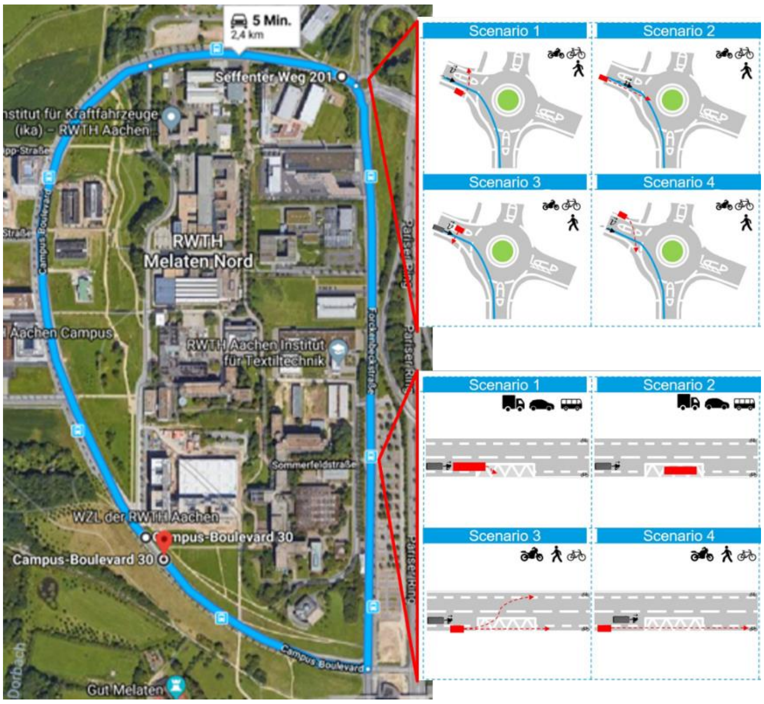


Figure 5 Test Site Aachen Campus Melaten Nord with symbolic Use Case Identification (Source: Google Maps)

4.1.2 Karlsruhe

Karlsruhe is located in the south-west of Germany and has about 300,000 residents. At this point of time, the test site used within SHOW is not fully specified yet. A preliminary plan is to have a connection from the Technologiepark in the east of the city to Karlsruhe Institute of Technology (KIT) Campus South via its Campus East. The route contains sections with different speed limits, including 30 km/h, 50 km/h and 60 km/h. The road network consists of mixed lanes for both public transport and regular traffic. Especially at KIT Campus South, the interaction rate with VRUs is very high. In addition, the route includes several constrictions, where the automated shuttles will have to cooperate with other traffic participants. Furthermore, the route contains multiple intersections.

4.1.3 Braunschweig

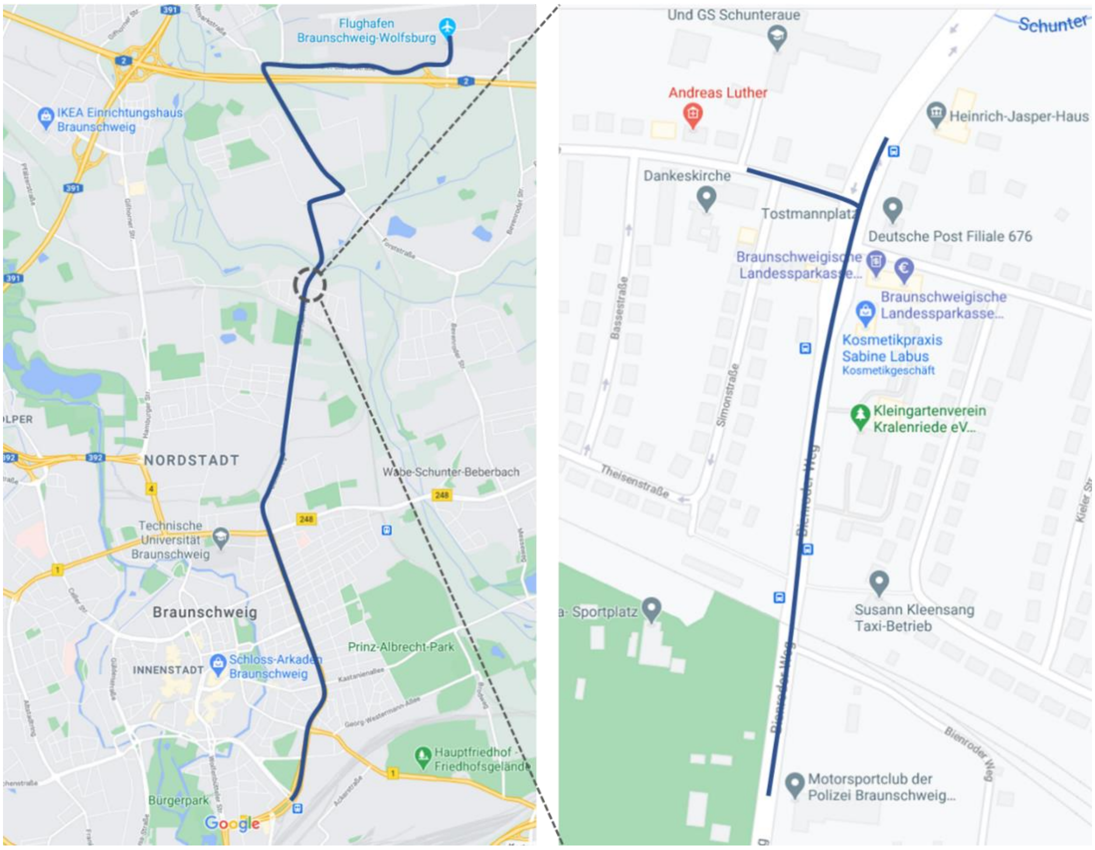
Originally, it was planned to conduct demo activities at the demo site Mannheim, Germany. Due to the insufficient number of demo vehicles and a partner leaving the demo site, Mannheim will be cancelled. In order to ensure and strengthen the overall performance of the German Mega Site, Braunschweig would be the new demo site, which has been approved by the Consortium. This change is currently under the project amendment process for approval.

The demo site Braunschweig locates in the northern part of Germany. The test area is part of the Test Bed Lower Saxony for automated and connected mobility. 2-3 vehicles with a maximum speed 50 km/h will be deployed and the demonstration focus is on DRT service with autonomous vehicles and vehicle platooning in urban and suburban areas. The addressed test cases include:

1) Automated vehicle with on-demand stops: DRT with fixed stops and including the possibility of a few virtual stops on the route. This test case is related to Use Cases 1.1 and 1.6.
2) Platooning in urban environment demo: Platooning showing logical coupling of vehicles, to be conducted with 2-3 vehicles on parts of the route, focusing e.g. on signalized intersections. This test case is related to Use Case 1.8.

The adopted route includes mainly urban areas and is connecting the main station in the city centre to a suburban area (airport/ DLR) with a route length of 10 km. Most segments of the route are equipped to accommodate autonomous vehicles. The overview of the demo site and the road test tracks are illustrated in Figure 6 (a) and (b).

Furthermore, the demonstration is planned to include 3 different weeks of operation with passengers during the demo period. Commuters will be transported between airport and DLR, most likely on workdays (Monday – Friday). The pre-demo operation will be conducted through a nationally funded project in 2021.



(a) route for shuttle with on-demand stops **(b) route for the platooning demo**

Figure 6 Overview of the demo site in Braunschweig, Germany (Map source: Google Maps, 2020).

4.2 The Austrian triplet Mega Pilot

4.2.1 Vienna

Vienna is not a SHOW site anymore and will be replaced by another site in Austria. At the time of writing, the replacement still is a process under discussion and will be finalised soon. Updated information will be provided in Deliverable D10.2, which is due in M18 of the project.

4.2.2 Graz

VIF develops an autonomous vehicle approaching urban environments in the Graz site. For development, they need several algorithms to build a safe and efficient driving function. For development and validation, a simulation platform (LGSVL Simulator, Carla, Microsoft AirSim) should help them build and test the driving function's functioning in a safe virtual environment before testing the software in a real urban environment with vulnerable road users.

The test site has some challenging urban environments with bus stops and pedestrians, busses, and public traffic. A mall and several shops are in the surrounding of the test environment.

Figure 7 illustrates one end stop of the planned route at the Graz site. The red line shows one possible route for the shuttle. There might be some difficulties with decision-making for mission- and motion planning due to pedestrians' strange behaviours and bus operation.

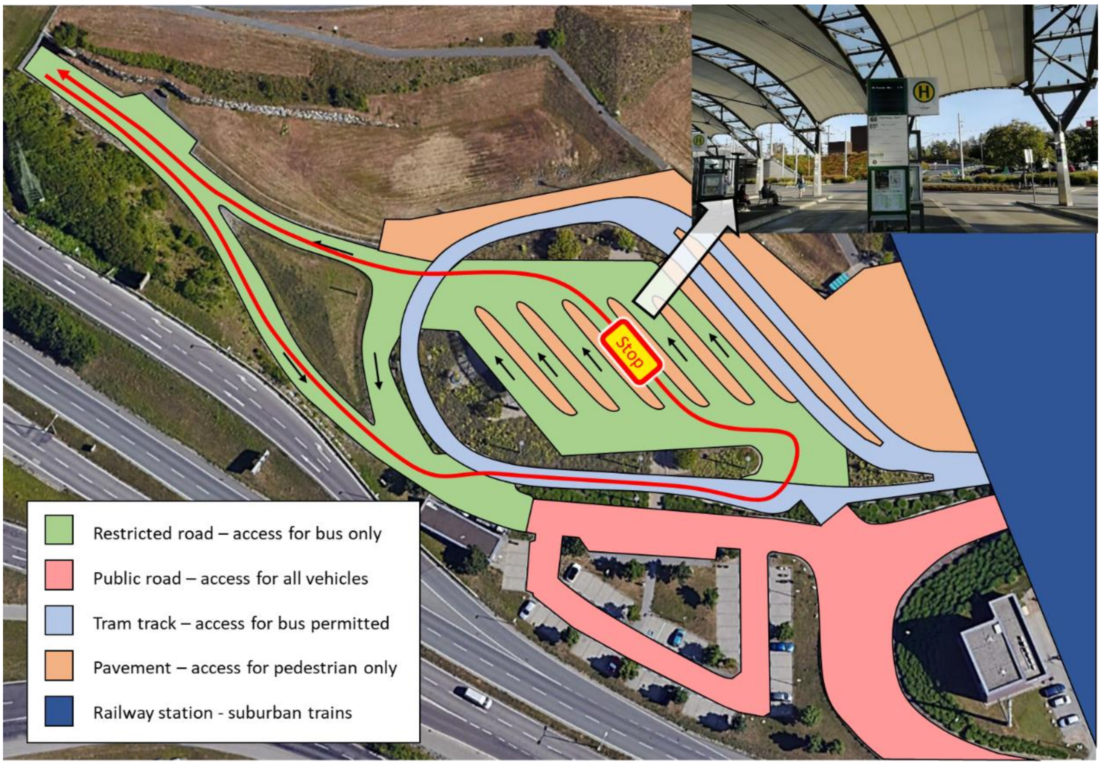


Figure 7 Planned route at the Graz site.

4.3 The Swedish twin Mega Pilot - Linköping

There are university, 370 companies, schools, daycare centres and residential houses at this demo site, shown in Figure 8. The main demo-site in Linköping is in the campus area. The demonstration track covers normal roads and a shared space section, where automated buses, pedestrians and bikes can share the space together. Currently, two out of three shuttles are already running clockwise in the campus area and will be also running in the residential area, indicated in the orange dash line area in Figure 8, later on. Currently, there 8 bus stops and the planned service period is from 8 to 18 on weekdays and from 10 to 17 on weekends.

The planned demonstration services are to improve user experience for all users and to provide a robust first/last mile solution to public transportation.

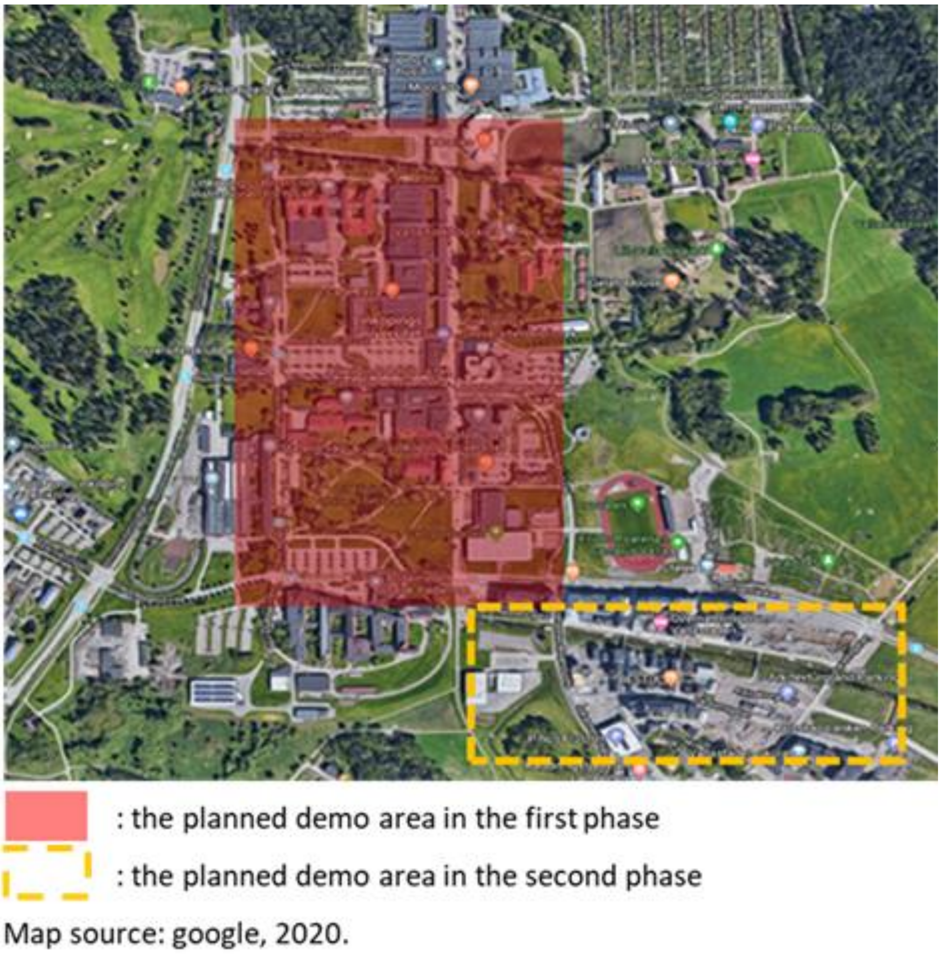


Figure 8 Overview of the demonstration areas at the demo site in Linköping (Source: Google Maps).

4.4 Spanish mega site

Simulations for the Spanish mega site are not planned according to the DoA [11], because Spanish partners have the focus on the pilot of the Madrid site and do not have efforts planned in WP10. Since the demonstrators of the Madrid pilot site show similarities to other performed simulations (e.g. self-learning DRT demo), a tracking of activities in Madrid is very interesting for WP10 to update the simulation models.

4.5 French mega site

The French pilot sites in Rennes and Rouen will not be considered for simulation in the first simulation iteration until M18 due to a re-focus of activities of partner VEDECOM as reported in the first amendment of SHOW. Since the activities of the French pilots include fixed-route shuttles and other simulations will be carried out for this scenario (e.g. in Karlsruhe, Aachen or Graz), the project will not be negatively impacted by not considering the French mega site for the first simulation iteration.

4.6 Brainport satellite site

The Brainport site (750,000 inhabitants) demonstration will take place in Eindhoven city (230,000 inhabitants). Eindhoven is the 5th largest city in the Netherlands, with a clear strategic interest in mobility innovations. Brainport site focus on operating automated cars (and optional buses) in a dedicated lane with possible interaction with traffic signal control and crossing vehicles, cyclists and pedestrians. The test will be running on a fixed route in the urban/sub-urban area, where an exclusive bus lane is available. The route will include several bus stops and signal-controlled intersections, as shown in Figure 9. Tested vehicles will plan their trajectories to stop at the bus stops to pick up and drop off passengers, and also stop at intersections for traffic signals or red light violation of pedestrians and cyclists. Additionally, platoon operation of automated passenger cars will be demonstrated in the test. Automated cars will be run in a vehicle platoon, involving platoon manoeuvres such as joining, platooning and exiting. Platoon operation allows a minimum cost for relocating automated vehicles as a demand responsive transit.

Figure 9 Overview of the Brainport area near Eindhoven and the dedicated bus lanes (Source: Google Maps).

4.7 Tampere satellite site

Tampere satellite site focuses on operating automated small buses on a fixed suburban route. The buses are to support a newly built tram line by extending the coverage of public transportation. The automated route involves interaction with the tram, a couple of crowded intersections and normal bus stops, where also other buses stop.

4.8 Trikala satellite site

Trikala is a medium-sized provincial city and the capital of the Trikala regional unit in the middle of Greece. It hosts a population of about 81,000 inhabitants (130,000 including the suburbs and nearby villages). The municipality of Trikala was formed in 2011 on occasion of the local government reform, which merged 8 former municipalities making them municipal units. The city hosts around 85,000 people commuting per day. In total there are 26 municipal buses operating on different lines across the city (15 bus lines operate in the city and its centre, while 11 bus lines connect with the surrounding cities or villages). The city residents use mainly driving, biking and walking for their commuting. Rural and peri-urban areas are underserved by public transport. Congestion mainly prevails around the grand open market area and the three bridges that cross the Litheos river, especially during rush hours.

Two demos have been planned for piloting in the municipality of Trikala. The first demo is encompassing two automated shuttles that will be operating on a fixed route (spanning 6.85 km long) connecting the city terminal with the intercity bus station (Figure 10). The automated shuttles will be encountering three 4-way signalized intersections, four T-intersections (to be converted to signalized), one roundabout and

13 pedestrian crossings during operation. Signal priority will be guaranteed for the automated shuttles at signalized intersections. They will be driving in both urban and peri-urban traffic conditions (parallel to bicycle lanes along specific portions of the route) and are expected to successfully handle illegal parking events via safe overtaking manoeuvres. Moreover, they will be servicing existing bus stops along the route.

The second demo is encompassing two automated passenger cars (BMW i3) that are expected to operate as robotaxis (DRT) and connect a peri-urban area of the Trikala regional unit with the intercity bus station. The vehicles (belonging to the vehicle fleet of CERTH) are currently equipped with SAE Level 2 automated functions, but they will be retrofitted to acquire SAE Level 4 automated driving capabilities so that they can operate driverless in public roads. However, it has to be stressed that the piloting of the second demo has not been confirmed yet due to legislative issues.

Both pilots will be running on road environments with flat terrain (median road inclination < 1%) and sharing space together with regular buses, passenger cars, and pedestrians in the intercity bus terminal. Moreover, all four vehicles will be remotely supervised from the city's traffic management centre via robust communication technologies, which will allow their teleoperation in case they enter failsafe mode due to internal (e.g. equipment failure) or external reasons (e.g. complex traffic situations, adverse weather conditions). Finally, the piloting of the demos is expected to demonstrate: a) the efficacy of the services in improving users' travel experience and providing first/last mile solutions to public transportation, and b) the limitations of the vehicles while performing in public roads that encompass mixed traffic flows and VRUs.

Figure 10 Overview of the automated shuttle fixed route at Trikala site (Source: Google Maps).

5 Partner Simulation Plans

This chapter aims at describing the planned simulations of the partners participating in WP10. Their connections to the SHOW sites are already stated in Table 2. As the focus between the partners might vary, multiple scenarios are defined. All of identified simulation scenarios are presented with a description and furthermore, they are linked to relevant simulation tools from chapter 2. In addition, expected results from the scenarios are identified and their addressed KPIs are listed.

5.1 e.GO MOOVE

SHOW Site: Aachen

Vehicles operating within the SAE L4 standard are committed to a restricted and defined operational design domain (ODD). This ODD can be decomposed into a limited number of functional scenarios, that can be identified from the relevant traffic scenarios and driving manoeuvres. A simulation framework can be divided into traffic simulations based on traffic models, cooperation simulations based on communication models and vehicle dynamics simulations based on vehicle models. As vehicle OEM, the focus of the e.GO MOOVE GmbH lies within the vehicle dynamics simulation part.

Realistic focus

e.GO MOOVE is planning to extract concrete scenarios from the use cases and to simulate the vehicle dynamics within these scenarios. By means of parameter variation, the edge cases can be detected and thereby a meaningful safety margin can be considered during operation. The necessary steps are vehicle model generation, map and scenario generation, scenario processing and analysis.

Data requirements from SHOW site

As vehicle OEM, all required data for vehicle simulation is accessible. At this moment, no data is known to be required from external sources.

5.2 FZI

SHOW Site: Karlsruhe

FZI will follow simulation scenario 1 as described in section 3.2. Consequently, the planned simulations include creating a virtual twin of the real-world fixed route in Karlsruhe and simulating an autonomous shuttle on that route in mixed traffic. The overall goal of the simulations is the development of highly automated driving (HAD) functions for shuttles. First, the high definition map of the fixed route will be created and enhanced and second, HAD functions will be integrated into the digital twin. Additionally, the simulation of traffic participants' behaviour (additional vehicles as well as VRUs) is planned. Furthermore, the simulation of intelligent and connected infrastructure is planned, including perception, data processing, communication and the effects of incidents on automated vehicles. All simulations will then be coupled using a ROS-based co-simulation platform.

Realistic focus

The overall goal of the simulations is to support the real-world pilot by first finding bottlenecks and critical areas on the route in Karlsruhe and later providing solutions to cope correctly with them. Thereby, the development of the shuttle's HAD functions is supported.

Data requirements from SHOW site

In order to set up the simulations for the fixed route in Karlsruhe, Germany, the route for the real-world pilot has to be chosen first and communicated to WP10. Afterwards, the geometric environment including the road network can be modelled in order to start the simulations.

5.3 DLR

SHOW Site: Braunschweig

The main idea is to establish and simulate the demonstrated DRT scenario with SUMO. The respective results can be used in WP13 for the impact assessment. According to the use cases, SUMO's simulation functions with focus on DRT and the modelling of automated vehicles will be examined and extended. The emphasis of the DRT modelling is placed on dynamic changes in road infrastructure (stops, road usages etc.). The communication tool for C2X in SUMO will be adapted accordingly. In addition, environmental, energetic and vehicular KPIs in SUMO will be examined and, if necessary, extended in line with the KPI identification of WP9.

Realistic focus

The focus will be put on the 10-km road test track. We will examine and, if necessary, enhance the main DRT functions and KPIs in SUMO according to the need of the applied use cases and the available resources for providing support on delivering representative simulation results. Regarding the behaviours of the automated vehicles, the corresponding models will be adjusted accordingly. The scope of the simulation related to activities and location may be adjusted due to possible changes in the planning.

Data requirements from SHOW site

In order to set up the corresponding simulation environment the infrastructure data, such as the information about network geometry, intersection control, parking places, especially along the road test track, are needed. Moreover, it is necessary to have the automated vehicles' geometrical, functional and technical data, e.g. maximum running speed, maximum and minimum acceleration and deceleration, reaction logic for adjusting the vehicular parameters in the simulation and examining/enhancing the related vehicle functions respectively. The trajectory data of the vehicles are also helpful for examining/improving the vehicle-related simulation results. In addition, the operation plans of the applied automated vehicles during the demonstration period are needed.

5.4 AIT

SHOW Site: The initial plan was to link the simulations to the Vienna site. As it is currently being replaced, an update regarding the SHOW site AIT's simulations will be linked to will be provided in D10.2.

The initial plan was to link the simulations to the Vienna site. Due to the decision of Vienna not to be part of the Austrian Triple Mega site, the previous efforts of AIT to simulate both DRT and the interaction of VRU with automated vehicles at transport hubs will be transferred towards other sites. First discussions will be initiated with the remaining Austrian sites (e.g. Salzburg) to elaborate the possibilities for applying the planned simulation methods. An update regarding the SHOW site for AIT's simulations will be provided in D10.2.

Demo Site 1: The impact of an AV-shuttle system will be simulated using a MATSim model in close cooperation with one of the test sites. The setup of this model will follow the procedures learned in the setup of a previous DRT MATSim model for Vienna. The simulations will include different scenarios for the shuttle system. This will include e.g. different fleet size, extension of service to different areas, different cost structures.

Demo Site 2: Microscopic simulations of transit stops and the interaction of the AV with vulnerable users will be one of the questions in focus. Simulation of transfer from high level public transport to AV. Boarding and alighting for AVs. This will be done for different sub-scenarios:

- Peak hour
- Extended intervals due to problems on a bus line cause large groups of waiting passengers, partially blocking the lane of the AV.
- Reduced waiting times by reducing the intervals of the bus and tram lines. The increased traffic of public transport vehicles affects the AV operations.
- Failure of railway operations causes large pedestrian flows from the railway station to the bus and tram stops.

by varying:

- origin destination relations,
- share of public transport usage (bus lines, tram, train),
- number of passengers and
- frequency of bus and tram services.

Realistic focus

For **Demo Site 1**, the aim is to evaluate the impact of an automated shuttle service under different settings, prediction of demand for the service, changes in modal splits, usage behaviour for different parts of the population. The exact goals will be established in close contact with partners at the relevant test sites.

For **Demo Site 2**, the aim is to simulate behaviour of VRU as well as AVs in station areas to enable a smooth operation of the AV service. The integration of C-ITS services into the simulation will be discussed and exact simulation goals will be established once the services will be defined in more detail. With SUMO the usage of the VEINS[2] toolbox is advised. This toolbox allows to implement C-ITS via various message and distribution protocols.

Data requirements from SHOW site

Demo Site 1: Scenario definitions including number of vehicles service are, cost-structure for usage.

Demo Site 2: Road and station layouts, Origin Destination matrices for the different road users for different scenarios. C-ITS parameters (message classifications, message protocols, location of roadside units (RSUs) and onboard units (OBUs)).

5.5 VIF

SHOW Site: Graz

[2] https://veins.car2x.org/

We use 3D rendered simulations with open-source programs like LGSVL Simulator CARLA or Microsoft AirSim. We want to use some existing Autoware and ROS algorithms to bring the software into the vehicle.

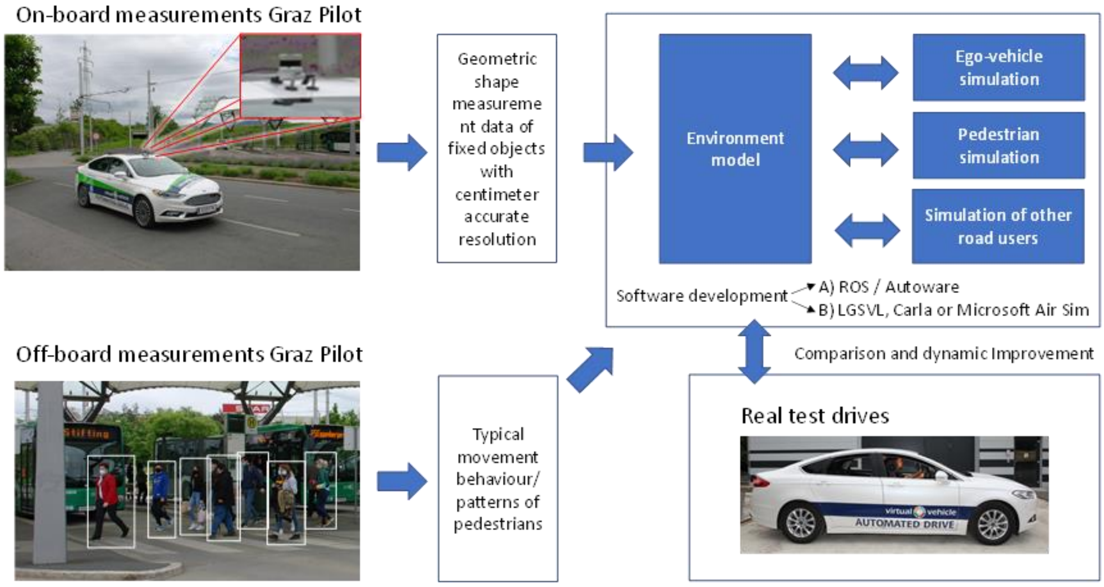


Figure 11 Embedding of simulation into Graz test site

Simulation activities are needed for the improvement of test drives in Graz. Figure 11 gives an overview of the planned workflow. First, measurement of the site will be taken, and geometric measurement data in centimetre accuracy will be recorded. The measurements should give more realistic simulations. An environment model will be the basis for further simulations like ego-vehicle simulation, pedestrian simulation, and other road users' simulation. There are different possibilities (ROS/Autoware or LGSVL/Carla/Microsoft AirSim) to simulate test drives, which should further improve driving functions.

Also, off-board measurements will be taken as input for the typical movement behaviour of pedestrians. This kind of data is essential when driving through the bus stop since many pedestrians are in this area. The information about pedestrians will be integrated into the overall simulation set-up. All measurements and simulations should improve real test drives.

Realistic focus

We want to analyse existing driving functions in the simulated world and test it in the real world. Several risks might occur. We have to face some organizational and legal issues (property rights, laws, safety, license to test autonomous vehicles). There is considerable work to be done without many resources, so that we will start with existing solutions and try to improve them (motion planning and control in a static environment). We are confident that we can perform simulations with our resources.

Data requirements from SHOW site

We will measure the environment with our sensors on the vehicle (LIDAR, cameras). Mostly, the road users' movements might be interesting for simulations of pedestrian movements to improve vehicle performance. We will use some open-source datasets in addition to our measurements.

5.6 DLR & VTI

SHOW Site: Linköping

The simulation scope is to cover both normal roads and the shared space areas microscopically. SUMO will be applied as simulation tool here. Moreover, not only the demonstrated DRT scenario but also the interactions between road users in the shared space area are considered in the simulation work. The results can be further used for impact assessment in WP13.

Realistic focus

The main simulation focus is put on the campus area, especially on the shared space area, where the main road users are cyclists, the demonstrated automated shuttles and pedestrians. The aims are (1) to get a better understanding on the possible impacts on introducing automated shuttles on bicycle infrastructure; and (2) to investigate if current available traffic simulation approaches can be used to simulate interactions between bikes and automated shuttles on a double directed and non-divided bike path. In order to achieve the above-mentioned aims the necessary features/functions will be defined and implemented in SUMO according to the demo site character. Some pedestrian-related effects will also be taken into account for reflecting the general behaviours which happen usually in a shared space area.

Regarding the DRT simulation, the focus will be on the simulation of the shuttles with the fixed bus stops and route. If the plan to have flexible stops, i.e. skipping stops when no demand exists, will be demonstrated, it will be considered in the simulation as well.

Data requirements from SHOW site

Video data within the shared space area is needed in order to investigate the interactions between bikes and the deployed shuttle and used as base for function extension in SUMO. Road infrastructure and traffic signal data, traffic demand and traffic flows at the major roads/intersections are required for setting up the simulation environment. Data related to the passengers getting on and off a shuttle at each stop is also needed. Moreover, it is necessary to get the operation plan (schedule, stops and routes) and the technical data of the demonstrated shuttles. The latter one also includes the reaction mechanism when facing unexpected events.

5.7 TNO

SHOW Site: Brainport

The simulations on the site will demonstrate automated driving on the bus lanes in Eindhoven, with solutions for smooth and safe intersection crossing with normal roads. The type of vehicles used will be L4 passenger cars, functioning as Demand Responsive Transit. If possible, also automated L4 buses will be tested.

The test site vehicles will be used in a software-in-the-loop coupling with the microsimulation software VISSIM, such that more accurate and reliable simulation results can be achieved and multiple simulations can be run.

The VISSIM microsimulation outputs will then be integrated in macroscopic models (New Mobility Modeller and Urban Strategy) to compute the impact on mode choice, traffic efficiency and environment if the tested demand responsive transit vehicle was introduced in the whole city of Eindhoven.

The interactive interface of Urban Strategy is depicted in Figure 12. Here, one can click around and add ‘controls’ to adjust the possible mobility options. For example, one can enable or disable DRTs in a certain area, or adjust the ticket price of DRTs. After setting the control, the New Mobility Modeller and Urban Strategy models are automatically run and within a few minutes the traffic efficiency output, modal split and impact on the environment can be visualised.

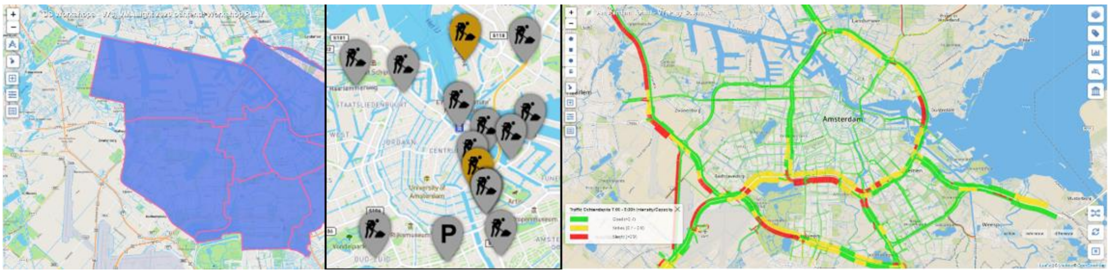


Figure 12 Overview of the Urban Strategy interface

Realistic focus

We will simulate a limited number of scenarios on the road with a limited number of vehicles. However, due to the software-in-the-loop coupling with VISSIM and coupling with macrosimulation platforms, we will be able to scale up and show results for introducing DRTs in the whole Eindhoven or Brainport area.

Data requirements from SHOW site

We need the software-in-the-loop coupling with VISSIM from the Brainport test site. Additionally, we will need several parameters such as average speeds, number of passengers and passenger car equivalent values as an input for our macroscopic simulation model.

Additionally, we will need information on mode choices made by passenger: who uses which mode, how attractive were they, what were the alternatives? This data is not necessarily gathered from the Brainport site but may also come from other satellite or mega sites where identical tests with demand responsive transit are performed.

5.8 VTT

SHOW Site: Tampere

VTT has planned to carry out safety and collision avoidance related scenario simulations with AVSS tool. The most interesting scenarios on the planned shuttle route are likely to be about interaction between the shuttle and other road users (tram, buses, pedestrians) at crowded bus stops and intersections. The findings from the simulation would feed into final AV logic/route design, e.g. about safe speeds at different locations.

Realistic focus

Simulate parts of the Tampere route and focus on difficult scenarios (vary other road user positions) and safety margins and speed/trajectory choices in them. One person month has been reserved for simulations. The simulations will be related to deliverable scenarios 1 and 3.

Data requirements from SHOW site

The simulations give input to final system and route settings.

5.9 CERTH/HIT

SHOW Site: Trikala

The aforementioned services (automated shuttles on fixed route – DRT) will be simulated microscopically with the use of the microscopic traffic simulation software SUMO. Simulations will consider operations both in normal roads and shared space areas. Core SUMO vehicle/driver models (i.e. car-following, lane changing, gap acceptance etc.) will be adapted (parametrized) in order to reflect actual automated vehicle behaviour (longitudinal/lateral motion, sensors' field of view) in case of normal driving operations, control transitions, failsafe (minimum risk manoeuvres) and teleoperation modes. If needed new functions will be developed so as to satisfy the latter modelling requirements (e.g. teleoperation device in SUMO). Different algorithms (vehicle dispatching, reservation methods, pick-up/drop-of locations) will be also considered for the DRT service. Finally, it is mentioned that SUMO does not currently possess explicit functionalities for modelling interactions of users (i.e. passenger cars, VRUs, buses, automated shuttles, robotaxis) in shared space areas). CERTH is planning to collaborate with DLR for the implementation of shared space modelling and simulation in SUMO. Simulation experiments will be conducted for different traffic demand levels.

Realistic focus

The primary focus of CERTH in the context of the SHOW simulation activities will be the parametrization of existing core SUMO vehicle/drivers to replicate the operation/motion of the automated shuttles and robotaxis in different traffic conditions with the highest possible fidelity (new novel vehicle/driver models will be developed if required). Moreover, existing SUMO functionalities with respect to DRT will be used to emulate the operation of robotaxis. The latter task will enable the conduct of preliminary impact assessment regarding the introduction of the two services in the Trikala road network. Dedicated KPIs pertaining to traffic efficiency, safety and environmental impacts will used to evaluate the effects of the services in the pilots areas for different demand levels. Secondly, efforts will be placed in the development of new dispatching algorithms for DRT and shared space modelling according to available resources. The aforementioned tasks will be conducted in close collaboration with DLR so as to expedite and scale up development process in SUMO that might possibly serve the needs of other pilot sites too.

Data requirements from SHOW site

The setup and execution of simulation experiments in SUMO requires collection of infrastructure data (network topology, intersection control, parking places, bus lines etc.), and demand data (origin-destination matrices, traffic flows at the major intersections, number of passengers per stop). Moreover, information about automated shuttles' and robotaxis geometrical, functional and technical data (e.g. maximum running speed, acceleration capabilities, field of view/reaction logic, available time budget in case of control transitions, actions in failsafe mode, manoeuvring capabilities in teleoperation mode etc.) is necessary. In addition, the operation plans of the public transport systems (buses) and the applied automated shuttles during the demonstration period are needed. The trajectory data of the shuttles are also helpful for examining/improving the vehicle-related simulation results. Finally, video data within the shared space area is needed in order to investigate the interactions between bikes and the deployed shuttle and used as base for function extension in SUMO.

5.10 NTUA

SHOW Site: The SHOW site NTUA's simulations will linked to is still under consideration at the time of writing. Most probably, the simulations will be linked to the Copenhagen site. An update will be provided in D10.2.

NTUA is planning to develop simulation trials with regards to driving behaviour under automated environments. Furthermore, insights into reaction times, conflicts, interaction with other vehicles and services are going to be investigated. More specifically, aspects that are going to be investigated are:

- Reaction time of drivers during different automation levels
- Impact on conflicts and environment based on different penetration levels and automation scenarios (all types of vehicles)
- Impact of dedicated lanes, road type, vehicle platooning and different penetration levels of autonomous vehicles on traffic, safety and environment
- Optimization of time-to-collision (TTC) or other surrogate safety measures for different automation levels.
- Optimization of level of service by providing information on traffic conditions or incidents.

Realistic focus

Association with the Copenhagen use case and investigation of driver reaction time during different automation level, as well as the impact of AVs on traffic flow, safety and environment. Machine learning investigation of impacts and prediction of the effects with regards to different automation levels, penetration rates and infrastructure constraints.

Data requirements from SHOW site

Site routing and geolocations of services as well as highly disaggregated traffic flow and traffic composition data.

6 Conclusions

The SHOW project includes a big number of pilots divided into Mega Sites, Satellite Sites, Follower Sites and a Technical verification and commissioning Site. The evaluation and results of these real-world pilots is supported and enriched by varying simulation activities, ranging from street level up to city or district level.

In chapter 2, the simulation tools that are used for the simulation activities within Work Package 10 were presented and described. In chapter 3, different simulation scenarios were introduced and linked to their addressed KPIs. Afterwards, the SHOW sites which are simulated by the partners in the first iteration were presented briefly in chapter 4. Finally, in chapter 5, the planned simulations including the realistic focus of the participating partners of WP10 were explained.

Next steps are to do the first iteration of the simulations utilising input from the pre-demo activities. The simulation results will be described in Deliverable D10.2, which is due in M18 of the project. Additionally, it will contain a revision of data inputs required from the SHOW sites during real-life activities. Finally, missing data such as information about the new plot site in Austria (replacing the Vienna site) and its link to the simulations in WP10 will also be provided in D10.2.

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Appendix I List of KPIs from A9.4

KPI Nr	Impact	Description	Measurement unit	Broader category	Impact area
1	road accidents	number of injury accidents in an area	accidents/year	safety	Safety
2	conflicts	number of conflicts encountered where time-to-collision (TTC) is less than a pre-determined threshold per 100 million kilometres	conflicts/km	safety	Safety
3	conflicts with VRUs	number of instances where pedestrians or cyclists were encountered	instances/km	safety	Safety
4	Time headway	Time between vehicles	seconds	safety	Safety
5	Reaction time	The time it takes to respond to a stimulus	seconds	safety	Safety
6	Travel time	Average duration of a trip inside the city centre per km of travel	min/km	traffic efficiency	Traffic efficiency
7	Distance	Average distance driven at one trip inside the city centre	km	traffic efficiency	Traffic efficiency
8	Average Speed	Average speed inside the city centre	km/h	traffic efficiency	Traffic efficiency
9	Occupancy rate	Average number of persons in a vehicle	#	traffic efficiency	Traffic efficiency
10	Amount of travel	person kilometres of travel per year in an area	km	VMT	Societal
11	Shared mobility rate	% of trips made sharing a vehicle with other	%	travel choice	Societal

12	Vehicle utilisation rate	% of time a vehicle is in motion (not parked)	%	vehicle use	Societal
13	Inequality in transport	to which degree are transport services used by socially disadvantaged and vulnerable groups, including people with disabilities	10 point Likert	equity	Societal
14	Job loss	Percentage of jobs that have a high probability of being replaced by computer automation within the next two decades	%	employability	Societal
15	Job gain	Number of jobs created by the implementation of computer automation, and other systems (sensors, cameras etc) used in autonomous vehicles within the next two decades	#	employability	Societal
16	User quality perceptio n	User perception of travelling quality	7 point Likert	user perception	User
17	User reliability perceptio n	User perception of travelling reliability	7 point Likert	user perception	User
18	User trust	User feeling of trust in the autonomous vehicle	7 point Likert	user trust	User
19	User safety perceptio n	User feeling of safety during travel	7 point Likert	user perception	User

20	Travel comfort	User perception of travel comfort	7 point Likert	user perception	User
21	Use of automated driving functions	Share of kms driven within the ODD when the driver decides to use automation		user experience	User
22	Perceived usefulness	Experienced usefulness	7 point Likert	user perception	User
23	willingness to pay	User willing to pay for the new mobility service			User
24	willingness to share a ride	User willing to share a ride in CAVs			User