# Integrated Traffic Simulation Developer Suite for Shared Automated Mobility

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**Abstract** Within the SHOW project (GA No 875530), real-life urban demonstrations across 22 cities were conducted, exploring and validating the integration of Cooperative Connected and Automated Mobility (CCAM) in various public transport schemes. The project employs extensive traffic simulations using different tools and approaches. This chapter outlines the development of an integrated simulation suite that combines elements from the diverse simulations. The simulation suite is a web-based open access tool and offers guidelines, steps, and mathematical definitions for simulating CCAM. Designed for researchers, practitioners and even non-experts, while providing insights and results valuable to city planners. By emphasizing key findings from simulations, the application of the suite and its support for decision-making become more tangible.

**Keywords** Traffic simulation · Automated transport systems · Simulation suite · Simulation transferability · Simulation levels

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# 1 Introduction

The EC Horizon 2020 project SHOW (SHOW) aims at developing and piloting shared automated mobility operating models towards Europe-wide adoption and beyond. During the project, naturalistic large scale field trials of automated vehicles of several types are taking place in 22 cities across Europe, in the form of real traffic urban (and peri-urban) shared mobility services, to investigate Automated Driving (AD) vehicles' integration in Public Transport (PT), Demand-Responsive transport (DRT), Mobility a Service (MaaS) and Logistics as a Service (LaaS) schemes. In addition, within the project, extensive traffic simulations are conducted to support the real-life demonstrations. The purpose of simulations in relation to real-life demonstrations is multifaceted. These simulation scenarios and tools are designed to enhance the outcomes of real-world pilot field experiments by offering supplementary support and insights. They effectively integrate SHOW sites into simulations to provide clarity on their value in real-life demonstrations. Key objectives of the simulations include:

- Refining driving algorithms and driving virtual test kilometers in the simulator to reapply in the field.
- Testing risky situations or advanced traffic scenarios that are difficult to reproduce in real sites.
- Providing results for impact assessment to enable better planning of CCAM in the future.
- Simulating network effects of pilot vehicles.

Three main simulation levels are examined, namely (i) street-level, (ii) city-level and (iii) simulations of Vulnerable Road Users (VRUs) in local areas. Different simulation tools and approaches have been used, optimal for each type of simulation and depending on the specific needs of different pilot sites. Consequently, a framework that combines all critical elements of the simulation approaches followed in each case such as key inputs, models and parameters (described in detail in Sect. 4) would be highly valuable. By standardising and packaging this framework through an integrated simulation suite, future users conducting CCAM simulation can be availed.

Simulating CCAM is an ongoing, challenging task, regardless of aims or scale. To handle its intricacies, currently, there is fragmentation in simulation approaches, and a plethora of tools that are used. Many overarching problems are similar, regardless of tool selection, while simulation practitioners face several common questions, with little external input to their problems.

This chapter aims to provide insights into the process followed for developing an integrated simulation suite. The simulation suite is designed to be a web-based tool that acquires a common pool of simulation data from the different simulation categories and use cases. It can be utilized for various purposes such as traffic, environmental and safety impact assessment, traffic flow analysis, and other related applications. The tool identifies the key parameters and possible methodologies to simulate automated driving and attempts to synthesize the simulations for all pilot sites of the SHOW project.

The SHOW simulation suite is formed largely as a response to this predicament, focusing on automated public transport schemes. This multi-layered, open and interactive tool will include and combine elements from diverse simulation approaches, methodologies, and tools, as well as offer guidelines, steps, and mathematical definitions for simulating automated mobility at different levels. Furthermore, the simulation suite provides transferability options and good practices where conducting such exercises to areas with little or no data.

The simulation suite is envisioned to be used by experts when solving practical problems in the field (e.g., city planning, urban policy implementation, and strategic decision-making), researchers when broadening the understanding of CCAM-oriented simulation as well as non-experts who wish to come into contact with the more technical aspects of these approaches.

This paper is organized as follows. In the next Sect. 2, the relevant research is presented, in which existing web-based tools are provided. In Sect. 3, the overall conceptualization framework about integrating the simulation suite tool for CCAM is presented. The architecture and components of the Simulation Suite are then following in Sect. 4. Finally in Sect. 5, the paper concludes with an overview of the general scope, practical applications of the tool, and the value it adds.

## 2 Relevant Global Research

Prior to the development of the SHOW Simulation Suite, extensive research was conducted to explore existing web-based tools, encompassing a range of tools, interfaces, and manuals, available to support authorities and policymakers. These resources were investigated for their utility in assisting authorities and policymakers to comprehensively understand the multifaceted impacts of CCAM on various aspects including traffic flow, traffic safety, environmental emissions, public acceptance, demand patterns, and potential shifts in travel behavior. This thorough exploration aimed to identify and exploit state-of-the-art technologies and methodologies, ensuring that the forthcoming SHOW Simulation Suite would effectively address the complex and evolving challenges of CCAM. Higher emphasis was placed in authority and policymaker tools as we expect that authorities and policymakers will be one of the main audience types for the SHOW Simulation Suite.

This initial exploration phase involved a comprehensive review of similar tools to understand their key goals, attributes and limitations. In this context, it was crucial to identify other initiatives associated with CCAM and explore whether similar tools had been developed, such as tools shared common functionalities (i.e. knowledge module) or objective and approaches relevant to the domain of CCAM. The similarity criteria encompass aspects such as the scope of functionalities, target users, underlying technologies, and intended applications. These criteria guide the comparison and assessment of the identified initiatives. To pinpoint relevant CCAM initiatives, the Automated Driving Roadmap document provided by the European Road Transport Research Advisory Council (2019) was reviewed. Additionally, the knowledge base on Connected and Automated Driving (CAD) established under the Horizon 2020 Action ARCADE (ARCADE) was consulted, encompassing a comprehensive list of all (up to date) projects related to CCAM.

These initiatives significantly shape the landscape of CCAM development up to date. Out of these ones, the LEVITATE Policy Support Tool (PST) (LEVITATE PST) and the ARCADE Knowledge Base (ARCADE) stand as the exclusive research endeavors equipped with comprehensive tools for CCAM, each one offering distinct functionalities. The SafetyCube Decision Support System (DSS) (SafetyCube Decision Support System) is also worth mentioning as a multifunctional road-safety decision tool and encyclopaedia.

- **LEVITATE PST**: The LEVITATE PST (LEVITATE PST) is the definitive decision support tool for CCAM interventions, emerging from the LEVITATE project in Horizon 2020, which stands for 'societal LEVel Impacts of connecTed and AutomaTed vehiclEs'. As an open-access, web-based system, it offers stakeholders access to methodologies, results, bibliography, documentation, CCAM guidelines, and a Decision Support System with forecasting and backcasting capabilities. Tailored to meet stakeholder needs, the PST serves as a comprehensive resource for informed decision-making in CCAM. More details can be found in Ziakopoulos et al. (2022).
- **ARCADE & FAME CAD Knowledge Base**: CAD Knowledge Base is a pivotal repository developed under the ARCADE (Aligning Research & Innovation for Connected and Automated Driving in Europe) project (ARCADE) and its extension FAME (Framework for coordination of Automated Mobility in Europe). It consolidates CAD information, spanning projects, regulations, policies, strategies, action plans, guidelines, and evaluation methodologies. More details can be found in the official website (ARCADE).
- **SafetyCube DSS**: The SafetyCube DSS (SafetyCube Decision Support System) is the main product of the SafetyCube project within the respective Horizon 2020 Programme. It aids evidence-based policy-making, offering interactive information on road accident risk factors and safety countermeasures. The corresponding knowledge module synthesizes documents on risks, impacts, injuries, and accident scenarios. The estimator module calculates the Economic Efficiency Evaluation (E3) of safety measures, incorporating effectiveness percentages and costs for cost–benefit analysis. More details can be found in Martensen et al. (2019).

While existing initiatives such as LEVITATE, ARCADE and FAME, and SafetyCube contribute significantly to the landscape of transportation research, there remains a notable gap in the availability of comprehensive simulation tools specifically tailored to address the challenges of automated mobility. Among the reviewed tools, only some are directly relevant to the domain of automated mobility.

Specifically, the LEVITATE PST that serves as a decision support tool for CAV interventions, lacks the intuitive and multi-level functionality provided by the SHOW Simulation Suite, which not only guides simulations but also includes examples and complementary data files essential for simulation. Similarly, while ARCADE and FAME's CAD Knowledge Base consolidates information from various projects and initiatives related to CAD, it lacks a dedicated tool for assessing the impact of automated mobility, a key objective of the SHOW Simulation Suite. Finally, the SafetyCube DSS aids evidence-based policy-making by providing information on road accident risk factors and safety countermeasures. However, its focus on road safety does not directly address the complexities of automated mobility.

The SHOW Simulation Suite fills the gap in available simulation tools by offering a comprehensive platform designed specifically for automated mobility. Its interactive features provide users with insights into the complexities of simulations conducted in the SHOW project, showcasing the seamless interplay between diverse simulations and addressing the multifaceted impacts of automated mobility on various aspects of transportation. SHOW pioneers a simulation suite that facilitates robust simulations and serves as an educational tool, providing invaluable insights and guidance to researchers at various career stages. The interactive material within the suite illuminates the intricacies of different simulation software employed, emphasizing a cohesive approach to address the complexities of automated mobility. Additionally, the suite goes beyond its role as a research tool, aiming to disseminate simulation results widely and make them accessible to researchers, policymakers, city planners, and practitioners. By providing an intuitive platform for exploring these results, SHOW contributes to a greater understanding of automated mobility and its implications for diverse stakeholders.

## 3 Conceptualization of an Integrated Simulation Suite Tool for CCAM

Within SHOW, different simulation tools and approaches ideal for each occasion were used, depending on the different pilot site needs and partner expertise. Pursuing to exploit this work and knowledge beyond the scopes of the project, the value of integrating it to a concrete knowledge base and tool to be used and further exploited by the broader CCAM community was conceptualized. To allow this, 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 conducted for different test sites of the project was required. As such, the development of the SHOW Simulation Suite has adopted an incorporated approach.

The main idea of the simulation suite is to combine the knowledge gained in simulating automated mobility and integrate the fundamental aspects of this procedure at its optimal level. This is being accomplished by the development of a web-based front-end tool that provides guidelines about simulation of automated driving and includes (i) useful insights for simulating automated mobility across the different pilot sites (i.e. simulation tools, required input data, parameters for modelling AD vehicles, behaviour models, etc.), (ii) simulation transferability approaches, (iii) interplay between simulations application and outcomes, and (iv) a library including visualised instructions in the used simulation modelling software and tools. Therefore, the simulation suite is designed to be a tool that constitutes a common pool of simulation outcomes, designs, and specifications for different types of simulation (microscopic traffic simulations, macroscopic traffic modelling) and use cases in the CCAM domain. By defining the type of results provided and emphasizing key findings, the application of the simulation suite and its support for decision-making become more tangible.

For this reason, the suite is designed to:

- Offer comprehensive information about the possible tools and layers available and used within SHOW, as well as suitable scenarios, such as varying percentages of automated vehicles penetration, and their potential impacts on traffic flow dynamics.
- Provide clear guidelines to assist users in defining their desired use case or study area for studying automated mobility and to further give directions for its simulation. A use case refers to a specific situation in which automated mobility could be utilized. It outlines the purpose, goals, and context of employing AD technology. Use cases can vary based on factors such as location, demographic, infrastructure, and purpose.
- Incorporate a detailed explanation of the mathematical principles that govern the simulation environments, enhancing user understanding and ability to utilize the tools effectively.

# 4 Structure of the Simulation Suite

## *4.1 Simulation Categories and Cases*

This subsection gives an overview of the categories of the simulation sites within the context of SHOW. This classification was conducted based on the respective real-life pilot activities of SHOW, the corresponding test site characteristics and their associated needs for simulation. All the simulation efforts were split into three dedicated categories as follows:

- **Simulations of VRUs in local areas**: This category covers applications focusing on VRUs and shared spaces. The scope of these simulations is the safety of all VRUs in the vicinity of AD vehicles, such as pedestrians, cyclists, etc. Passengers on board in vehicles are considered out of the scope of this cluster of simulations. For most SHOW pilot cases, the bus stop is the situation in which an AD vehicle comes close to VRUs consisting mainly of possible passengers. Most contributing experts considered a bus stop as an important element from the point of view of an ego vehicle serving this bus stop. This means that a bus stop is an essential part within the simulations street level simulations, where safety and pedestrian aspects need to be included with the focus always lying on one vehicle. In some cases, the scope is to study the interactions of AD vehicles with pedestrians and not necessarily passengers. This is especially important in bus terminals with a higher number of pedestrians, where AD vehicles need to pass through. In this case, also the focus may also include analyzing dwelling time (how long passengers would need to egress and board a vehicle) and its influence on traffic flow and time management, ensuring comprehensive understanding and optimization of urban mobility dynamics.

- **Street level simulations**: In street level simulations, both operation routes and served stops are pre-defined and fixed. However, various parameters can be adjusted to investigate interactions between different types of road users and explore AD-logic and safety issues. These parameters include factors such as vehicle speeds, acceleration rates, reaction times, and behavior models for CCAM, pedestrians and cyclists. Microscopic traffic simulation techniques are employed, either independently or coupled with other simulation-related tools, to facilitate this analysis. Furthermore, the respective focus is put rather on the test site level than on the whole city/region level. Accordingly, fluctuations/shifts in transport mode choice is not the primary focus here.
- **City level simulations**: In this category, automated shuttles are simulated at city level using DRT services. The city level scenario includes both DRT on fixed routes as well as station-based DRT services with fixed stations but without fixed routes for door-to-door services. A critical difference to simulations of VRUs is that simulation herein 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 traffic, environmental and safety impact of AD vehicles for different implementations of automated DRT services. The extension from local to city wide simulations enables the DRT simulations to address additional Key Performance Indicators (KPIs) like the modal split changes (i.e. the share of each mode choice in number of trips or distance travelled) and others (i.e. reduction in travel time for passengers using DRT services, changes in kilometers traveled due to shifts in travel behaviour, etc.) due to the introduction of automated DRT services, compared with above categories (street and city level simulations).

#### 4.1.1 Study Cases

The simulation categories and use cases are the initial aspects of the first layer (Simulating Automated Mobility) of the simulation suite, as shown in Fig. 1. Firstly, this aspect concerns the three simulation categories that are examined within the simulation efforts of the SHOW project namely simulations of VRUs in local areas, Street-level and City-level simulations. This implies that as a first step, the SHOW Simulation Suite web-based tool users will be able to choose the category that they are interested in. Secondly, the user will be prompted by the tool to choose among specific study areas ("use cases") of the eleven (11) pilot sites i.e., Brainport, Graz, Karlsruhe, Klagenfurt—Carinthia, Linköping, Madrid, Monheim am Rhein, Rome, Salzburg, Tampere and Trikala. The three simulation categories matched with the corresponding pilot based use cases are presented in Table 1.

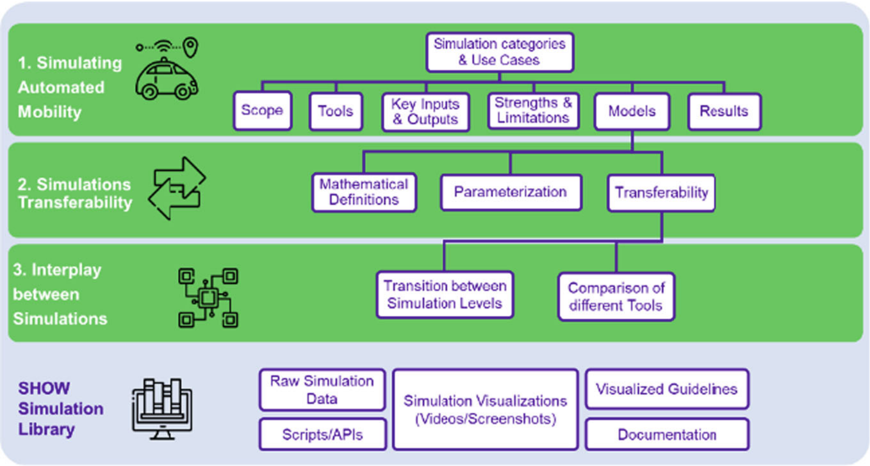


**Fig. 1** Components of SHOW simulation suite. *Source* Authors' own picture

**Table 1** Simulation categories and corresponding pilot sites

| SHOW Pilot sites | Simulation tools | Simulations of VRUs | Street level simulations | City level simulations |
|---|---|---|---|---|
| Brainport | VISSIM, New Mobility Modeller, Urban Strategy, SIL Simulator | | | X |
| Graz | ROS, Autoware simulator, SUMO | X | X | |
| Karlsruhe | ROS, SUMO, Menge, CARLA, Gazebo | X | X | |
| Klagenfurt—Carinthia | SUMO | | | X |
| Linköping | SUMO | X | X | |
| Madrid | AIMSUM | X | X | |
| Monheim am Rhein | SUMO | X | X | |
| Rome | AnyLogic, TransCAD | | X | |
| Salzburg | MATSim, SUMO | | | X |
| Tampere | AVSS | X | X | |
| Trikala | SUMO | | X | |

## 4.2 Architecture of Simulation Suite

Within the three aforementioned simulation categories and the 11 pilot sites operating CCAM, different simulation scenarios and use cases were investigated. Moreover, it is important to note that the term "simulated scenario" refers to the various inter-use cases investigated for each pilot site. For example, a pilot site integrating a point-to-point shuttle may simulate different operational speeds for the shuttle, thereby running corresponding scenarios for each speed variant.

In order for this to succeed, the SHOW simulation suite is designed to compose three different layers, as shown in Fig. 1, namely (i) Simulating Automated Mobility, (ii) Simulation Transferability, (iii) Interplay between Simulations as well as the SHOW simulation Library, which is the repository of fundamental information regarding simulating automated mobility of each layer.

The structure of the Simulation Suite website comprises multiple sections. Positioned at the top of the home page, users are able to discover a fixed navigation bar facilitating easy access to pivotal sections, including About, Street Level Simulations, City Level Simulations, VRU Simulations, and the SHOW project. Additionally, nested within the sections of Street Level Simulations, City Level Simulations, and VRU Simulations, a secondary navigation panel will present options directing users to the SHOW simulation pilot sites. Within these choices, users will encounter further options, each leading to distinct layers of the Simulation Suite, namely Simulating Automated Mobility, Simulation Transferability, and Simulation Levels Connection. This organization essentially mirrors the structure of the simulation suite depicted above, conveying a seamless transition from the tool framework to the web page format.

A number of fruitful aspects stem from the development of the SHOW Simulation Suite for external users, be they researchers or practitioners. Specifically, for each layer, the following generalization and practical capabilities are indicatively provided:

- Users can consult the *Simulating Automated Mobility* layer in order to acquire initial details of the approach of simulating automated mobility, increase their intuition on the topic and become aware of the potential advantages but also caveats of each approach. Moreover, they can become acquainted with some of the horizontal high-level results of CCAM simulations, which can in turn formulate and hone their own research and application scopes more accurately.
- Users can exploit results of the *Simulation Transferability* layer in order to peruse the followed methodologies and to examine more specialised mathematical/ modelling approaches in detail, informing them of the solutions adopted within the SHOW project and thus setting a well-established precedent for CCAM simulation. Furthermore, detailed transferability capacities are showcased, allowing the projection of existing simulation outcomes to other cases, while also providing guidance for shifting from microscopic to macroscopic levels and some tips for combining different available simulation software packages.

- Users can browse the contents of the *Interplay between Simulations* layer provides applied examples for shifting between different scale levels, showing the obtained outcomes to be expected of such processes. This layer also provides comparisons of different tools. These outcomes can be information sources for users wishing to select between available simulation packages.

In addition, the user will receive a multifaceted supply of information- related and stemming from the addressed SHOW pilot sites contexts—that will help them both (i) to navigate and exploit better the contents of the Simulation Suite (e.g. Scope, Key Inputs and Outputs, Strengths and Limitations) and (ii) to learn about the characteristics of the utilized networks and adapt and cross-compare them to the tool users' own networks, in order to create more trustful CCAM Simulation Scenarios. Possible restrictions may relate to the available transport modes in each network, its overall size, and the type of CCAM operation (i.e. mixed traffic environment, dedicated lanes, confined environments).

## *4.3 Simulating Automated Mobility*

This layer of the Simulation Suite includes general information on simulating automated driving. Specifically, after selecting the desired simulation category and use case, the simulation suite user is able to be informed about the scope of the studied automated mobility use case, the implemented simulation tool, the key inputs and outputs, strengths and limitations of the followed methodology, the models that were applied and the results of the respective simulation. A step-by-step tutorial layout is incorporated for each scenario and use case, so as to accelerate comprehension by third parties and junior researchers.

- **Scope**: Along with the scope of the studied use case, the most important information is given to the user regarding the importance of this use case investigation (i.e. relevance to real-world challenges, potential to demonstrate the capabilities and benefits of autonomous vehicles, etc.) 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.).
- **Tools**: Details on the tools employed in this context and a thorough discussion concerning their pertinent technical specifications is provided. This also includes an in-depth discussion of why these particular tools were chosen for the CCAM implementation, highlighting the unique features and capabilities of the tools that contribute to the overall effectiveness of the conducted simulations.
- **Key inputs and outputs**: For simulating automated mobility use cases, various inputs are required. These include real-world traffic data, road network layouts, vehicle specifications, behavioral models, environmental conditions, and user

preferences. For instance, historical traffic flow data from a city, road maps indicating lane configurations, vehicle acceleration and deceleration capabilities, and user demand patterns can all serve as input data for the simulation. Those, as applicable for each use case and scenario, are defined here. Additionally, the simulation generates a range of outputs, including vehicle trajectories, travel times, fuel consumption, emissions, and user satisfaction metrics. Visualization of simulated traffic patterns, statistics on average travel times for different routes, and analysis of carbon dioxide emissions are some examples of the outputs produced by the simulation.

- **Strengths and limitations**: Strengths and limitations of the simulation may vary depending on the specific use case and scenario being analyzed. One strength of the simulation could be its integration of real-world traffic data, which provides realistic simulation outcomes. Incorporating actual traffic flow data allows for an accurate representation of congestion patterns and dynamic traffic conditions. A limitation of the simulation could be the lack of pedestrian traffic modeling, which may underestimate potential conflicts. Ignoring pedestrian behavior could lead to an underestimation of safety hazards and unrealistic simulation outcomes in urban areas with heavy foot traffic.
- **Models**: In the simulation, various models are employed to simulate individual vehicle behavior and decision-making regarding lane changes. Models employed in the simulation may vary depending on both the specific use case and the simulation tool utilized. For instance, the Intelligent Driver Model (IDM) may be used as the car-following model to simulate vehicle acceleration and braking behavior, while the MOBIL model could be employed to simulate lane-changing manoeuvers based on perceived benefits.
- **Results**: Results from the simulation are primarily focused on quantifying the impact of automated mobility services on various metrics related to traffic (e.g., traffic flow, average speed, etc.), environment (e.g., traffic emissions, energy use, etc.) and safety (e.g., traffic conflicts, accidents, etc.). The list of all metrics can be found in SHOW Deliverable 9.2 (Anund et al. 2020).

Focusing on the site interface, as for example, the tab selection interface showcasing the Madrid pilot site navigation is displayed in Fig. 2.

## *4.4 Simulation Transferability*

In this layer of the Simulation Suite, which is the second layer as shown in Fig. 1, more technical information is given to the user, i.e. specifications of the followed models. Specifically, the mathematical definitions as well as parametrization and the possibility of transferability is 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 mobility in specific.


**Fig. 2** Madrid pilot site: scope. *Source* Authors' own picture

- **Mathematical definitions**: In traffic simulations, various mathematical definitions are utilized to model vehicle movement, traffic flow, congestion, and other related phenomena. For instance, some key mathematical definitions commonly used in traffic simulations are traffic flow models, car-following models (e.g., the Intelligent Driver Model) and lane-changing models (e.g., MOBIL model). Hence, the models used in each simulation use case are included in this part along with the specific formulas, variables, and guidelines for usage, enabling comprehensive analysis and simulation of various traffic scenarios. As an example, Fig. 3 shows the mathematical definitions of the applied models within Madrid pilot site simulations.
- **Parameterization**: The parameters used for modelling AD vehicles are presented as there are many differences between modelling human-driven vehicles and AD vehicles and, therefore, by these specifications, an in-depth understanding

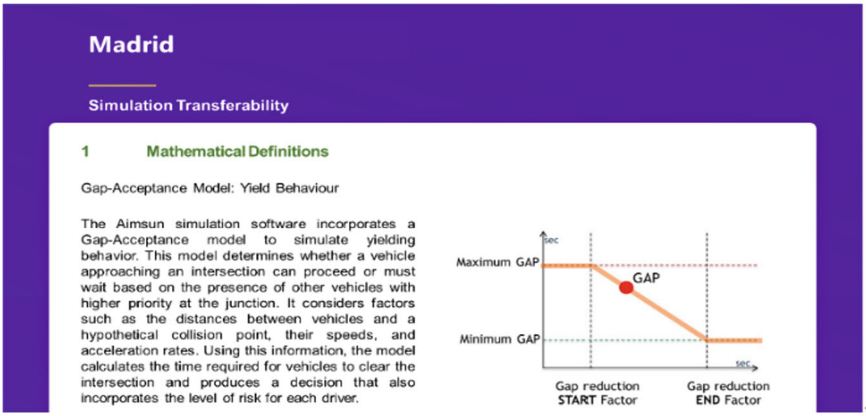


**Fig. 3** Madrid pilot site: mathematical definitions. *Source* Authors' own picture

of modelling AD vehicles will be accomplished (e.g., acceleration and deceleration profiles, reaction time, sensor characteristics, control algorithms, vehicle dynamics, etc.).

- **Transferability**: A discourse on any potential and specific type of transferability of the outcomes across varying simulation scenarios is also included. It is fundamental to investigate and present how the different simulations of each simulated pilot site and their outputs can potentially be combined, as well as how the followed models and indicators could be transferred. As established, traffic flow models can be classified as microscopic, mesoscopic or macroscopic; indeed, within the SHOW project, simulations across all three modelling scales were conducted. The macroscopic models (and mesoscopic models as well) employ aggregated parameters on velocity, density and flow, while microscopic models consider individual vehicle behavior. The vehicle-level simulations are a separate category, as the approach is different from the one that depicts micro–macro (or micro-meso) simulations combination, in order to be combined with the remaining simulation models. 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 2021; Forcadel and Zaydan 2016; Helbing 2007) 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, e.g. Tympakianaki et al. 2022), speeds (e.g. Zheng et al. 2017) and headways (Li and Chen 2017).

As an example, Fig. 3 shows the mathematical definitions of the applied models within simulation. As there are differences between modelling human-driven vehicles and AD vehicles there is a need for an extensive understanding of modelling AD vehicles and thus makes this discussion invaluable in comprehending the intricacies and disparities inherent in traffic simulation and consequently is considered as a critical aspect of the Simulation Suite.

### *4.5 Interplay Between Simulations*

The third and the final layer of the tool, is designed to actually present the followed procedure and results of the application of any interplay between simulations. Furthermore, if any transferability methods proposed in the previous layer (second layer) were utilized, their respective results and steps are also delineated within this layer. Specifically, the given information of this layer serves as a comprehensive guide, aiming to elucidate the process of combining outputs from the different pilot sites simulations, addressing the methodologies employed, and navigating the prospects of transferring these approaches across simulations.

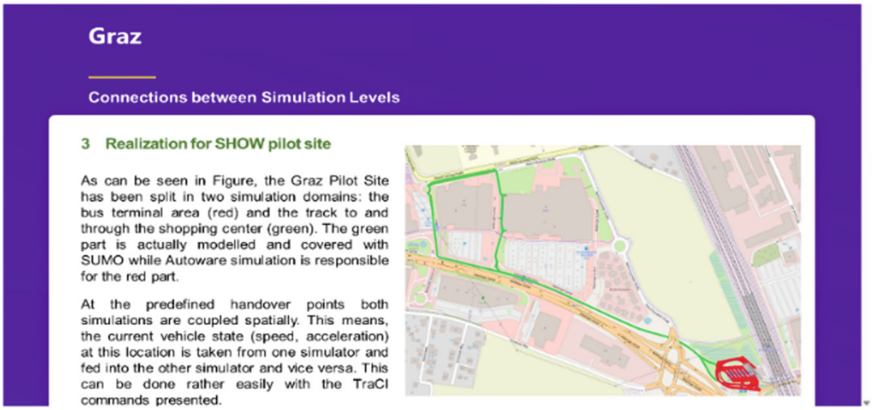


**Fig. 4** Graz pilot site: transition between simulation levels. *Source* Authors' own picture

- **Transition between simulation levels**: The information included will delve into the concept of transition levels, offering insights into the upscaling process, whether from microscopic to macroscopic simulations or vice versa, essential for a comprehensive impact assessment of automated fleets. This involves the exploration of strict mathematical transformations and the identification of transferable traffic flow parameters or indicators utilizing tools.
- **Comparison of different tools**: Additionally, a section comparing different simulation tools used across sites in cases that was applicable provides a comprehensive analysis for combining simulations that utilized varied simulation tools, ensuring a cohesive understanding of the diverse methodologies employed.

For instance, Fig. 4 illustrates the approach taken at the Graz site, where different simulation tools are interconnected to validate the pilot site. In Graz, two simulation levels are utilized to assess safety risks and traffic dynamics. Street level simulations, conducted with SUMO, focus on traffic flow and congestion without considering vehicle sensors or environmental occlusions. Meanwhile, VRU-level simulations, employing AWSIM, simulate vehicle sensors realistically within a 3D environment, reducing the gap between simulation and reality. Integrating these simulation levels offers a comprehensive understanding of traffic dynamics while minimizing discrepancies between simulation and real-world scenarios. This chapter discusses the process of coupling SUMO with other simulators to leverage their combined advantages effectively.

## *4.6 Library of Simulations*

The SHOW simulation Library is created to be the static repository of fundamental information regarding simulating automated mobility of each Simulation Suite layer.

More specifically, it includes all important data in appropriate format in order to be easily downloaded and used by the user in their tutorials/educational exercises. This kind of data is:

- **Raw simulation data**: Raw results extracted from the traffic simulation tool, which enable further filtering and processing in an alternative manner.
- **Scripts/APIs**: Includes scripts and/or APIs used in the respective simulation, which allow users to directly utilize relevant scripts for similar cases or within the same simulation tool.
- **Simulation visualization**: Recorded videos and screenshots from the simulation procedure that aid in familiarizing users with the simulation software.
- **Visualized guidelines**: Offers visualized guidelines across different use cases and software.
- **Documentation**: Relevant documentation for automated mobility use cases including research papers, traffic simulation instructions or tutorials, theoretical background documentation of behavioral models and algorithms, etc.

## 5 Conclusions

The core objective of the SHOW simulation suite is to seamlessly merge the insights garnered from simulating automated mobility, ensuring optimal integration across various simulation levels. This encompasses scalability, robust data analysis, and the cohesive synthesis of fundamental aspects to achieve a comprehensive understanding. This is accomplished by the development of the web-tool that is presented in this chapter, 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 SHOW findings at the maximum possible degree. Furthermore, significant advancement will be made as in the tool all possible data and information are collected, enhancing in this way the data availability for each site. Specifically, this process gives deeper insights into the pilot sites with indicators that cannot be directly measured in real-life pilot sites as well as make comparisons between real and simulation data. 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. One fundamental advantage lies in the integration of diverse simulation levels (microscopic and macroscopic), yielding generalized outcomes rather than independent ones, each resulted from distinct objectives. Another fundamental benefit is that by up-scaling data, in many cases there will be the possibility to generate more detailed data for automated mobility. This means that as the volume of data increases, it allows for the creation of more detailed and nuanced insights into automated mobility systems and their performance. For instance, by collecting data from a larger geographic area or a greater number of vehicles, researchers can better understand the intricacies of AVs behaviors and interactions, leading to more informed decision-making and improved system design.

From the user side and beyond the project, the SHOW Simulation Suite is useful for every researcher who is interested in simulating automated mobility, being and expert or not in traffic simulation. For this reason, the suite is designed in order to provide information about the possible tools and layers, suitable scenarios, and guidelines and to further give directions about the user's desired simulation scenario or use case or study area. Moreover, as already mentioned in the previous sections, more mathematical information are given by using the tool as well. This means that simulation experts will also gain knowledge through the documentation provided by the tool, as automated mobility is under investigation and hence there are significant challenges in simulating automated driving.

Finally, the included SHOW simulation library could make the tool also beneficial for city planners as well as practitioners, such as professionals actively involved in urban planning, policy implementation, or related fields who can utilize the simulation suite to inform their decision-making processes and operational strategies. Key results from each analyzed use case and level are archived, enabling interested stakeholders to guide future city management through appropriate strategies. Therefore, the simulation suite could also guide interested stakeholders in the future management of cities by using suitable strategies, as transportation systems will be fundamentally affected by the evolution of automated driving.

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## References

Anund A et al (2020) SHOW Deliverable 9.2: Pilot experimental plans, KPIs definition & impact assessment framework for pre-demo evaluation. https://show-project.eu/wp-content/uploads/2022/10/D9.2-Pilot-experimental-plans-KPIs-definition-impact-assessment-framework-for-pre-demo.pdf

ARCADE (Aligning Research & Innovation for Connected and Automated Driving in Europe) project. Funding from the European Union's Horizon 2020 research and innovation programme. https://www.connectedautomateddriving.eu

Cardaliaguet P, Forcadel N (2021) From heterogeneous microscopic traffic flow models to macroscopic models. SIAM J Math Anal 53(1):309–322. https://doi.org/10.1137/20M1314410

European Road Transport Research Advisory Council (ERTRAC) (2019) Connected Automated Driving Roadmap. https://www.ertrac.org/wp-content/uploads/2022/07/ERTRAC-CAD-Roadmap-2019.pdf

Forcadel N, Zaydan M (2016) Derivation of a macroscopic LWR model from a microscopic follow-the-leader model by homogenization. IFIP Adv Inf Commun Technol 494:272–281. https://doi.org/10.1007/978-3-319-55795-3_25

Helbing D (2007) From microscopic to macroscopic traffic models. Perspect Look Nonlinear Media 122–139:2008. https://doi.org/10.1007/bfb0104959

LEVITATE (Societal Level Impacts of Connected and Automated Vehicles) project. Funding from the European Union's Horizon 2020 research and innovation programme. https://levitate-project.eu/

LEVITATE connected and automated transport systems PST (Policy Support Tool). https://www.ccam-impacts.eu/

Li L, Chen X (Michael) (2017) Vehicle headway modeling and its inferences in macroscopic/microscopic traffic flow theory: a survey. Transp Res Part C: Emerg Technol 76:170–188. https://doi.org/10.1016/j.trc.2017.01.007

Martensen H, Diependaele K, Daniels S, Van den Berghe W, Papadimitriou E, Yannis G, Elvik R (2019) The European road safety decision support system on risks and measures. Accid Anal Prev 125:344–351. https://doi.org/10.1016/j.aap.2018.08.005

SafetyCube (Safety CaUsation, Benefits and Efficiency) Funding from the European Union's Horizon 2020 research and innovation programme. https://www.safetycube-project.eu/

SafetyCube Decision Support System. https://www.roadsafety-dss.eu/

SHOW (SHared automation Operating models for Worldwide adoption) project. Funding from the European Union's Horizon 2020 research and innovation programme, GA No 875530. https://show-project.eu/

Ziakopoulos A, Roussou J, Chaudhry A, Hu B, Zach M, Oikonomou M, Veisten K, Hartveit KJ, Brackstone M, Vlahogianni E, Thomas P, Yannis G (2022) The LEVITATE policy support tool of connected and automated transport systems. In: Proceedings of the 9th transport research arena TRA 2022. Lisbon, Portugal. https://doi.org/10.1016/j.trpro.2023.11.566

Tympakianaki A, Nogues L, Casas J, Brackstone M, Oikonomou MG, Vlahogianni EI et al (2022) Autonomous vehicles in urban networks: a simulation-based assessment. Transp Res Record 03611981221090507. https://doi.org/10.1177/03611981221090507

Zheng L, He Z, He T (2017) A flexible traffic stream model and its three representations of traffic flow. Transp Res Part C Emerg Technol 75:136–167. https://doi.org/10.1016/j.trc.2016.12.006