Data Flow Management Requirements for Virtual Testing of Highly Automated Vehicles

René Degen, M.Sc.
(Cologne University of Applied Sciences, Germany
Uppsala University, Sweden);

Alexander Nüßgen, M.Sc.
(Cologne University of Applied Sciences, Germany
Uppsala University, Sweden);

Marcus Irmer, M.Sc.
(Cologne University of Applied Sciences, Germany
Uppsala University, Sweden);

Florian Klein, M.Sc.
(HHVISION GbR, Germany);

Dr. -Ing. Christian Schyr.
(AVL Deutschland GmbH, Germany);

Prof. Dr. Eng. Mats Leijon
(Uppsala University, Sweden);

Prof. Dr. rer. nat. Margot Ruschitzka
(Cologne University of Applied Sciences, Germany);

Abstract

Efficient simulation environments for the development, calibration and approval of highly automated vehicle systems are regarded as a decisive key to accelerating technological progress in this field. Especially urban environments with their high diversification of requirements pose a particular challenge.

This paper presents a virtual co-simulation approach for highly automated vehicle systems and uses it to demonstrate the data management requirements for a co-simulation platform such as AVL Model.CONNECT™. The basis for this is a real urban driving cycle for modern hybrid vehicles to investigate emissions, consumption and range as well as the effects of highly automated driving functions on these parameters.

Figure 1 schematically shows the data structure in the project based on the procedure for agile software development.

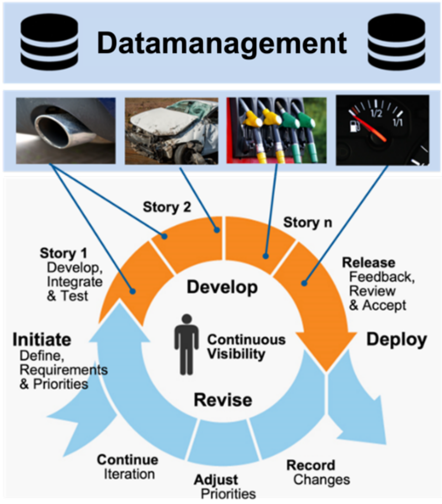

Figure 1: Schematic representation of data expenditures in the urban virtual test field

The urban virtual test field connects real vehicles on the test bench with real human road users in a virtual urban traffic environment [1]. Not least due to the demand for real-time capability, the underlying data volume is enormous.

1. Introduction

Advanced Driver Assistance Systems/Autonomous Driving (ADAS/AD) are becoming more and more important in the automotive industry. It is expected that automated vehicles will provide promising advantages in transportation and mobility [2]. By now, modern vehicles are already equipped with different kinds of assistance functionalities [3]. At the same time, the amount of traffic accidents is degreasing continuously [4]. The causal relation is unambiguous and reinforces the predicted expectations associated with this technological progress. In this context, the legislature has allowed Level 4 automated driving functions on public roads in Germany since 2021 [5, 6]. This leads to the expectation that the market for ADAS will continue to grow in the future.

Besides the opportunities ADAS offer to the vehicle safety, they also increase the vehicles complexity and the testing effort. Especially in urban areas the diversity of situations and requirements is enormous. Therefore, extensive testing possibilities and environments are necessary to enable further technological progression. Here, digital test environments have a big part of testing solutions for highly automated vehicle functionalities, whereby the importance of data management is increasing continuously.

This publication presents a virtual test environment for highly automated vehicle functionalities in urban areas, based on which the data flow between the different soft- and hardware parts of the test filed is shown. Due to this and the expectations of real time testing, the requirements for virtual test environments in general could be derived.

2. Virtual Test Field

This chapter describes the general structure of the virtual test field and its main components: the city model, pedestrian model and vehicle model. Further, a representative urban driving cycle based on a georeferenced model of the Cologne inner city is introduced. Here, different typical urban traffic scenes are included to apply traffic reality to the data amount and variation of the virtual test environment.

a. Virtual Test Field Structure

To represent real urban traffic realistically, the interaction between pedestrians and the automated vehicle as well as a realistic urban environment are crucial. Figure 2 shows the general setup of the virtual test field on which the work is based.

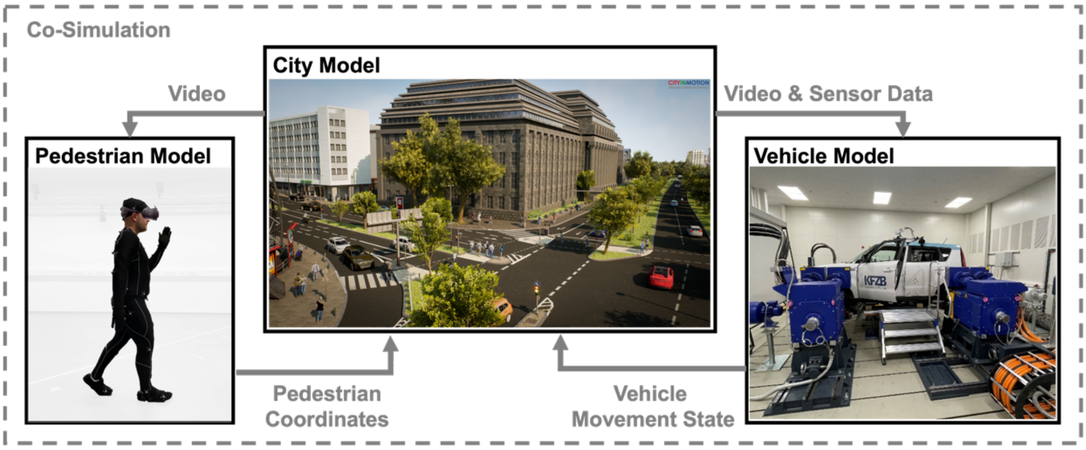

Figure 2: Schematic setup of the virtual test field and its different components

The main part is a highly realistic and georeferenced model of the Cologne inner city around the so called "Breslauer Platz". This highly detailed model, which covers about three squared kilometres, is implemented in a virtual reality (VR) environment. This environment includes pedestrian and vehicle avatars, which are steered and controlled by external models in external environments. The pedestrian model is fitted by real human movements collected by a motion capture hardware. Further, a vehicle on a testbed steers the vehicle avatar in VR. Driving dynamical parameters and resistances are added by a preceding simulation model. The interaction between the different system architectures is coordinated with the help of a co-simulation environment.

b. Urban Traffic Cycle

For the reproducibility and comparability of the virtual test field, a representative driving cycle is necessary. In this work a cycle with an overall distance of about 500 meters is chosen, including 5 action points and 3 typical urban traffic situations, and is completed in about 120 seconds. For this propose, the area around the so called “Konrad-Adenauer-Ufer” next to the “Breslauer Platz” is sufficient because it includes a high level of traffic as well as less frequented areas, different kinds of street architectures and places of pedestrian-vehicle interaction. The chosen area for the driving cycle is shown in Figure 3.

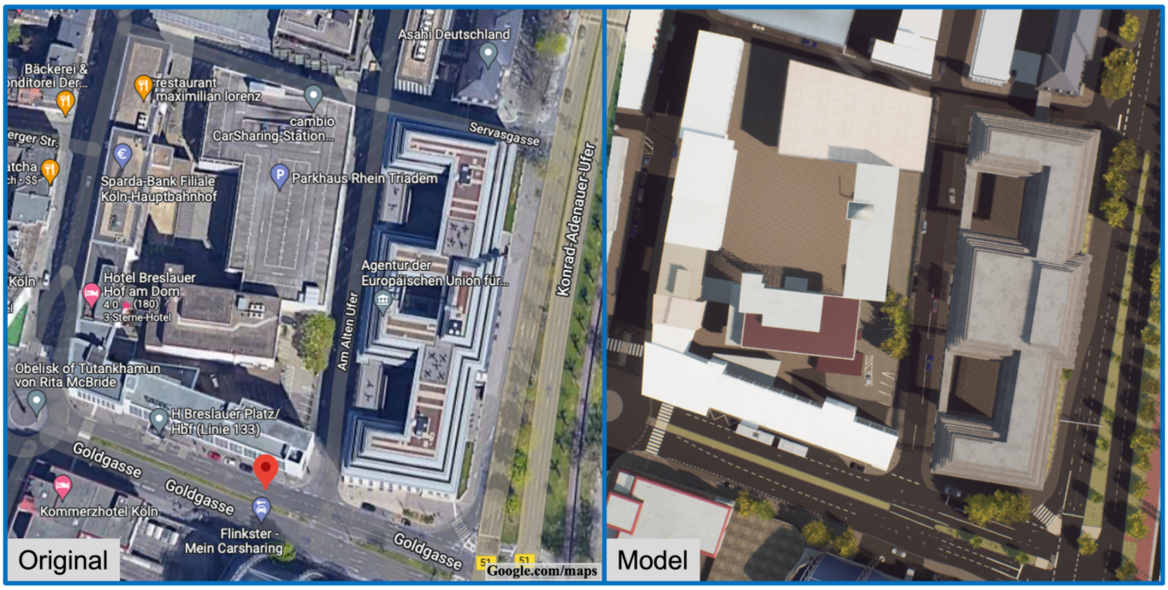

*Figure 3: Inner city area in which the urban driving cycle is located
left: Google maps, right: City model*

Due to the exact replication of the real urban area, the city model includes height coordinates, traffic signs and road courses. Additionally, the model represents the buildings dimensions, surfaces and appearance. Further, artificial pedestrian and vehicle traffic complete the model. Combining these traffic reality issues results in an urban cycle with different possibilities of variations and adjustments. The general course of the urban cycle including the traffic interaction points is shown in Figure 4.

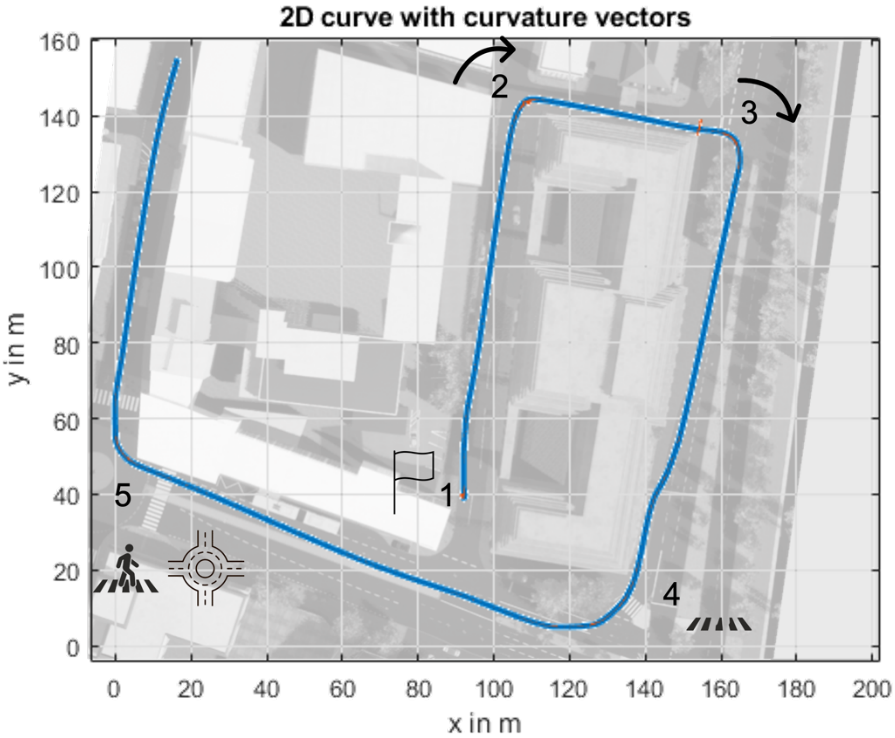

Figure 4: Driving cycle including scaling and action points

The cycle starts at the crossroad "Am Alten Ufer" and continues by two following right curves to the high frequented street "Konrad-Adenauer-Ufer". After about 120 meters a crosswalk follows in the curve to the "Goldgasse" by changing to a separated turn-off line. At the end of the "Goldgasse" a crosswalk follows in front of a roundabout, where the trajectory of the cycle runs into the "Johannisstraße".

In addition to different speed profiles, various environmental influences such as weather and lighting conditions, traffic intensity and shading can also be set. Further, it is possible to select and chance the cross walk and human machine scenarios.

3. Data Flow of the Virtual Test Field

To achieve a functional and efficient virtual environment for highly automated vehicles, it is important to not only evaluate, which kind of data is needed to combine several software components and to define or use given interfaces, but also at which time point it is needed. Thus, data management and data flow are critical parts of design process. Inside of the setup, three independent models for the city, a pedestrian and a car with sensors have to be implemented and united by co-simulation. This means that all models must be data consistent within itself but also inside the virtual environment. For this purpose, standardized transmission protocols such as the User Datagram Protocol (UDP) are used to communicate between the software components. For the synchronization of the different hard- and software environments with various sampling rates, common clock times and time stamps are used.

a. City Model

The city model provides the basic environment with static objects. It defines the trajectory as shown in Figure 4. To create an environment as close to reality as possible, the whole city model is georeferenced including height coordinates. In addition, all buildings, other static objects such as streetlights, flora, traffic signs or street courses in the immediate surrounding of the considered area are modelled, textured and placed in accordance with the real area. Finally, light sources and weather conditions are added to the environment to achieve a realistic representation. Figure 5 illustrates schematically the data flow inside the city model.

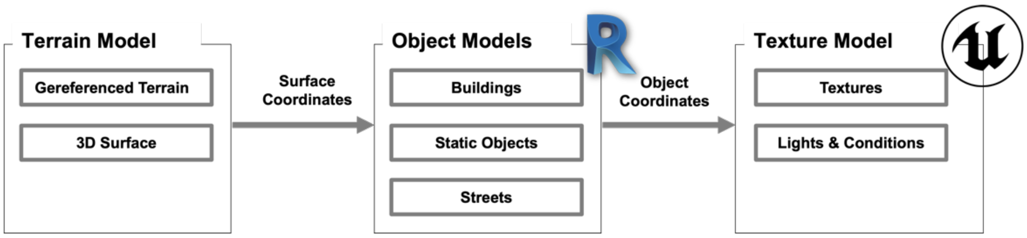

Figure 5: Data flow of the city model architecture

b. Pedestrian Model

The pedestrian model is controlled via motion capture in real time to enable interaction with the digital environment. Therefore, an OptiTrack optical motion capture system is used. Motive is the corresponding software for OptiTrack motion capture cameras. Its internal skeleton solver estimates the position and rotation of each bone at each time frame based on the actual measured markers attached to a person's body. The update rate can get up to 360 Hz. To forward the data to an external engine like the Unreal Engine, data is provided via the NatNet interface. NatNet provides unicast and multicast transmission via UDP. Motive functions as a NatNet server. Each skeleton consists of 21 bones as rigid bodies connected by joints. Each bone has a unique ID inside the skeleton and is provided as an integer. Furthermore, the position and rotation are provided as floats. The position of each bone consists of three values for each axis. The rotation data consists of four values since it is represented in quaternions. Inside Unreal Engine this data is received via an implemented NatNet client and forwarded to the animation pipeline. Inside the animation pipeline, data is applied to an arbitrary pedestrian avatar that can be chosen by the user. The process of applying motion capture or animation data onto a character is called retargeting. Retargeting enables the possibility to apply any animation data from any person under test onto any avatar while maintaining the body proportion of the avatar despite the body proportions of the test person. After applying the data of the 21 bones onto the avatar's skeleton under several restrictions, a realistic and biomechanically correct movement in real time is achieved.

In addition to provide an experience as immersive as possible for the person under test (PuT), a head mounted display is used. This provides the video data as stereoscopic rendering of the digital environment directly to the PuT. This enables the possibility to not only see the real body movement via the pedestrian avatar and the city environment but also enables interaction with the vehicle under test (VuT). In Figure 6, the data flow of the pedestrian model is shown.

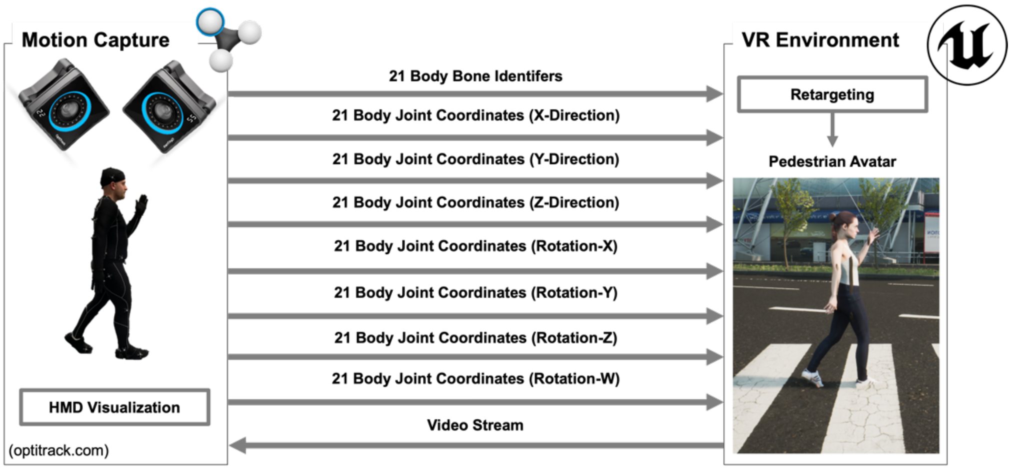

Figure 6: Data flow of the pedestrian model architecture

c. Vehicle Model

The vehicle model is calculated as a five body model in real time with a refresh rate of 50 Hz based on the given trajectory as shown in Figure 4, the vehicle type used and the driving situation. The driving situation is estimated by the real vehicle inside the vehicle test bed. Therefore, steering angle, breaking torque and driving torque is measured on the vehicle test bed and forwarded as three float values. In addition, the height coordinates of the ground underneath the tires and body in the city model are calculated by using raytracing and also forwarded as five float values. This input data is utilized as input for the vehicle physics model. The vehicle physics model calculates the resistance values for the vehicle test bed and the orientation and position for each wheel and the body for visualisation of the vehicle avatar in the VR. Inside the virtual environment with the physically correct behaviour of the car, probabilistic sensor models such as LIDAR, radar or camera are implemented.

Analog to the pedestrian model, the video data is forwarded to the visualisation device inside the vehicle test bed to show the virtual environment with all its components to the driver.

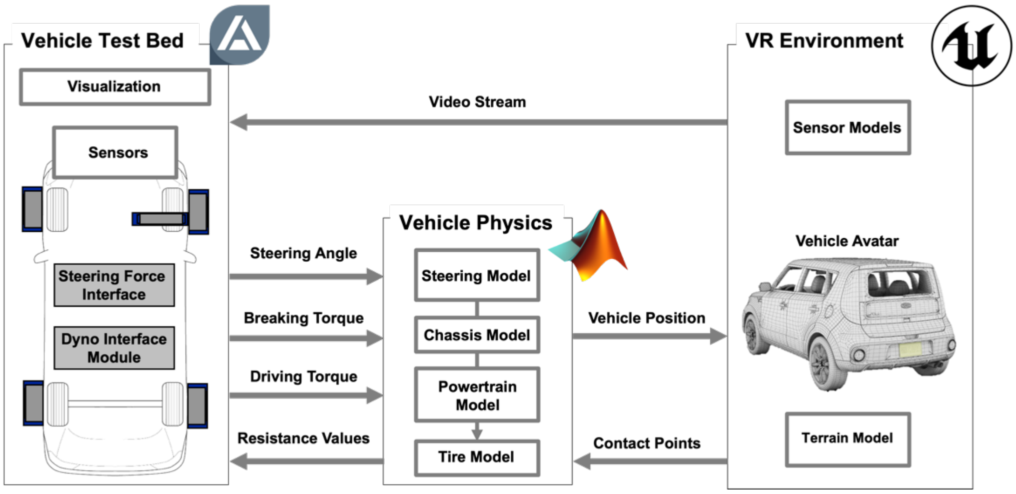

Figure 7: Data flow of the vehicle model architecture

4. Evaluation of the Virtual Test Field

In the frame of this chapter, the virtual test field is evaluated by a representative parameter set of the introduced driving cycle. For this propose the overall system, including interfaces and model architecture is shown in Figure 8.

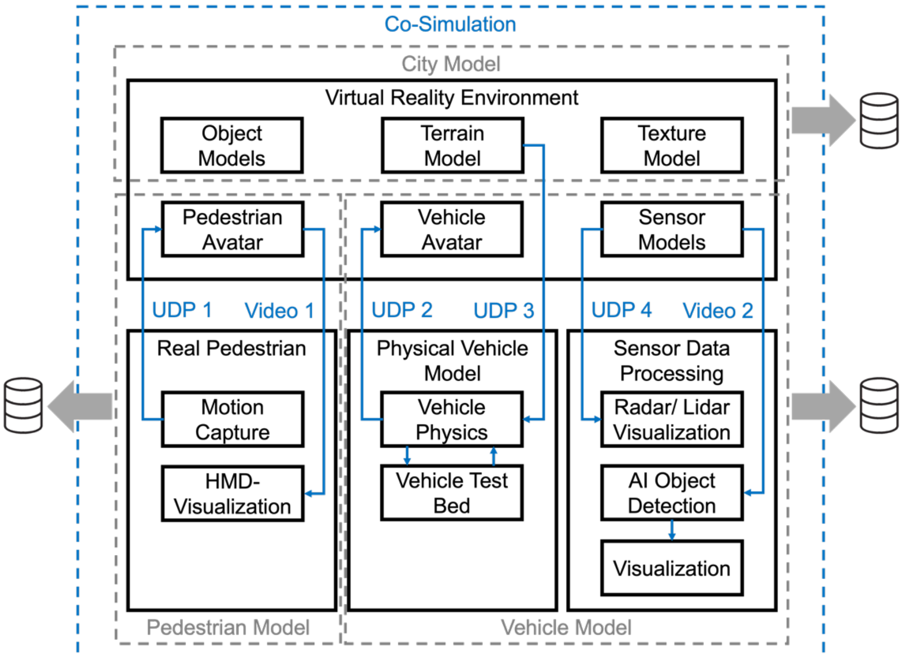

Figure 8: Scheme of the co-simulation model data flow

As described in chapter 3, next to video mostly the UDP interface is used for data exchange between the different development environments. Additionally, each model itself saves the native generated data in separated data storage and provides the necessary data for the other co-simulation participants.

For the evaluation the following set of parameters is chosen:

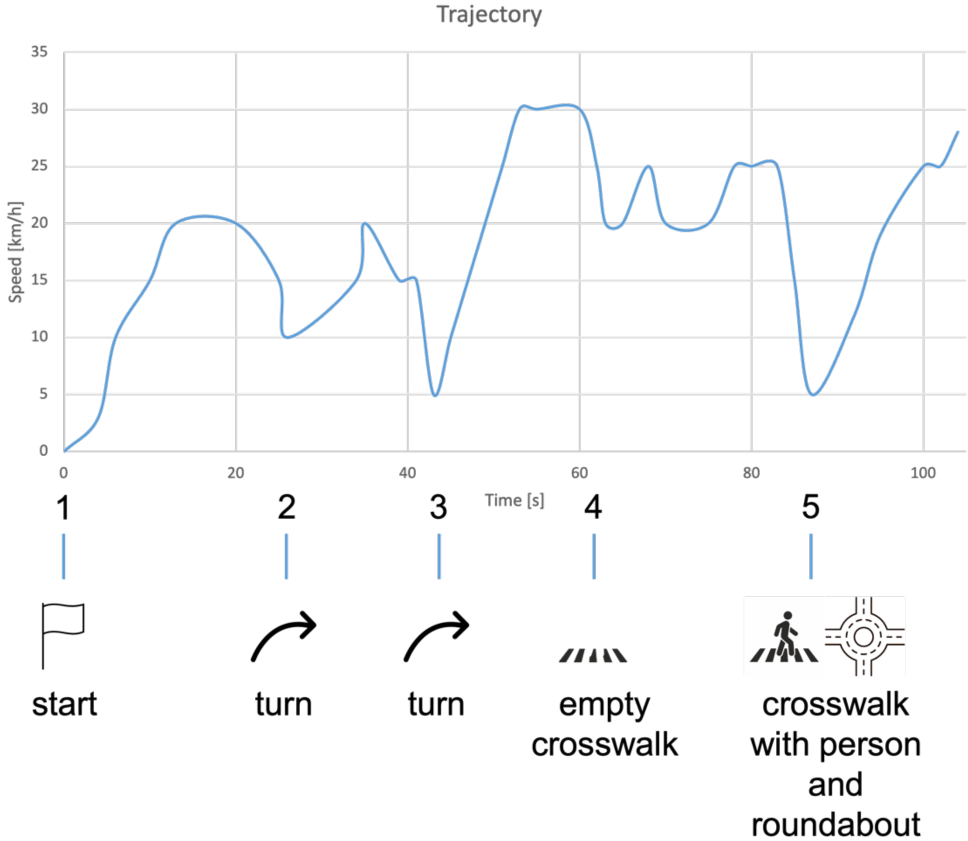

Figure 9: Speed settings for the driving cycle

The range of velocity keeps between 0 and about 30 kilometers per hour. Due to the different action points, the acceleration fluctuates significantly. Furthermore, the artificial traffic is set to zero and the light conditions are imitated the daylight. At the second crosswalk, a human-machine interaction takes place as a pedestrian crosses.

The resulting data efforts of the individual interfaces are listed in Table 1 as an example.

Table 1: Data rates of the system interfaces based on a representative setup

Nr.	**Interface**	**Data Rate**
1	UDP1 (360 Hz | 672 Byte)	0.23 MB/s
2	Video 1 (90 Hz | Full HD)	1 GB/s
3	UDP2 (200 Hz | 1200 Byte)	0.2 MB/s
4	UDP3 (50 Hz | 20 Byte)	0.001 MB/s
5	UDP4 (120 Hz)	0.74 MB/s
6	Video 2 (50 Hz)	15 MB/s
	Sum:	1.02 GB/s

With the assumptions made previously, one run of the drive cycle results in a total of 122.4 GB of data.

5. CONCLUSION

The present work shows the requirement and complexity of data management of a co-simulation platform for highly automated vehicle systems using the example of a simple urban city cycle. The core message of the work lies in the choice of a suitable architecture of the co-simulation platform in order to be able to handle the data sets in an optimal and automated way. Due to the high data volumes, there is otherwise a risk of data loss, misinterpretation, or blurring.

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