PROJECT of the PEGASUS FAMILY

VERIFICATION VALIDATION METHODS

Final Event 21 / 22 November 2023

Empirical Simulation Validation

Comparing proving ground and simulation data of an SAE Level 4 System

Hardi Hungar, Gerald Temme, Fin Heuer, Björn Bahn

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

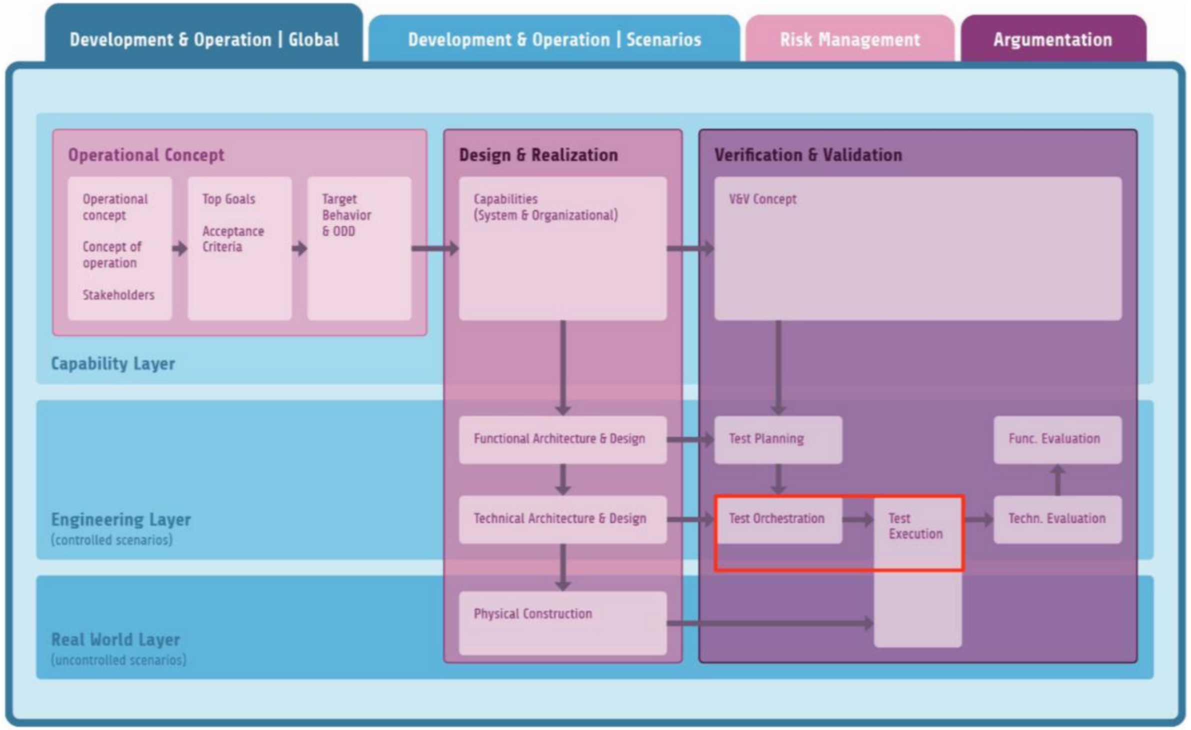
Classification in VVM Context

Goal:

- Empirical simulation results validation by overall system validity analysis
- Focus on evaluation of the degree of realism in a detailed simulation for automated vehicles

Test Execution:

- Realisation within a simulation and on a proving ground
- Within simulation use of a SAE level 4 automation as software in the loop (SiL) model
- On the proving ground use of same automation as part of an automated research vehicle
- Simulation validation for controlled scenarios based on comparison of collected data from both conditions



Test Execution - Component Setup

Requirements for a comparison:

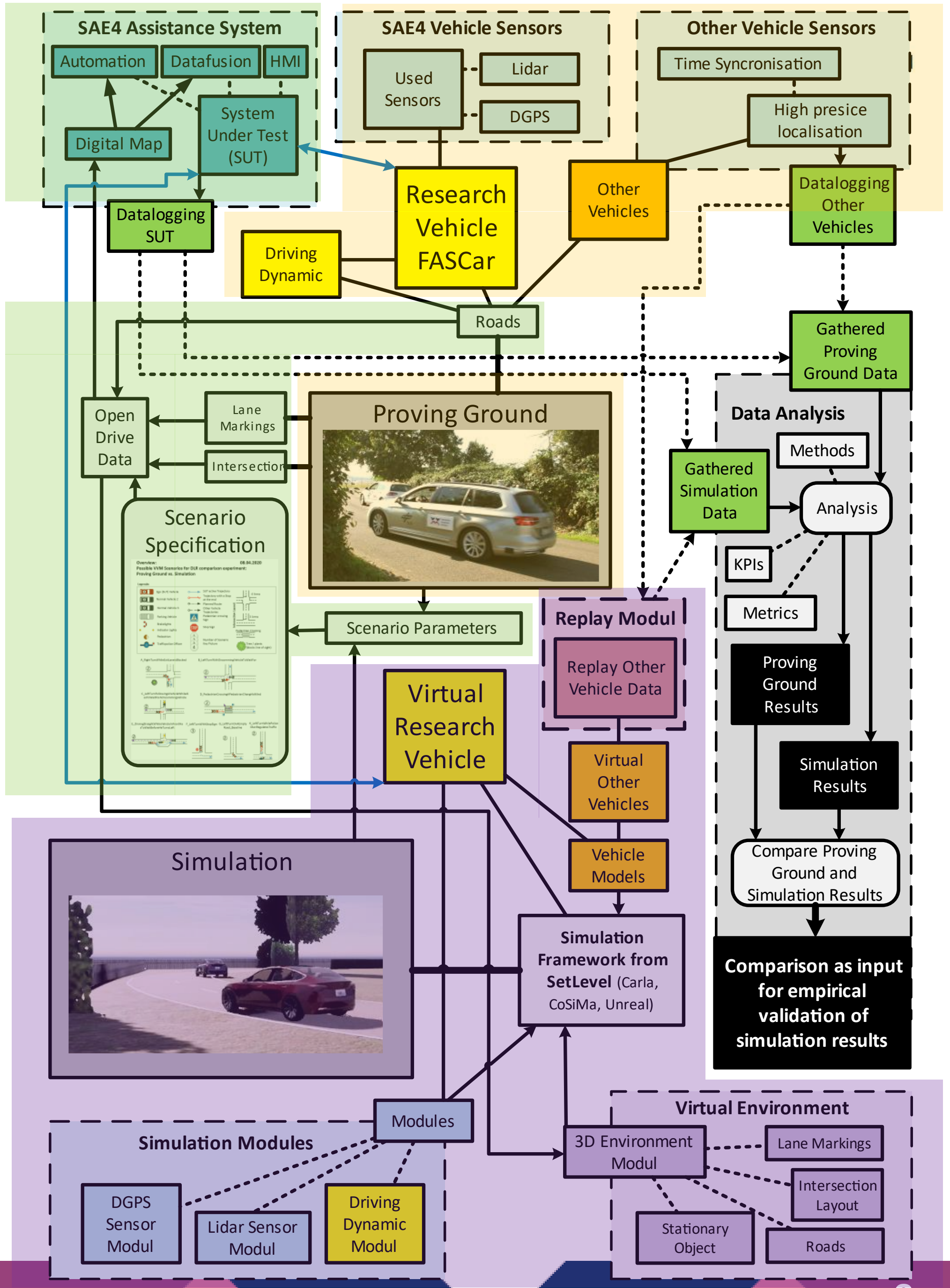
- Same scenarios and parameters
- Same OpenDRIVE based digital map
- Same SAE level 4 automation as system under test

Proving Ground Components:

- Research Vehicle FASCar
- Using LiDAR, GNSS\DGPS sensor setup
- Other automated traffic

Simulation Components:

- Unreal engine based simulation framework
- Virtual environment as digital twin
- Simulation modules for vehicle dynamic and sensors
- Module for replaying the other vehicles from the proving ground

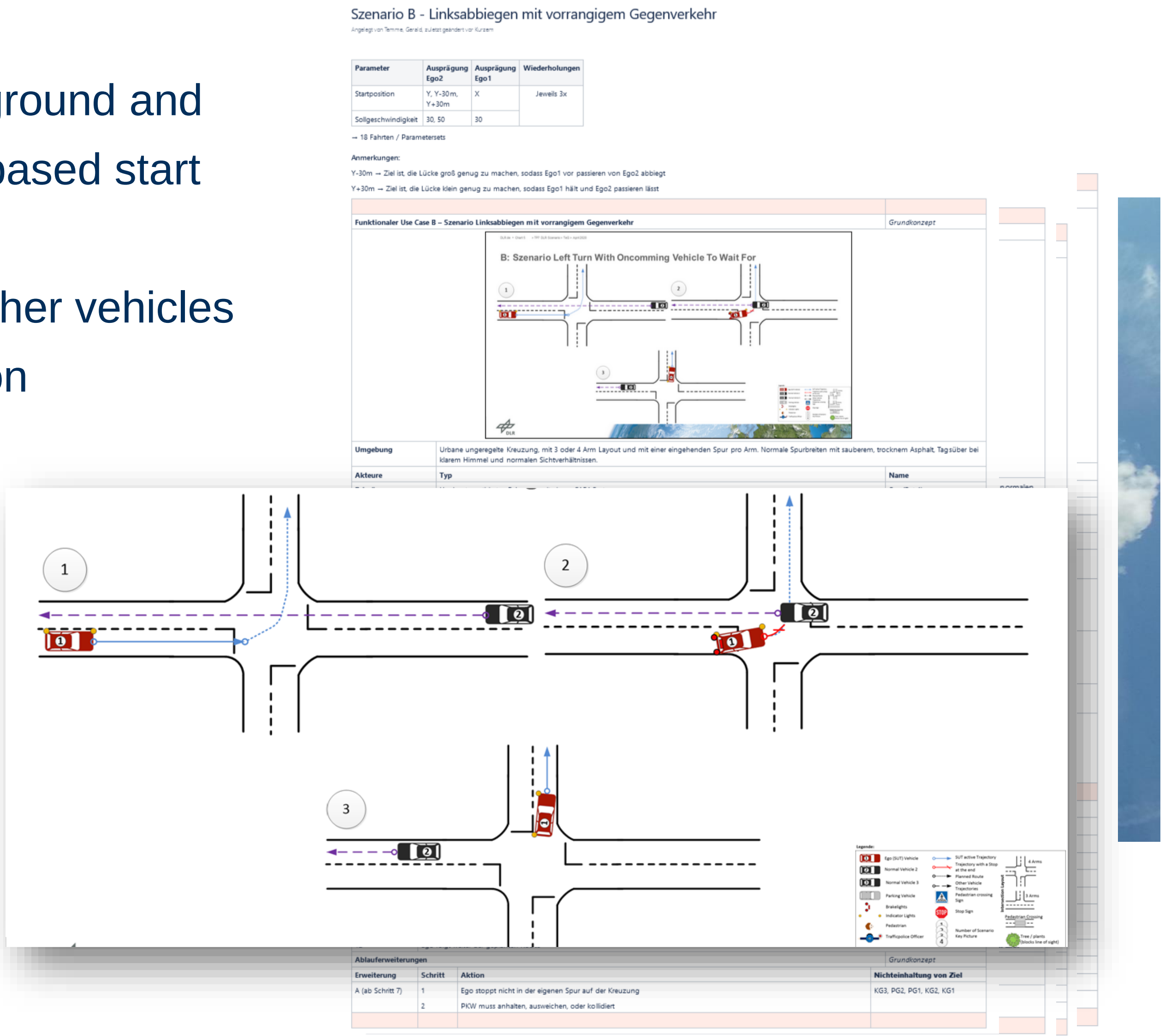


Addressed Scenarios

VERIFICATION VALIDATION METHODS

- Realisation of comparable scenarios for proving ground and simulation with synchronized vehicles via a time based start trigger
- Using logged proving ground trajectories of the other vehicles to create a comparable behaviour within simulation

- Driven Scenarios:
  - Straight driving reaching speed limit
  - Follow-up journey of two automated vehicles
  - Turning left without oncoming traffic at maximum speed
  - Sensor test without obstacle
  - Sensor test with obstacle
  - Parked vehicle blocks lane
  - Left turn with priority oncoming traffic



Technical Details

Test Environment – Reality and Simulation

- Digital, highly precise road map for ADORe automation created from OpenDRIVE data
- Digital Twin for simulation visualisation by OpenDRIVE data enhanced with surrounding environment

Realität
@ Goggle maps view

Simulation
@ Unreal bird view

Technical Details

Research Vehicles and SAE Level 4 Automation

System Under Test (SAE Level 4 Vehicle)

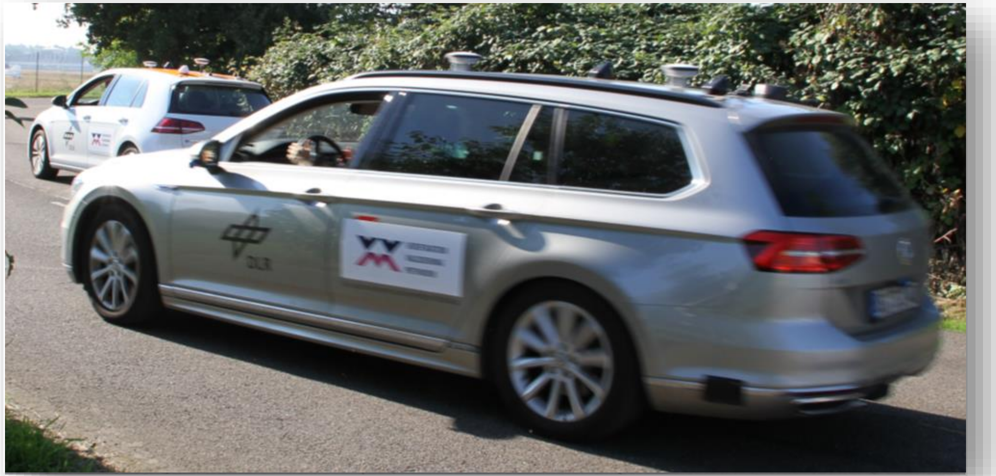
- Name: Viewcar II
- Obstacle detection by three front LiDAR sensors
- Localisation via GNSS
- Automation by ADORe

Other automated traffic

- Name: FASCar-E
- Follows automated a given route *(using ADORe)*
- Localisation via GNSS

ADORe (Automated Driving Open Research)

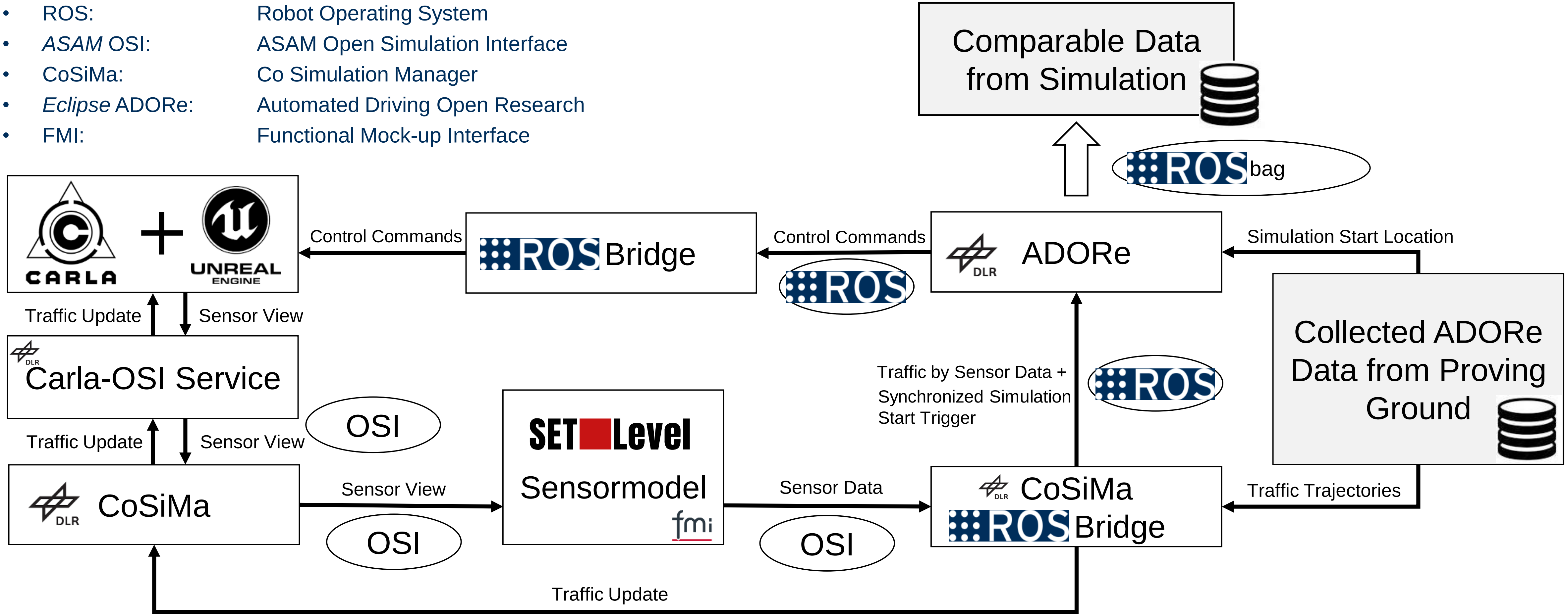
- a open, modular software library and toolkit for decision making, control and simulation of automated vehicles



Technical Details
Simulation Tool Chain

Legend:

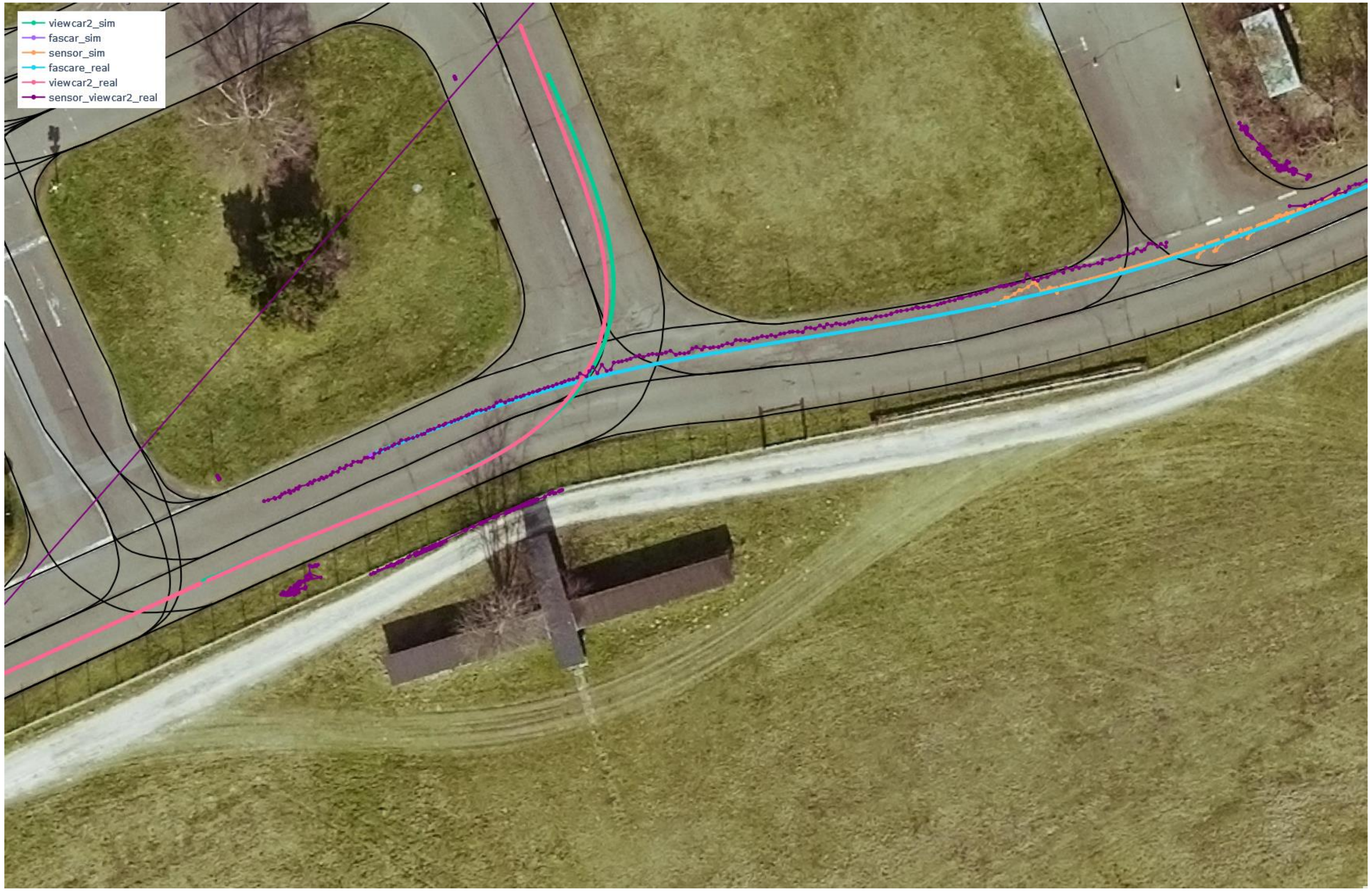
- CARLA: an Open-source simulator for autonomous driving research
- ROS: Robot Operating System
- *ASAM* OSI: ASAM Open Simulation Interface
- CoSiMa: Co Simulation Manager
- *Eclipse* ADORe: Automated Driving Open Research
- FMI: Functional Mock-up Interface



Impressions of the Data Collection

Example Results of Left-Turn Scenario

- Overview of the simulated and real trajectories from a top view
- Sensor detections deviate between simulation and reality
- Trajectory of HAD-system is nearly the same
- “Decisions” of the HAD-system are the same

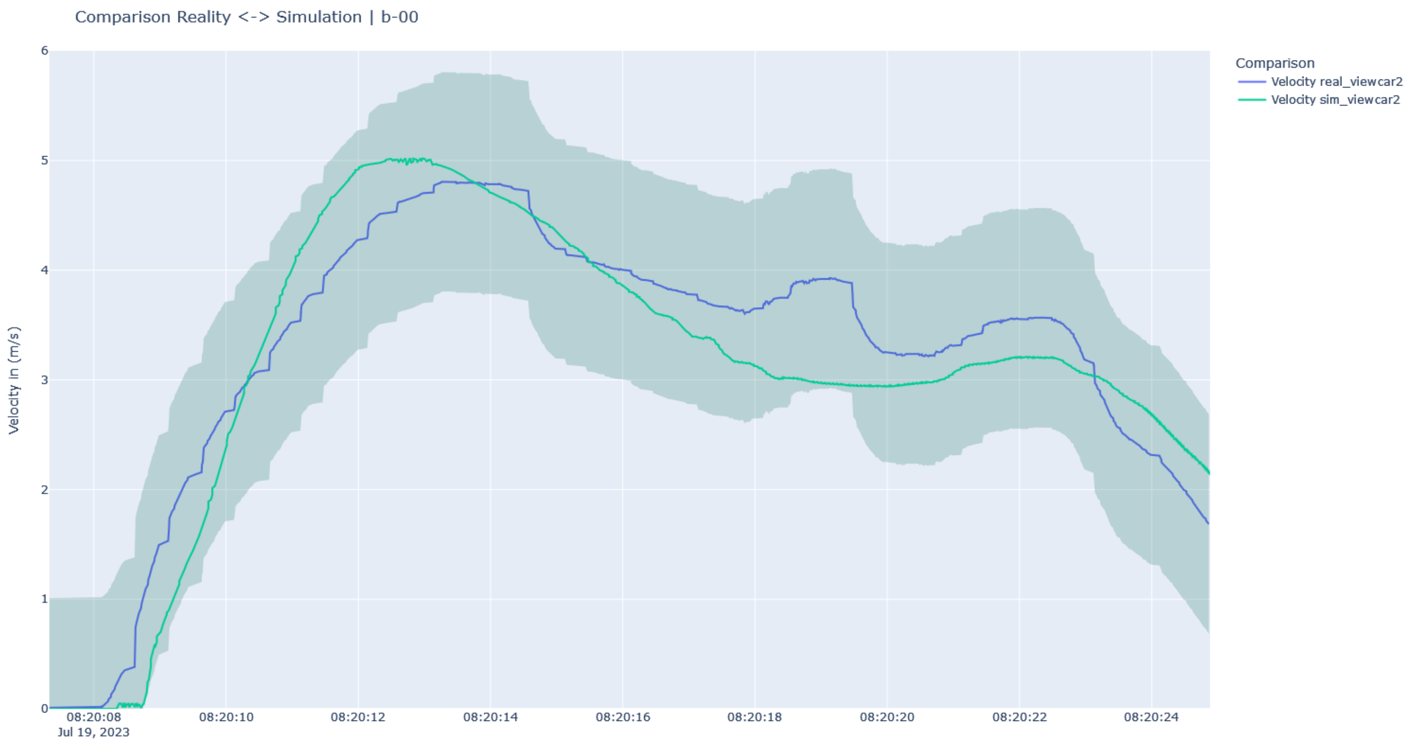


Example Results of Left-Turn Scenario

- Video shows time-aligned data from real test drives and simulation
- The vehicle to the left (automated) wants to perform a left-turn
- A challenging vehicle arrives from the right
- The gap is large enough that the automation decides in simulation and reality, that it will perform the left turn prior to the oncoming vehicle is on the intersection

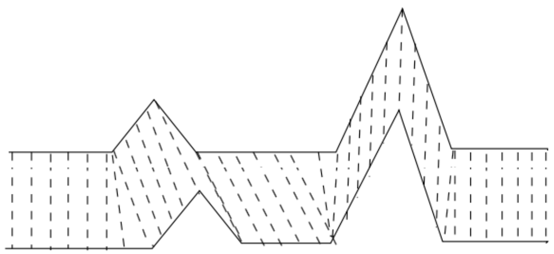
Velocity over Time

- Velocity of HAD in simulation vs. reality
- Overall course approximately equal
- Deviations in start, increase, variability, … between simulation and reality
- To decide whether the simulation is valid, an illustrative velocity accuracy criterion of ± 1 m/s is displayed (gray band)
- The illustrative criterion is met

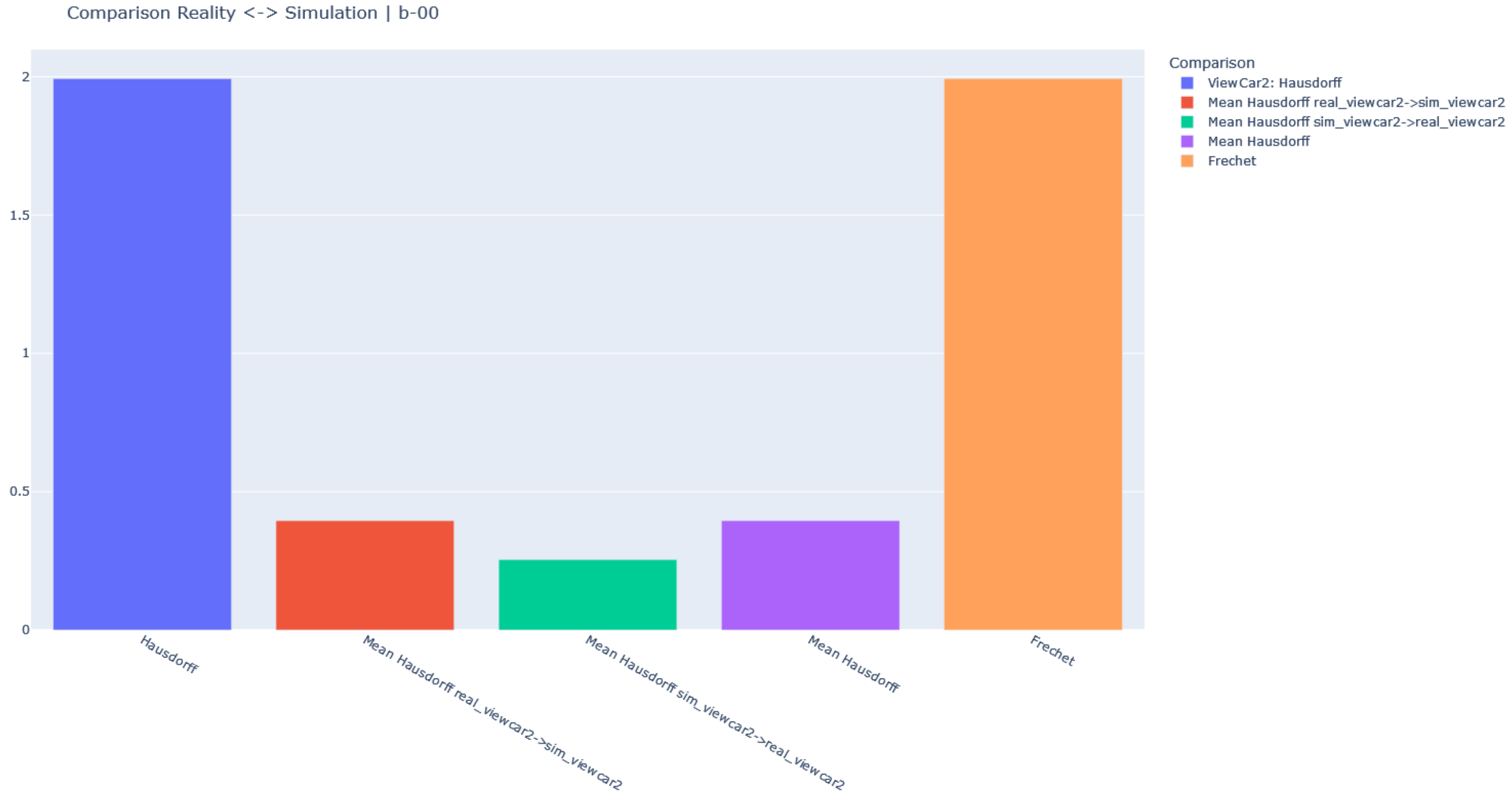


Trajectory Metrics

- Frechet
  - Maximal length of point distance between trajectories (time monotonic)



- Hausdorff
  - Similarly based on point to trajectory distance, simpler
    - Non-monotonic, not symmetric
  - *maximal* or *mean* values as metrics for full trajectories
  - *maximal* in most cases the same *as* Frechet

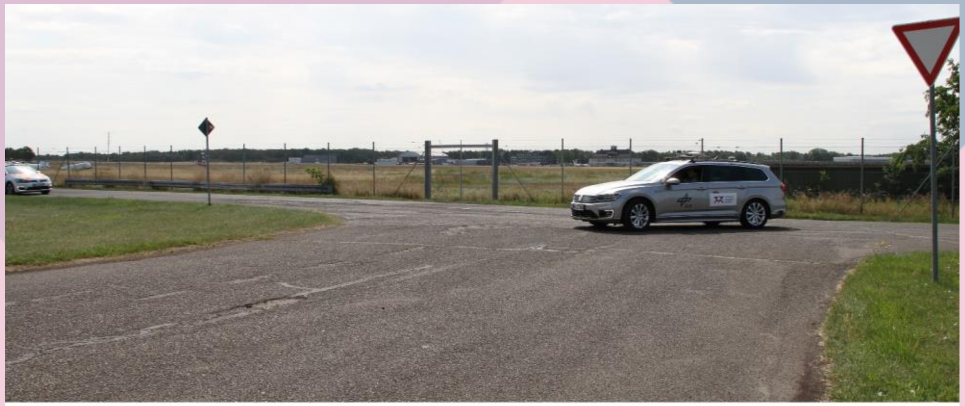


Conclusion

- **The activity demonstrates the ability of simulation to accurately replicate reality and validate SAE 4 automation systems**, given that
  - Accurate (valid) models for automation components and environment are available
  - Validity constraints for the models employed are observed
    - E.g. challenging environmental conditions may lower the level of significance
  - The simulation is set up carefully
    - Validity checks under controlled conditions must be performed
- **Deviations will nevertheless be observed** and must be taken into account in determining the level of significance of the simulation results
  - In particular the modeling of perception chain needs attention
    - E.g. ghost objects for LiDAR are underrepresented in employed sensor models
- **The use of simulation in safety argumentations must be well integrated with other sources of factual evidence**

VERIFICATION
VALIDATION
METHODS

Thank you!



PROJECT of the PEGASUS FAMILY

VDA LEITINITIATIVE

A project developed by the VDA Leitinitiative
autonomous and connected driving

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag