A SCENARIO-BASED SIMULATION FRAMEWORK FOR TESTING OF HIGHLY AUTOMATED RAILWAY SYSTEMS

VEHITS2025 | Intelligent Vehicle Technologies

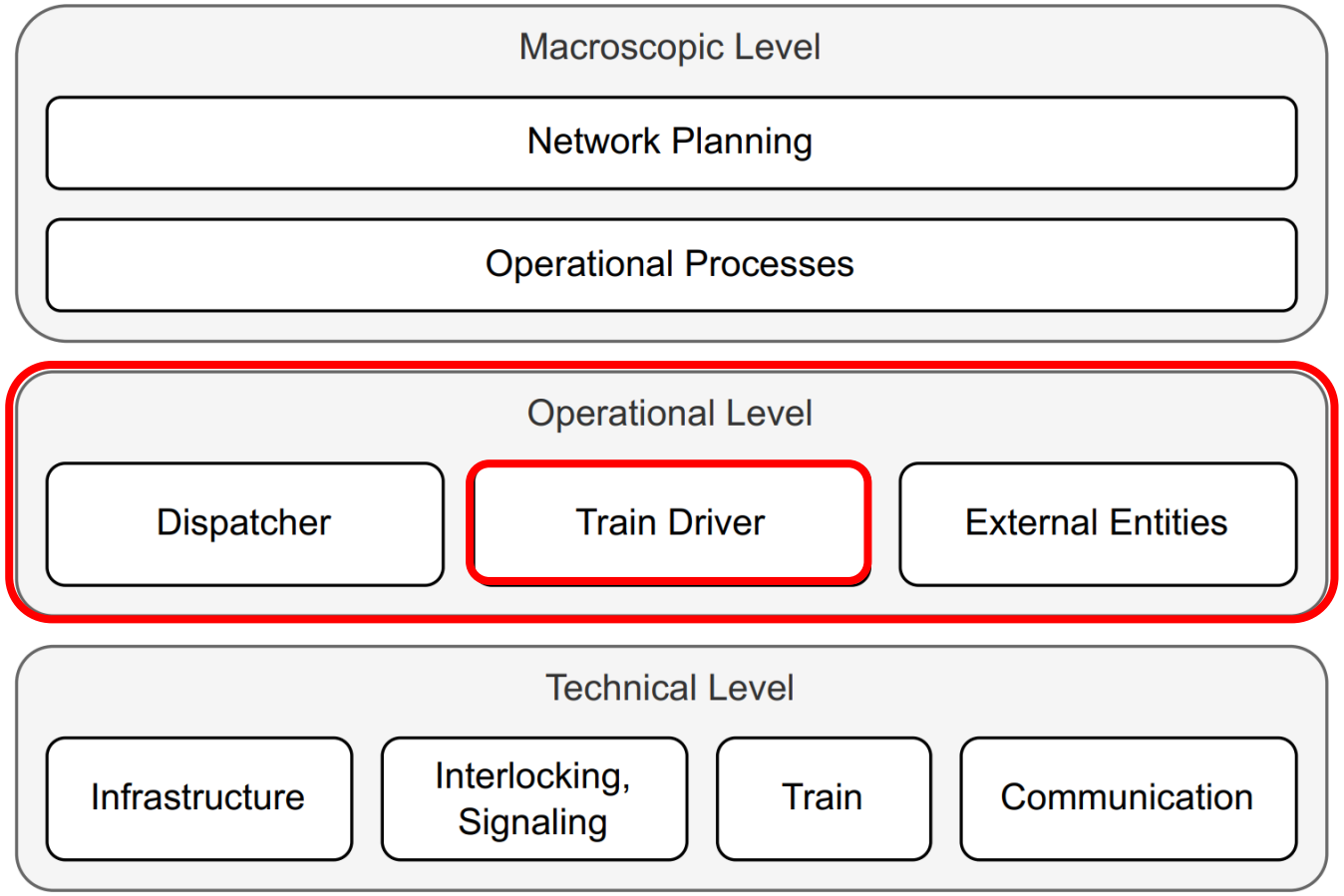
Michael Wild, Jan Steffen Becker, Carl Schneiders, Eike Möhlmann

Overview

- Motivation scenario-based testing in the railway domain
- Traffic sequence charts (TSC) for requirement and test scenario specification
- Test-framework
- Closed loop play-out engine
- Proof of concept

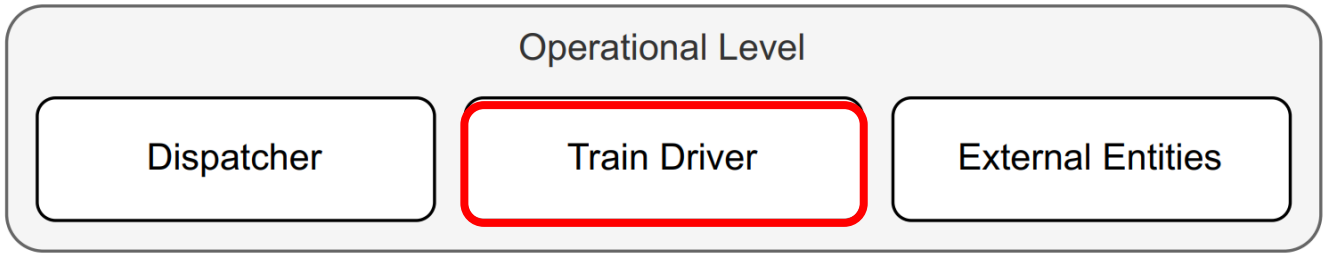
Motivation for scenario-based testing in the railway domain

Operations in the railway domain are safeguarded at various levels

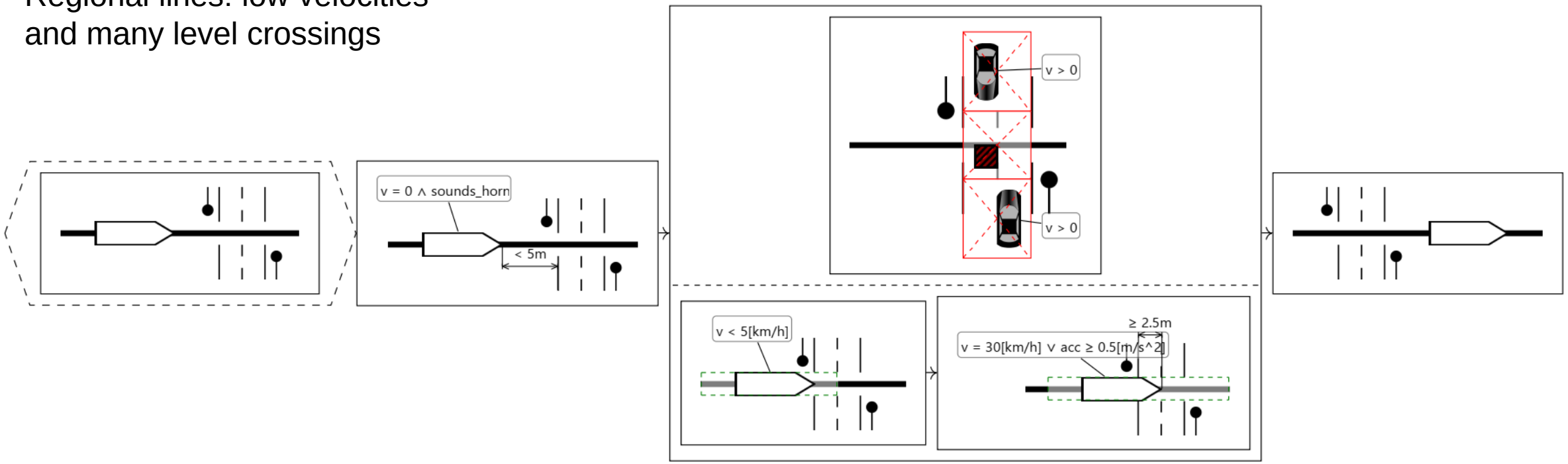


Wild, Michael, et al. "Towards Scenario-Based Certification of Highly Automated Railway Systems." *International Conference on Reliability, Safety, and Security of Railway Systems*. Cham: Springer Nature Switzerland, 2023.

Required behaviour of train driver at unprotected level crossing

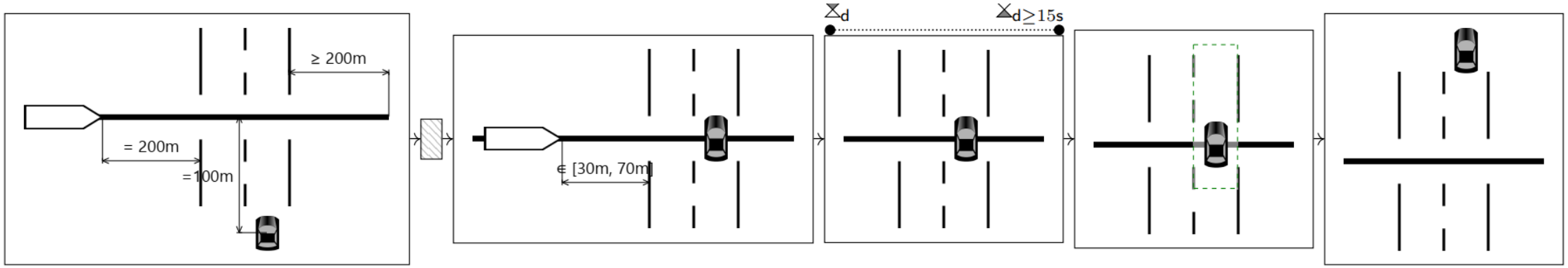


Regional lines: low velocities
and many level crossings

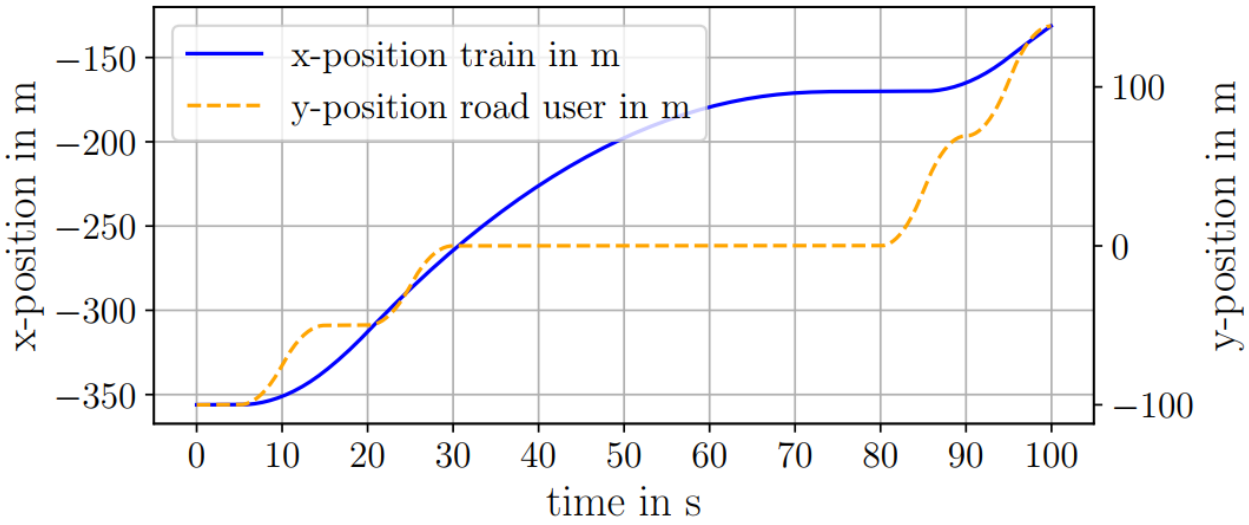


Michael Wild, German Aerospace Center (DLR), 4.4.2025

Test scenario that allows to test required behaviour



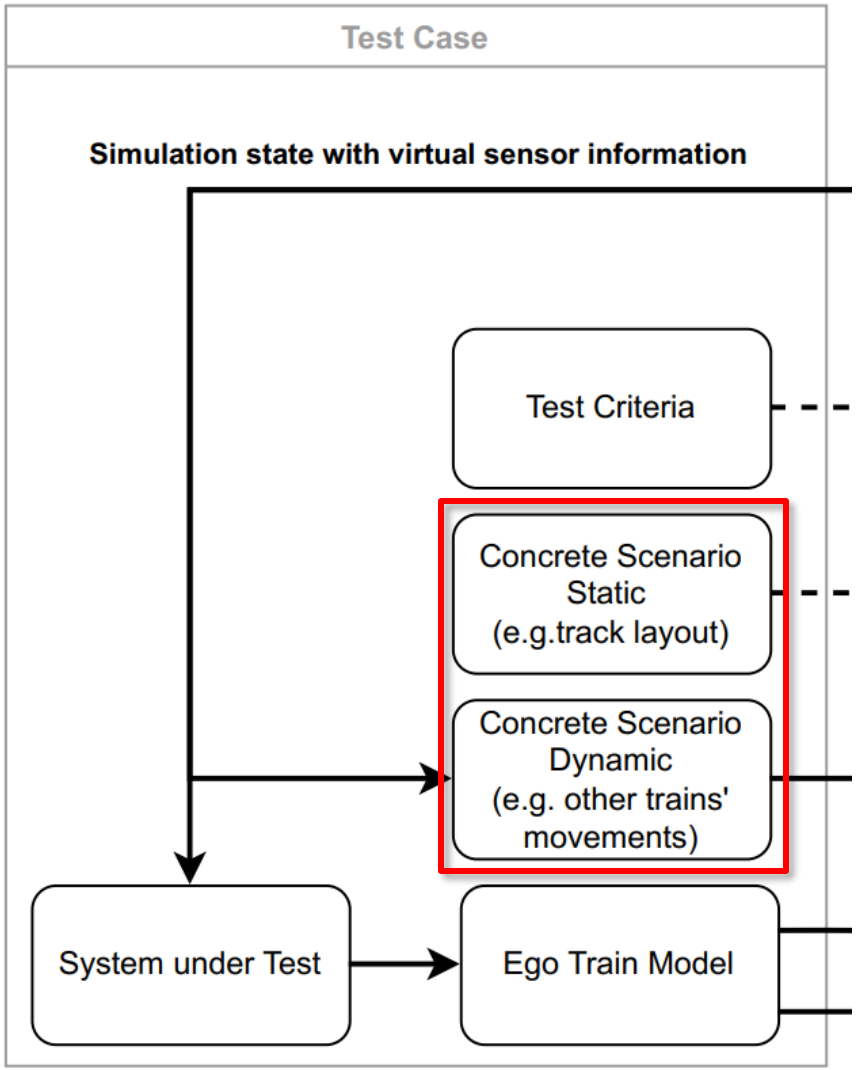
Abstract Scenario → SMT Solver → Reference Scenario



- Reference scenario fullfills TSC-test by construction
- System under Test is free to diverge from the trajectory --> Does not imply violation

Borchers, Philipp et. al “TSC2CARLA: An Abstract Scenario-Based Verification Toolchain for Automated Driving Systems.” Science of Computer Programming 242 (May 1, 2025): 103256. https://doi.org/10.1016/j.scico.2024.103256.

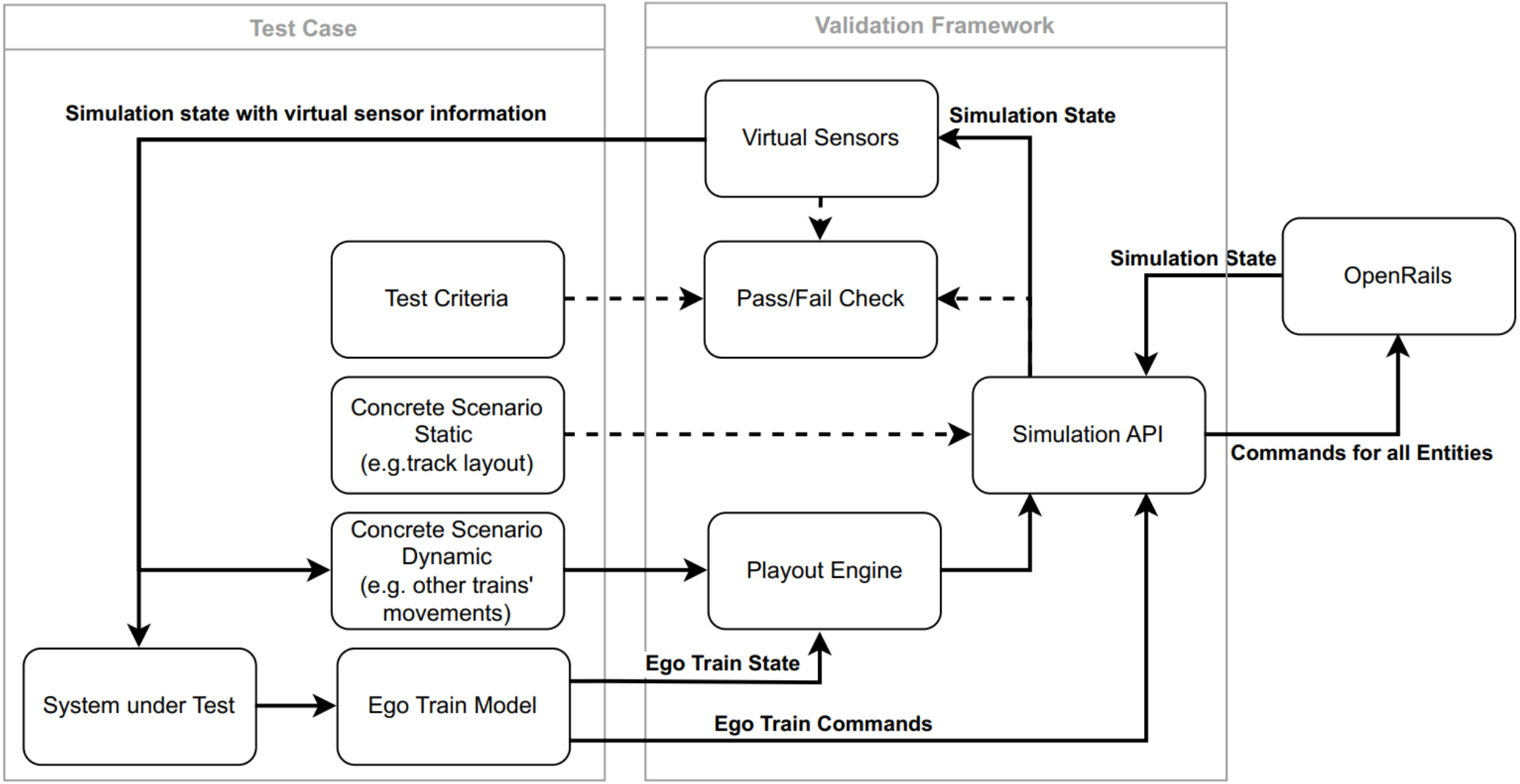
Test-framework



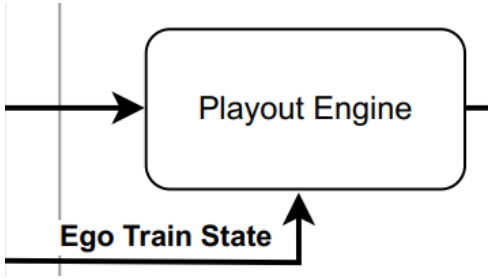
Abstract Scenario → SMT Solver → Reference Scenario

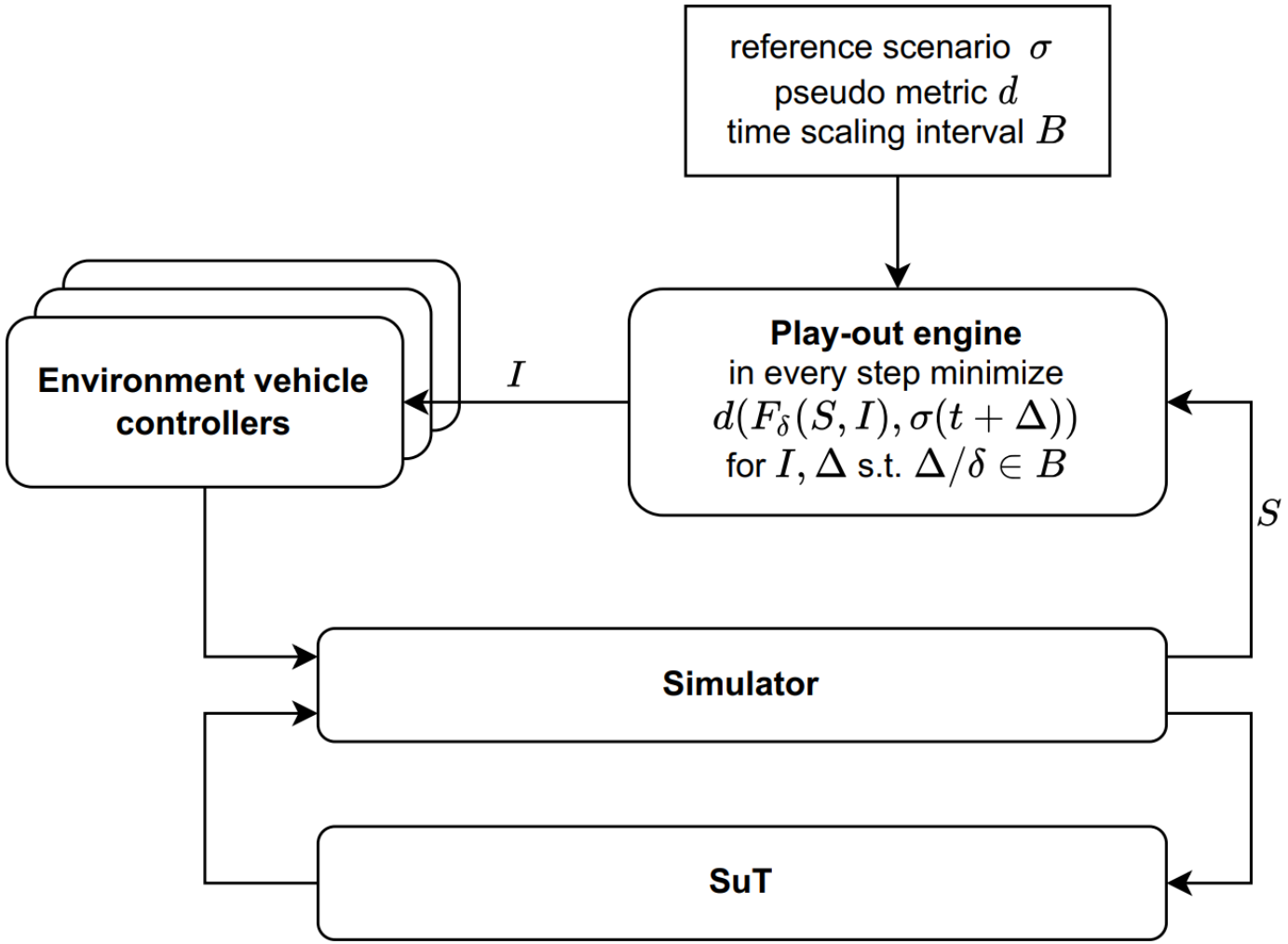
DLR

Test-framework



Closed Loop Playout Engine



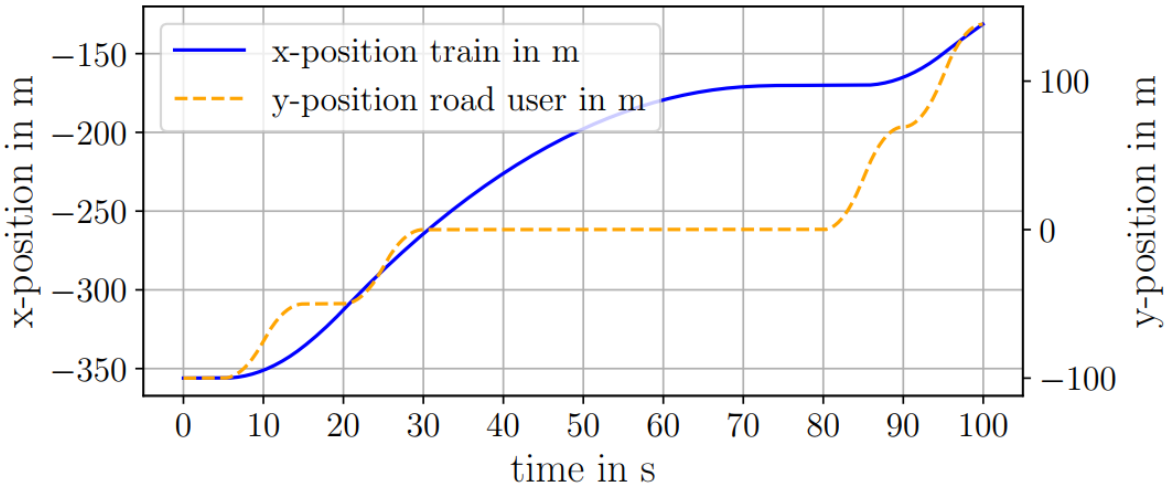


F: Forecast function
S: State
I: Optimal control signal
δ: Simulation timestep
t: Time
Δ: Scenario timestep

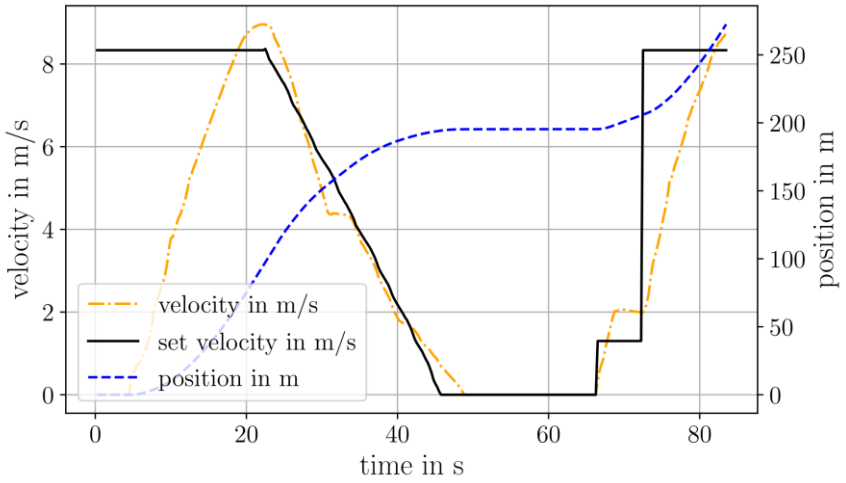
Allows reactive test execution, i.e., simulated traffic participants are able to react to the SuT

Proof of Concept

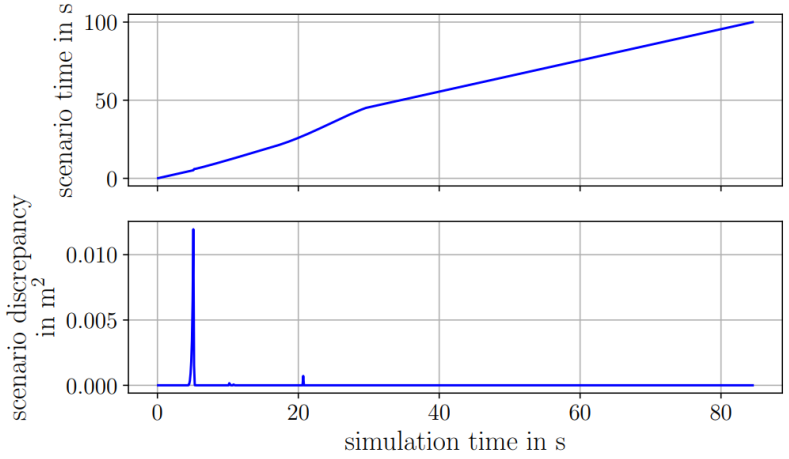
Reference Scenario



SUT (PID controller)

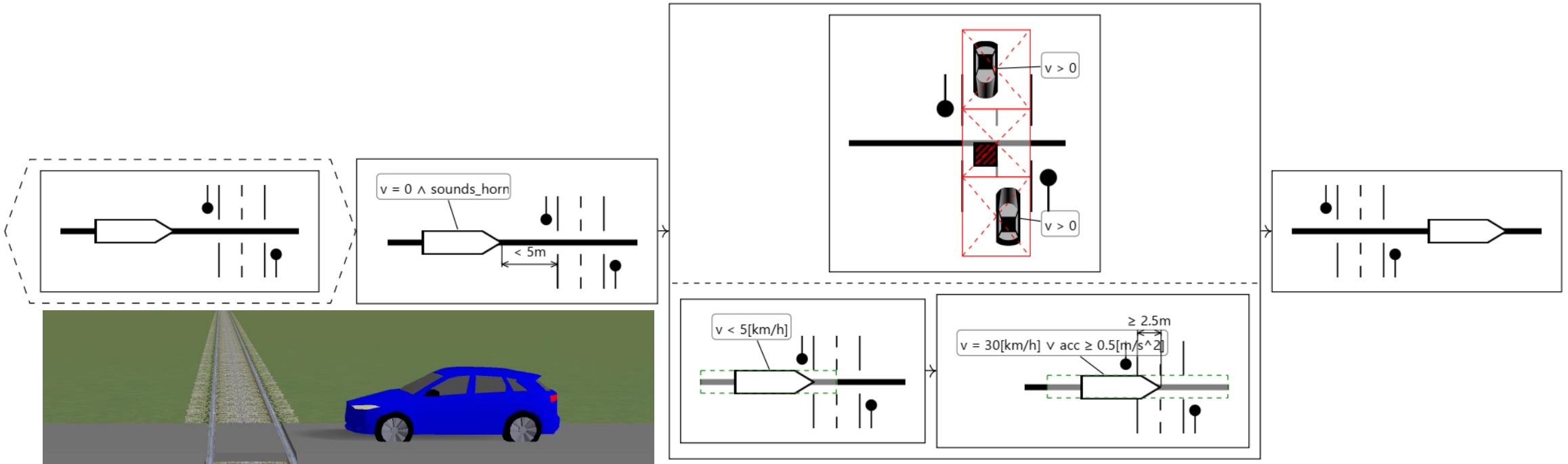


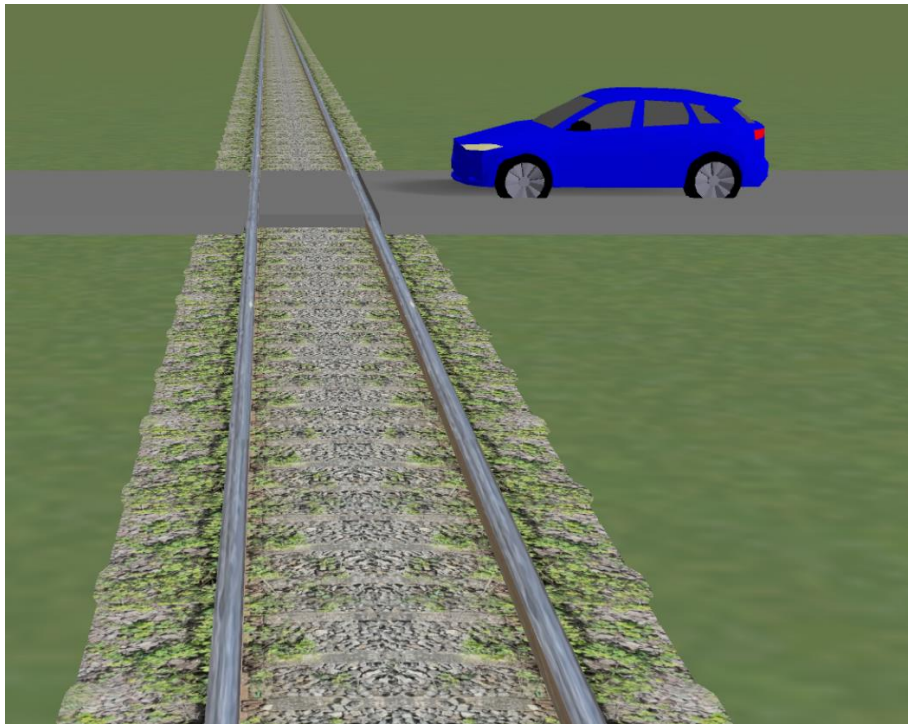
Rescaling



- Test scenario is not left:
  - scenario discrepancy is below 0.015 m²
    --> The positions of train and car deviate by at most 12 cm

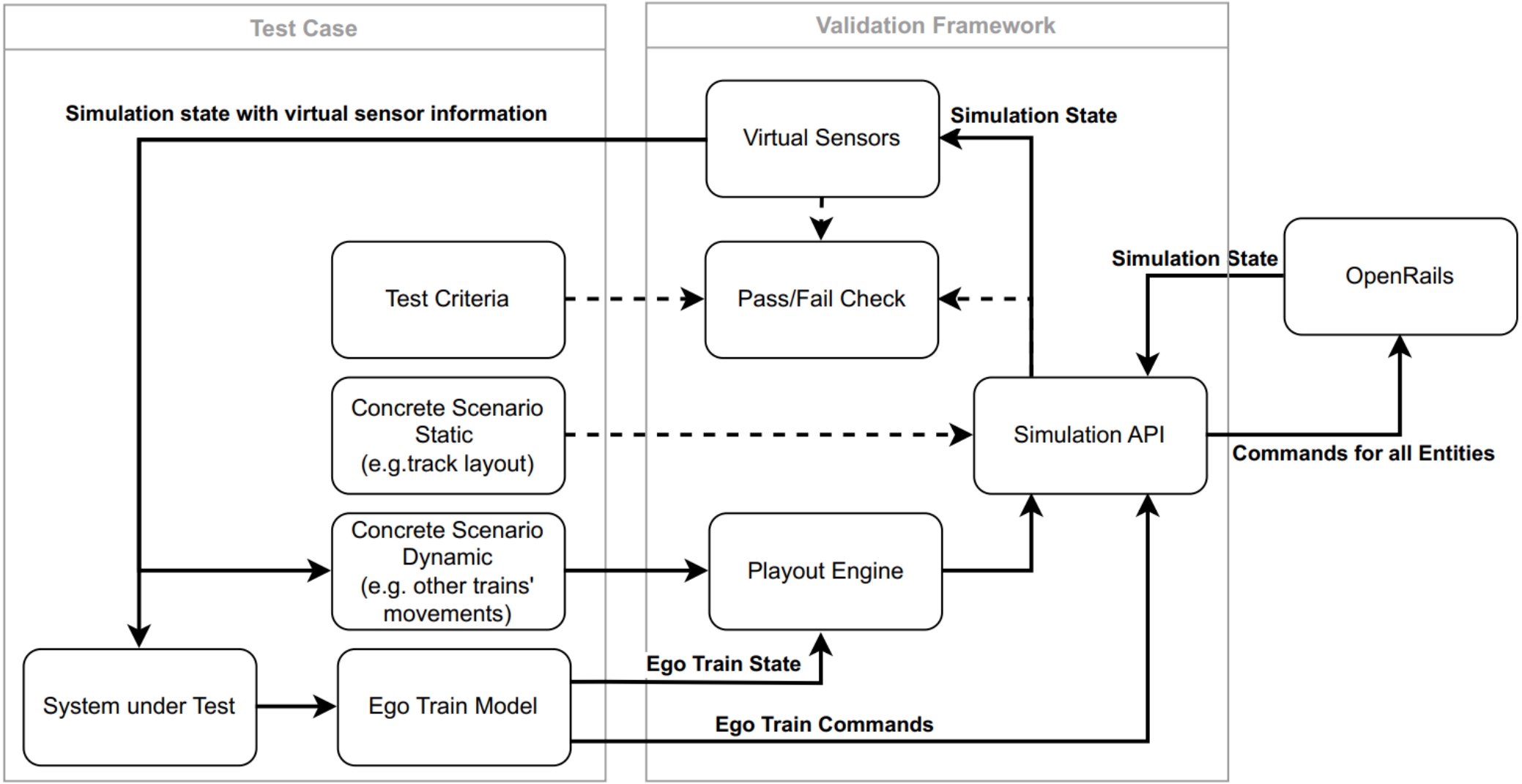
Proof of Concept



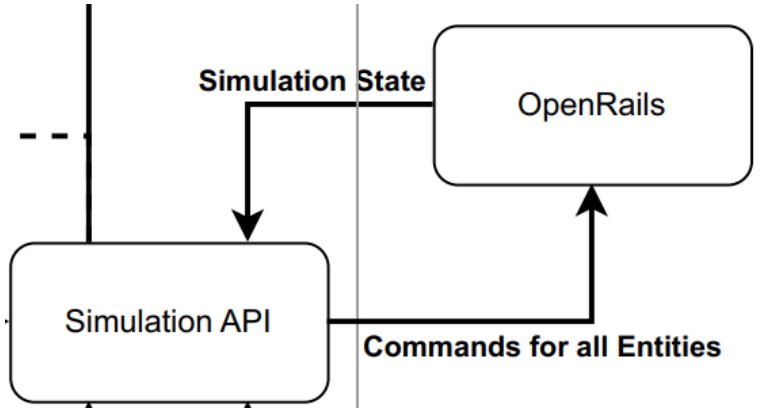


- Test scenario is not left:
  - scenario discrepancy is below 0.015 m^2 --> The positions of train and car deviate by at most 12 cm
- TSC-requirement is obeyed.
  - Currently based on expert observing the rendering
  - Future work: TSC-Monitors

Testframework



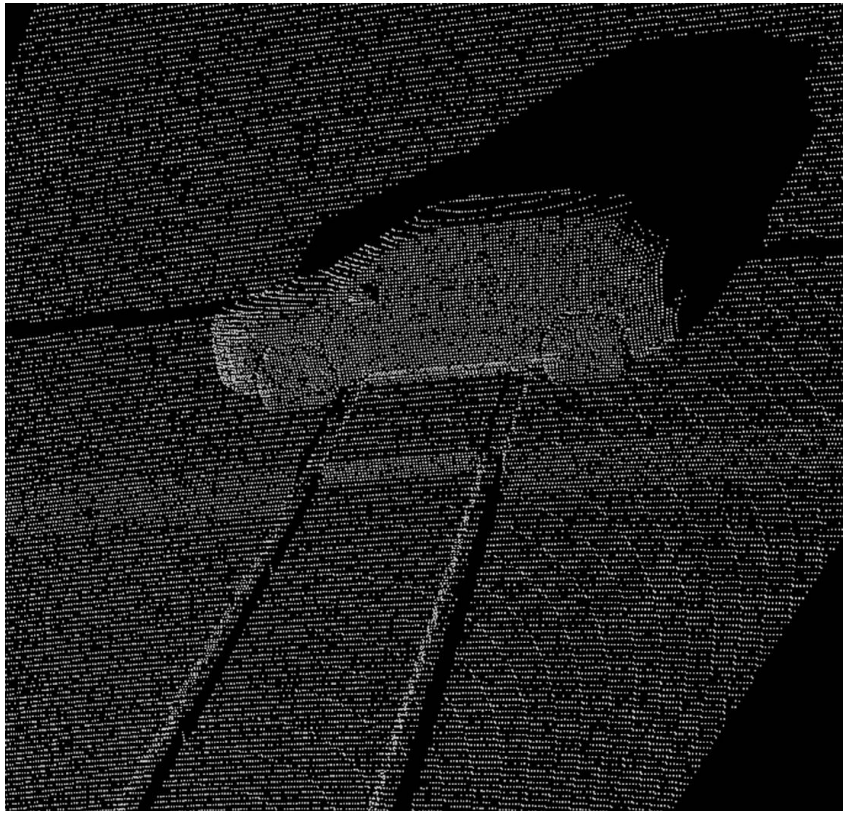
Simulation API and Extension of OpenRails



- OpenRails is open source

- OpenRails includes:
  - Accurate model of train physics
  - Web interface
  - Option to create routes

- We added:
  - Point Cloud Simulation
  - Sensor model configuration and stream
  - Determinism
  - Extended interface to control environment
  - automatic generation of routes (also from OSM, next slide)



Conclusion

- We introduced and evaluated a test-framework for highly automated railway systems, focusing on the operational level

- We developed and demonstrated a novel reactive play-out method using temporal rescaling

- We extended the open source train simulator OpenRails and demonstrated its suitability

Conclusion

- We introduced and evaluated a test-framework for highly automated railway systems, focusing on the operational level
- We developed and demonstrated a novel reactive play-out method using temporal rescaling
- We extended the open source train simulator OpenRails and demonstrated its suitability

Future work

- Modeling different (more complex) scenarios, with additional trains, e.g. an overtaking scenario.
- Extend the framework to split a whole (real) line seamlessly into atomic operational scenarios and apply the presented framework for the parts.