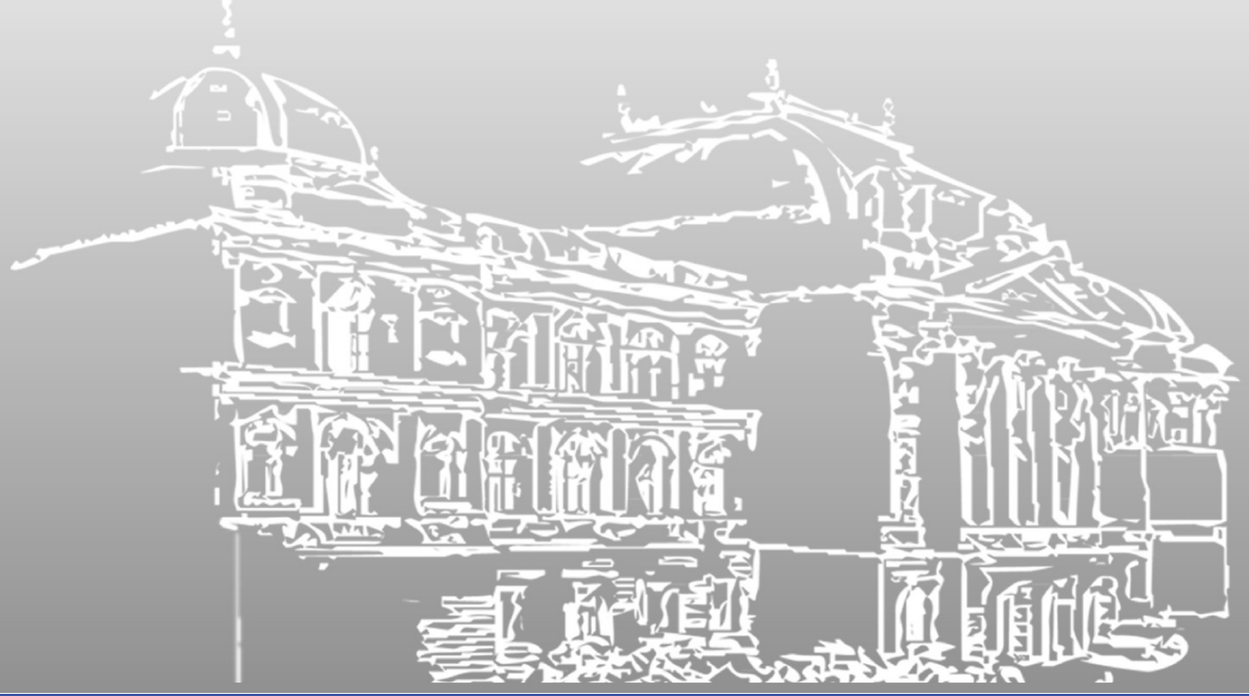


Deterministic Stress Testing Method for Generation of Critical Scenarios

Dipl.Ing. Demin Nalic

Institute for Automotive Engineering

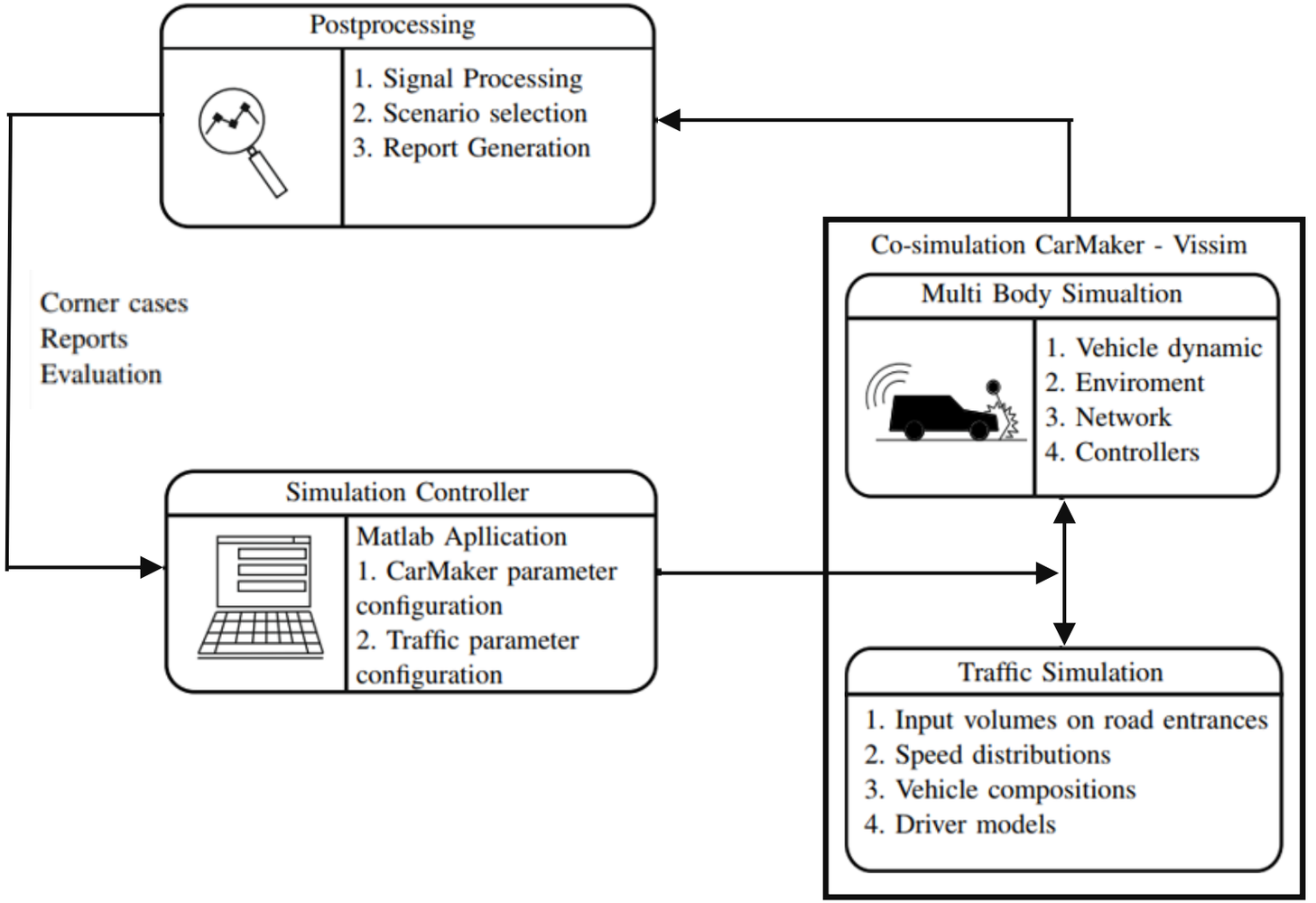
Contents

- Motivation
- Co-Simulation framework
- Test framework in Vissim - DLL Framework
- Deterministic Stress Testing Method (DSTM)
- Results and Summary

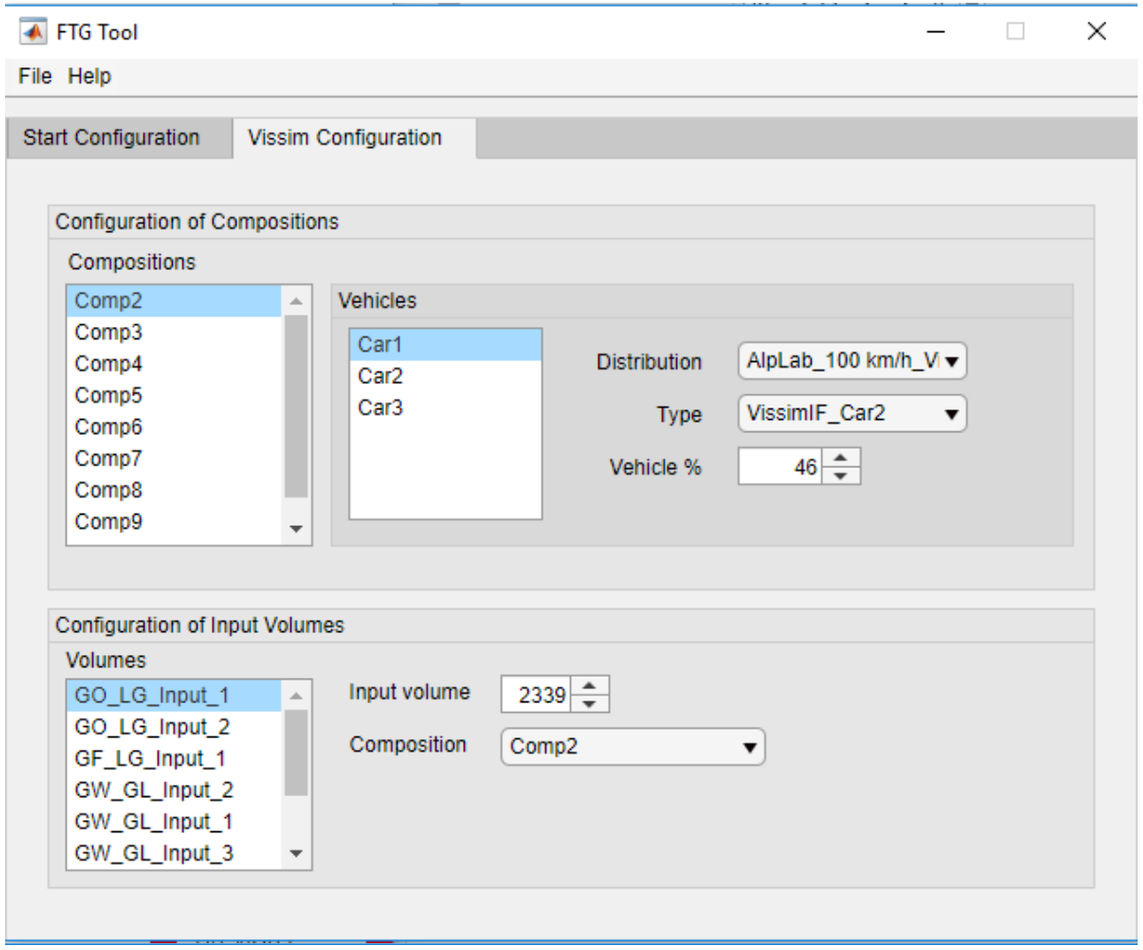
Motivation: Requirements for the virtual test environment

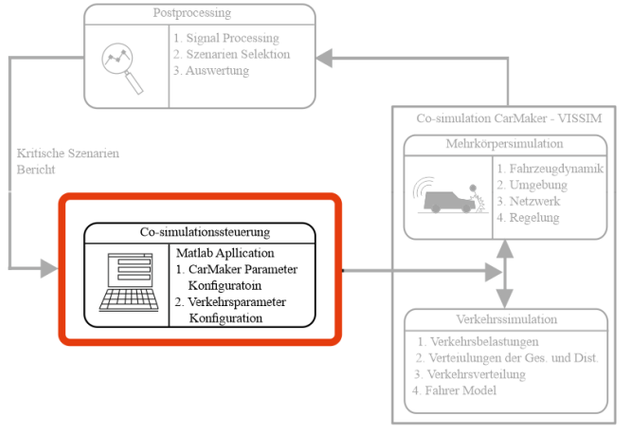
- Virtual testing of ADS/ADAS
- Requirements:
  - Complex and realistic vehicle models
  - Implementation and adaptaion of suitable algorithms
    - Vehicle dynamics
    - Assistant systems
    - Sensors
  - Realistic vehicle environment and visualisation
  - Realistic and stochastic traffic

Co-Simulationsframework: Concept



Co-Simulationsframework: MATLAB Application

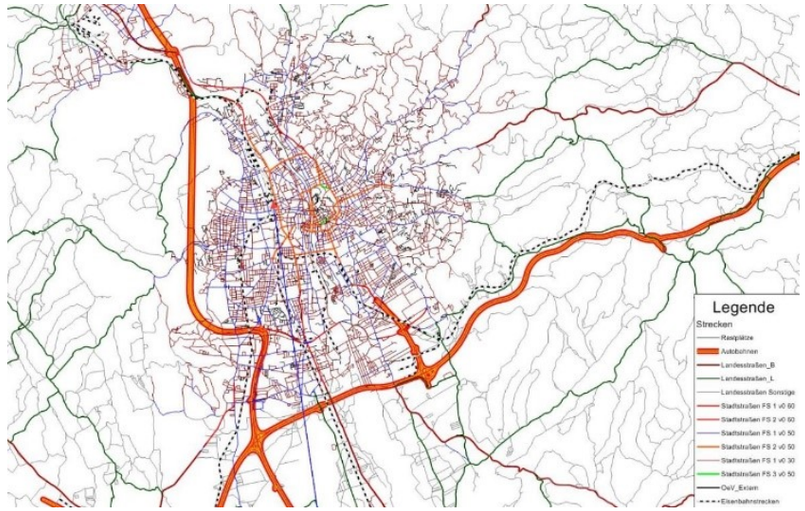


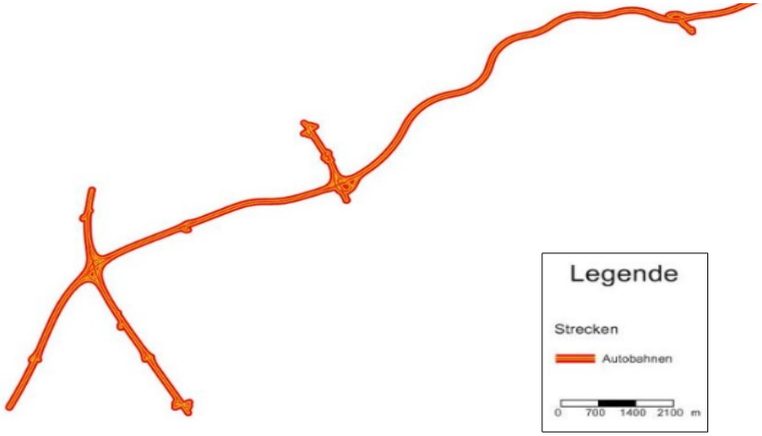


Co-Simulationsframework: Cluster Mode

Traffic data from the ALP.Lab test road

- 21 Counter points
- Measurement time 01.10.2017 – 31.03.2018
- Vehicle inputs, vehicle compositions, driver models and speed distributions are calibrated and modelled





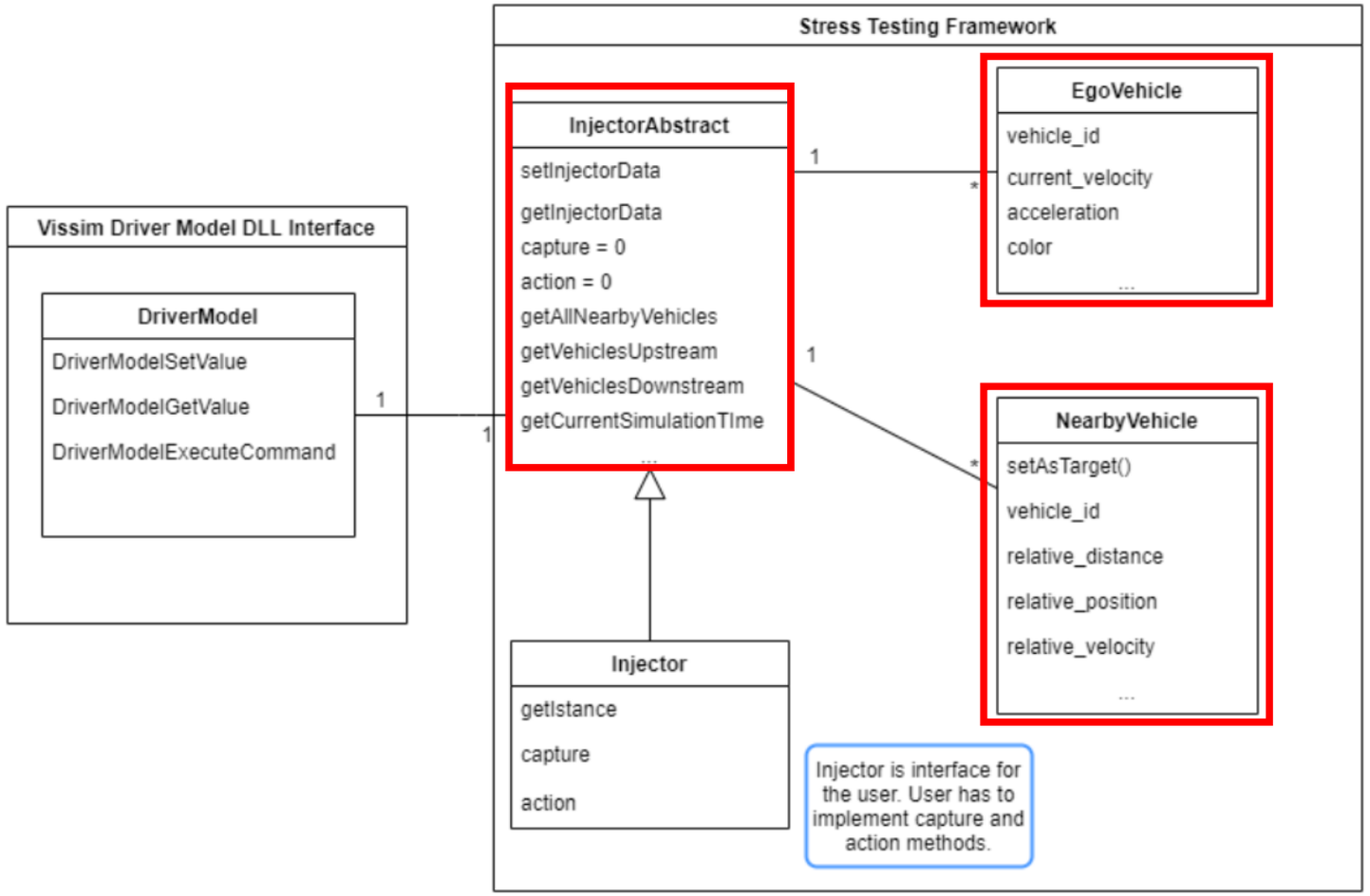
DLL Framework: Motivation und Concept

Safety relevant scenarios are rarely ocure in the IPG-Vissim Co-Simulation

Solution:

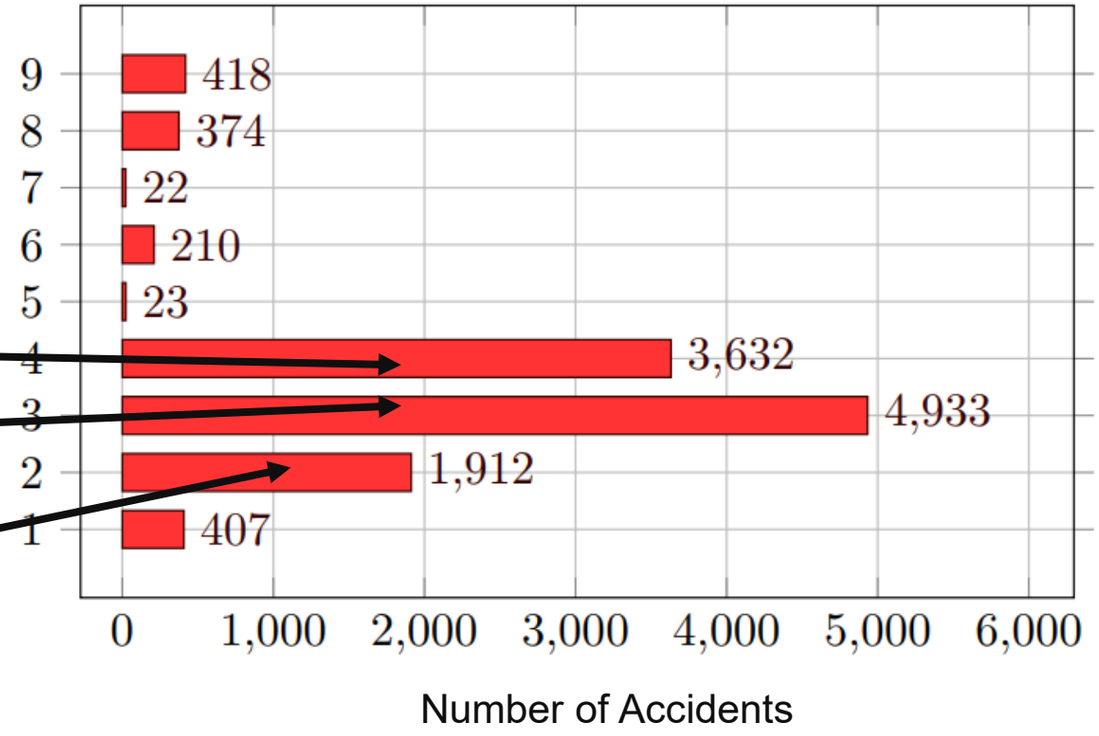
- Manipulation of traffic participants
- External Driver Model DLL Interface
- Framework is based on the Vissim interface provided in C++
  - Manipulation
  - ADS functionalities
  - Test cases for different applications (Platooning, Collon stability etc.)

DLL Framework: Concept



Deterministic Stress Testing Method

- Accident database of Statistic Austria
- 9 Accident types
  - Each accident type has subtypes
- For the DSTM 2 accident types:
  - Longitudinal scenarios
    - Stationary vehicle
    - Moving vehicle with speed reduction
  - Lateral scenarios
    - Lane change

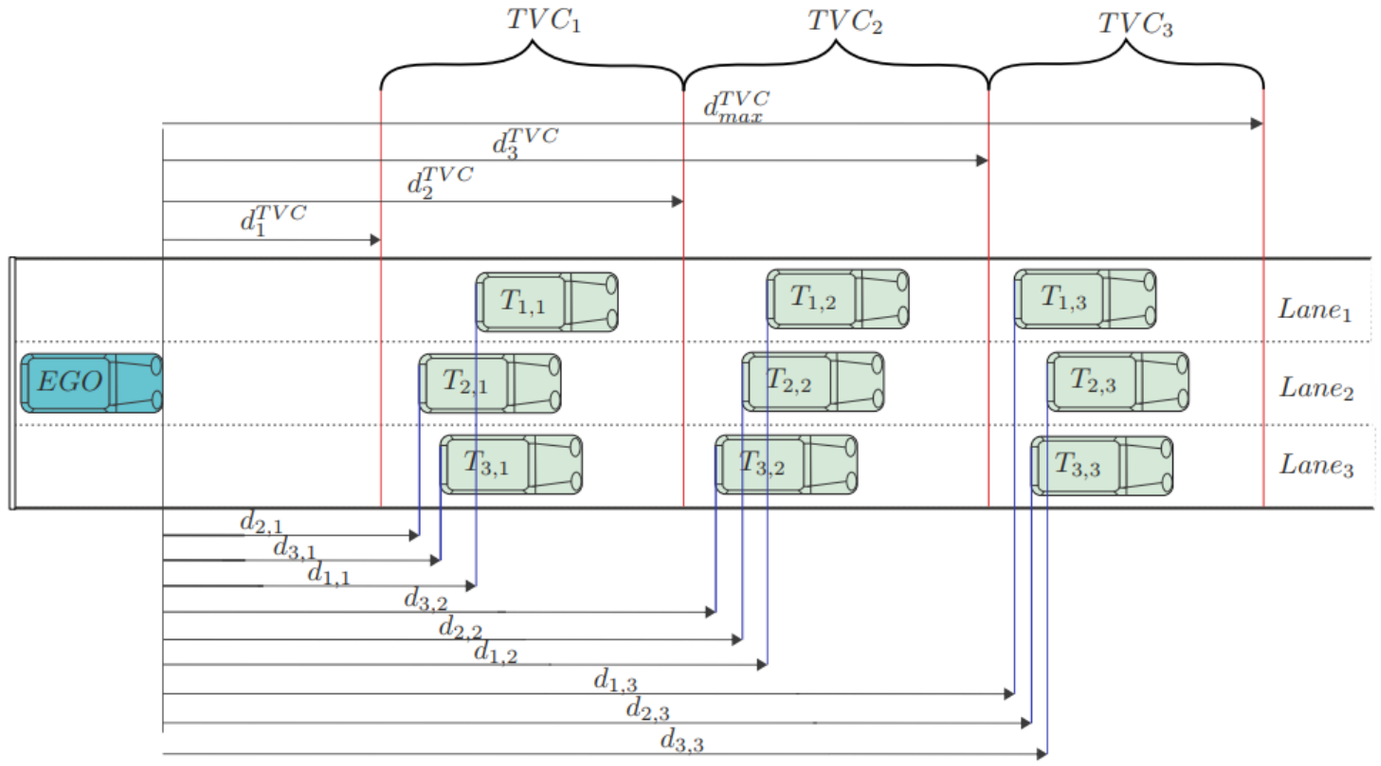


Stress Testing Method: Longitudinal scenarios

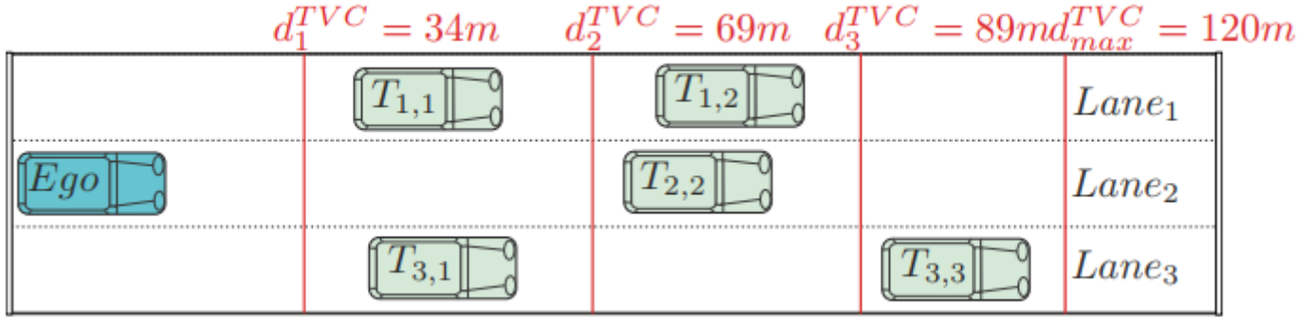
- Three columns
  - TVC_1, TVC_2, TVC_3
- Distances to the target vehicles
  - $d_{\mathrm{i,j}}$ with index i for the current lane and index j- for the column
- Calculation of the event matrix

$$\mathbf{E}_T^{l^2} = \begin{bmatrix} e_{1,1}^{l^2} & e_{1,2}^{l^2} & e_{1,3}^{l^2} \\ e_{2,1}^{l^2} & e_{2,3}^{l^2} & e_{2,3}^{l^2} \end{bmatrix} \in \mathbb{R}^{2x3}$$

$$\mathbf{E}_T^{l^3} = \begin{bmatrix} e_{1,1}^{l^3} & e_{1,2}^{l^3} & e_{1,3}^{l^3} \\ e_{2,1}^{l^3} & e_{2,3}^{l^3} & e_{2,3}^{l^3} \\ e_{3,1}^{l^3} & e_{3,3}^{l^3} & e_{3,3}^{l^3} \end{bmatrix} \in \mathbb{R}^{3x3}$$



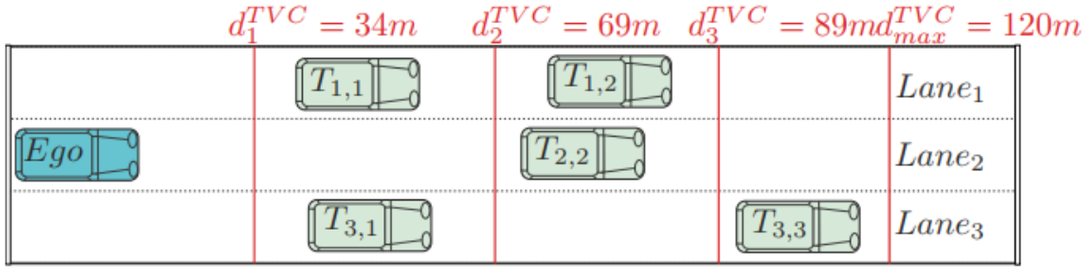
Stress Testing Method: Longitudinal scenarios



$$\mathbf{E}_T^{l^3} = \begin{bmatrix} e_{1,1}^{l^3} & e_{1,2}^{l^3} & e_{1,3}^{l^3} \\ e_{2,1}^{l^3} & e_{2,3}^{l^3} & e_{2,3}^{l^3} \\ e_{3,1}^{l^3} & e_{3,3}^{l^3} & e_{3,3}^{l^3} \end{bmatrix} \in \mathbb{R}^{3x3} \qquad e_{i,j}^{l^2} = e_{i,j}^{l^3} = \begin{cases} 1, & d_1^{TVC} < d_{i,j} < d_2^{TVC} \\ 1, & d_2^{TVC} < d_{i,j} < d_3^{TVC} \\ 1, & d_3^{TVC} < d_{i,j} < d_{max}^{TVC} \\ 0, & otherwise \end{cases} \qquad \mathbf{E}_T^{l_3} = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}$$

Stress Testing Method: Longitudinal scenarios

- Definition of relevant combinations



$$\mathbf{E}_T^3 = \begin{bmatrix} 1 & \mathbf{1} & 0 \\ 0 & \mathbf{1} & 0 \\ 1 & 0 & 1 \end{bmatrix}$$

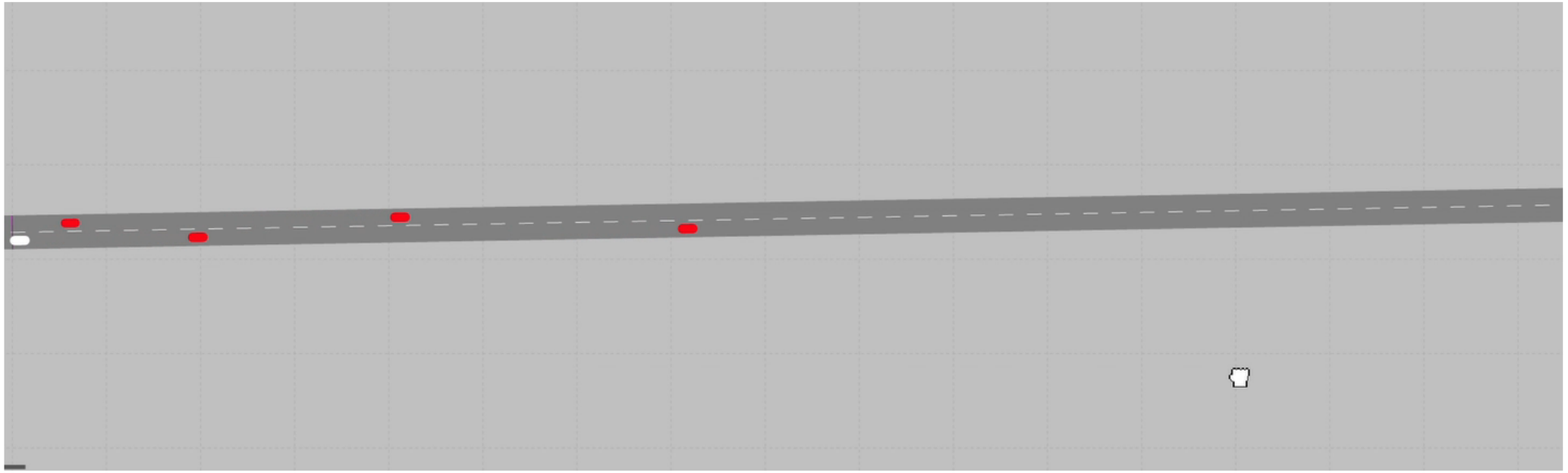
$$\mathbf{C}_q^{l_3} = \begin{bmatrix} X & \mathbf{1} & X \\ X & \mathbf{1} & X \\ X & X & X \end{bmatrix}$$

$$e_{1,2} = e_{2,2} = c_{1,2} = c_{2,2}$$

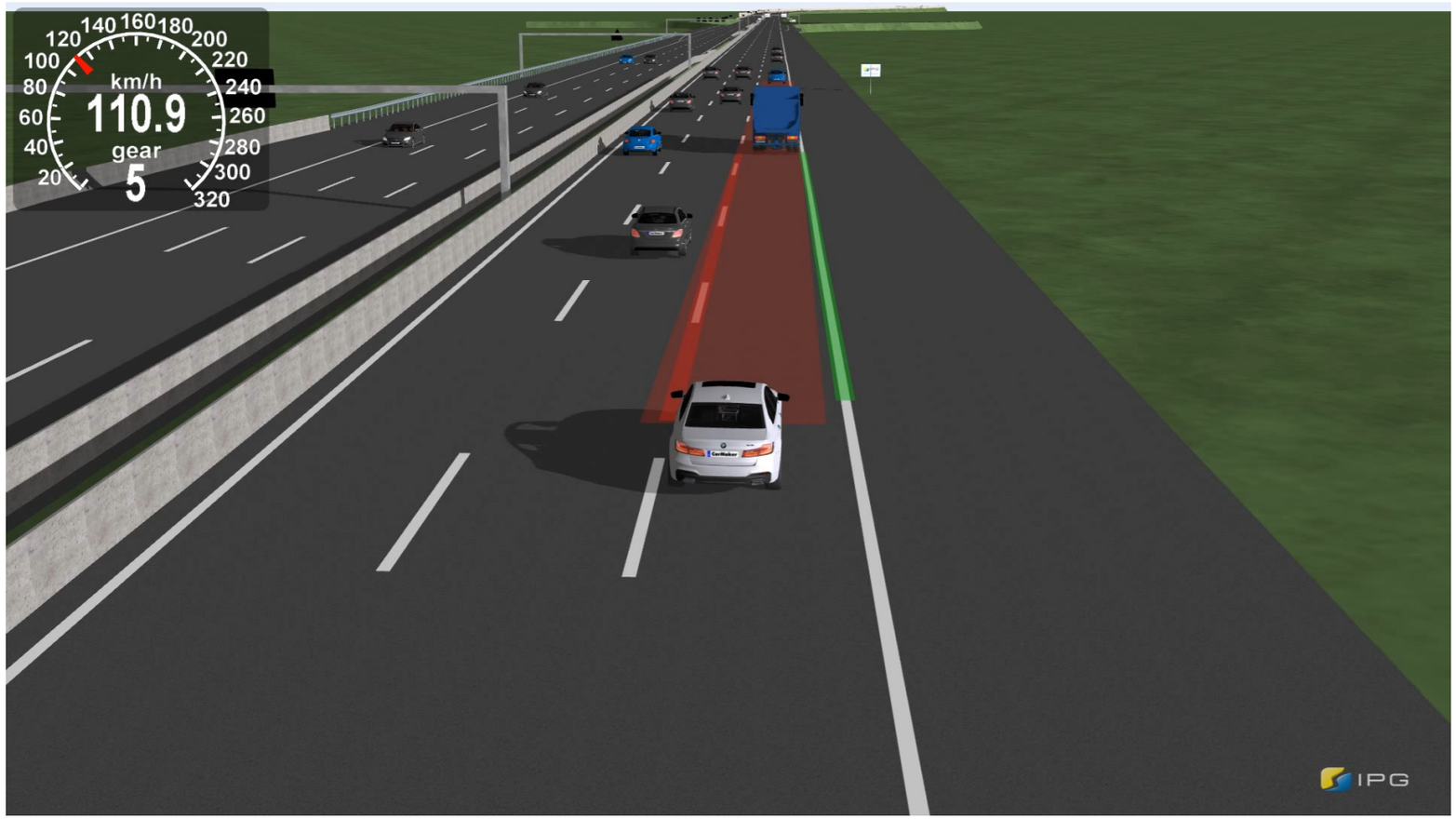
$$\mathbf{C}_q^{l_3} = \begin{bmatrix} c_{1,1}^{l_3} & c_{1,2}^{l_3} & c_{1,3}^{l_3} \\ c_{2,1}^{l_3} & c_{2,2}^{l_3} & c_{2,3}^{l_3} \\ c_{3,1}^{l_3} & c_{3,3}^{l_3} & c_{3,3}^{l_3} \end{bmatrix} \in \mathbb{R}^{3x3}$$

	$c_{1,1}^{l_3}$	$c_{1,2}^{l_3}$	$c_{1,3}^{l_3}$	$c_{2,1}^{l_3}$	$c_{2,2}^{l_3}$	$c_{2,3}^{l_3}$	$c_{3,1}^{l_3}$	$c_{3,2}^{l_3}$	$c_{3,3}^{l_3}$
$\mathbf{C}_1^{l_3}$	1	X	X	1	X	X	1	X	X
$\mathbf{C}_2^{l_3}$	X	1	X	X	1	X	X	1	X
$\mathbf{C}_3^{l_3}$	X	X	1	X	X	1	X	X	1
$\mathbf{C}_4^{l_3}$	1	X	X	X	X	X	X	X	X
$\mathbf{C}_5^{l_3}$	X	X	X	1	X	X	X	X	X
$\mathbf{C}_6^{l_3}$	X	X	1	X	X	X	1	X	X
$\mathbf{C}_7^{l_3}$	X	1	X	X	X	X	X	X	X
$\mathbf{C}_8^{l_3}$	X	X	X	X	1	X	X	X	X
$\mathbf{C}_9^{l_3}$	X	X	1	X	X	X	X	1	X
$\mathbf{C}_{10}^{l_3}$	X	X	1	X	X	X	X	X	X
$\mathbf{C}_{11}^{l_3}$	X	X	X	X	X	1	X	X	X
$\mathbf{C}_{12}^{l_3}$	X	X	X	X	X	X	X	X	1

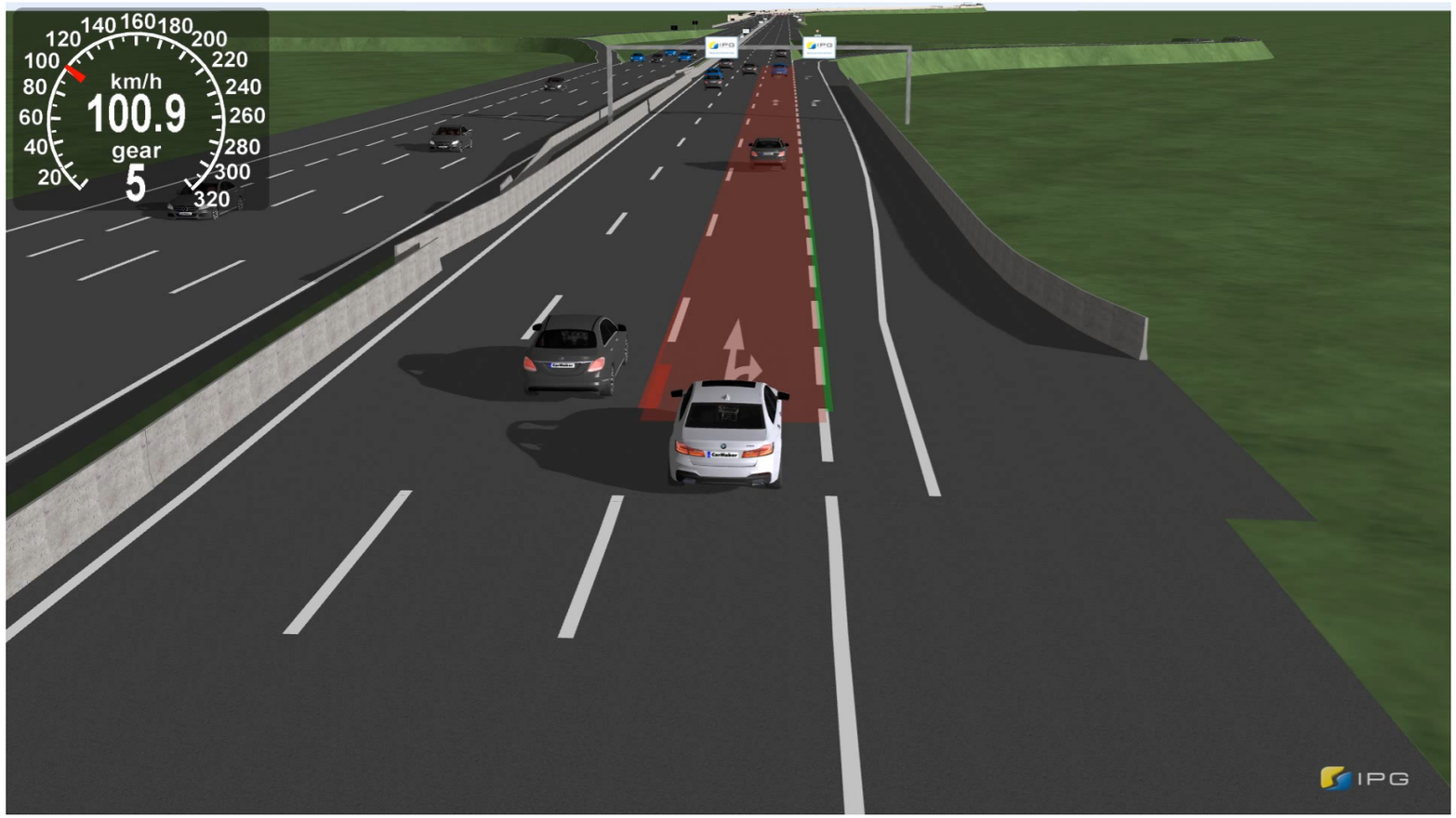
Stress Testing Method: Longitudinal scenarios – Vissim implementation



Stress Testing Method: Longitudinal scenarios – With collision

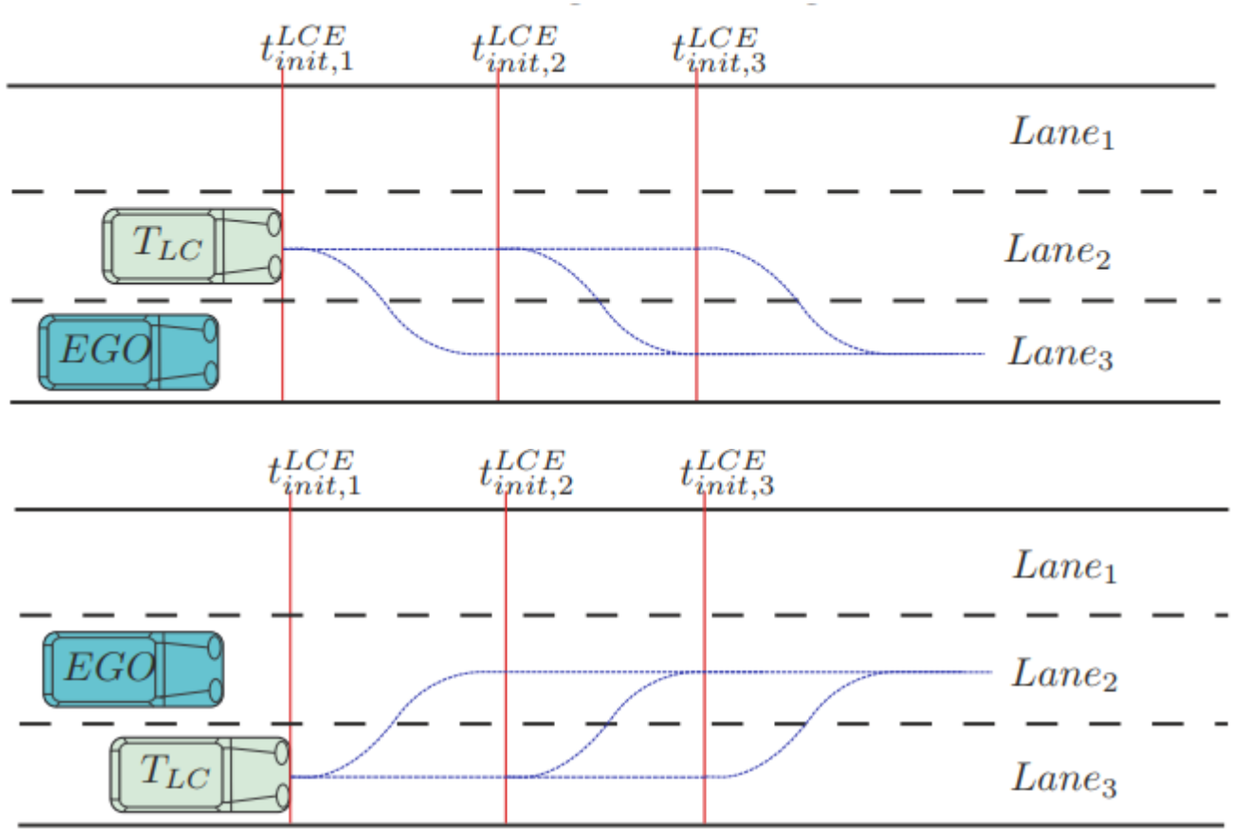


Stress Testing Method: Longitudinal scenarios– Speed reduction

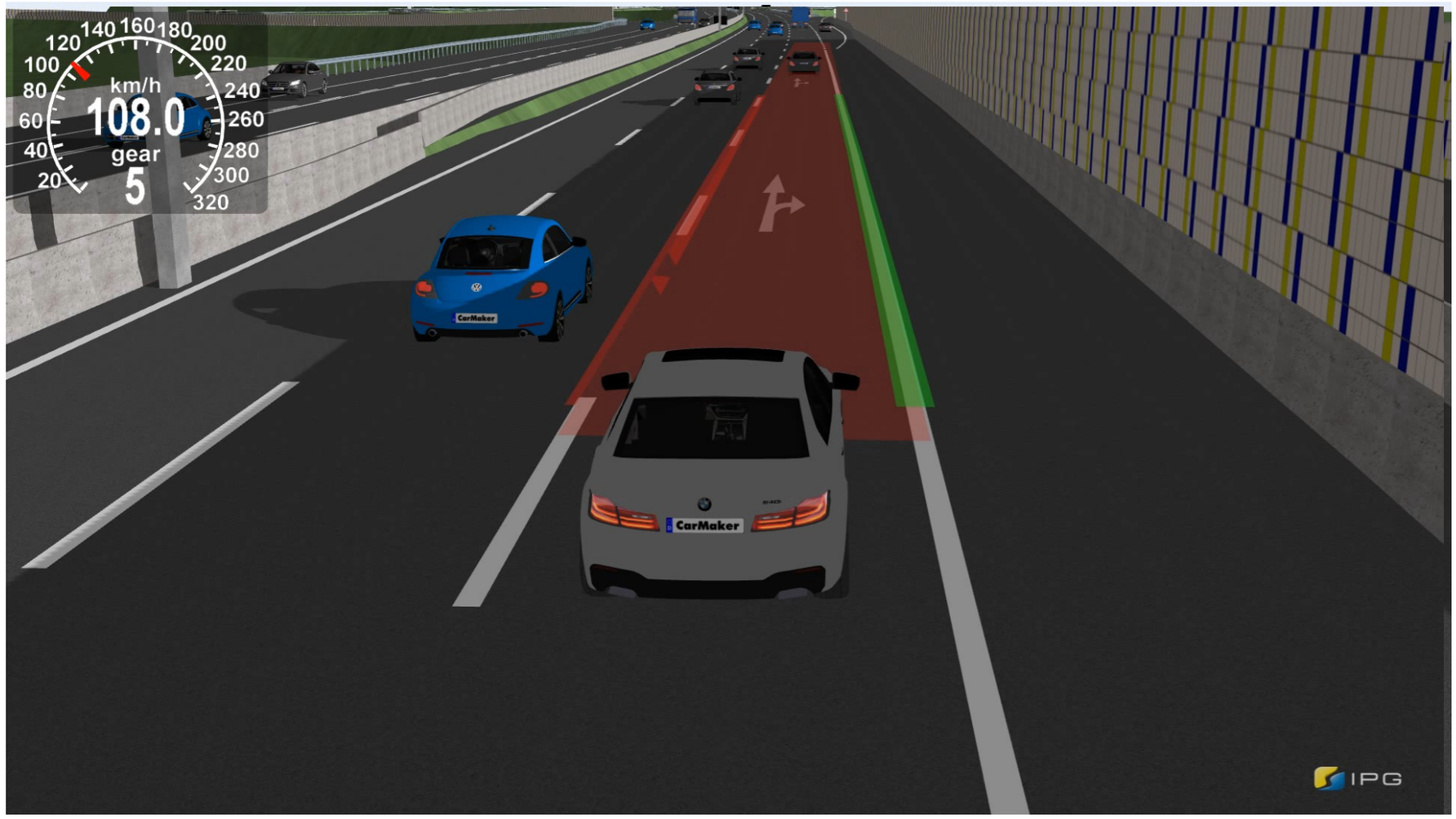


Stress Testing Method: Vertical scenarios

- Lane change to left and right



Stress Testing Method: Vertical scenarios - Video



Stress Testing Method: Results

- Simulation with 1000 test kilometers with and without DSTM
  - Evaluation
    - Collision
    - Cut-In‘s
    - Near-Collisions (Distance and TTC)

	Without DSTM	With DSTM
Collisions	None	47
Near Collisions	68	289
Cut-In‘s	167	723

Summary

- With DSTM, the number of detected scenarios can and has been increased.
- With additional metrics, there is the possibility of generating and detecting further scenarios
- Provocation of critical maneuvers / scenarios
- Expanded the testing process
- Possibilities for various other applications for testing ADAS / ADS

Literatur und Publikationen

[1] Nalic, D., Eichberger, A., Fellendorf, M., Hanzl, G., & Rogic, B. (2019). *Development of a Co-Simulation Framework for Systematic Generation of Scenarios for Testing and Validation of Automated Driving Systems.*. 1-7. Beitrag in 22nd IEEE International Conference on Intelligent Transportation Systems, Auckland, Neuseeland.

[2] Nalic, D., Pandurevic, A., Eichberger, A., & Rogic, B.. *Design and Implementation of a Co-Simulation Framework for Testing of Automated Driving Systems*. 1-6. Beitrag in Electric-Vehicle, Smart-Grid and Information Technology, Jeju, Südkorea.

In preparation

[3] Nalic, D., Li, H., Pandurevic, A., Eichberger, A., & Wellershaus, C. (2020). Stress Testing Method for Scenario Based Verification of Automated Driving Systems.

[4] Nalic, D., Pandurevic, A., & Eichberger, A. (2020). Software Framework for Testing of Automated Driving Systems in a Dynamic Traffic Environment.

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