SAFEADARCHITECT

Handling residual risk in traffic situations with occluded road users

Bernd Gassmann, Shreya Dey, Ignacio Alvarez, Fabian Oboril, Kay-Ulrich Scholl, Intel Labs

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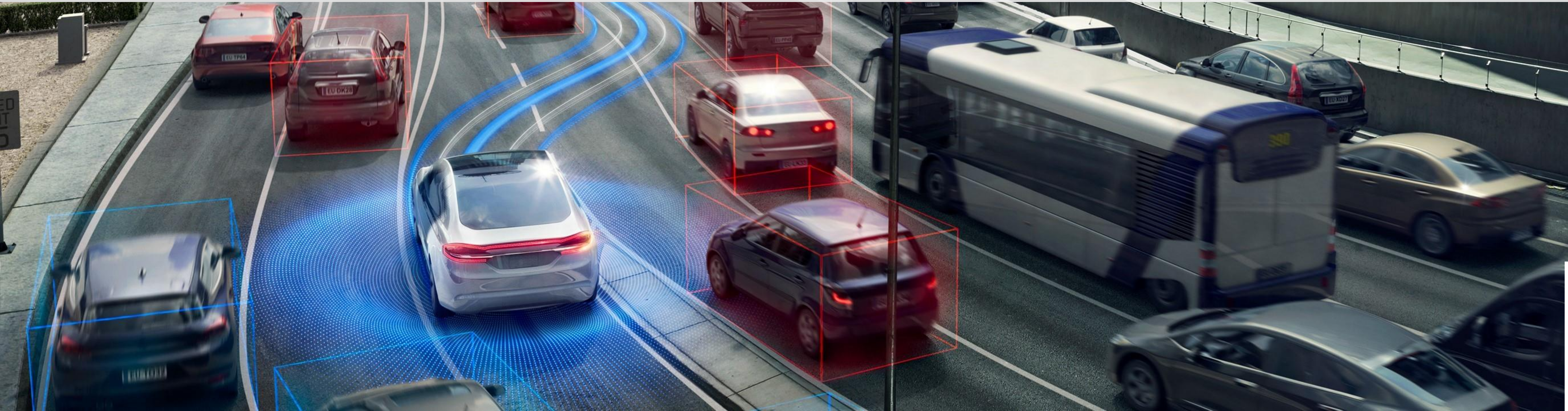

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SafeADArchitect[1]

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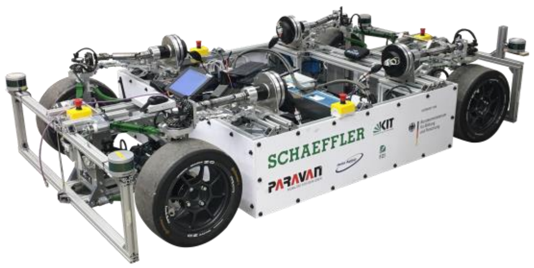
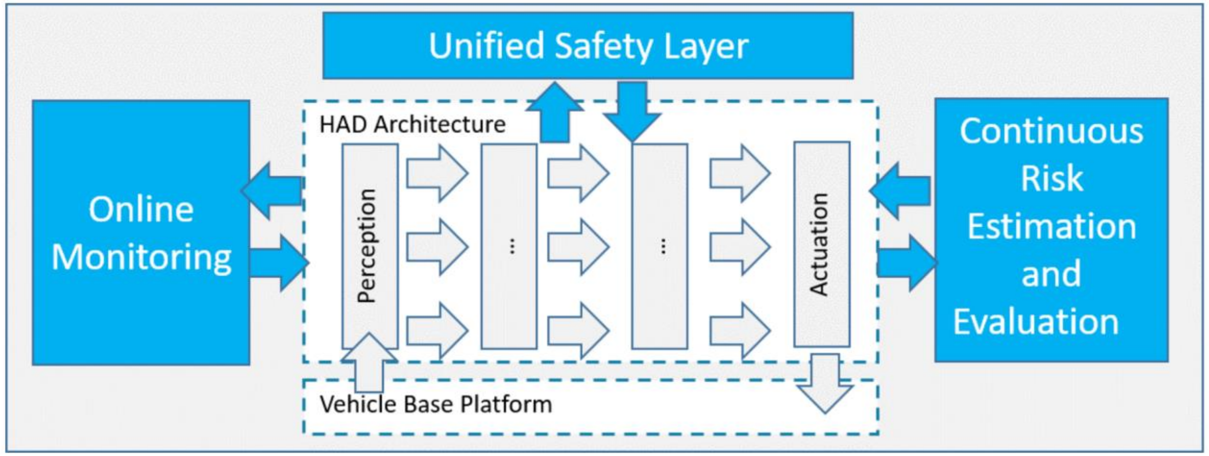
- Research project: overall system architecture that takes into account uncertainties and risks at various levels in order to safeguard autonomous vehicles
- Continuous risk assessment, monitoring and minimization at run-time
- Develop risk-sensitive safety layers
- Demonstrator for tests in the test area autonomous driving Baden-Württemberg



OSCAR



[1] https://www.safeadarchitect.de/

Safety Layer: Monitor architecture

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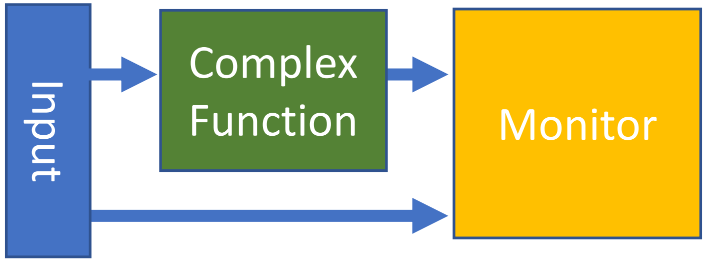
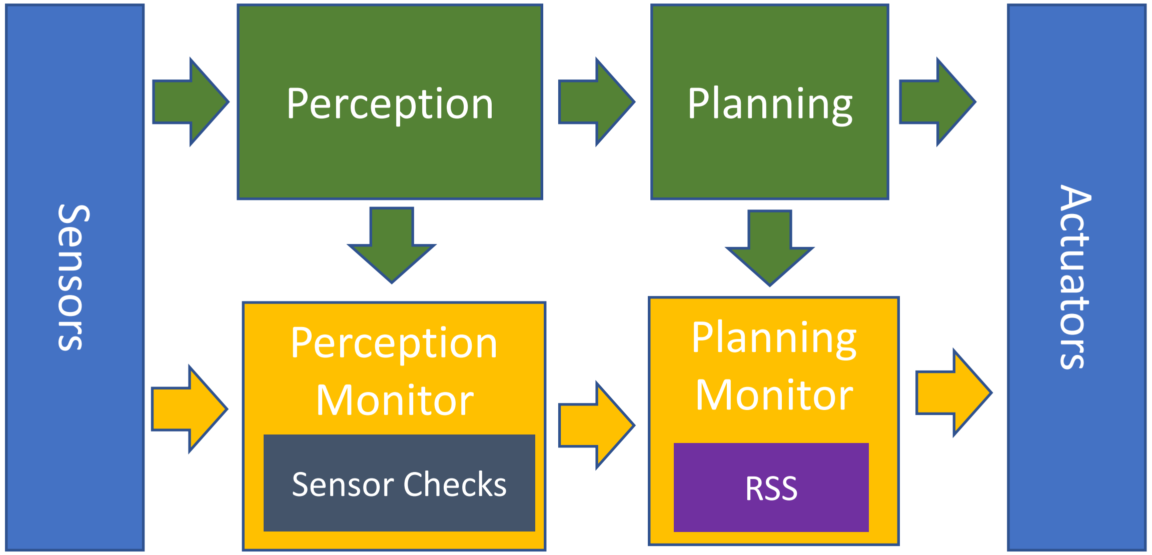


Monitor architecture[1]



- Safety Layer:
  - Monitor executed on second channel
- Planning Monitor:
  - Responsibility-Sensitive Safety (RSS) [2]
- Perception Monitor:
  - Ensure input to RSS is correct
  - Lightweight sensor checks to protect against common errors in perception system[3]

[1] I. ISO, “26262: Road vehicles-Functional safety,” International Standard ISO/FDIS, vol. 26262, 2011.
[2] S. Shalev-Shwartz, S. Shammah, and A. Shashua, “On a formal model of safe and scalable self-driving cars,” arXiv:1708.06374, 2017
[3] C. Buerkle , F.Geissler, M. Paulitsch and K.U. Scholl “Fault-Tolerant Perception for Automated Driving A Lightweight Monitoring Approach”, https://arxiv.org/abs/2111.12360

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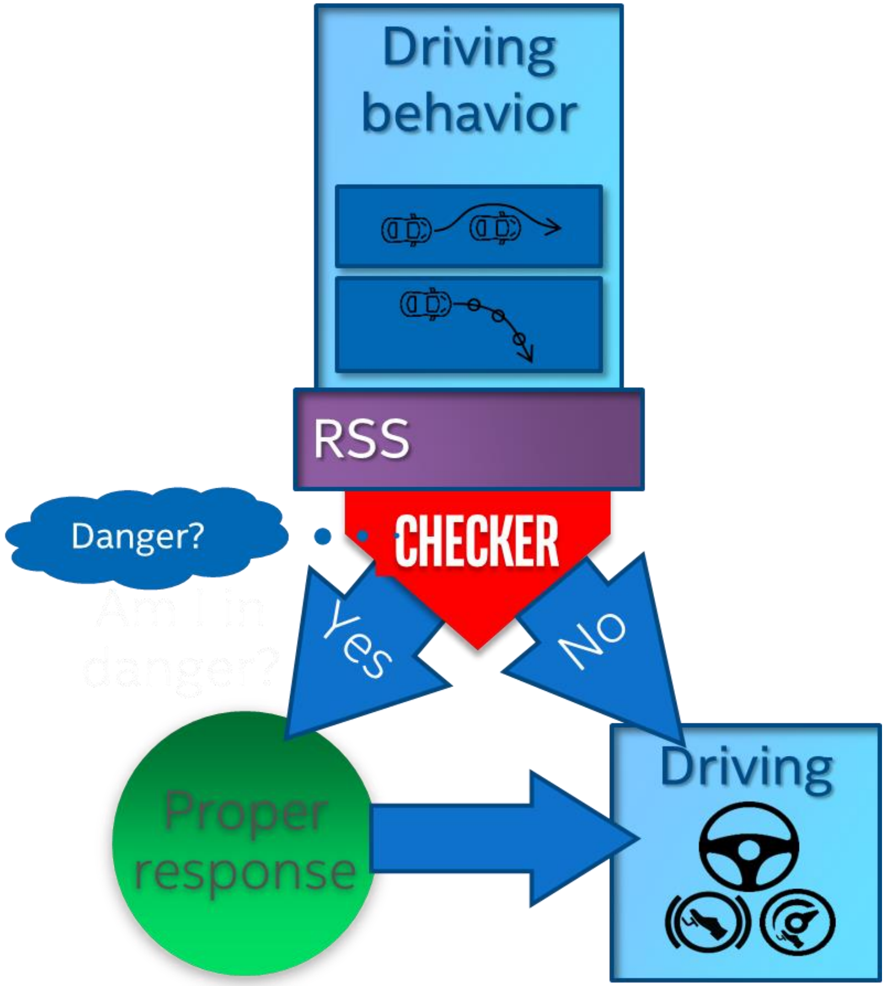
Responsibility-Sensitive Safety (RSS)

- Open, transparent, technology neutral **safety model** for autonomous driving
- RSS digitizes the implicit rules of human driving, **providing a check on AV decision-making**
  - Defines the threshold between safety and danger
  - Provides appropriate response: how can the AV escape from a dangerous situation
  - Flexible, culturally tunable



Rules to model common sense behaviors for driving safely

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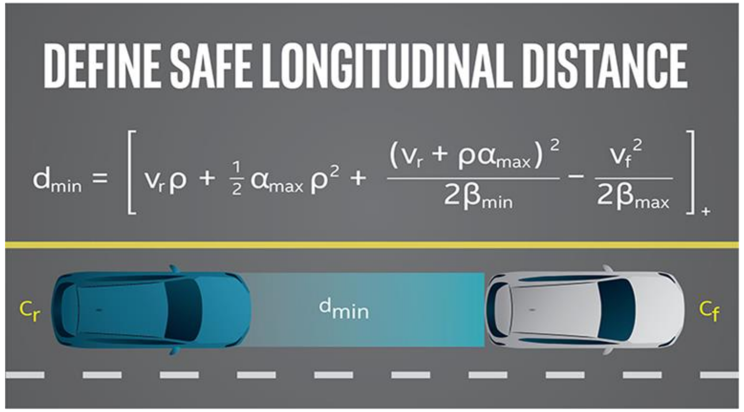
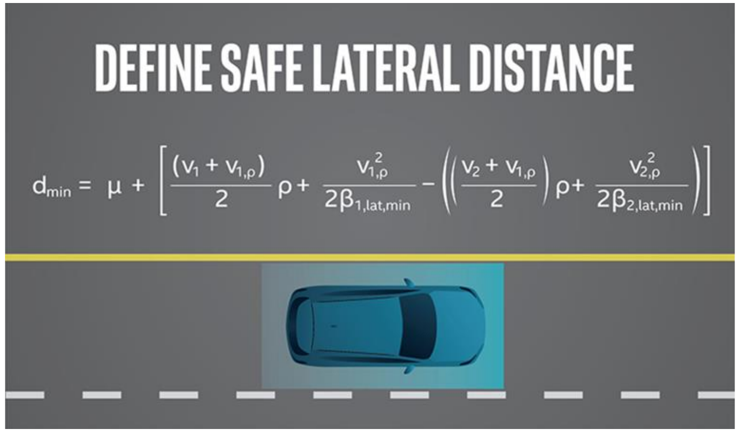


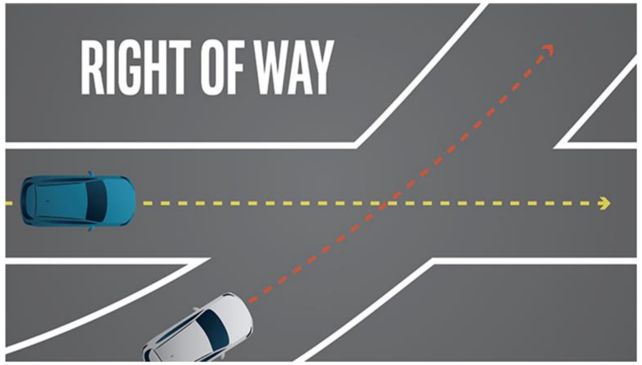
RULE 1.

Do not hit the car in front (longitudinal distance)



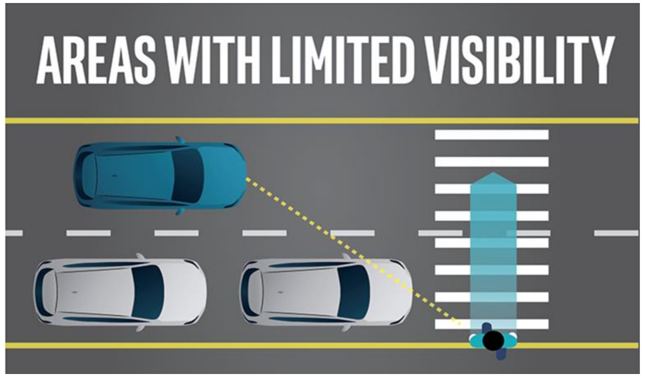
RULE 2.

Do not cut in recklessly (lateral distance)



RULE 3.

Right of way is given, not taken



RULE 4.

Be cautious in areas with limited visibility

RULE 5.

If the vehicle can avoid a crash without causing another one, it must

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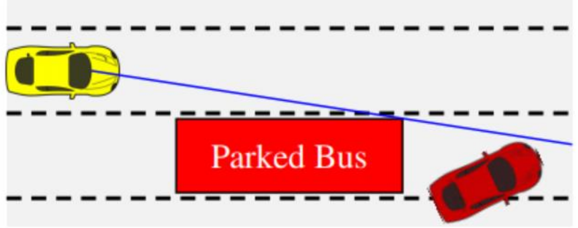
Rule 4: Be cautious in areas with limited visibility

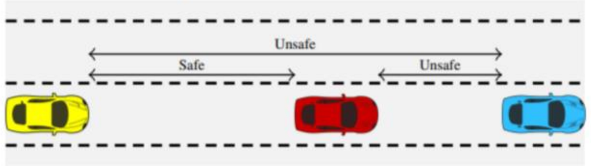
- A vehicle must perform a proper response also with respect to occluded road agents
- At any occluded position there might be an object
  - Any possible reasonably foreseeable speed
  - Appropriate behavior of the others (no „unreasonable situations“)
  - Other vehicles behave RSS „conform“



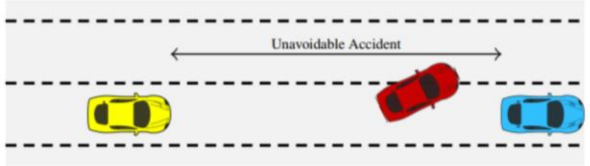
Example reasonalbe speed:
Yellow vehicle can expect that the red (occluded) vehicle will not change to its lane from behind the parked bus exceedingly fast

Example others behave according to RSS:
Yellow vehicle can expect, that the red one behaves according to RSS and does not change its lane out of a sudden based on an unsafe situation, e.g. because of a standing blue vehicle (occluded from yellows vehicle point of view)

Danger Threshold time



Exposure Time



Implementation: Occlusions with RSS

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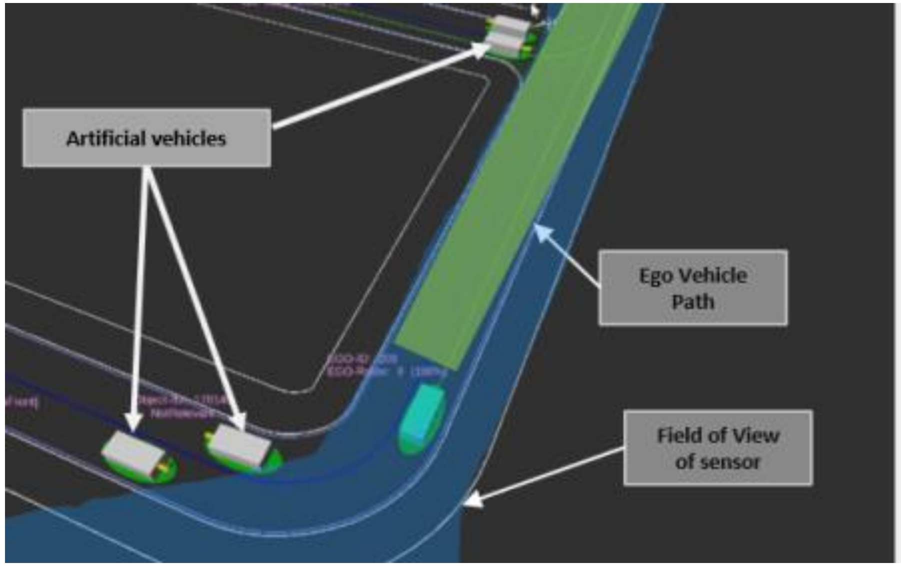
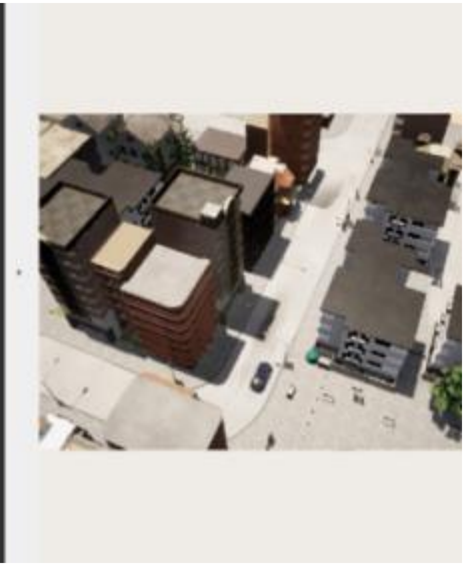
- Basis: Field of view
- Determine occluded lane regions
- Placement of „resonably forseeable " virtual vehicles at region borders
- RSS Evaluation of those „artificial vehicles"





Example: Determine occluded lane regions

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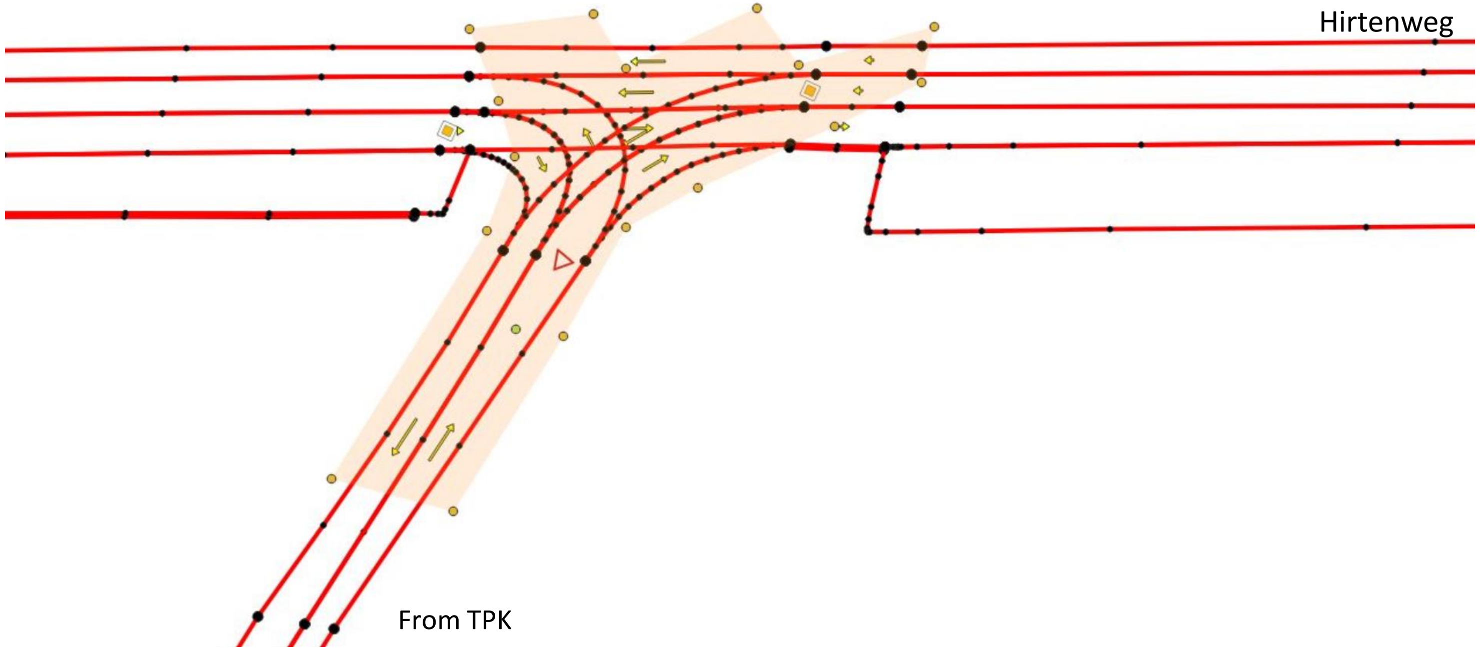
- Perception Input: Freespace Polygon (orange)



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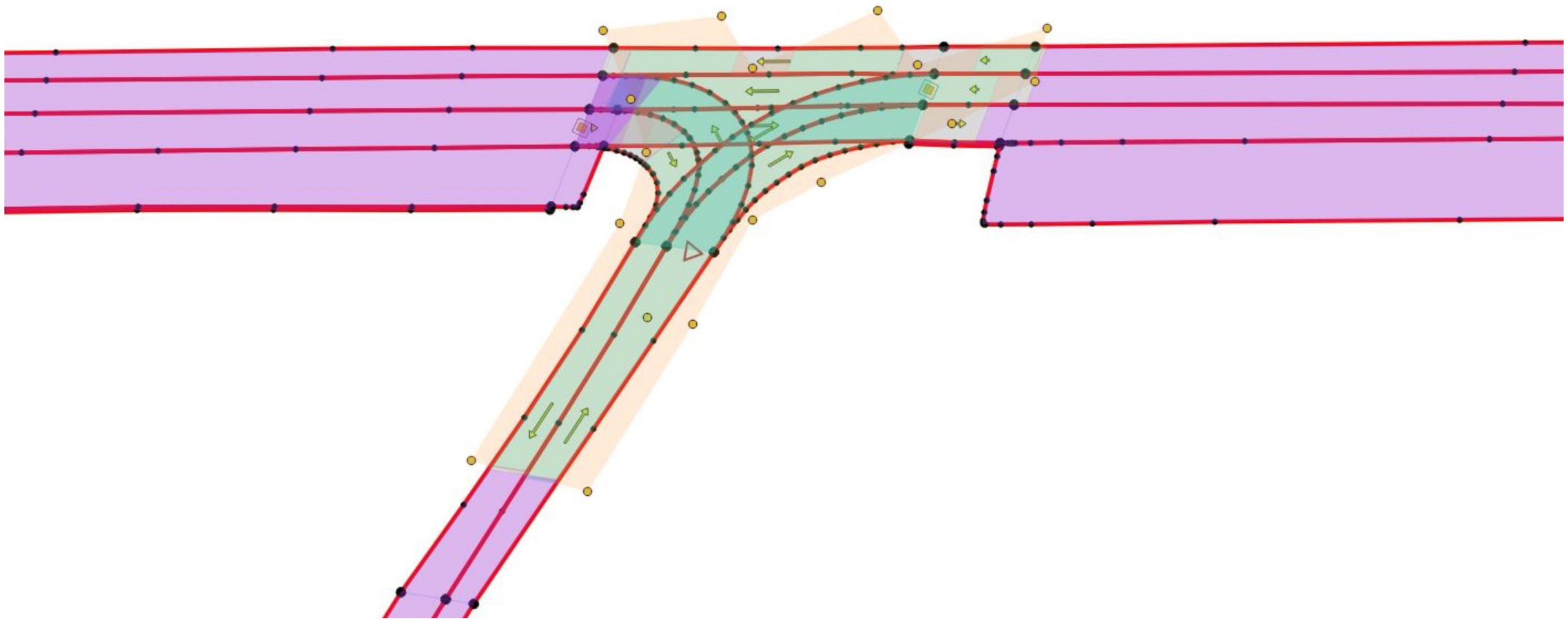
Example: Occluded lane regions

- Split lane into regions:
  - Visible region (green)
  - Occluded region (purple)
  - Partly visible/occluded border regions (grey)



Example: Placement of virtual vehicles

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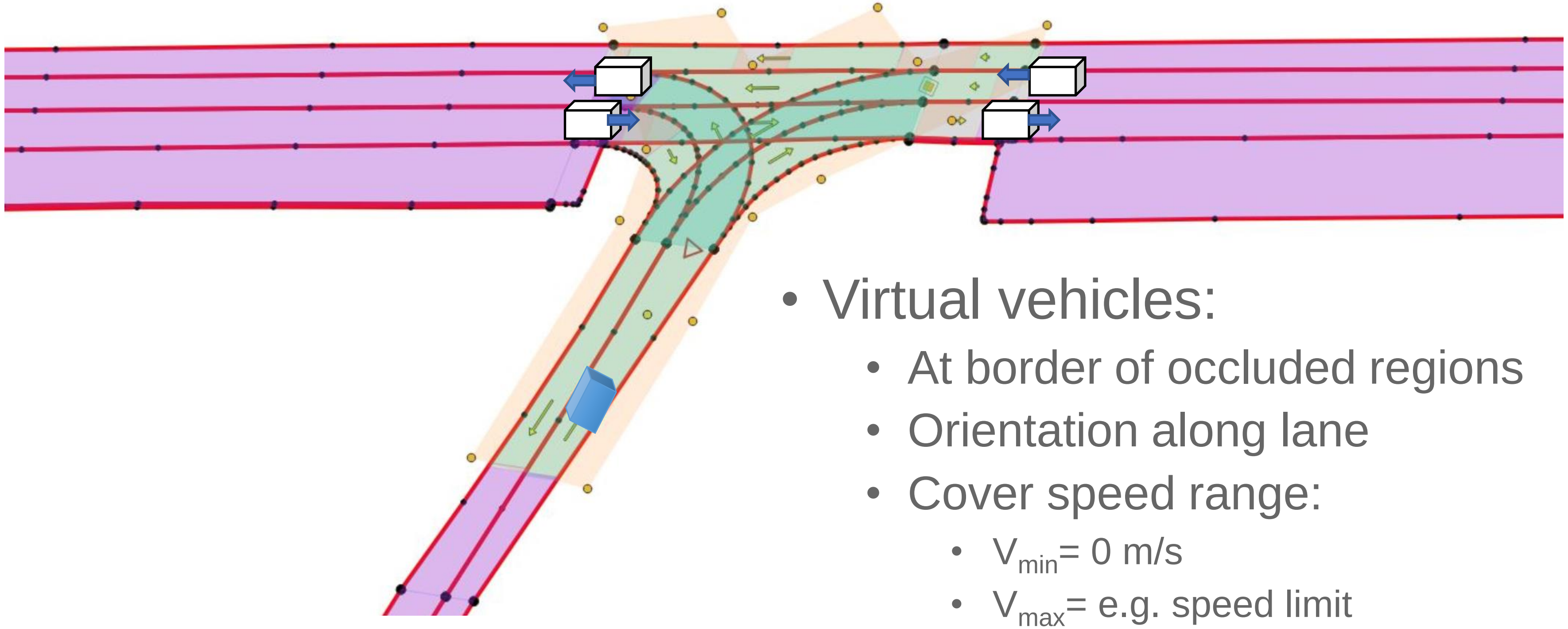

- Virtual vehicles:
  - At border of occluded regions
  - Orientation along lane
  - Cover speed range:
    - V_{min} = 0 m/s
    - V_{max} = e.g. speed limit

Experimental setup with CARLA

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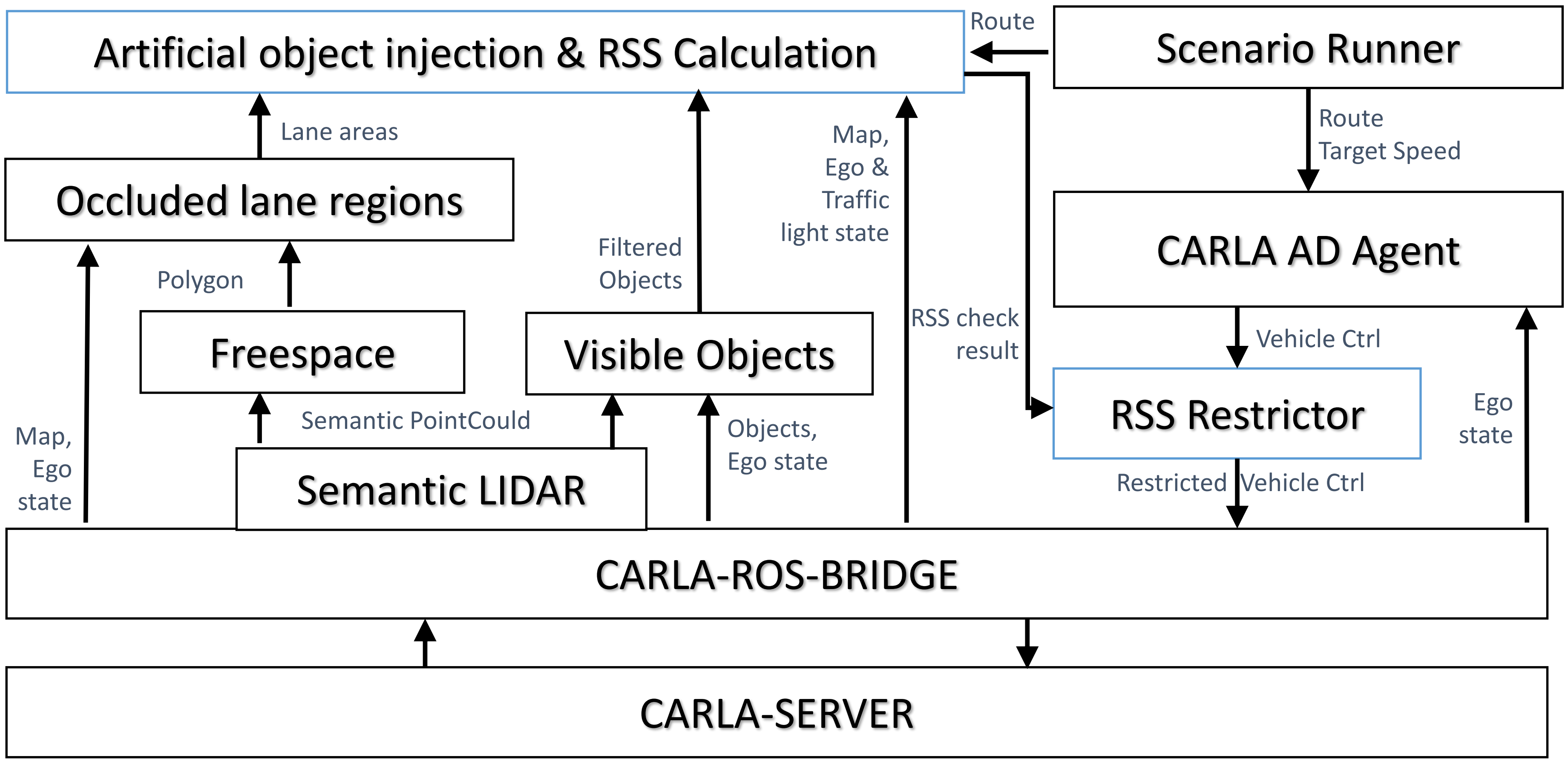

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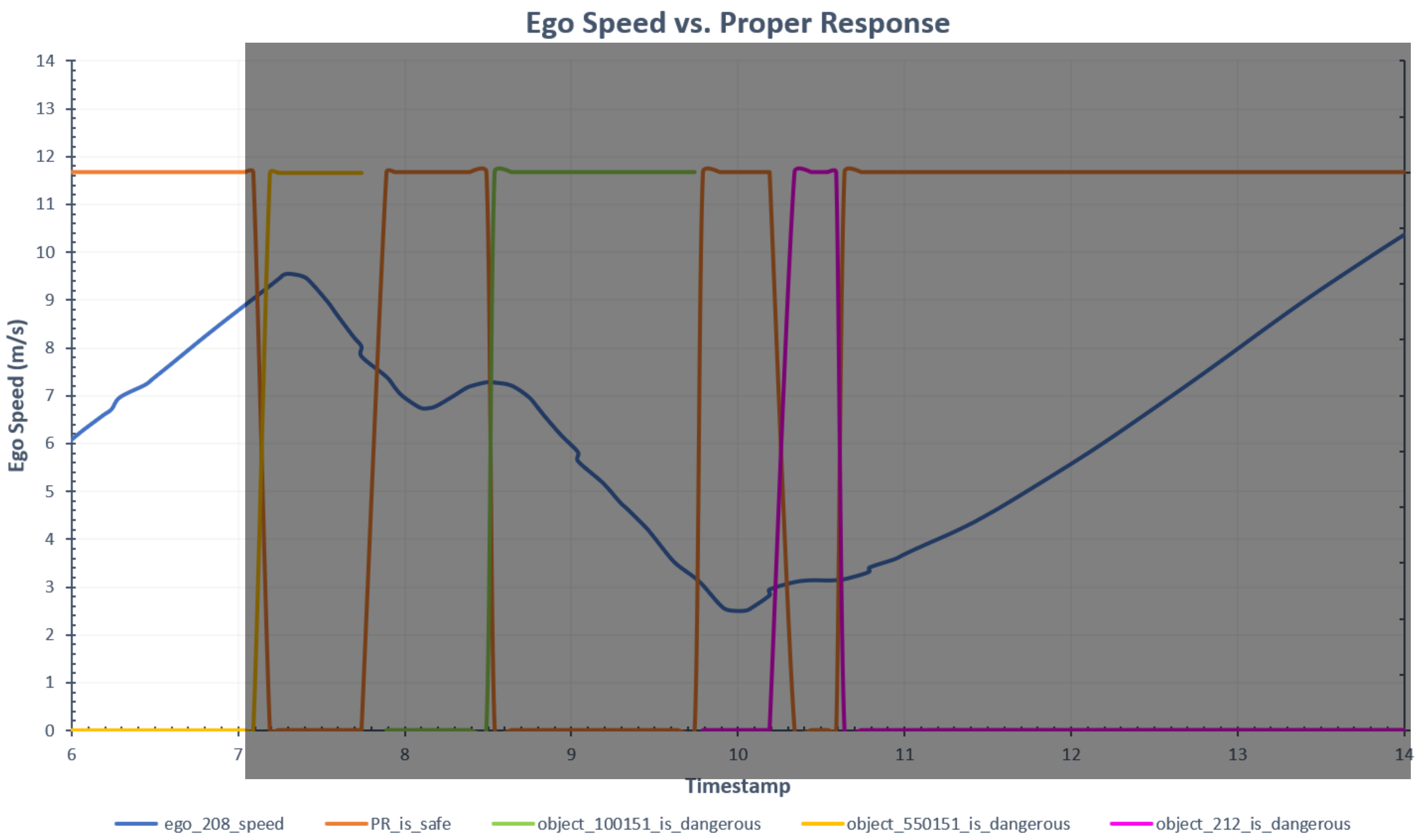
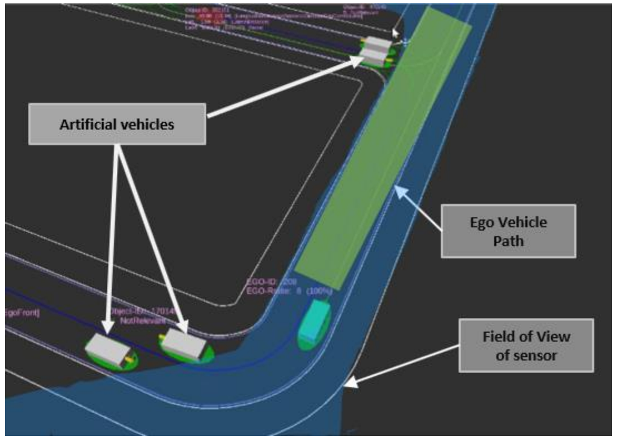
Scenario Town02: Acceleration





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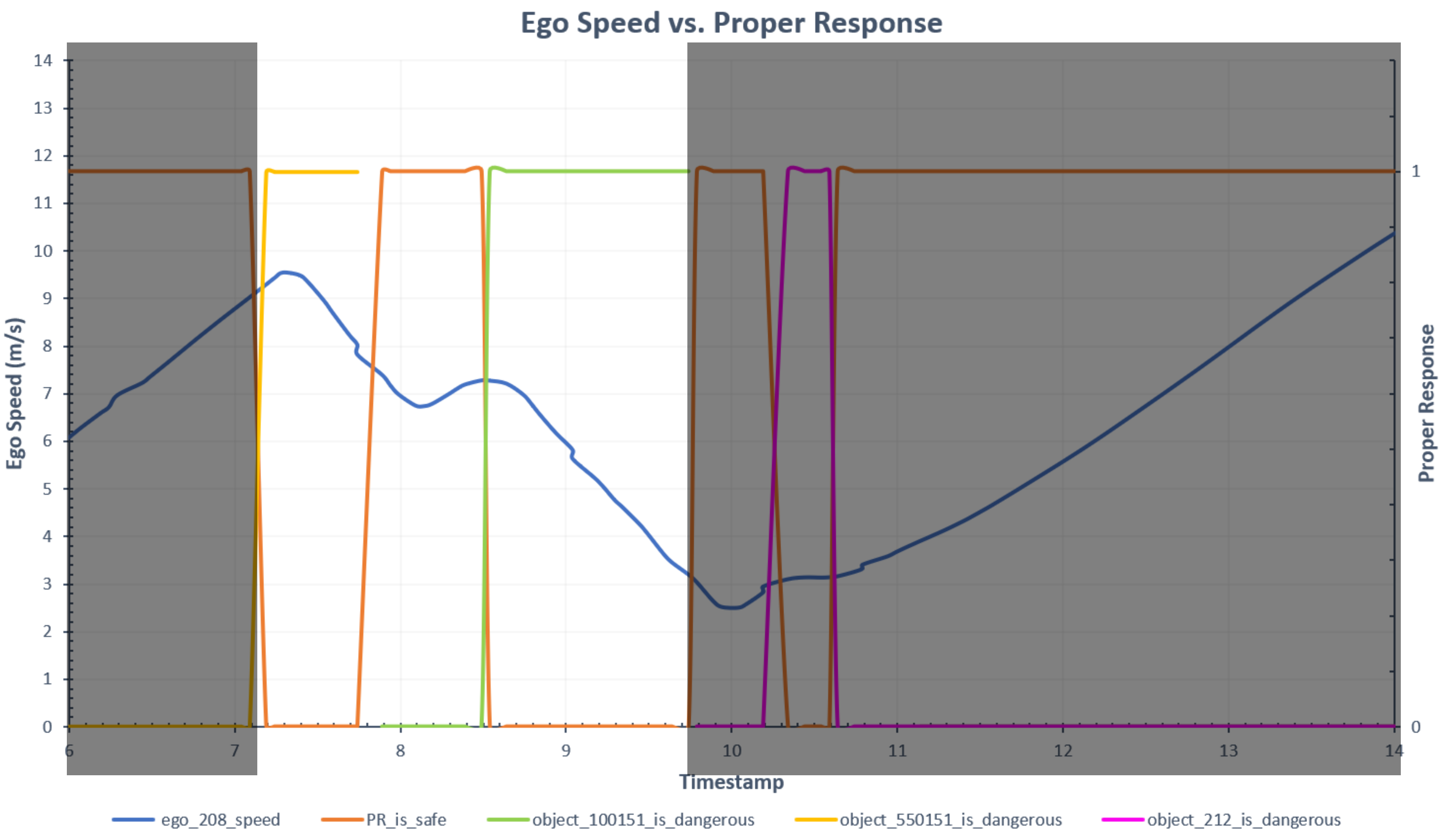
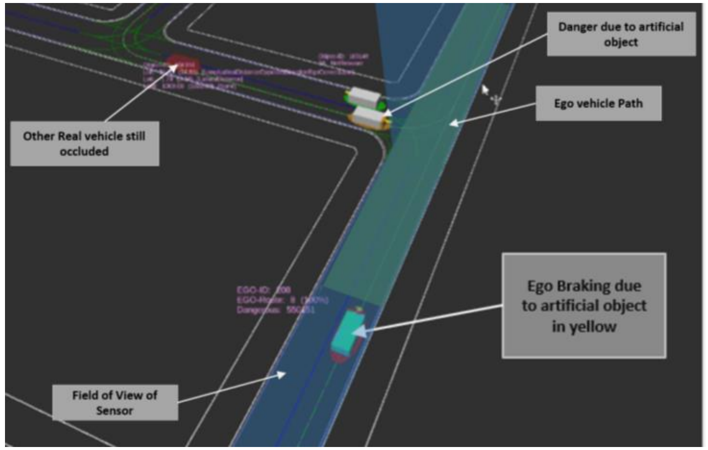
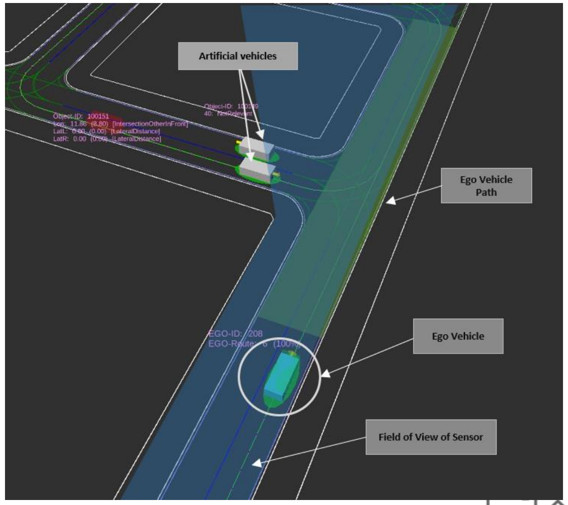
Scenario Town02: Braking arfificial vehicles







Scenario Town02: Braking real vehicle

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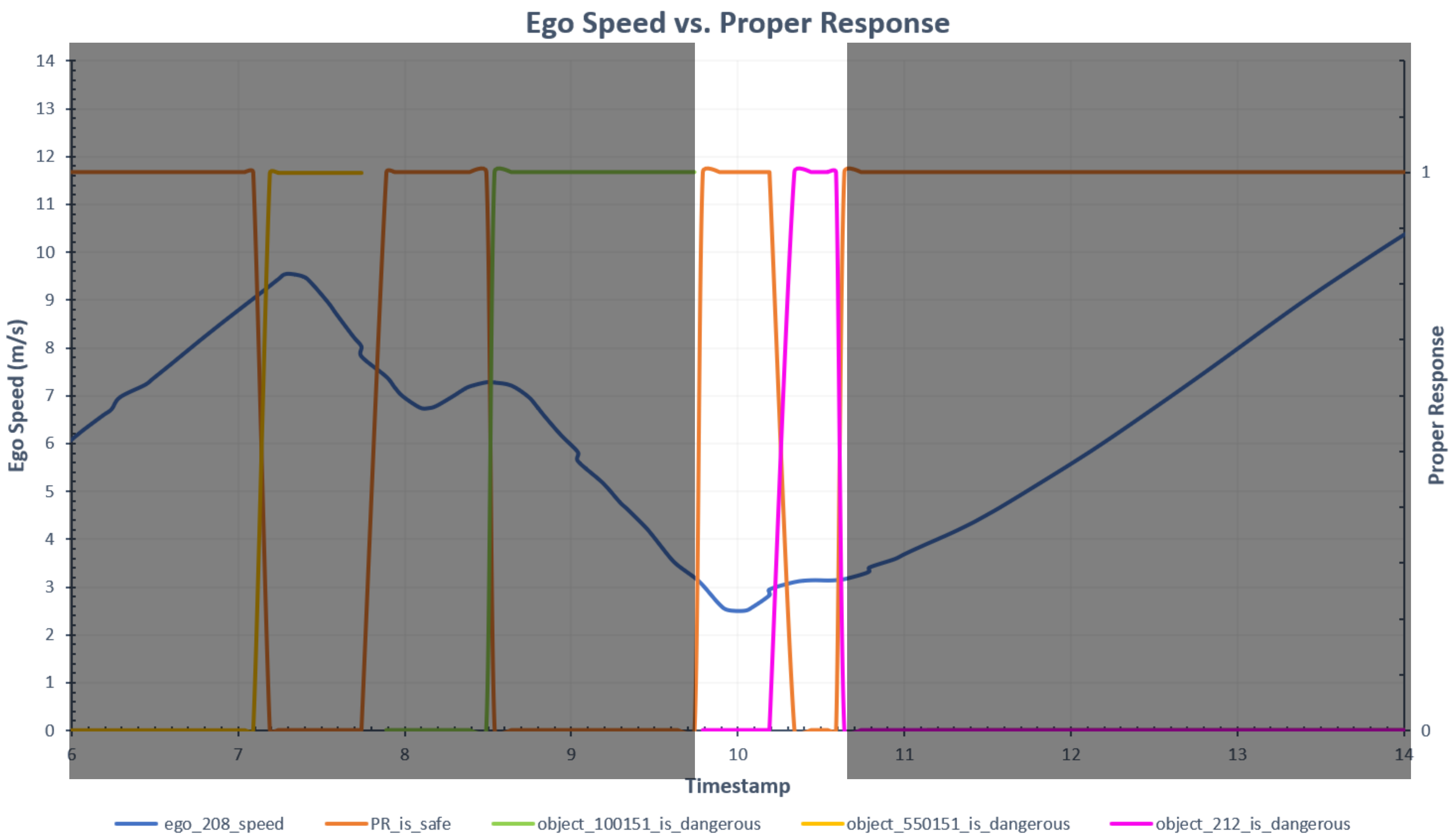

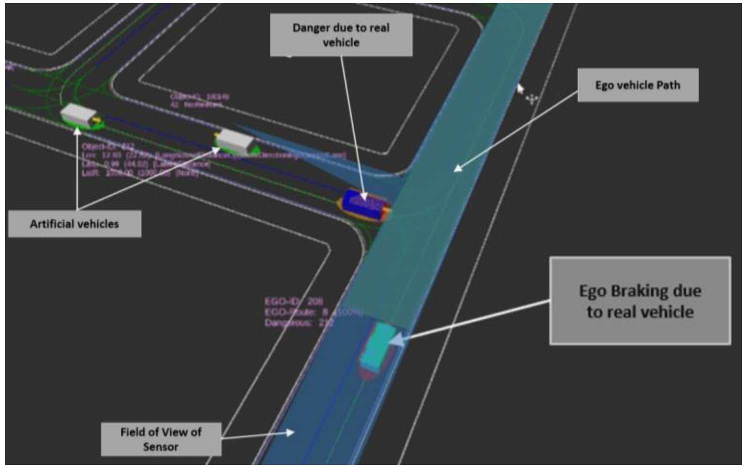

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Scenario Town02: Influence RSS Parameter

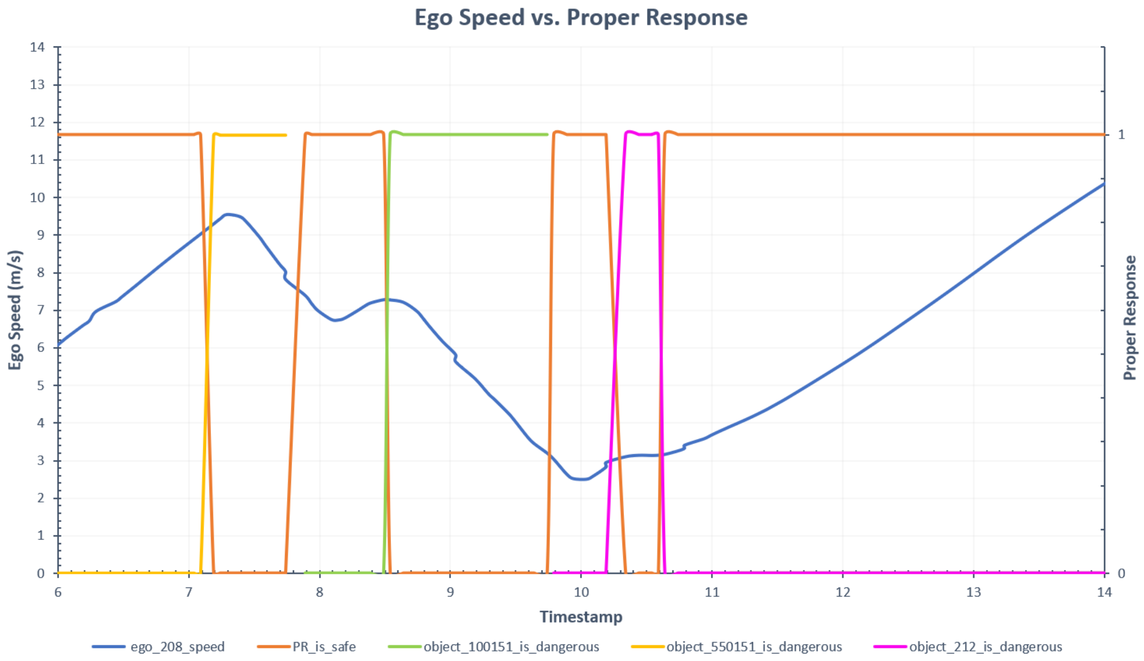
China ITS Standard RSS parameter
$brake_{min}$: -3.6 m/s^2
$brake_{max}$: -6.1 m/s^2
$accel_{max}$: 1.8 m/s^2
response-time: 0.2 s

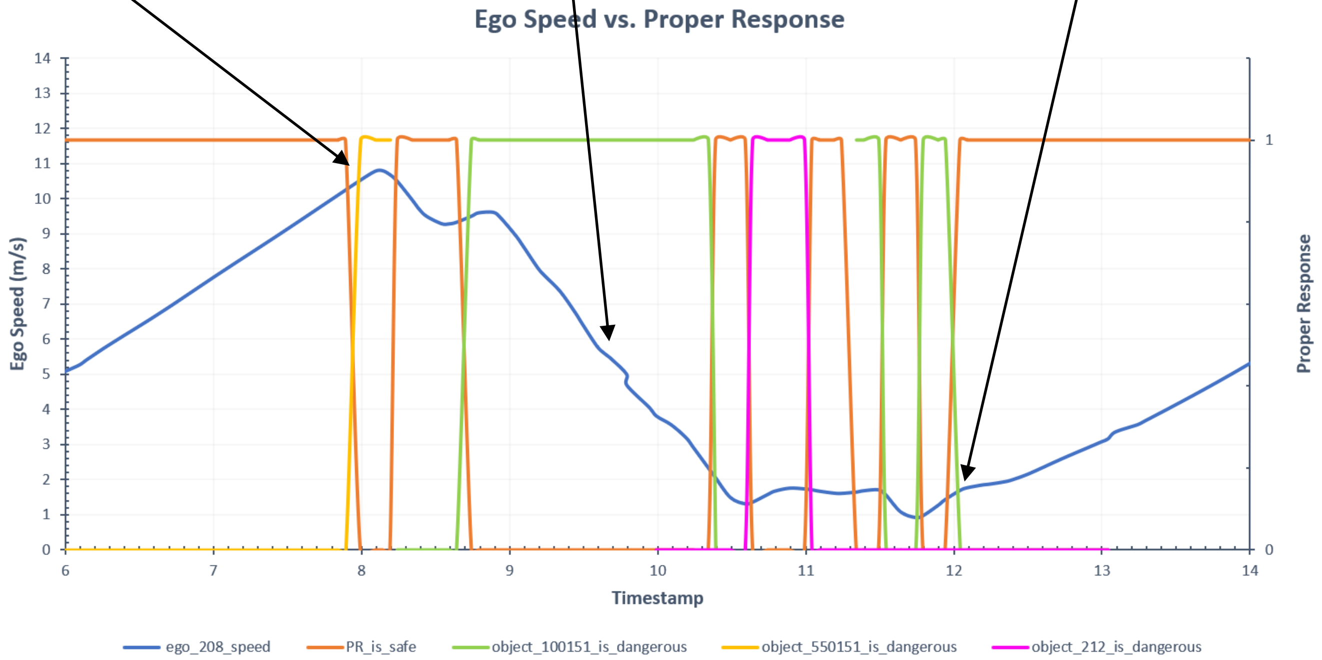
Assertive RSS parameter
$brake_{min}$: -6.0 m/s^2
$brake_{max}$: -6.1 m/s^2
$accel_{max}$: 1.8 m/s^2
response-time: 0.1 s

Later braking

Harder braking

Increased passage time





Scenario Town02: Usability

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Conservative/C-ITS RSS parameter
$brake_{min}$: -3.6 m/s^2
$brake_{max}$: -6.1 m/s^2
$accel_{max}$: 1.8 m/s^2
response-time: 0.2 s

Assertive RSS parameter
$brake_{min}$: -6.0 m/s^2
$brake_{max}$: -6.1 m/s^2
$accel_{max}$: 1.8 m/s^2
response-time: 0.1 s

Very Assertive RSS parameter
$brake_{min}$: -10.5 m/s^2
$brake_{max}$: -11.0 m/s^2
$accel_{max}$: 0.0 m/s^2
response-time: 0.1 s

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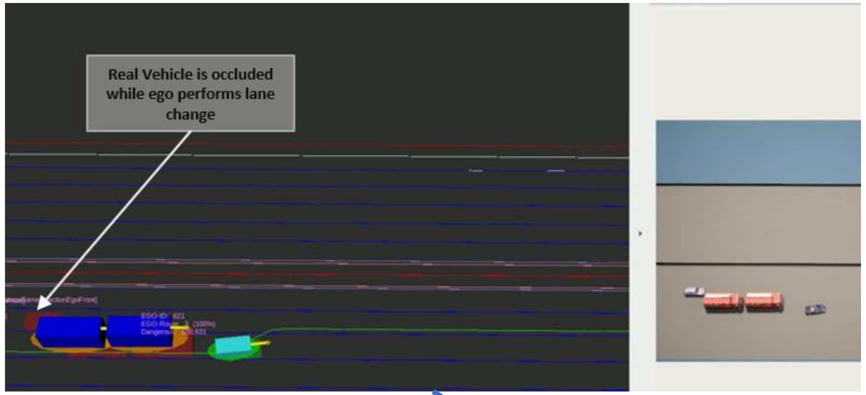
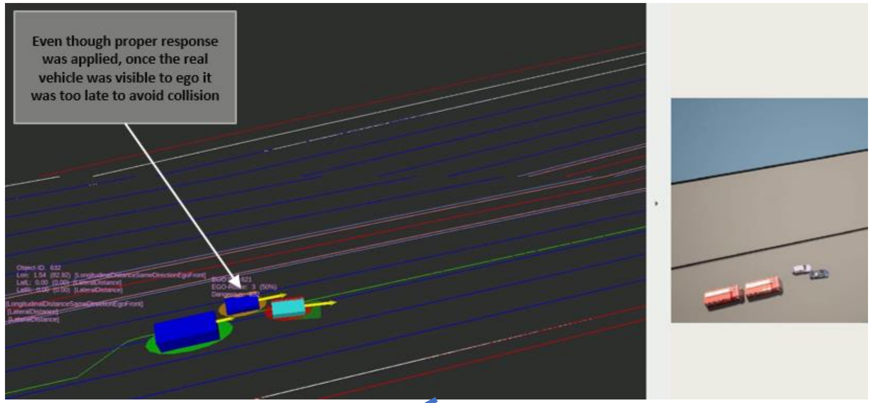
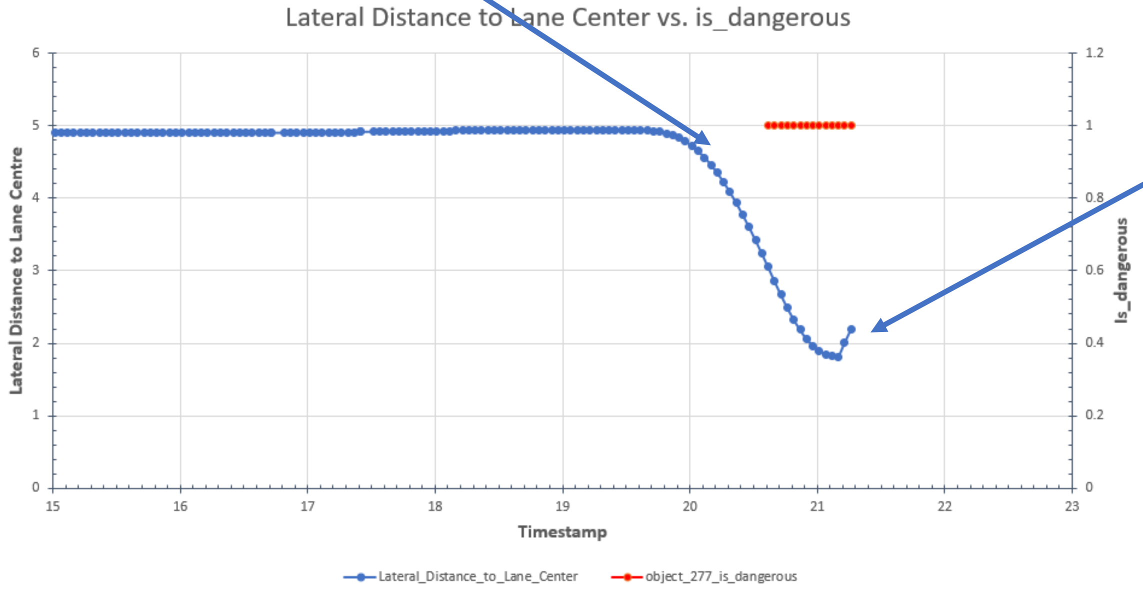
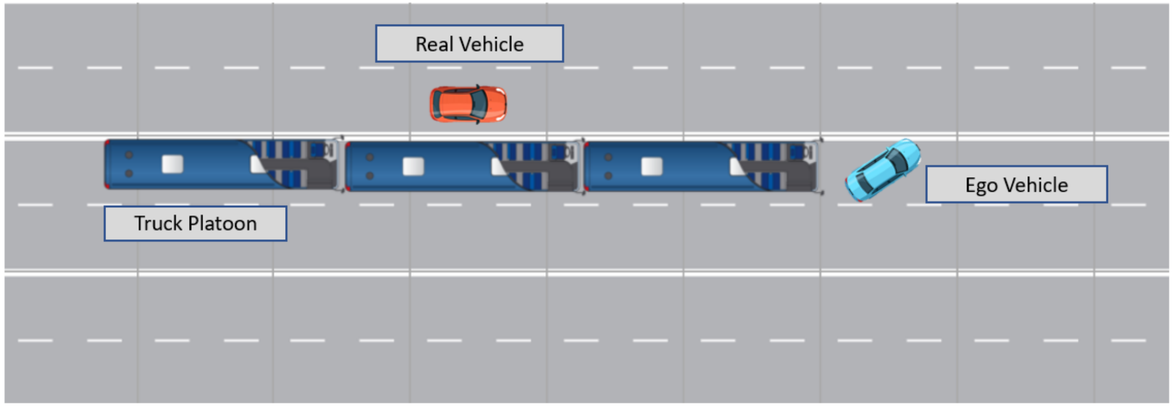
Highway scenario: without virtual objects







Speed of other real vehicle : 180 km/hr



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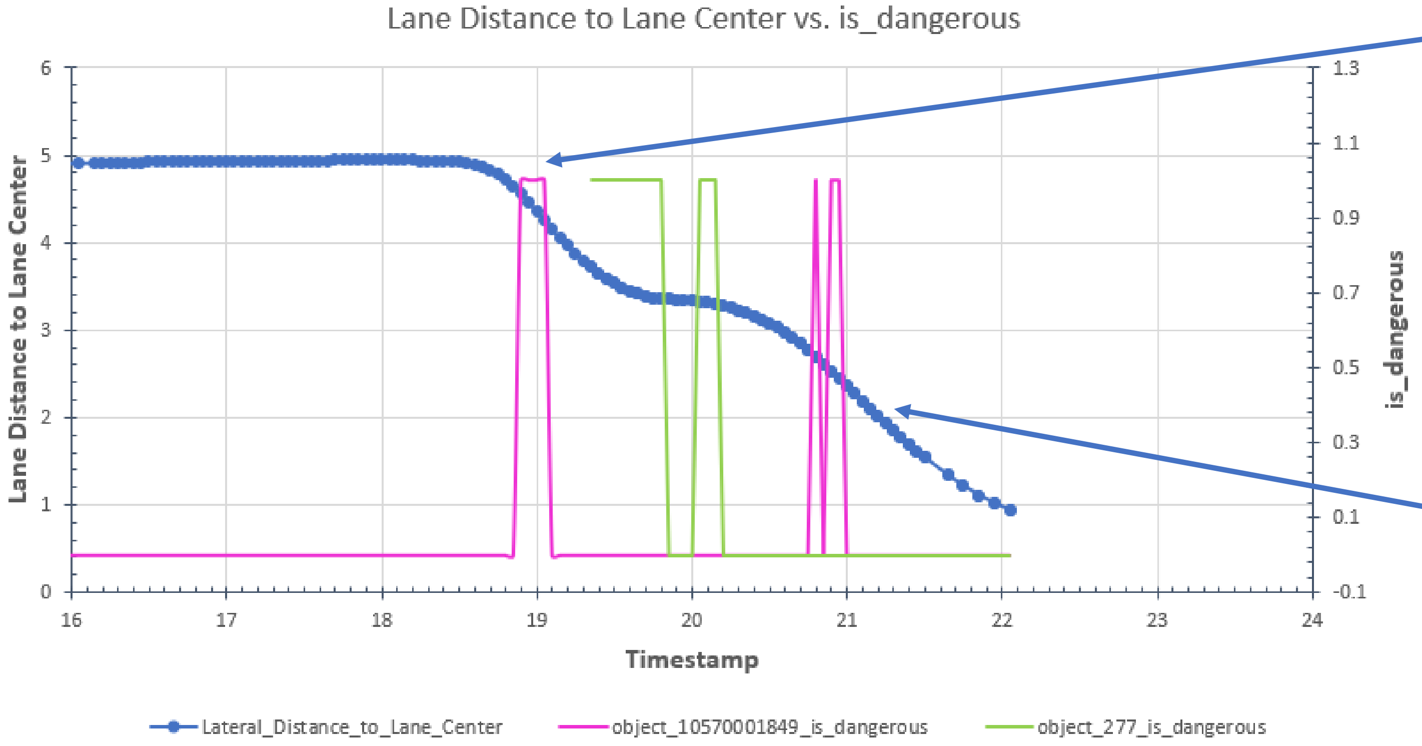
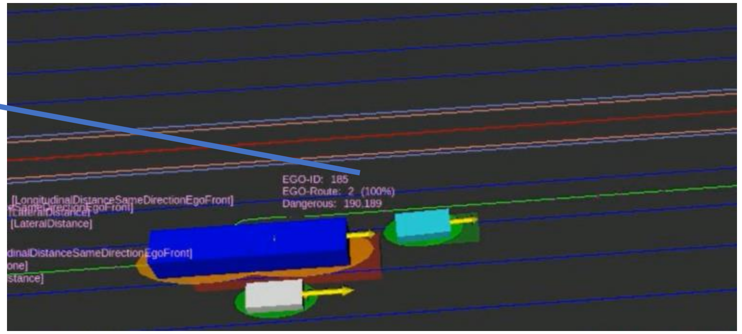
Highway scenario: with virtual objects





Speed of other real vehicle : 180 km/hr

Speed of artificial vehicle: 160 km/hr

Highway scenario: Usability curve driving

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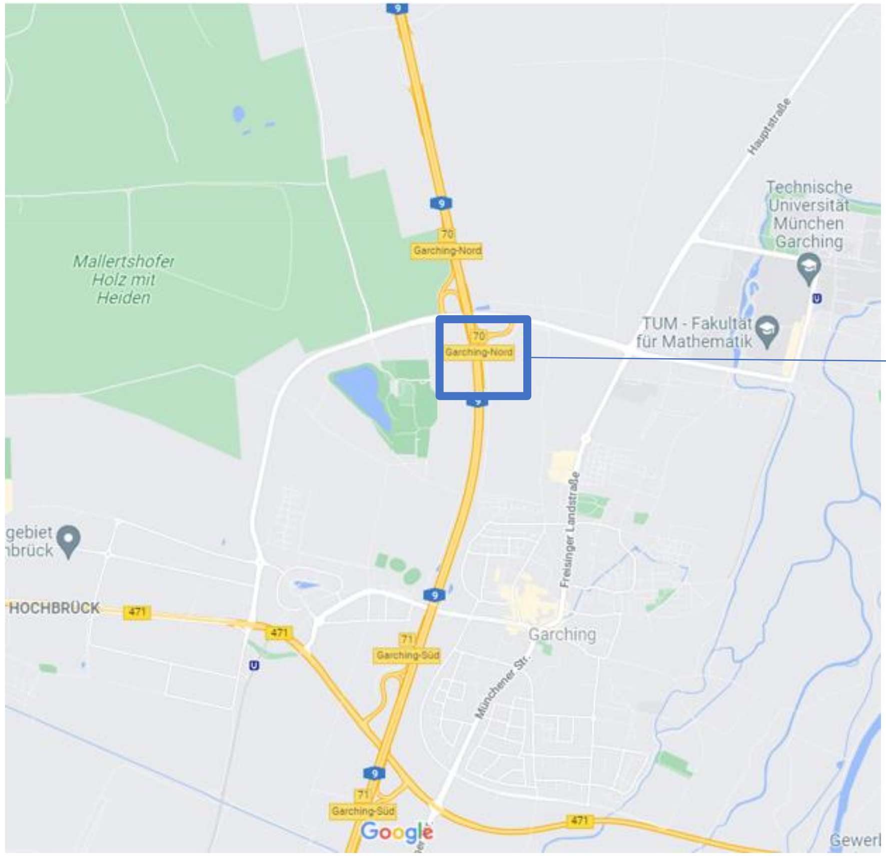

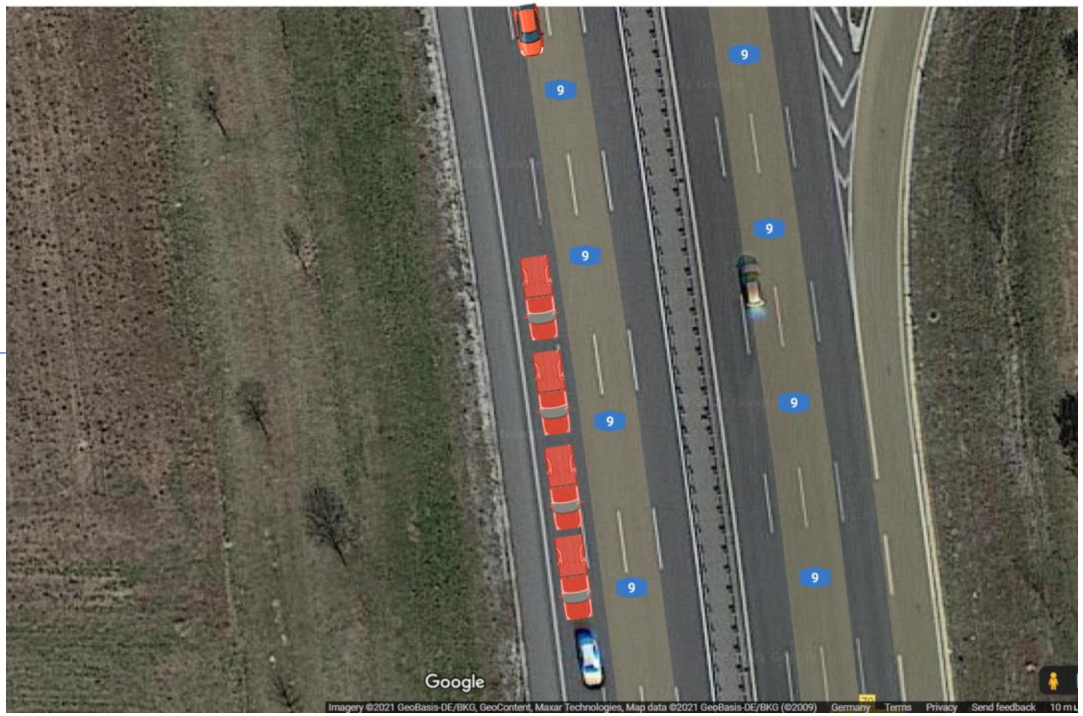

Highway scenario: Usability curve driving

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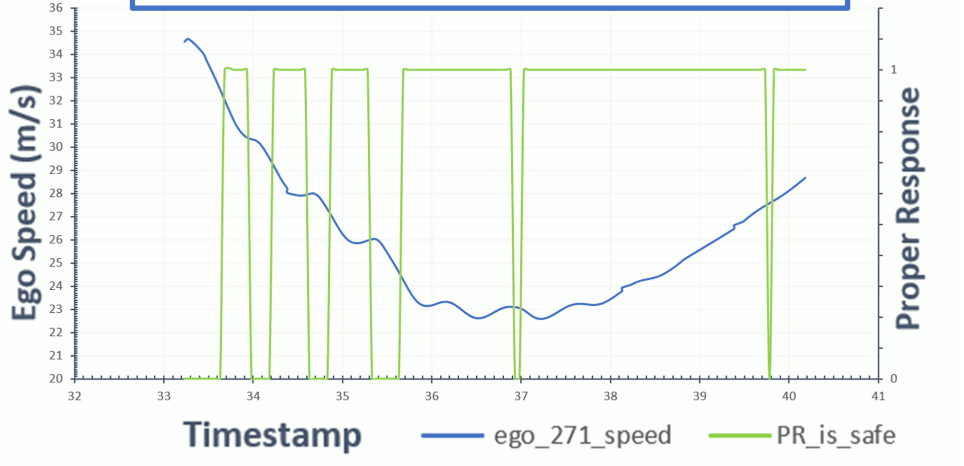
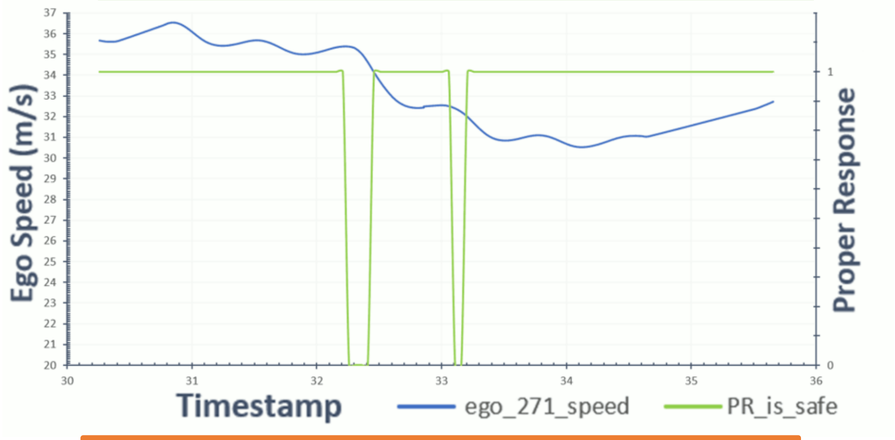
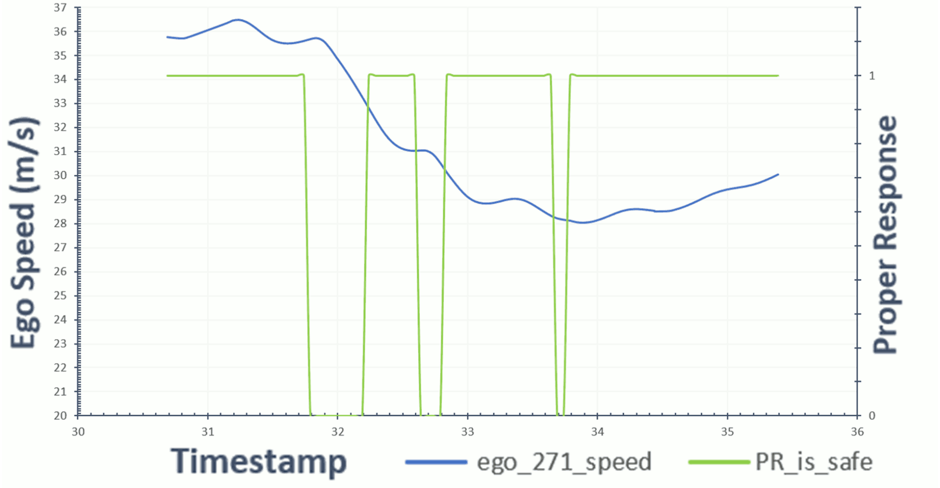
Conservative/C-ITS RSS parameter



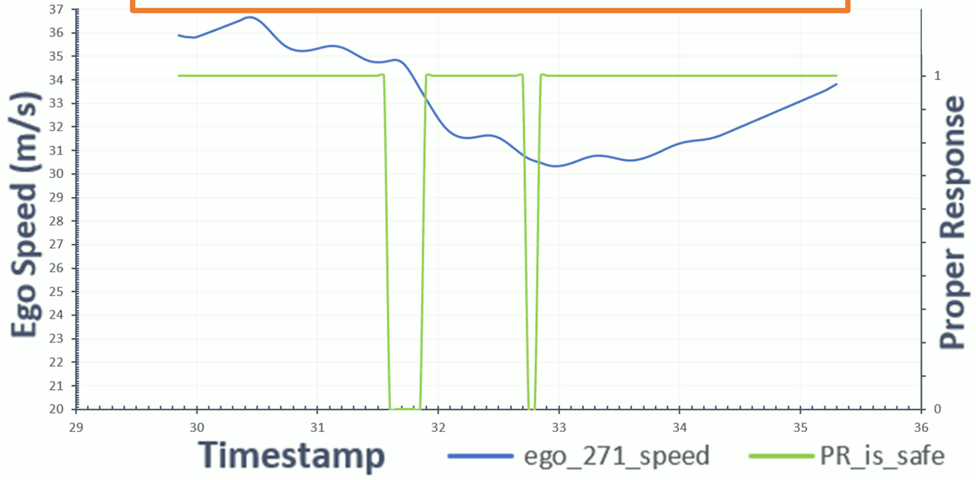
Very Assertive RSS parameter



Assertive RSS parameter



Assertive RSS parameter
Virt. Object speed$_{min}$ = 50 km/h



How to parametrize virtual objects?

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- Standard IEEE 2846 „Assumptions for Models in Safety-Related Automated Vehicle Behavior"
  - Minimum set of assumptions regarding reasonably foreseeable behaviors of other road users that shall be considered
- Virtual Objects:
  - RSS model parameter values to select
    - Conservative vs. Assertive
  - Artificial object states to expect
    - Standing still vs. driving at some reasonable delta speed
    - While worst case could even be a ghost-driver
  - Potentially even different parametrized virtual objects could be placed at once

Residual risk ⇔ Traffic flow

Derive Reasonably Foreseeable worst-case Assumptions for Occluded Road Users

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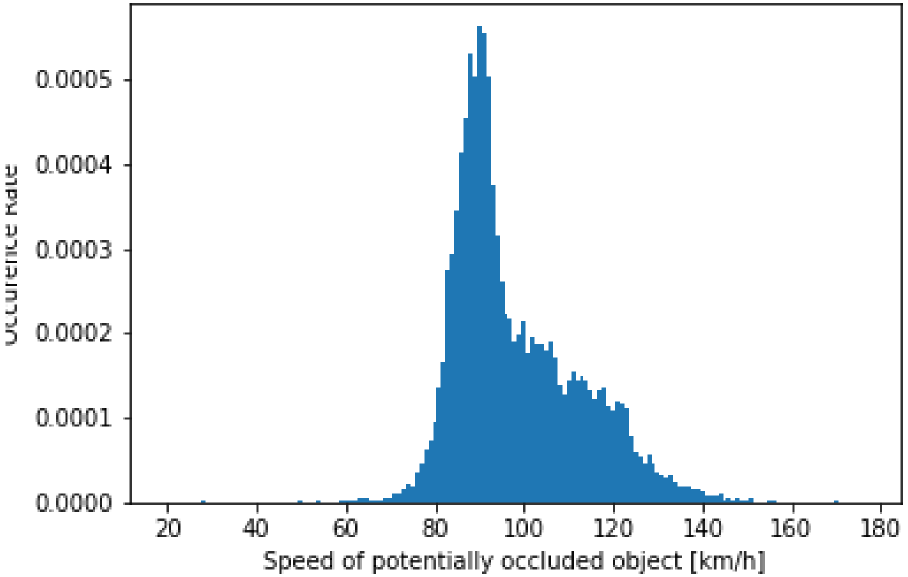
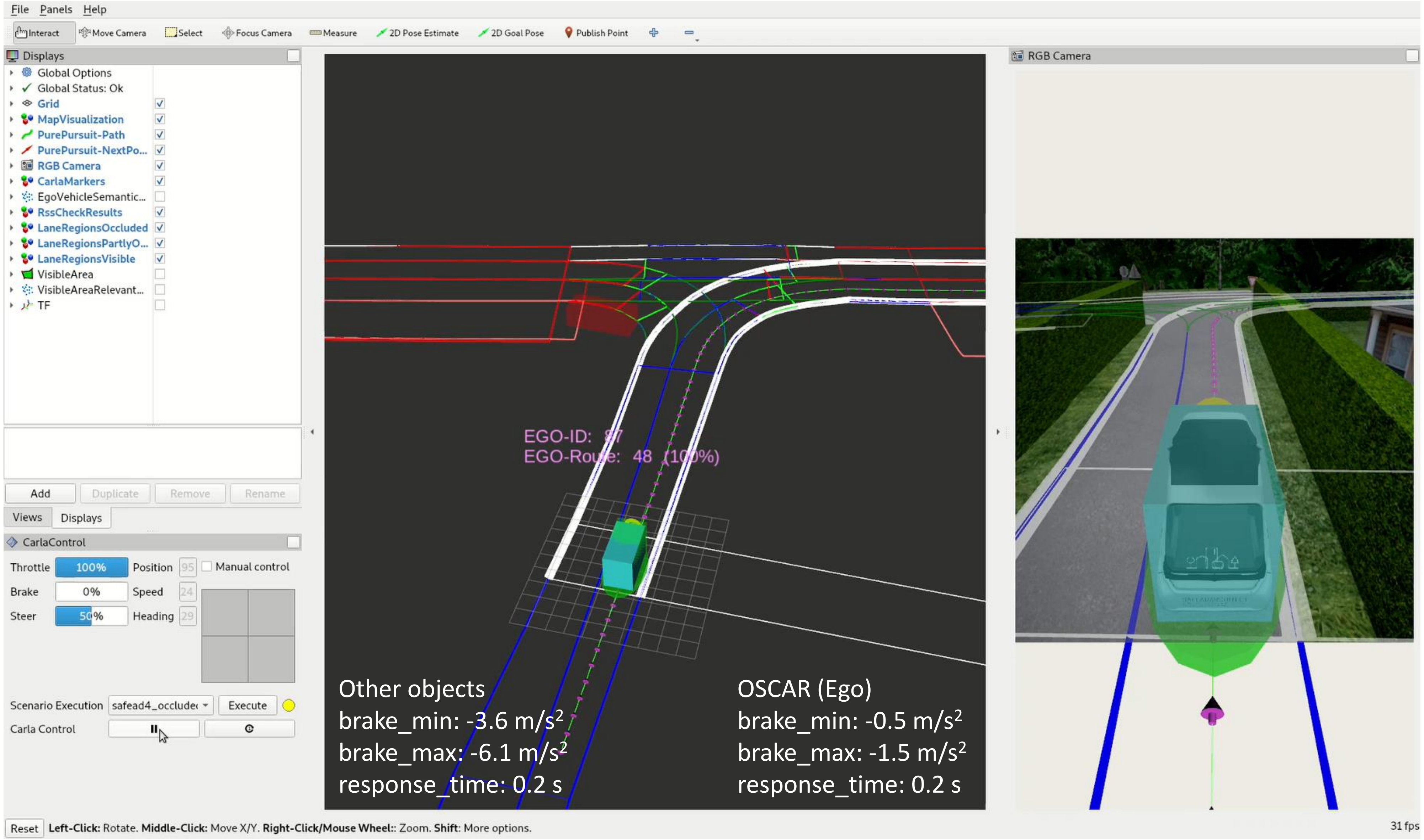
- Highway example
  - Key parameter: assumed speed
- HighD Dataset
  - Likelihood that leading vehicle is significantly slower ≤ 1.2 %

Confidence interval	Forseeable Speed
3σ (99.73 %)	87 km/h
4σ (99.99 %)	68 km/h
5σ (99.9999 %)	20 km/h



HighD-Dataset: Occurrence rate of situations where a (potentially occluded) lead vehicle is at least 20 km/h slower than a rear vehicle.

SafeAD scenario: Collision OSCAR



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SafeAD scenario: Artificial objects OSCAR

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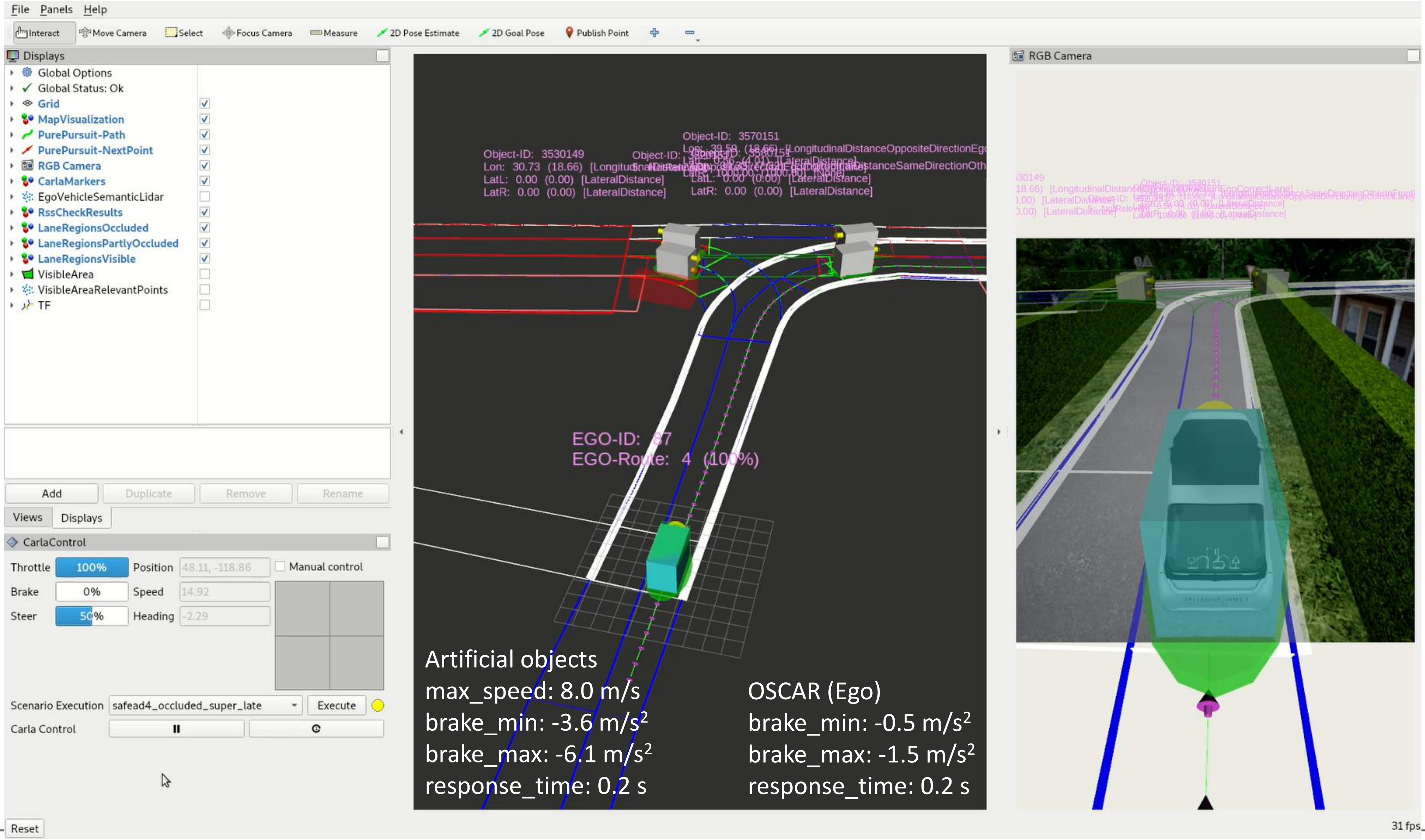

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Summary

- Virtual Objects in occluded areas appyling RSS lead to cautious driving and mitigate dangerous situations introduced by occluded objects
- Different attributes of virtual objects and the selection of applied RSS-parameter values influence the residual risk as well as the utility in daily traffic
- Selecting conservative RSS model parameters might even increase utility measures in some occlusion scenarios
- Only the analysis of many critical scenarios and their variations will provide a balance between utility and residual risk in the field

Paper: Bernd Gassmann, Shreya Dey, Ignacio Alvarez, Fabian Oboril, Kay-Ulrich Scholl: Application of Responsibility-Sensitive Safety in areas with limited visibility: Occlusions in RSS, submitted for publication.

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