PROJECT of the PEGASUS FAMILY

VERIFICATION VALIDATION METHODS

Mid-Term Presentation 15 / 16 March 2022

Criticality Metrics: Introduction and their Use in Practice

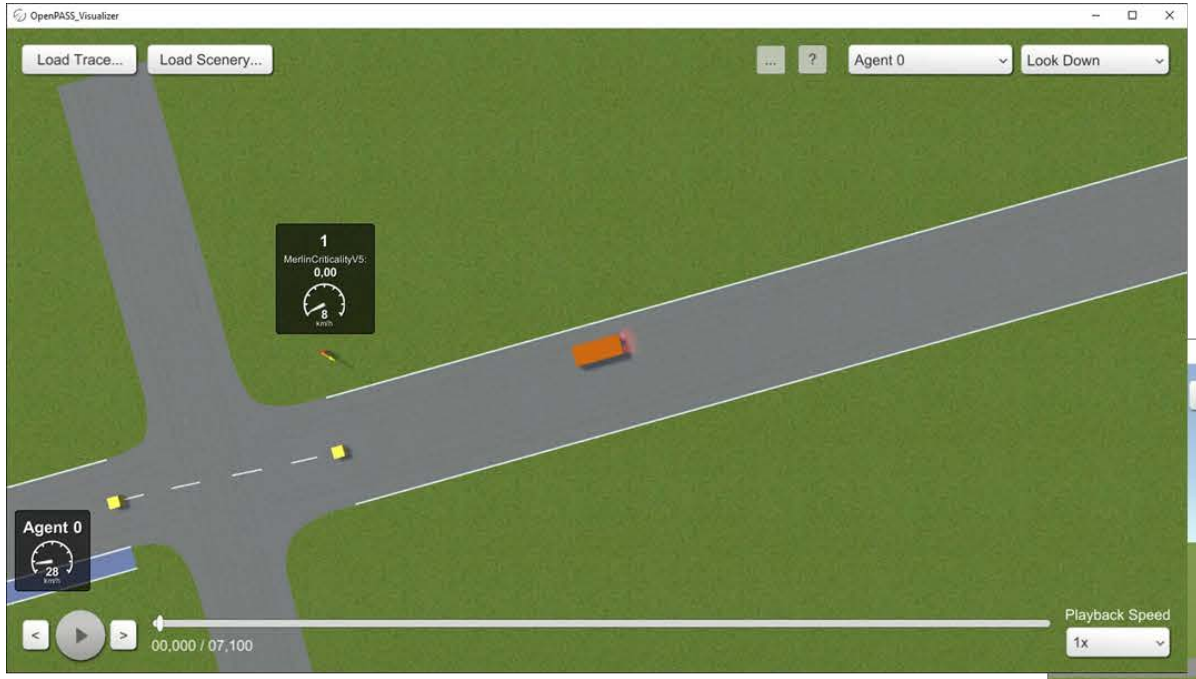
Martin Bollmann, ZF

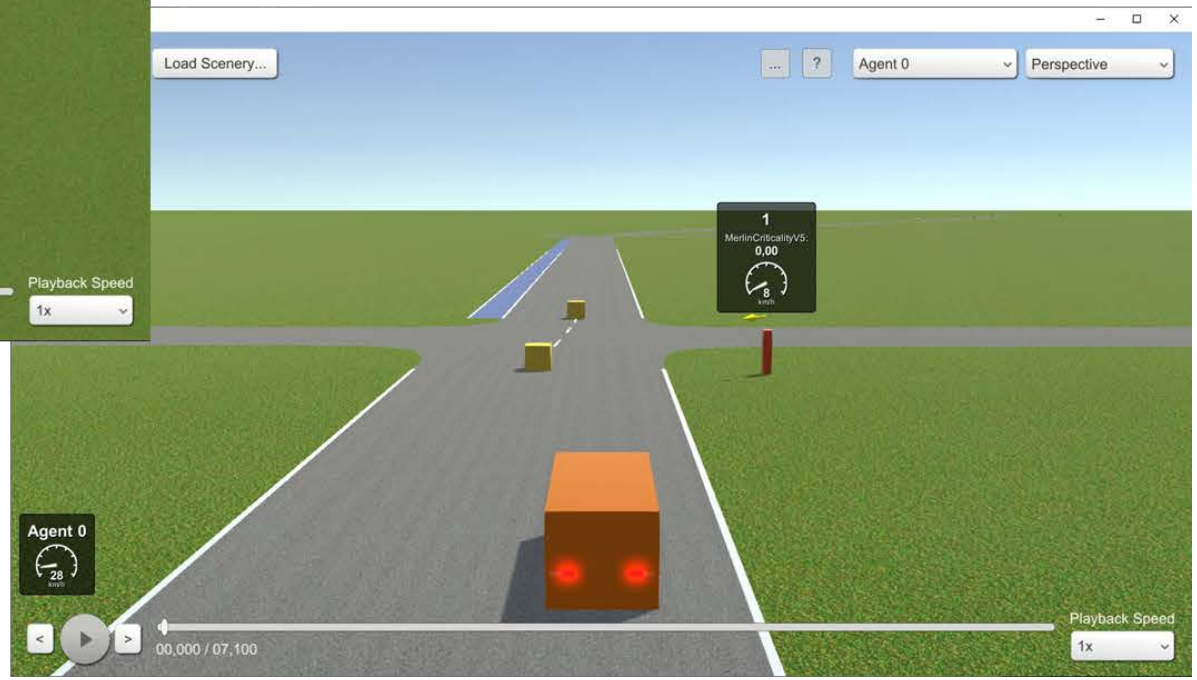
Supported by:

Federal Ministry for Economic Affairs and Climate Action

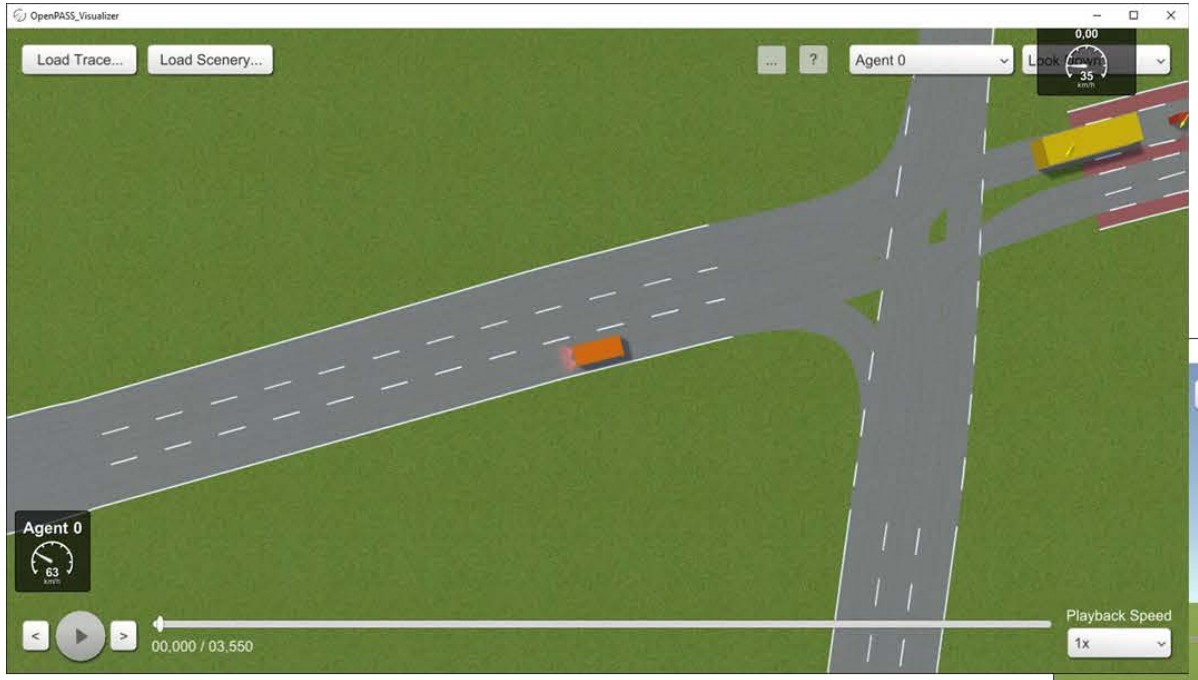
on the basis of a decision by the German Bundestag

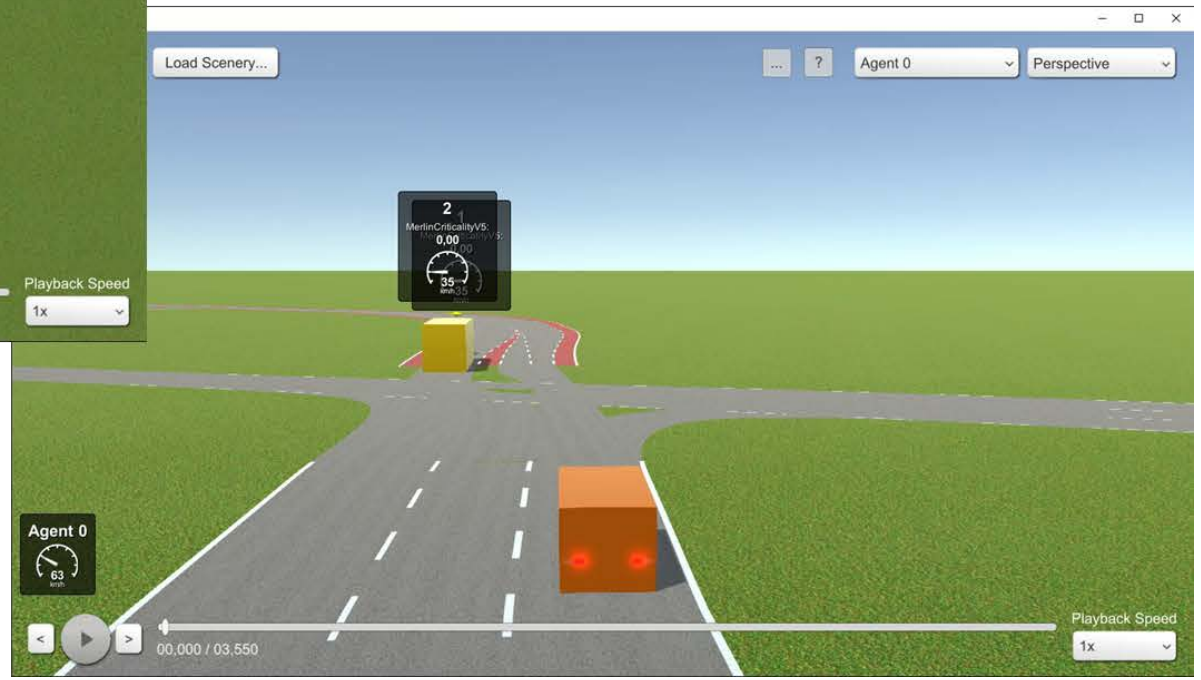
Near Crash w. Pedastrian



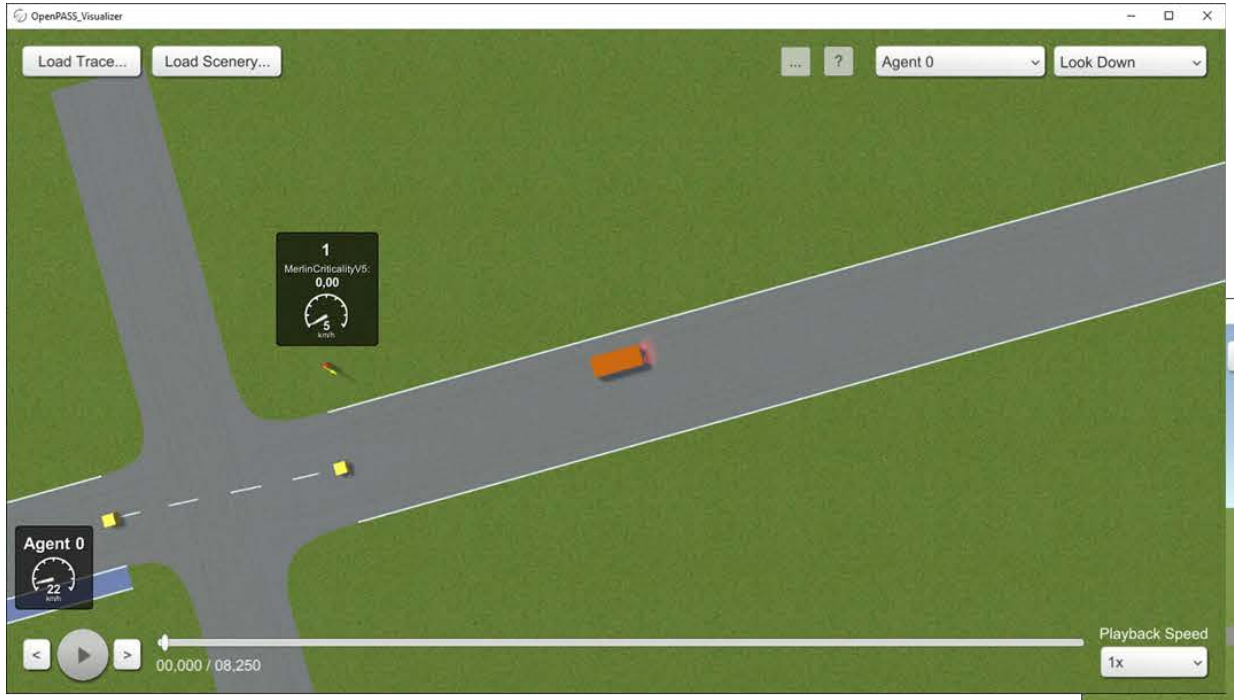


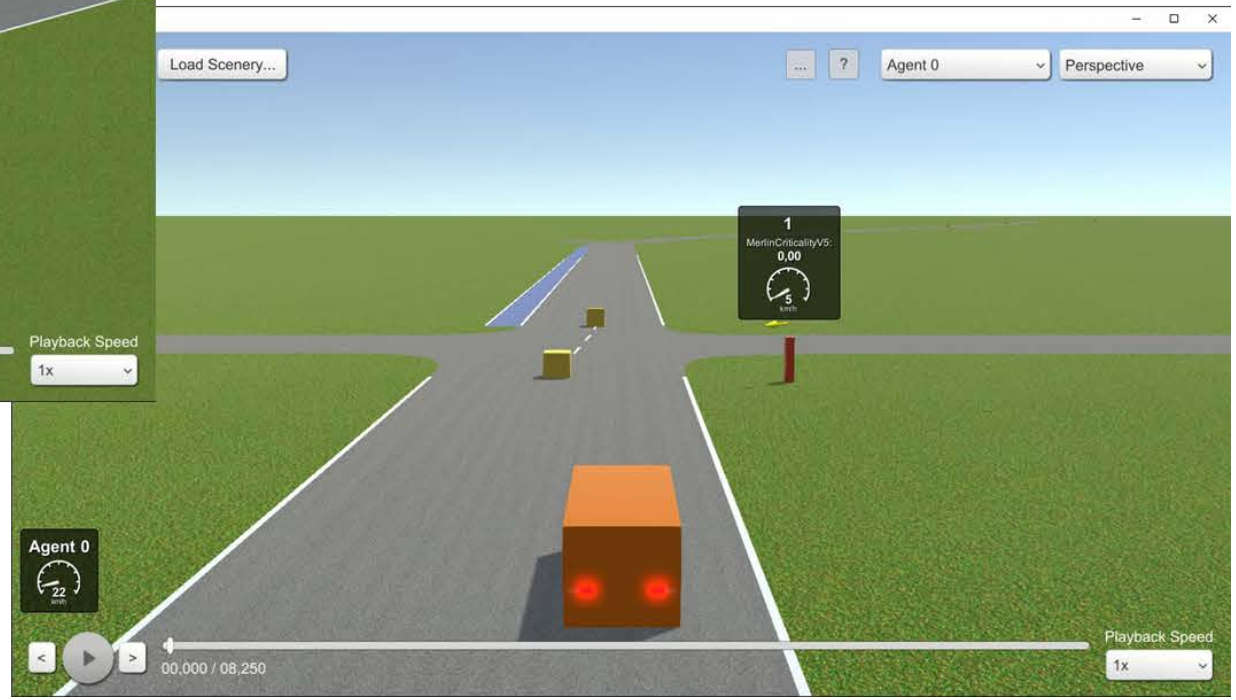
Near Crash w. Car



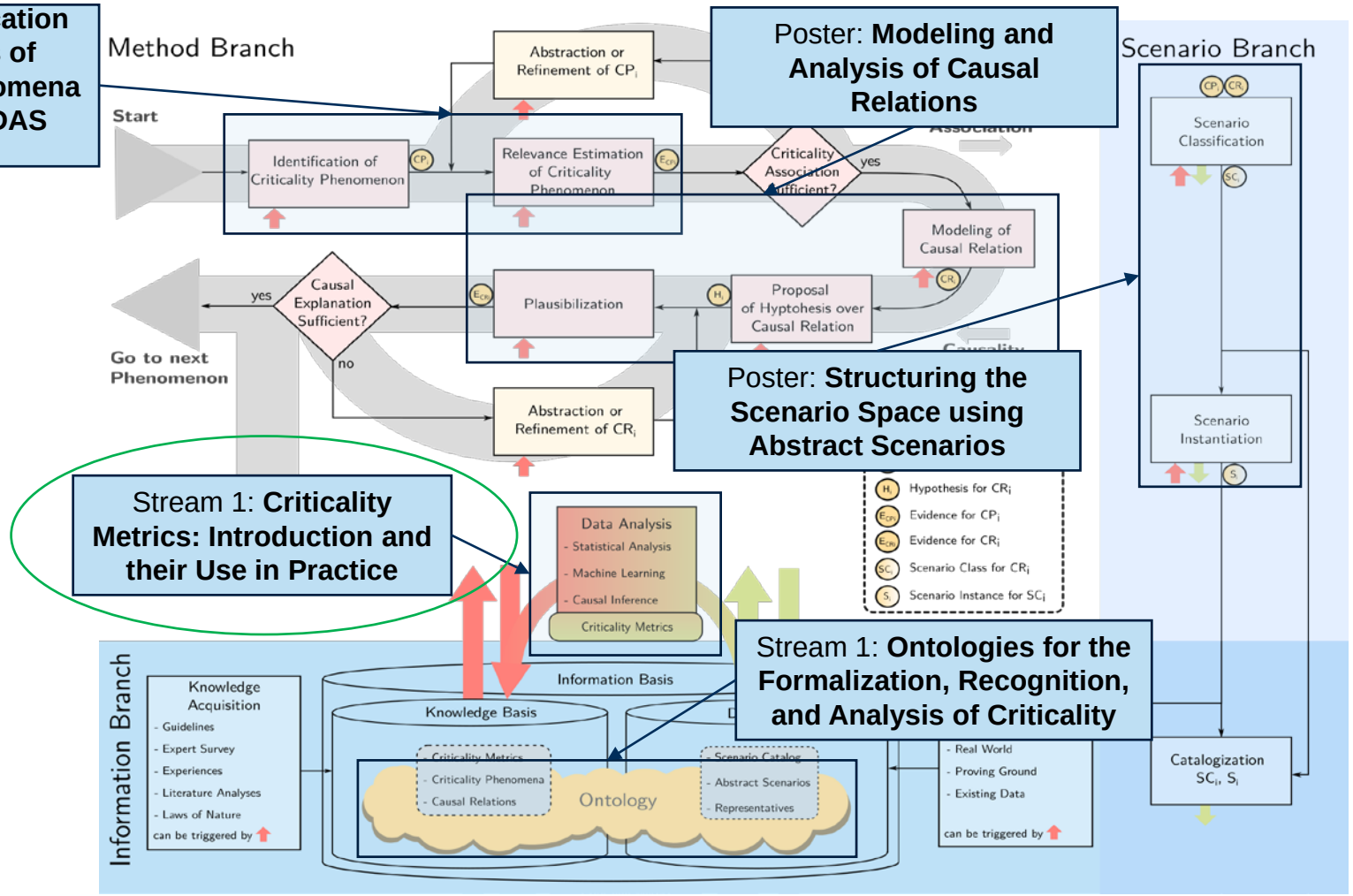


Crash w. Pedestrian





Criticality Metrics – Introduction

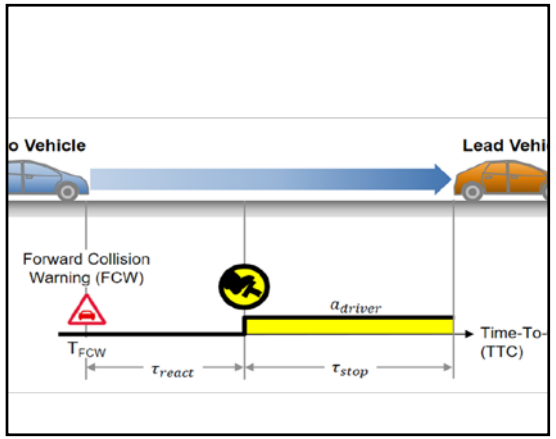


criticality should be able, to detect types of Scenarios, that are hazardous in general. By analyzing crash databases, we will get hazardous segments and regions, by searching for the number of crashes with or without harm per segment length or per time period. But all the near crashes, that could be challenging to a driving intelligence (that could be a human driver or an autonomous driving function) won't be taken into account. To be able, to do a criticality analysis like shown in the presentation before, a more differentiated measure would be necessary.

- Criticality describes the **possibility** a crash would occur in the ongoing scenario.
- Criticality as a **metric** and **not a controller**

Classes of criticality measures (see also [4])

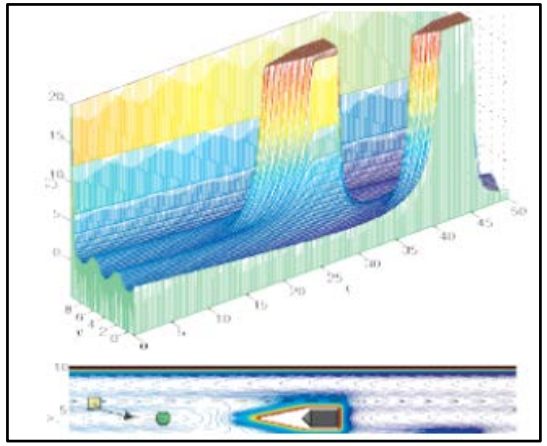
Simplified measures



Quelle: Kapse, Ritesh& Sasidharan, Adarsh. (2019)

- Measures based on simplified geometric and physical relations between objects

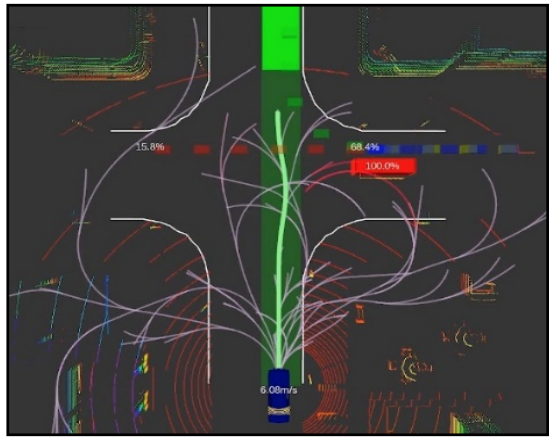
Potential-based



Quelle: Wolf, Michael & Burdick, Joel. (2008)

- Object motion induces spatial potential
- Superposition of potentials creates criticality

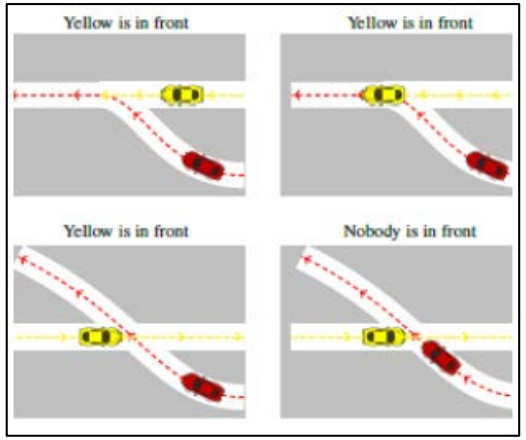
Trajectory-based



Quelle: Ackerman, Evan (2019)

- Prediction of near-future trajectories
- Estimation of collision probabilty

Rule-based

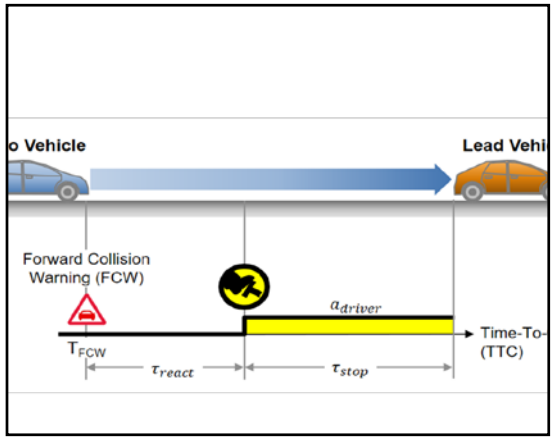


Quelle: Shalev-Shwartz et.al. (2017)

- Distinction of scenarios according to rules or maneuvers
- Appropriate measures for given scenarios

First discussion of the classes criticality metrics

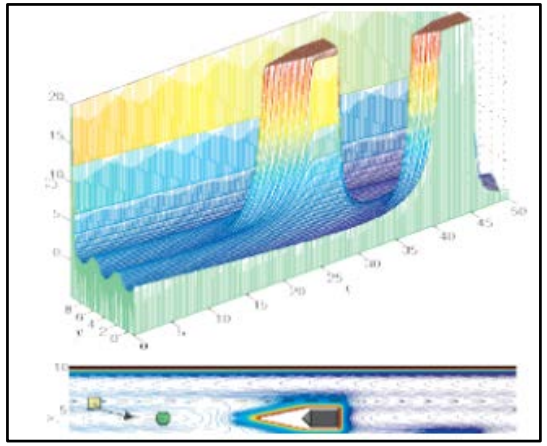
Simplified measures



Quelle: Kapse, Ritesh& Sasidharan, Adarsh. (2019)

- are a quick and rough estimation to get a feeling for criticality
- But in most cases, the metrics are just limited to a limited space of functional scenarios

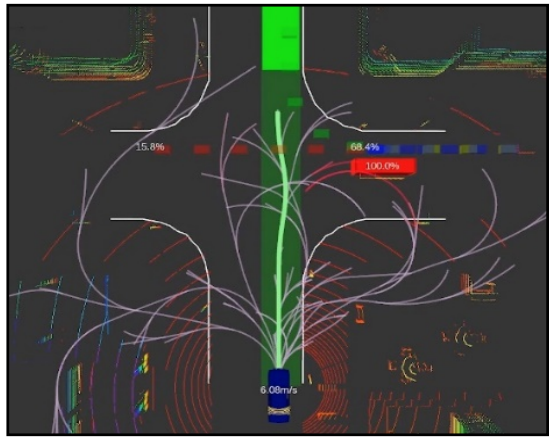
Potential-based



Quelle: Wolf, Michael & Burdick, Joel. (2008)

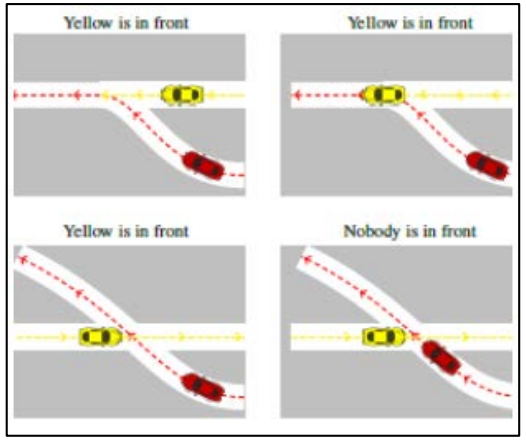
- The potential- and the trajectory-based metrics are able to handle all known types of scenarios

Trajectory-based



Quelle: Ackerman, Evan (2019)

Rule-based



Quelle: Shalev-Shwartz et.al. (2017)

- are a quick and rough estimation to get a feeling for criticality
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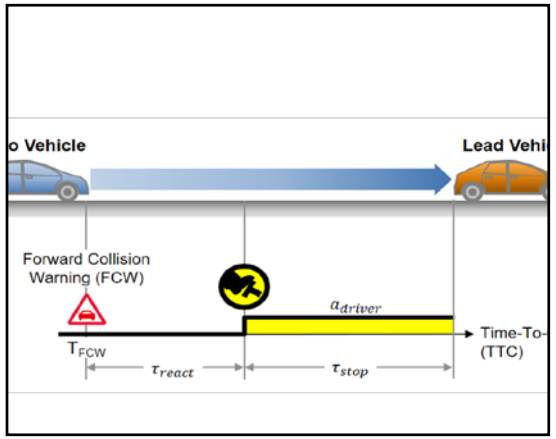
Metrics, used in Presentation

VERIFICATION VALIDATION METHODS

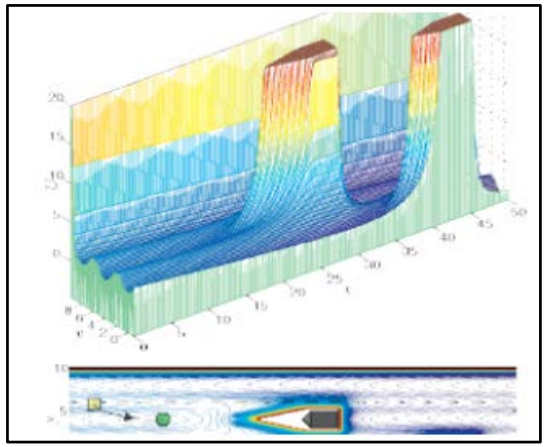
Simplified measures



Quelle: Kapse, Ritesh& Sasidharan, Adarsh. (2019)

- E.g TTC (not in the slides)

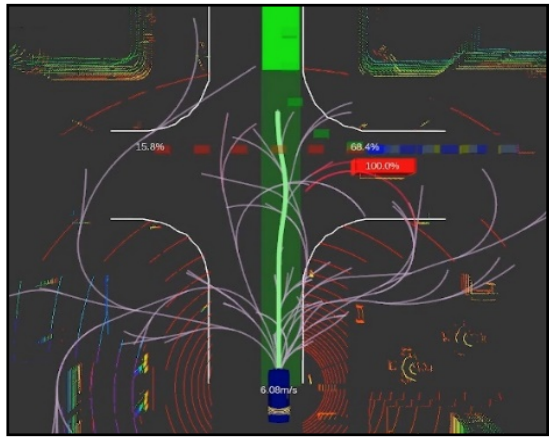
Potential-based



Quelle: Wolf, Michael & Burdick, Joel. (2008)

- MerLin

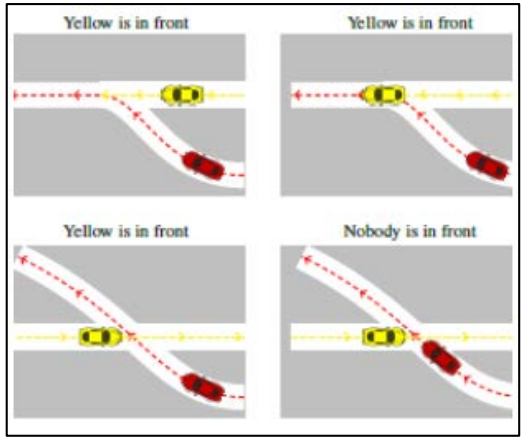
Trajectory-based



Quelle: Ackerman, Evan (2019)

- COP
- ETM

Rule-based



Quelle: Shalev-Shwartz et.al. (2017)

- Actualy not analyzed

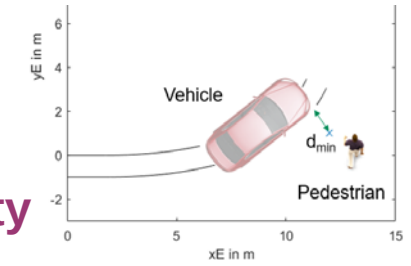
Criticality Metrics

Evasion Threat Metrics – ETM (Bosch)

Assessment of criticality considering the injury probability

- Predict motion of ego vehicle and other road user
- Estimate **min. predicted distance to other road user: d_{min}**
- If $d_{min} \leq 0$ → collision
  - Predict collision velocity
  - Predict **injury probability**

Two metrics united: **d_{min}** and **injury probability**



Input:

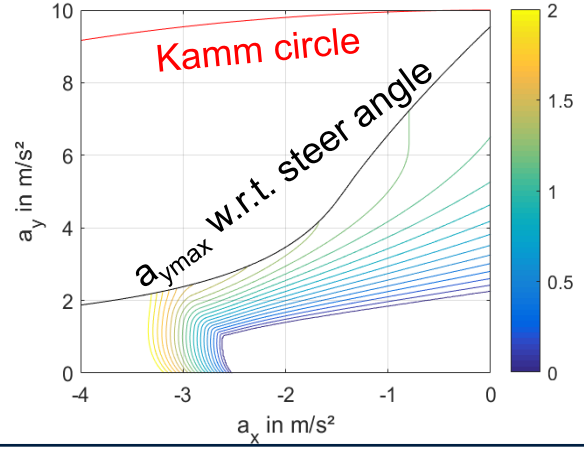
- Current distance to other road user
- Velocity
- Acceleration

Output:

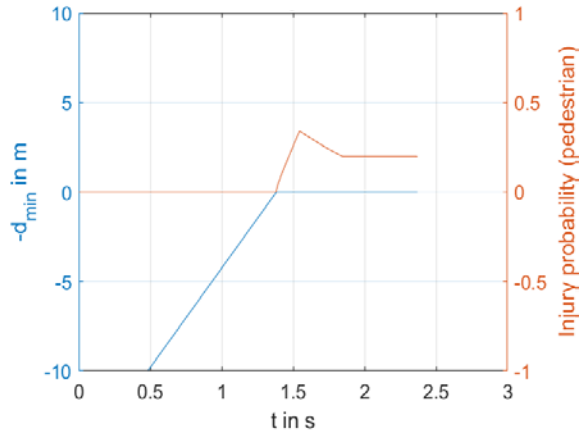
for a set of maneuvers consisting of braking and steering

- d_{min}
- Injury probability

Iso-lines d_{min} in m



Metrics over time



Benefits:

- Gather continuous criticality information and prediction including crash considerations
- Usable for offline and online purposes

Criticality Metrics

MerLin

The approach is based on potential theory. Each object is surrounded by a potential, i.e., a spatial function.

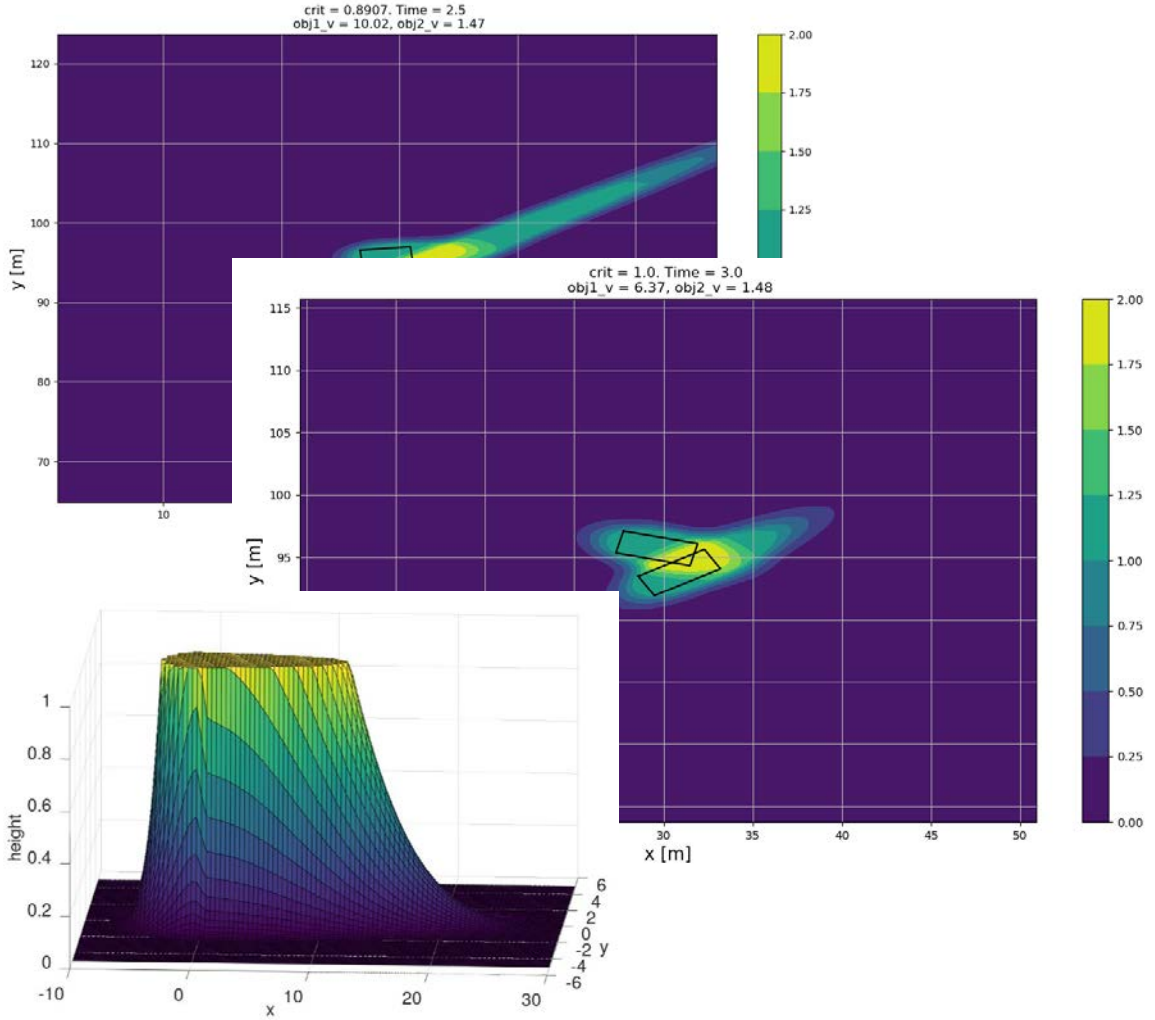
For a set of these objects the product of their potentials can be calculated.

As a criticality measure, we propose either:

- The maximum of the product or
- The spatial integral of the product

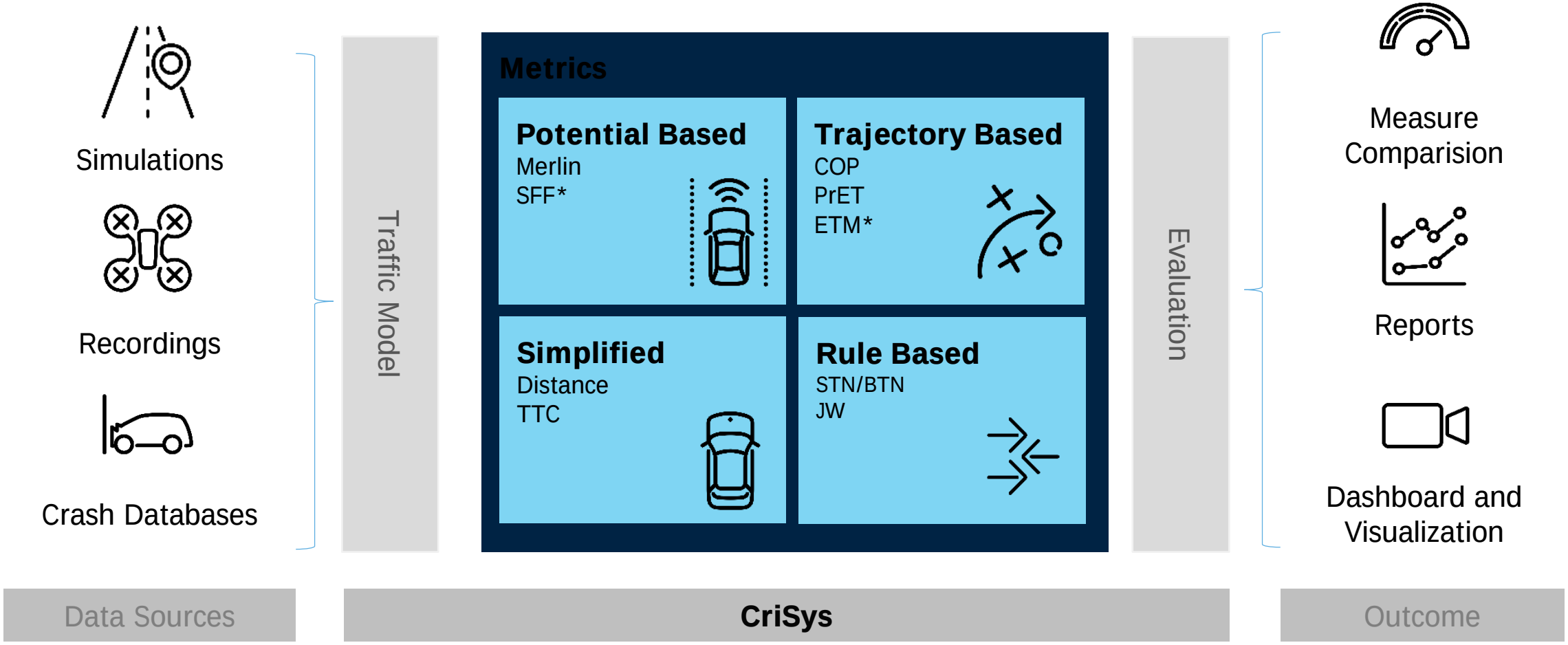
MerLin Advantages:

- Fulfills above requirements
- External influences easily addable (weather, road conditions, ...)
- Potential further development towards crash severity

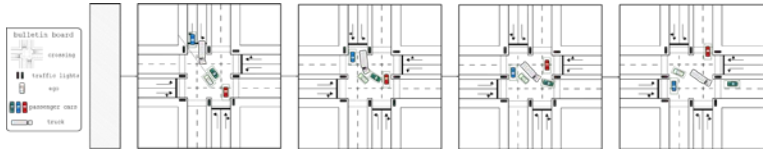


CriSys – System Overview

Application in a nutshell

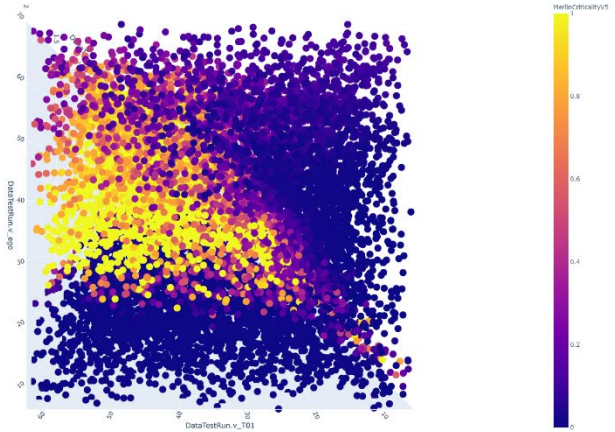


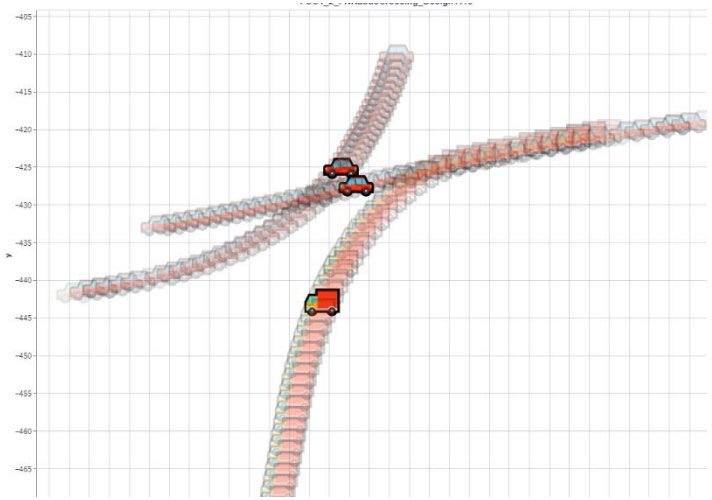
FUC1-2 – difference between Metrics



VERIFICATION VALIDATION METHODS

MerLin





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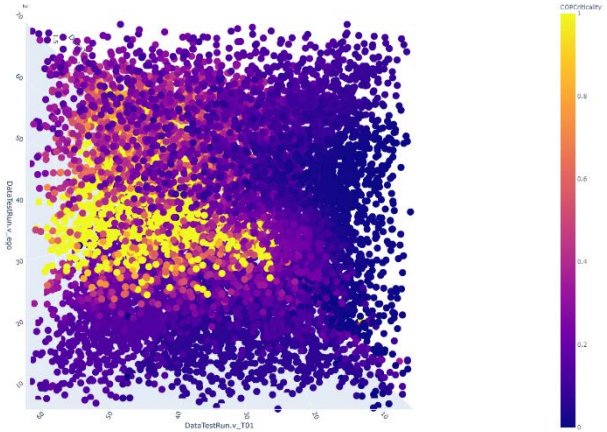
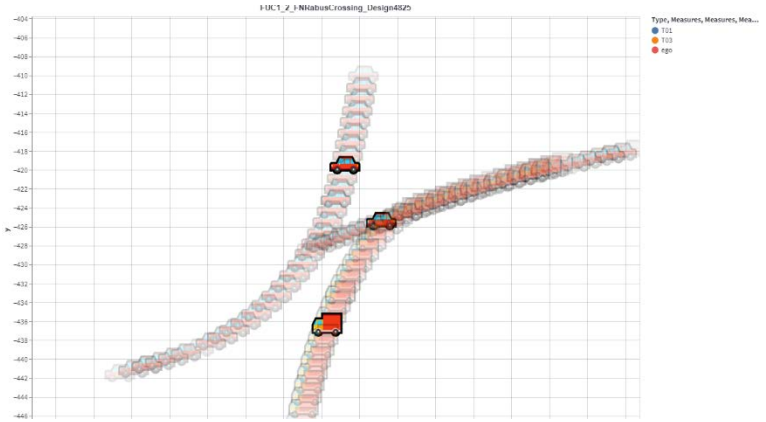
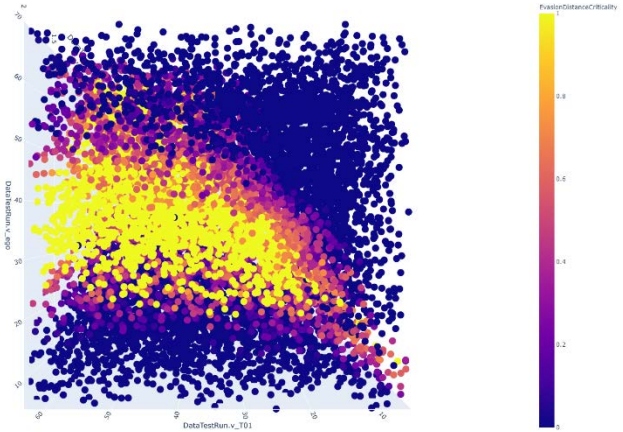
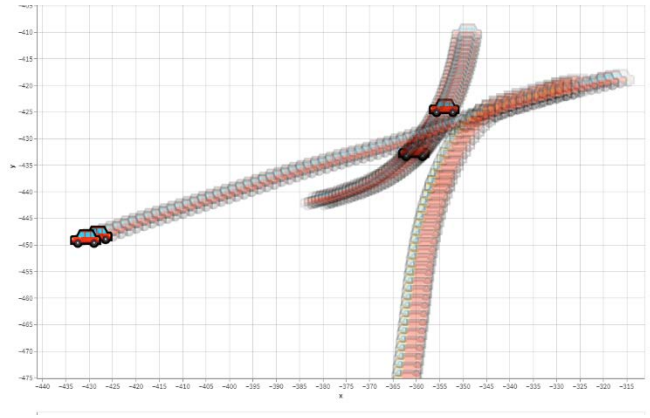


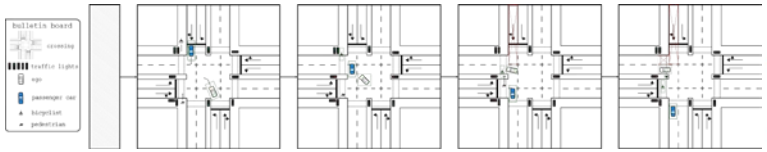


ETM





FUC1-1 – difference between Metrics



VERIFICATION VALIDATION METHODS

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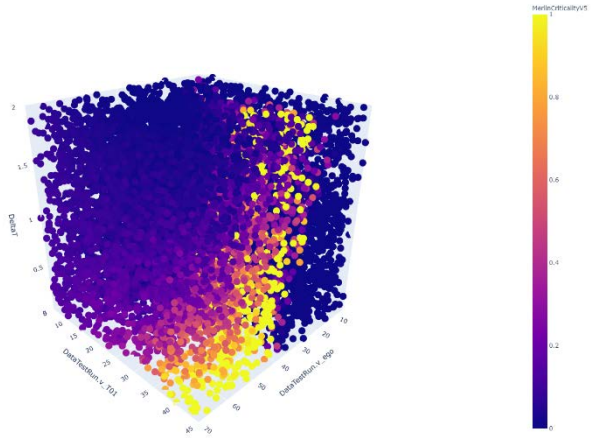

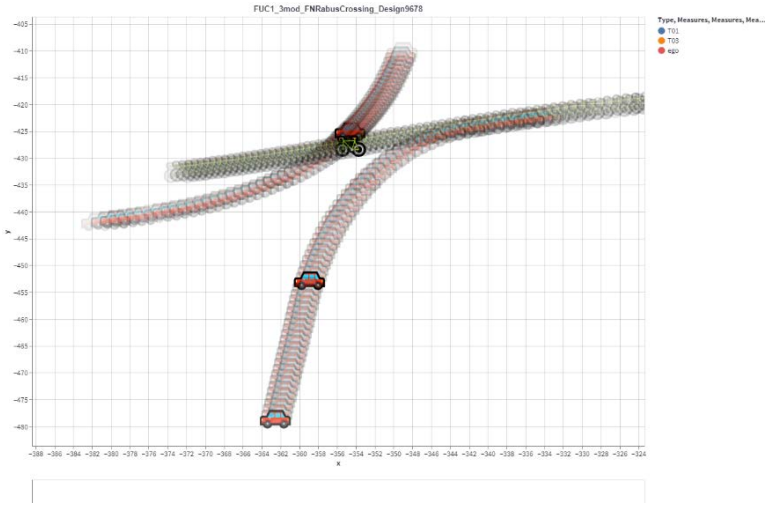

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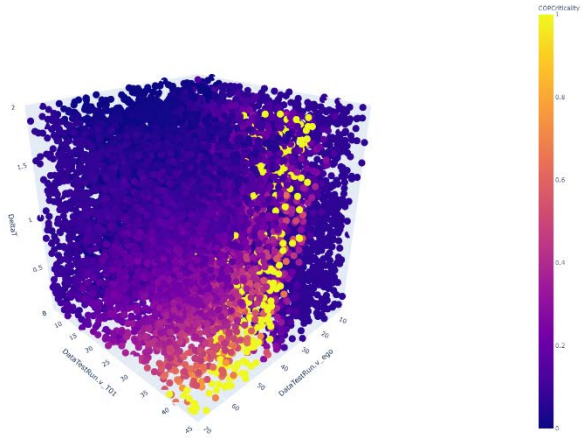
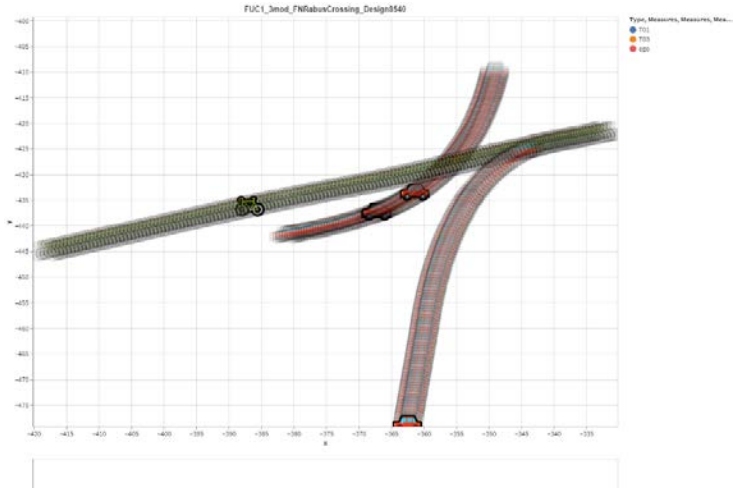
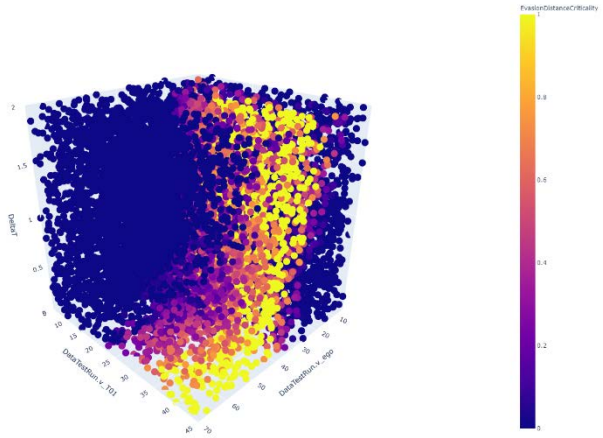
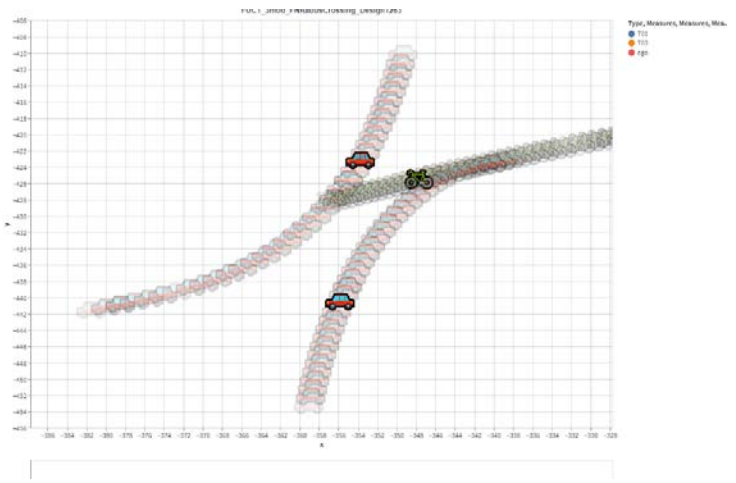


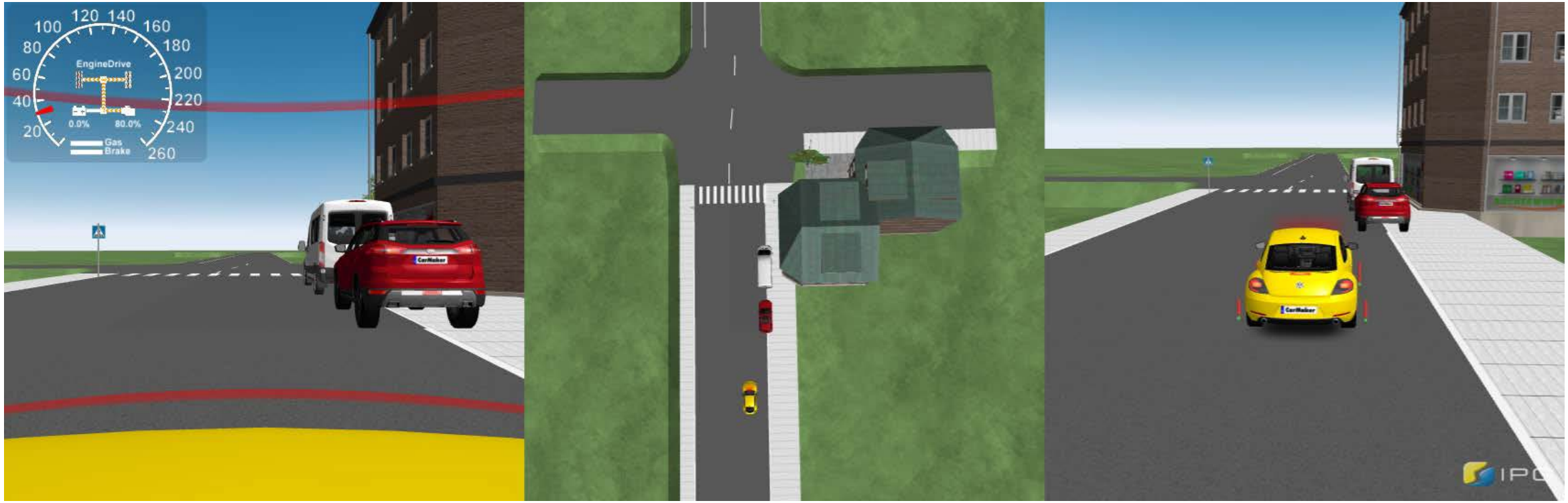


ETM

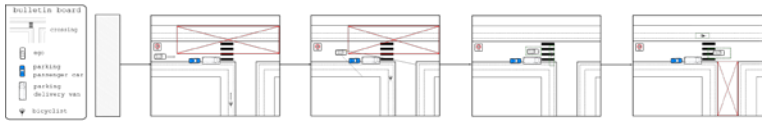




FUC2-3


120 140
100 160
80 180
60 200
40 220
20 240
260
EngineDrive
0.0%
80.0%
Gas
Brake

FUC2-3 lv – ability to detect Phenomena



VERIFICATION VALIDATION METHODS

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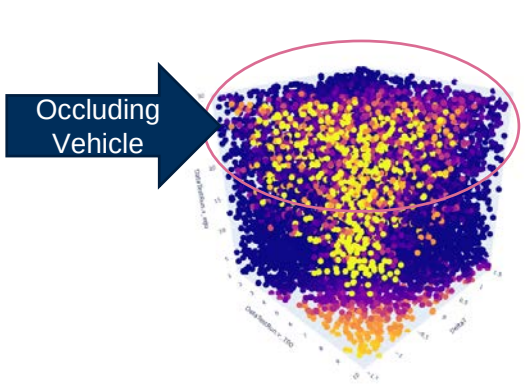

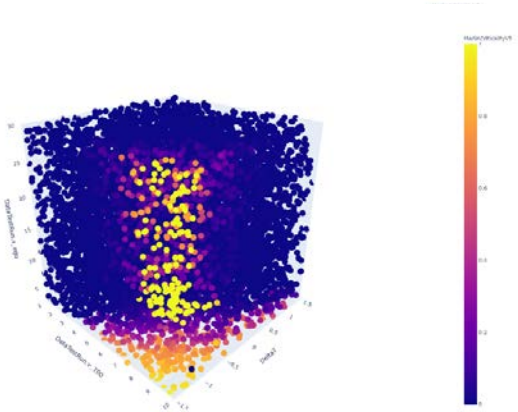

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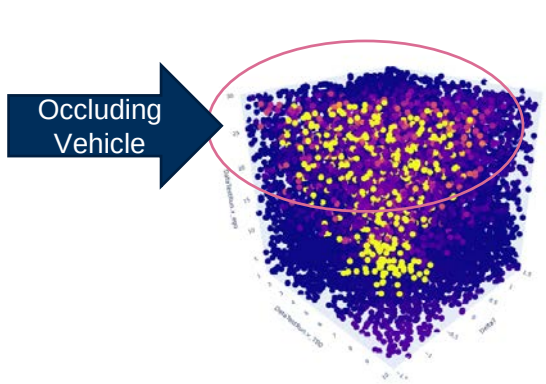

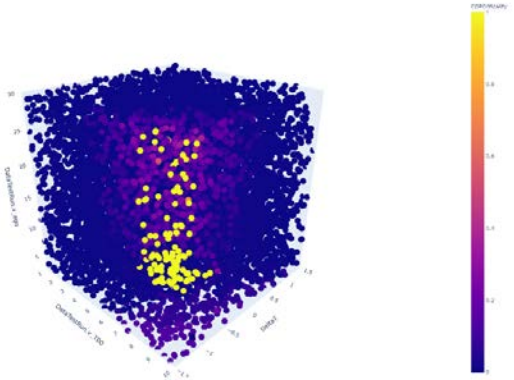

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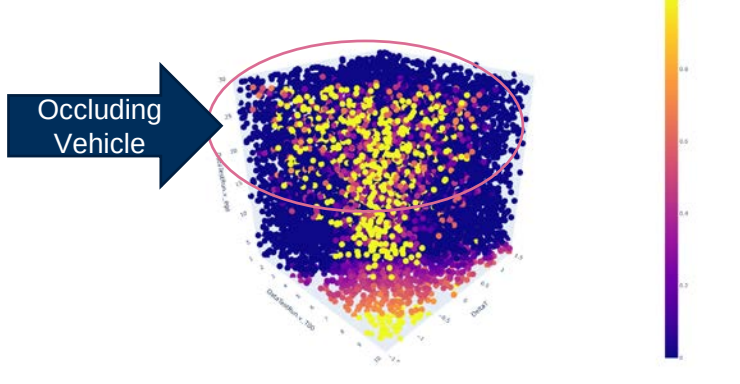
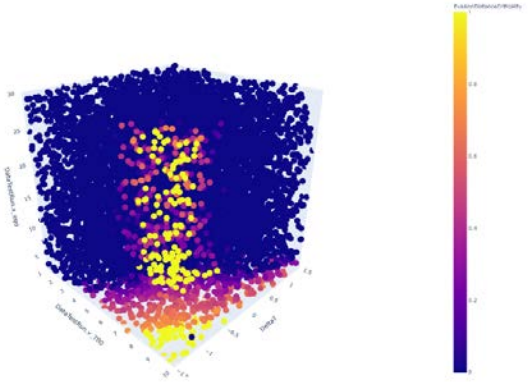
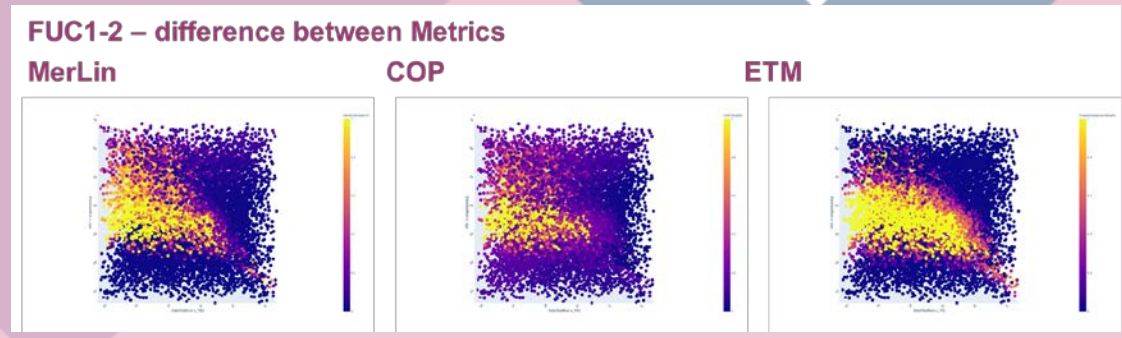
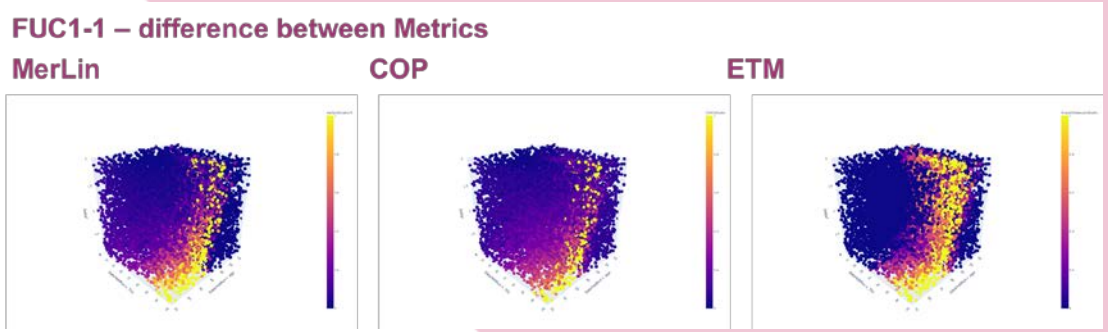




Conclusion (1)

- The critical region in a parameter space could be monitored by all the three compared metrics (the wedge in v-v-Plane (FUC1-2) respectively the furrow in the 3D-perspective (FUC1-1)
- The analyzed metrics differ in the borderline of the critical region. This could be understood as a different interpretation of criticality for near crashes.
  - Where the ETM has a clear, but huge high critical region, with a sharp edge to the uncritical regions.
  - The COP and the MerLin have much more noise in their borderline and smaller high critical regions.

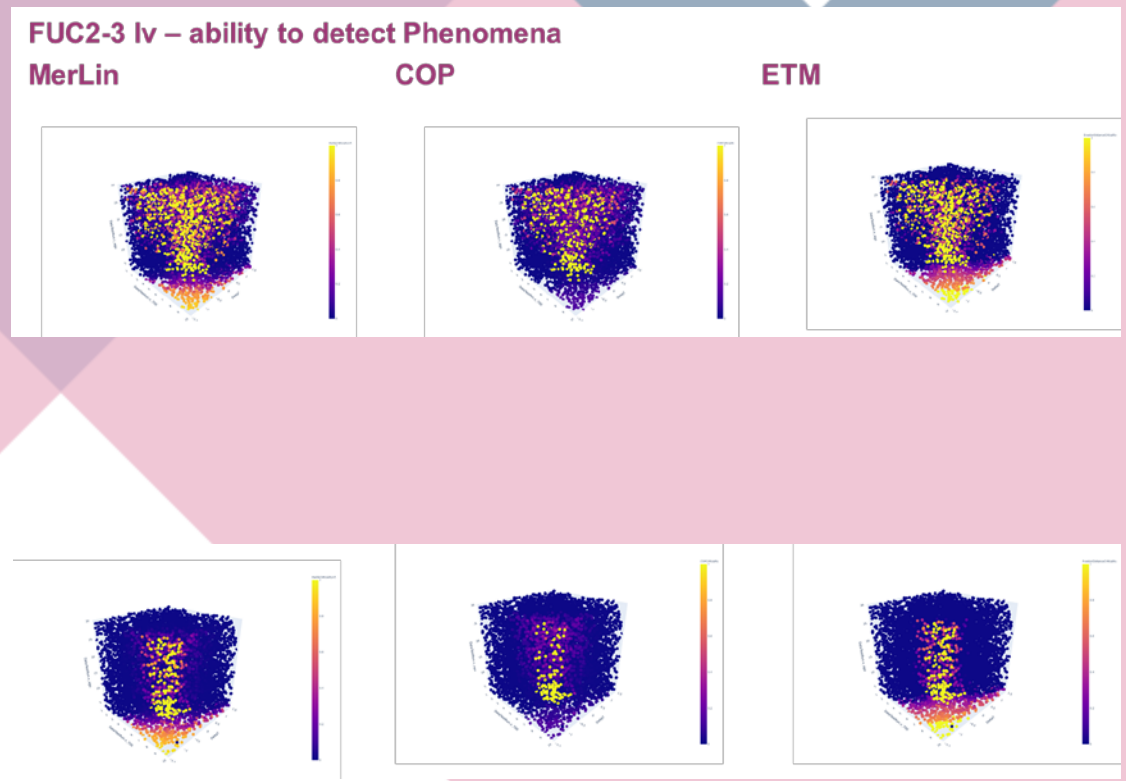




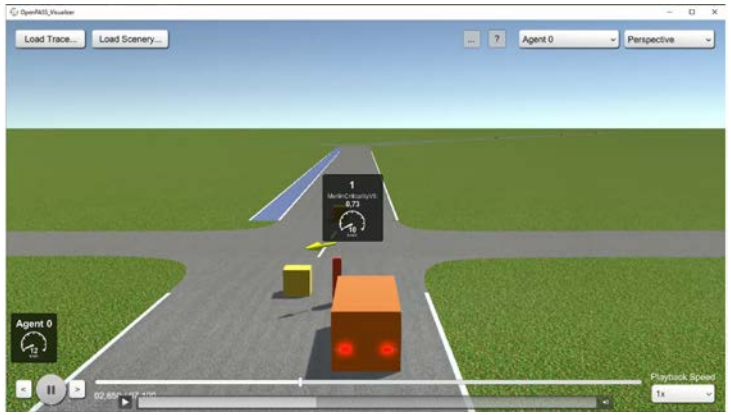
Conclusion (2)

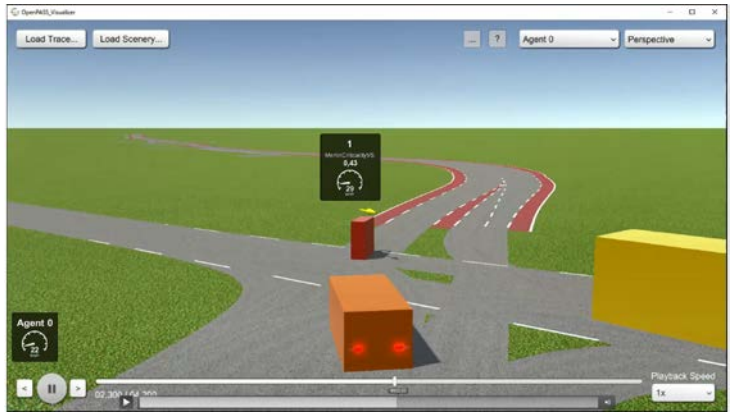
- All three analyzed measures were able, to show the criticality increasing influence of a prior introduced criticality phenomenon.
- Where all measures shown just a small high critical region for FUC2-3 without occlusion (that came from a crash of the pedestrian in the side of the car)
- The criticality region gets much bigger, if parked cars on the roadside occlude the crossing pedestrian.

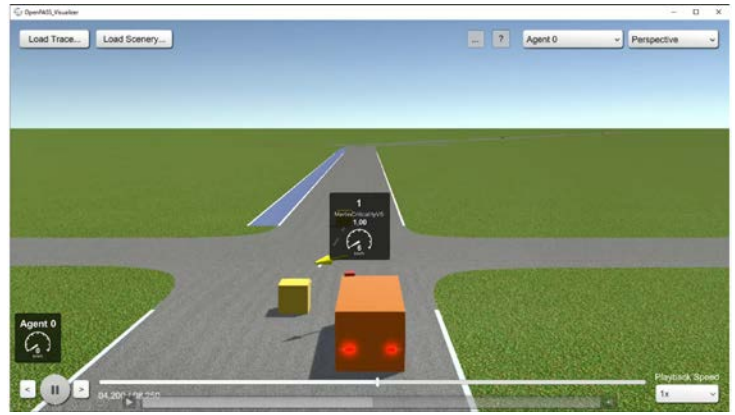
- The ongoing analysis of criticality metrics and suggestions, which one should be chosen in which purpose or problem description, will be in scope for deliverable to the end of Q2/22, that will be published as a VVM Result as well

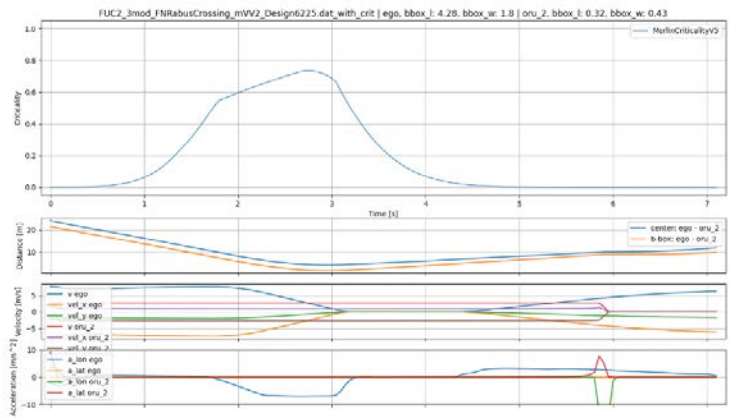


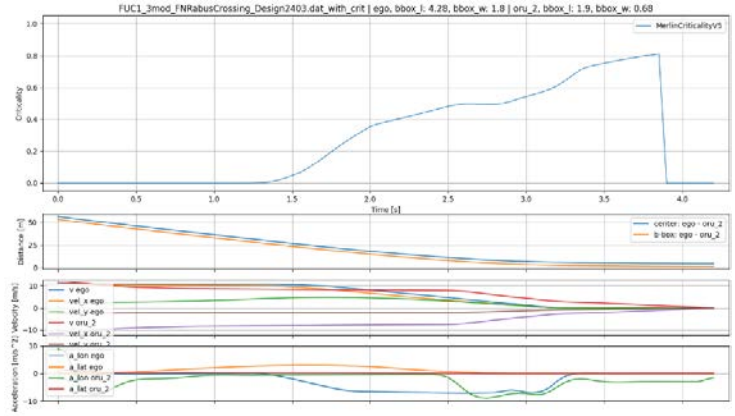
Summary: Criticality on introduced Examples

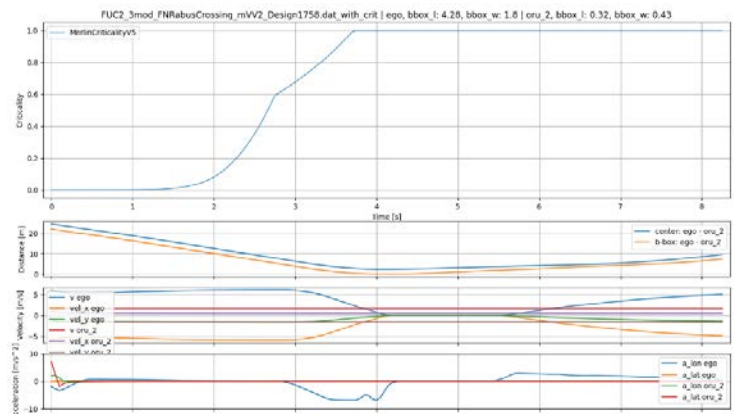












Summary

- We have introduced criticality metrics with
  - their purpose / their neccessarity
  - Clustered in groups by the characteristic they are calculated
- Introduced two of the metrics in detail (see linked Posters)
  - ETM
  - MerLin
- Introduced CriSys (see linked Poster too)

- Showed the criticality result for a multidimensional variated parameter space in
  - FUC1-1
  - FUC1-2
  - FUC2-3
- In this multidimensional criticality results, we have seen, that each measure gives that likely results, that we were able to understand and detect criticality phenomena

- The criticality results in detail are differing in regions a lot, which gives us a hint, it matters a lot, which measure you chose for your detailed evaluation

VERIFICATION
VALIDATION
METHODS

Thank you!

Martin Bollmann, ZF

PROJECT of the PEGASUS FAMILY

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

Criticality Metrics – Introduction

- To validate functions, used in an autonomous Vehicle, one important requirement for these functions is safety driven. Where the differentiation in crash and no-crash is not sufficient, it needs a measure, to get a more quantified result, describing the behavior of participating traffic objects and their trajectories. Criticality should represent the measure, to get the assessment, how unsafe functions of an autonomous vehicle had solved tested Scenarios.

- criticality should be able, to detect types of Scenarios, that are hazardous in general. By analyzing crash databases, we will get hazardous segments and regions, by searching for the number of crashes with or without harm per segment length or per time period. But all the near crashes, that could be challenging to a driving intelligence (that could be a human driver or an autonomous driving function) won't be taken into account. To be able, to do a criticality analysis like shown in the presentation before, a more differentiated measure would be necessary.

- Criticality should provide a measure, how challenging a single scenario was for a determined driving intelligence. For a first purpose, the measure would enable the development of autonomous driving functions, challenging their functions with a spread of challenging scenarios or, in combination with the previous point, compare the handling of the driving function under development (DFuD) with the initial criticality, identified for specified criticality phenomenon (CP) or segment. In a later purpose, such a measure would give opportunity, to standardize the evaluation of learner driver.

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