PEGASUS FAMILY

VERIFICATION VALIDATION METHODS

EUCAD 2020

Next development step for safety assessment of L4/5 vehicles within PEGASUS-Family

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VV-METHODS PEGASUS Family – Overview

- **Agenda**
  - Overview - VV-Methods and PEGASUS Family
  - Goals and Project Structure
  - Safety Argumentation and Integration of presented Approaches
  - Criticality analysis – Core Element at the social / traffic layer of the Safety Argumentation

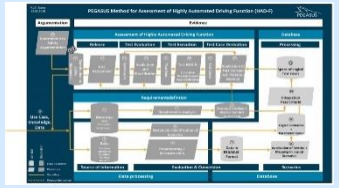
VV-METHODS PEGASUS Family – Publicly-funded Projects in Germany

- The **PEGASUS Family** focuses on development / testing methods and tools for AD systems on highways and in urban environments

PEGASUS

https://www.pegasusprojekt.de/en/home

- Scope: **Basic methodological framework**
- Use-Case: L3/4 on highways
- Partners: 17



PEGASUS FAMILY

VV-Methods

- Scope: **Methods, toolchains, specifications for technical assurance**
- Use-Case: L4/5 in urban environments
- Partners: 23 partners
- Timeline: 07/2019 – 06/2023

SET Level 4to5

- Scope: **Simulation platform, toolchains, definitions for simulation-based testing**
- Use-Case: L4/5 in urban environments
- Partners: 20 partners
- Timeline: 03/2019 – 08/2022

+ future projects of the PEGASUS Family

2016 2019 **Time**

VV-METHODS – Project Setup

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- **Funded by** Ministry of Economics and Technology (BMWi)
- **Start, Runtime** 07/2019, 4 years
- **Budget total** 47M€
- **Partners**

VV-METHODS – Main Goals

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Systematic control of test space

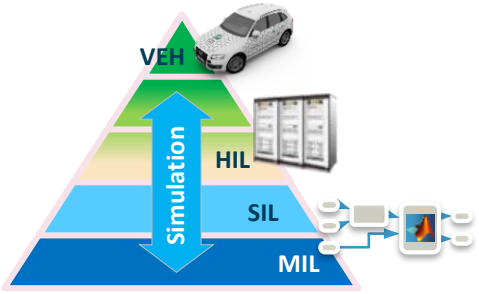
- Methods to optimize (and reduce) the test parameter space to a manageable minimum

Industrial defined interfaces for systems and components

- Definition of incremental tests of subsystems and overall systems

Significant shift from real-world testing to simulation

- Methods for seamless testing across all test instances



VV-METHODS – Structure & Goals

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∞ → n

Goal I – Systematic control of test cases

- Understand relevant phenomena & traffic behaviors
- Involve traffic law perspective
- Approach a **nominal behavior**
- Identify **enveloping tests**

Goal II – Industrial interfaces

- Common methods for systematic breakdown of technical contracts, requirements & tests
- Agreed rules for **component exchange** between OEM and supplier
- Efficient **variant-release**, preservation of test-results of unmodified components
- Integration of **systems of different manufacturers**.

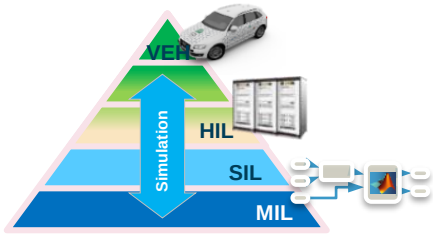
Criticality analysis

Safety assessment & safety concepts

Rules for system and test requirements

Test infrastructure

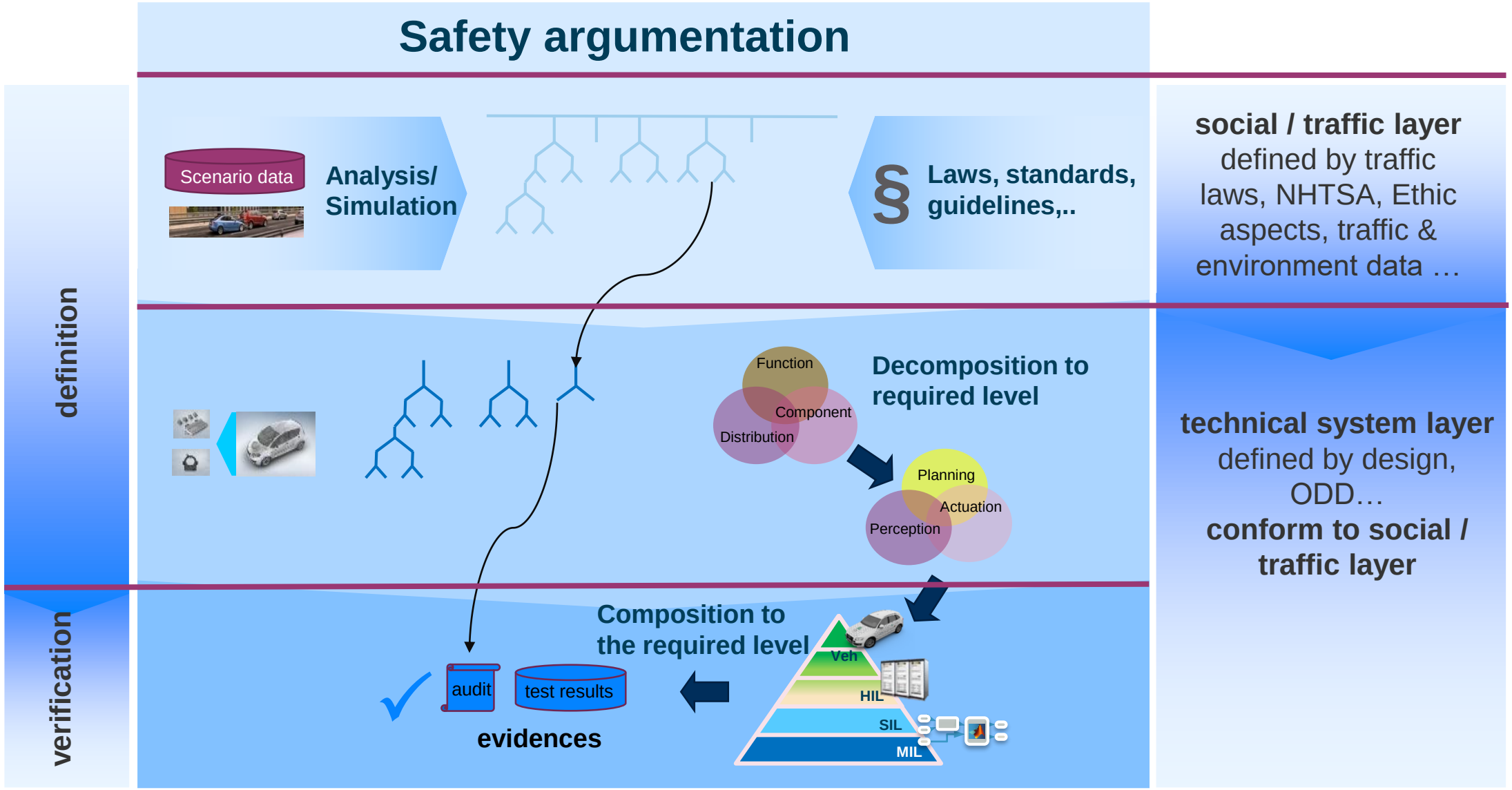
- Simulation (Level 4 to 5)
- HW in the loop
- Proving ground
- Field test



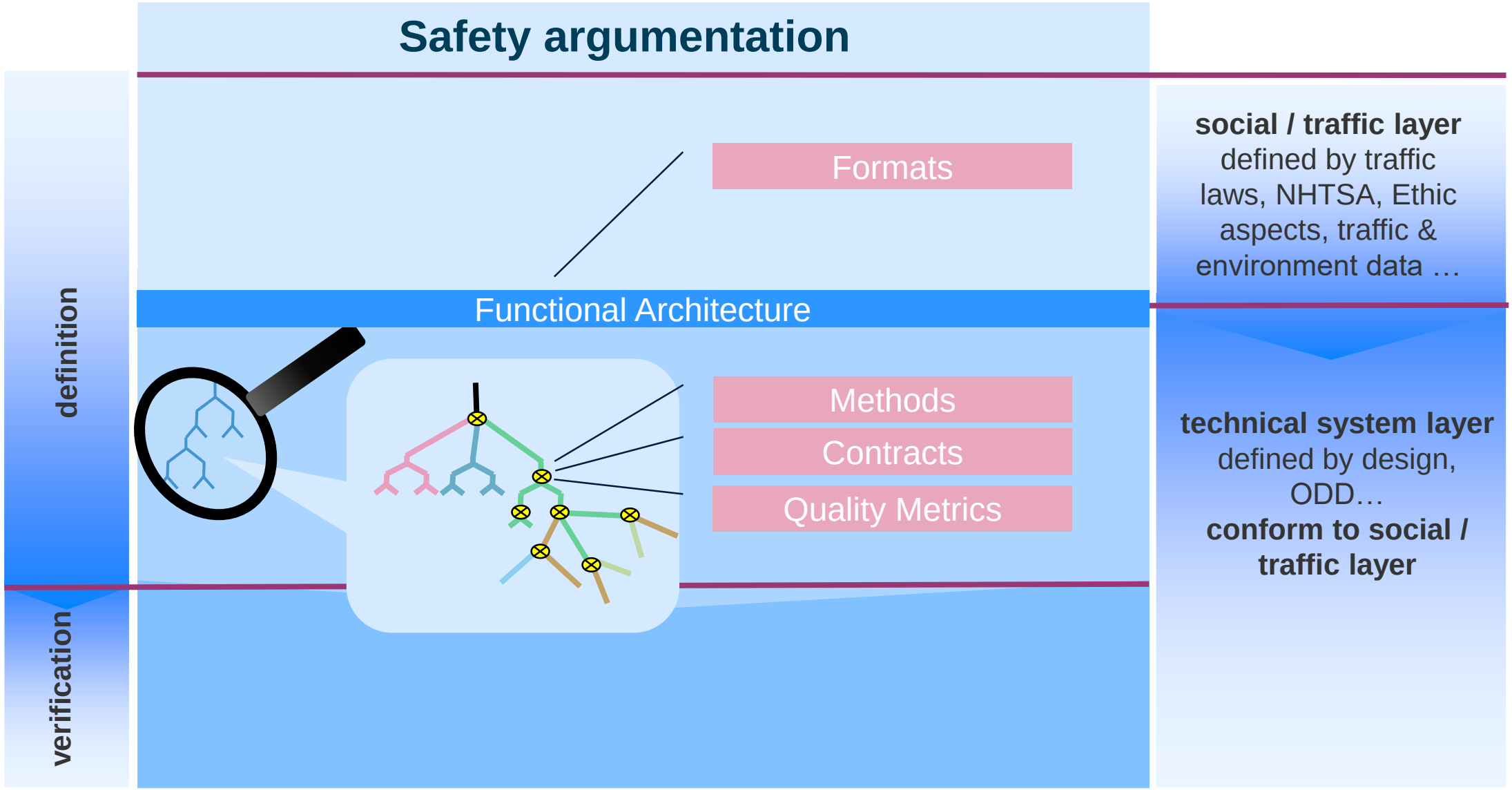
Goal III – shift to simulation

- Seamless use of virtual and real artefacts
- Efficient integration of simulation into the test-infrastructure with focus on
- **Seamless testing** across functional test infrastructures
- Efficient **distribution of test efforts** (Sim-Real).

VV-METHODS – Safety Argumentation



VV-METHODS – Safety Argumentation



VV-METHODS – Safety Argumentation

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Why safety argumentation?

It is a systematic approach to the requirements flow. It enables and supports the project goals

- structuring the inputs of open world traffic behaviour and law perspective.
- enable the systematic breakdown of contracts.
- define quality-requirements to simulation.

What is needed?

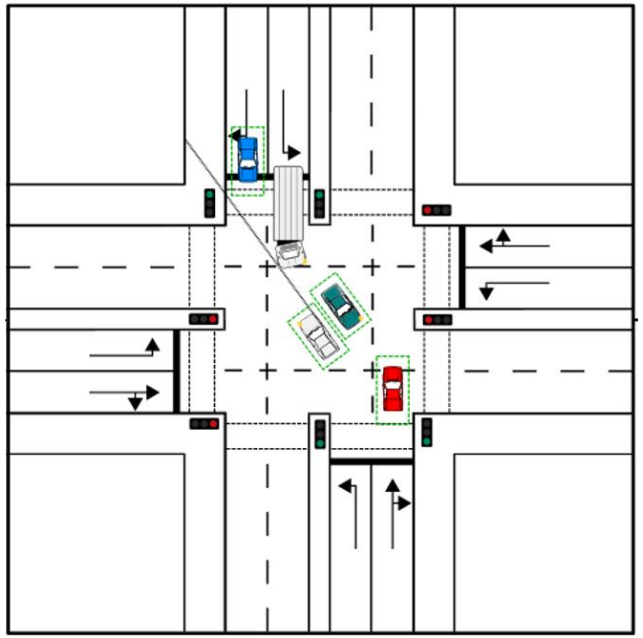
- **Contracts** based on **assumptions and guarantees** define shape the safety argumentation – thus supporting **industrial interfaces** (based on open standards)
- **Methods** for definition and brake-down of contracts.
- **Quality criteria and metrics** to define social and technical contracts
  e.g. the **Positive Risk Balance** could be considered a quality criteria on a high level of the social layer.
- **Formats** e.g. the functional architecture as a structuring method for knowledge.

VV-METHODS – Safety Argumentation starting point

Develop a **deep understanding** for the structure of the open context with respect to the emergence of criticality and its conditions. Two approaches are followed:

Criticality Analysis (CCA)

- Identification and **modelling** of **relevant influencing factors** associated with criticality
- Improved understanding of **criticality phenomena** by analysis of causal relations
- Abstraction leads to classification of scenarios and **condensation of test space**



Phenomenon Signal Model (PSM)

- Identification and modelling information flow between actors and environment
- Improved understanding of conditions of acting and possible actions
- Considering law and society leads to **description of target behavior**

Criticality Analysis in a Nutshell

Criticality Analysis

$$\{\infty \mapsto n\}$$

- **Criticality Phenomena**
- **Causal Relations**
- **Abstract Scenario Catalog**

- How can we find all the **relevant artifacts** for the **safe operation** of fully **automated vehicles** within an infinite-dimensional space?

- Extract associations → phenomena
- Find plausible explanations → causalilty
- Use abstraction → catalogization

- **Assumptions**
  - Since humans are able to drive safely, there are finitely many criticality phenomena an human can transfer learned pattern to new situations.
  - The relevant criticality phenomena leave traces in a continously growing data basis.

Criticality Analysis in a Nutshell

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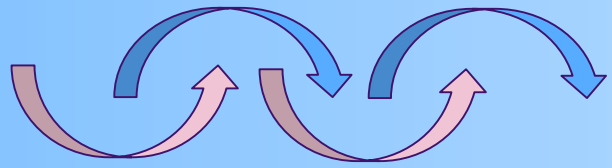
Initial Criticality Phenomenon
Expert-knowledge, data-analysis, initial metrics, empirical relevance e.g. accident analysis, ontology,…

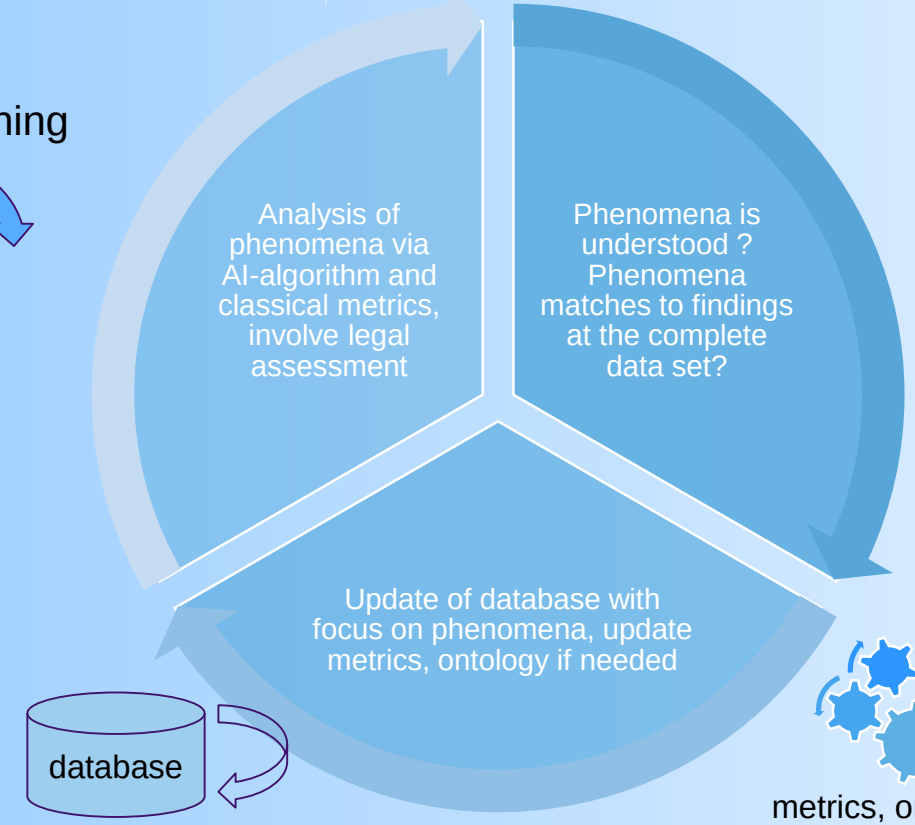
understood phenomena:
Causal Relation
(Plausible Causality) new metrics, data,…

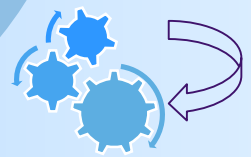
Next phenomena,
interexchange of phenomena

supervised machine learning



empirical analysis and metrics

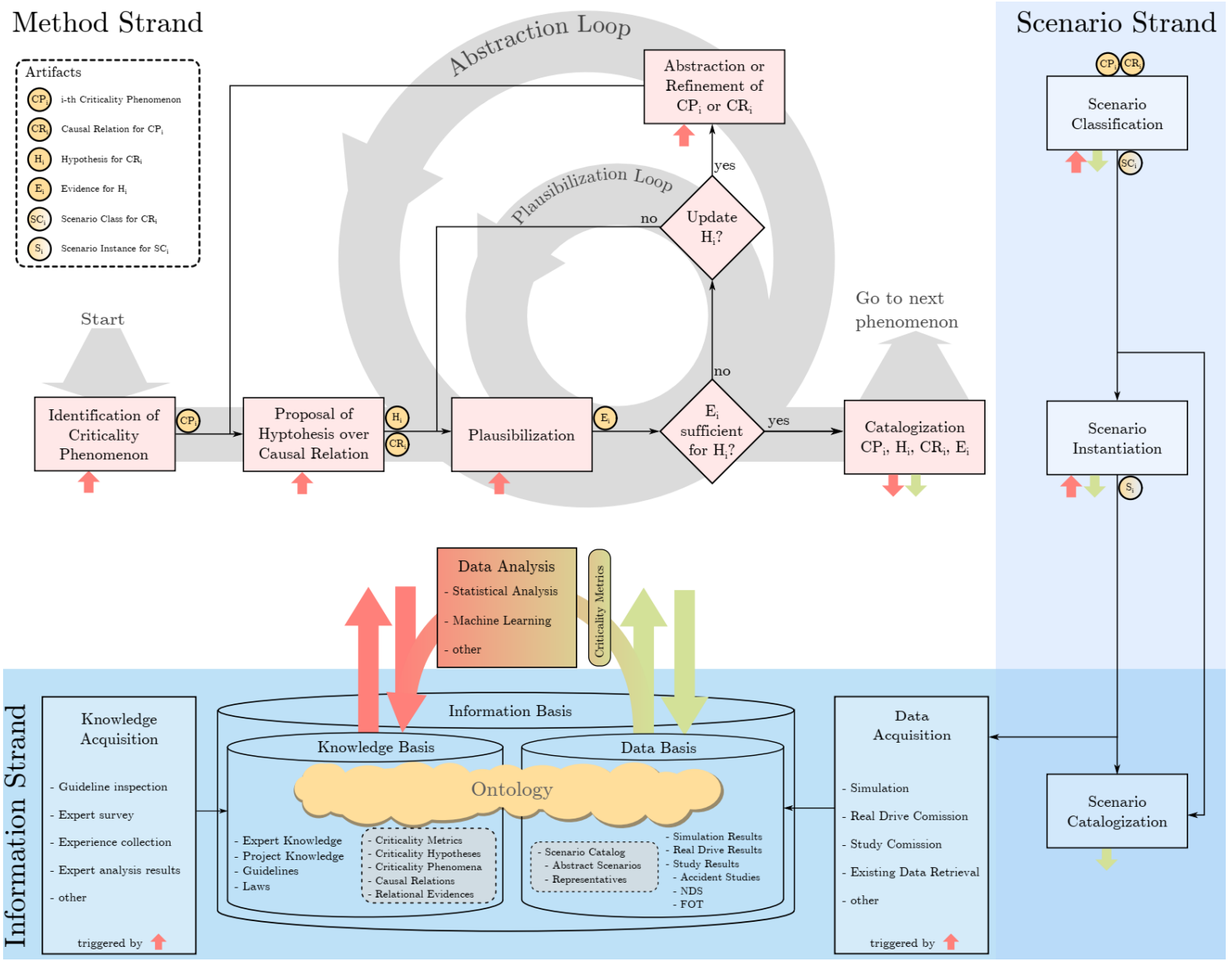




metrics, ontology, simulation

Convergence: all relevant phenomena in data basis explained?

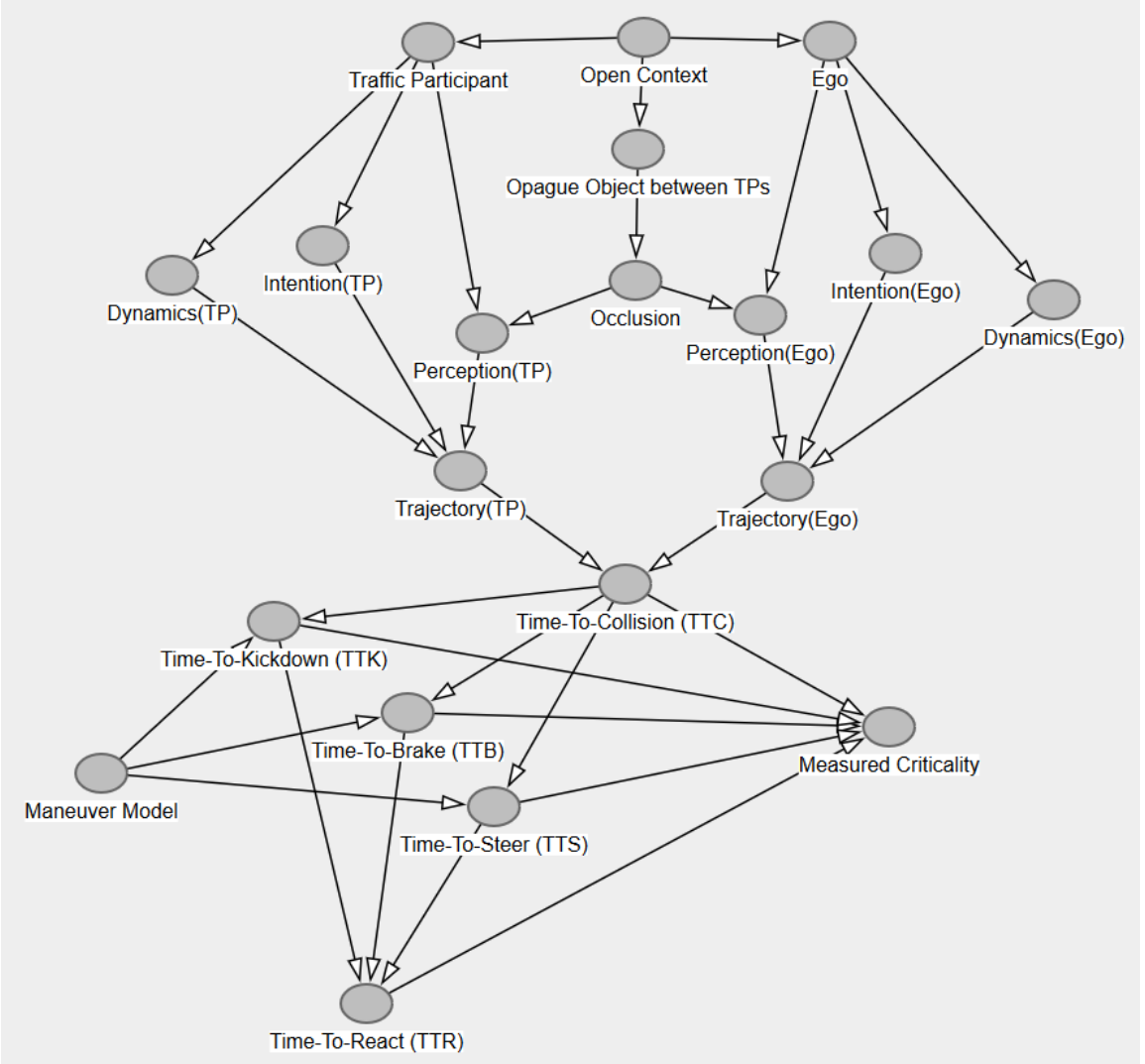
Criticality Analysis – Overview of Methodology



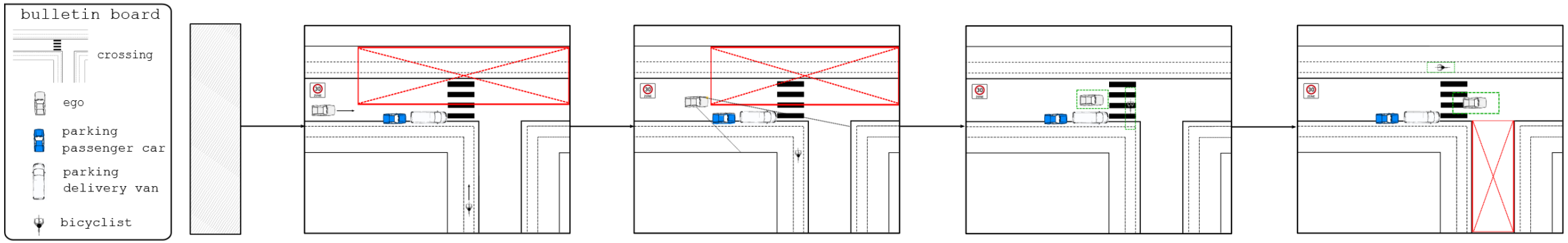
- **Method Strand** – Identification of criticality phenomena, proposal of causal relations, evidence for plausibility of hypotheses
- **Information Strand** – Knowledge and data management for the criticality analysis, Ontologies
- **Scenario Strand** – Scenarios as the “substrate” of the criticality analysis, a means for structuring as well as “test” description

Example: the causal relation ‚Occlusion‘

- Use directed acyclic graphs (compatible with tools s.a. Matlab, R etc…) to represent **hypotheses about** the underlying **causalities**
- Incorporate **criticality metrics** in DAGs as to make criticality measurable, e.g. using Time-To-Collion
- Collect evidences for the causal relation ‚Occlusion‘ and use **abstraction/refinement** when necessary



Example: abstract scenario ‚Occluded Bicyclist at T-intersection‘

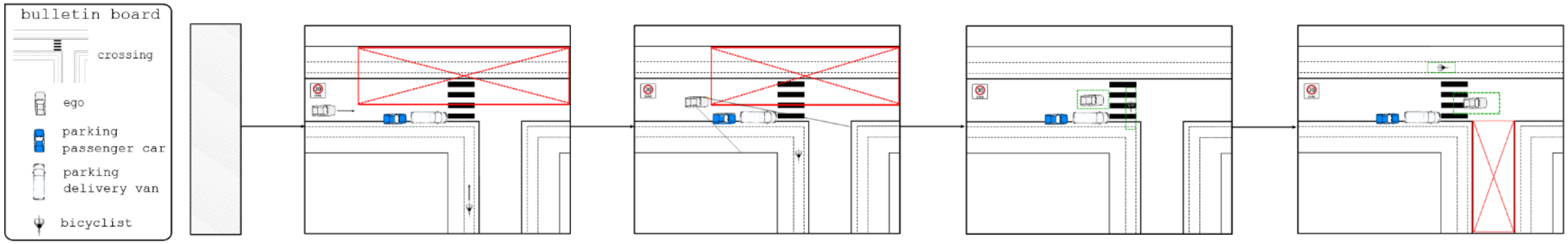


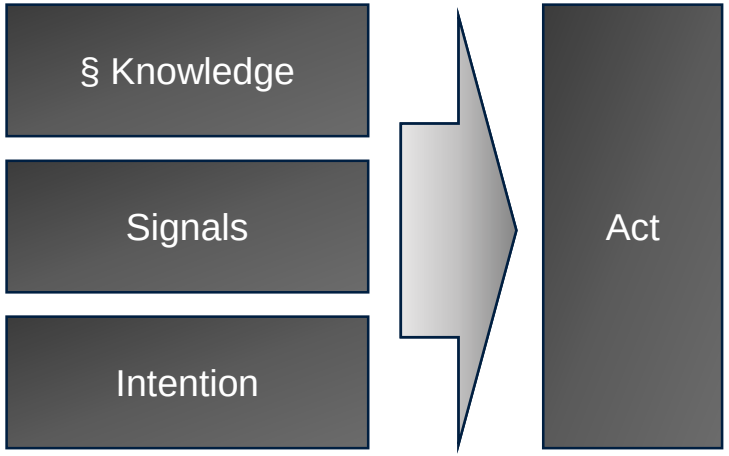
- Evaluate criticality metrics on scenarios (real drive or simulation) with and without occlusion in order to validate the causal relation ‚Occlusion‘
  → Set up experiments using framework of statistical hypothesis testing

- Build up catalogue of abstract scenarios and mechanisms for instantiation to more concrete scenarios

- Derive suitable abstract scenario classes with respect to phenomena and causal relation
  → Use zone graphs for classification

Phenomenon-Signal-Model

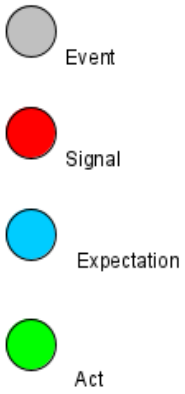


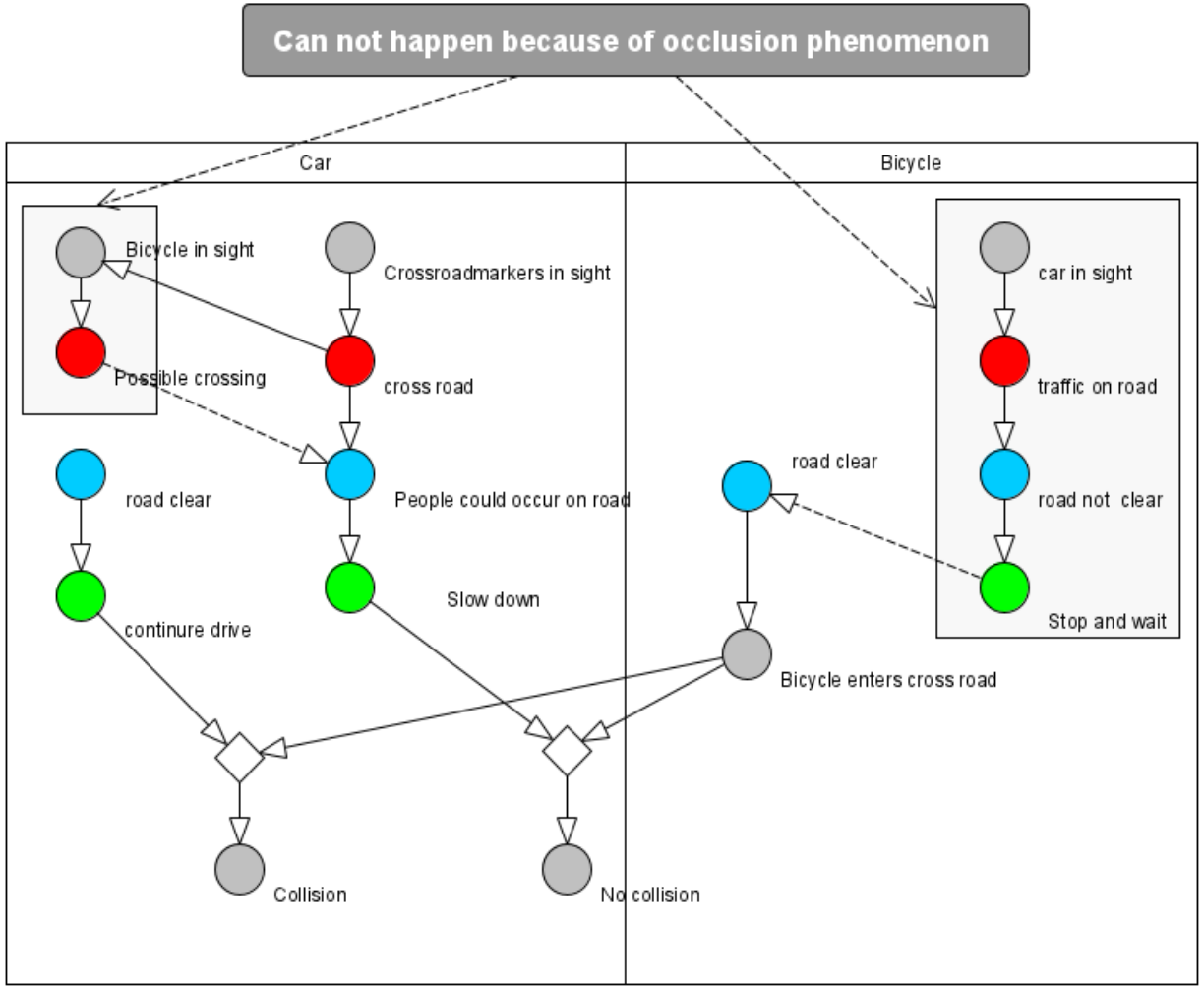


- The **Phenomenon-Signal-Model** analyzes causal relations at the level of flow of information
- **Basic question**:
  - Which events happen, what is needed to becoming meaning (=Signal) and how change this knowledge and intention of participants?
  - What is the (informational) cause of an act?
- **Intended use**: formal analysis of scenarios for the use in simulation, in order to identify target behaviors
- **Result**: Information based causal relations

Example

- Some part of the graph could be impacted by occlusion phenomenons
- At every step it could be analyzed what traffic rules would require
- Formalization of such graphs is onging work





VV-METHODS – Summary

- **VV-Methods and SETLevel4to5 are successors of PEGASUS** and build on its results.
  Main goal: Enabling and industrialization of AD system.
- **Safety Argumentation is main element and enabler**
  - Systematical flow of requirements – can be decomposed into 3 main layers.
  - Quality criteria and metrics are building the basis to define contracts within the safety argumentation.
- **Criticality Analysis** – Core element at the social / traffic layer of the safety argumentation
  - **Managing dilemma of completeness and condensation of test space**

- **Next steps**
  - Publification of Criticality Analysis in 2020
  - Further development of Phenomenon Signal Model, Ontology, overall method and safety metrics concept

Backup