VERIFICATION
VALIDATION
METHODS

SET Level Final Event
Munich 11.-12. October 2022

Application of SET Level results in the VVMethods Project

Roland Galbas, Robert Bosch GmbH
Christian Neurohr, German Aerospace Center (DLR) e.V.
Philipp Rosenberger, FZD
Gerhard Schunk, Valeo

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

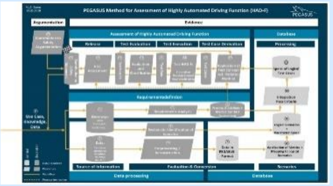
History - PEGASUS Family

- 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: L3/4/5 in urban environments
- Partners: 23 partners
- Timeline: 07/2019 – 06/2023

SET Level

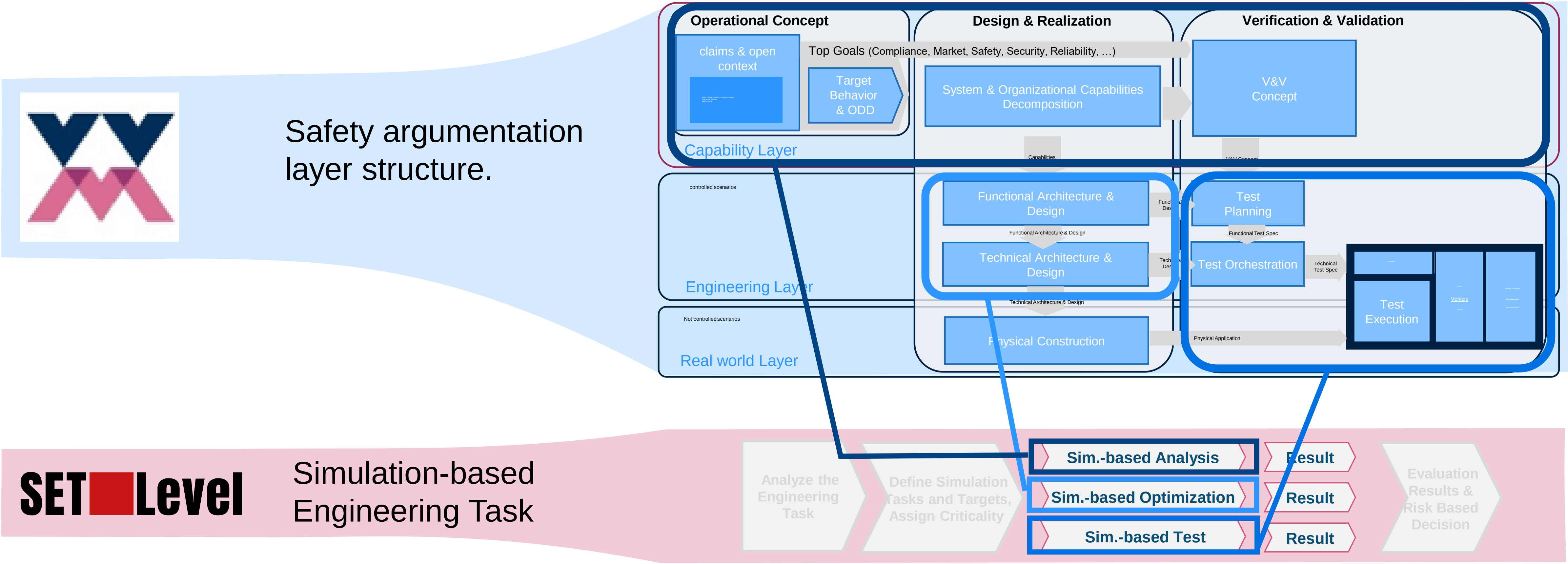
- Scope: **Simulation platform, toolchains, definitions for simulation-based testing**
- Use-Case: L3/4/5 in urban environments
- Partners: 20 partners
- Timeline: 03/2019 – 10/2022

\+ future projects of the PEGASUS Family

2016 — 2019 — **Time**

SET Level - Processes Link to VVM

(1) Application use case: Simulation-based Engineering Task

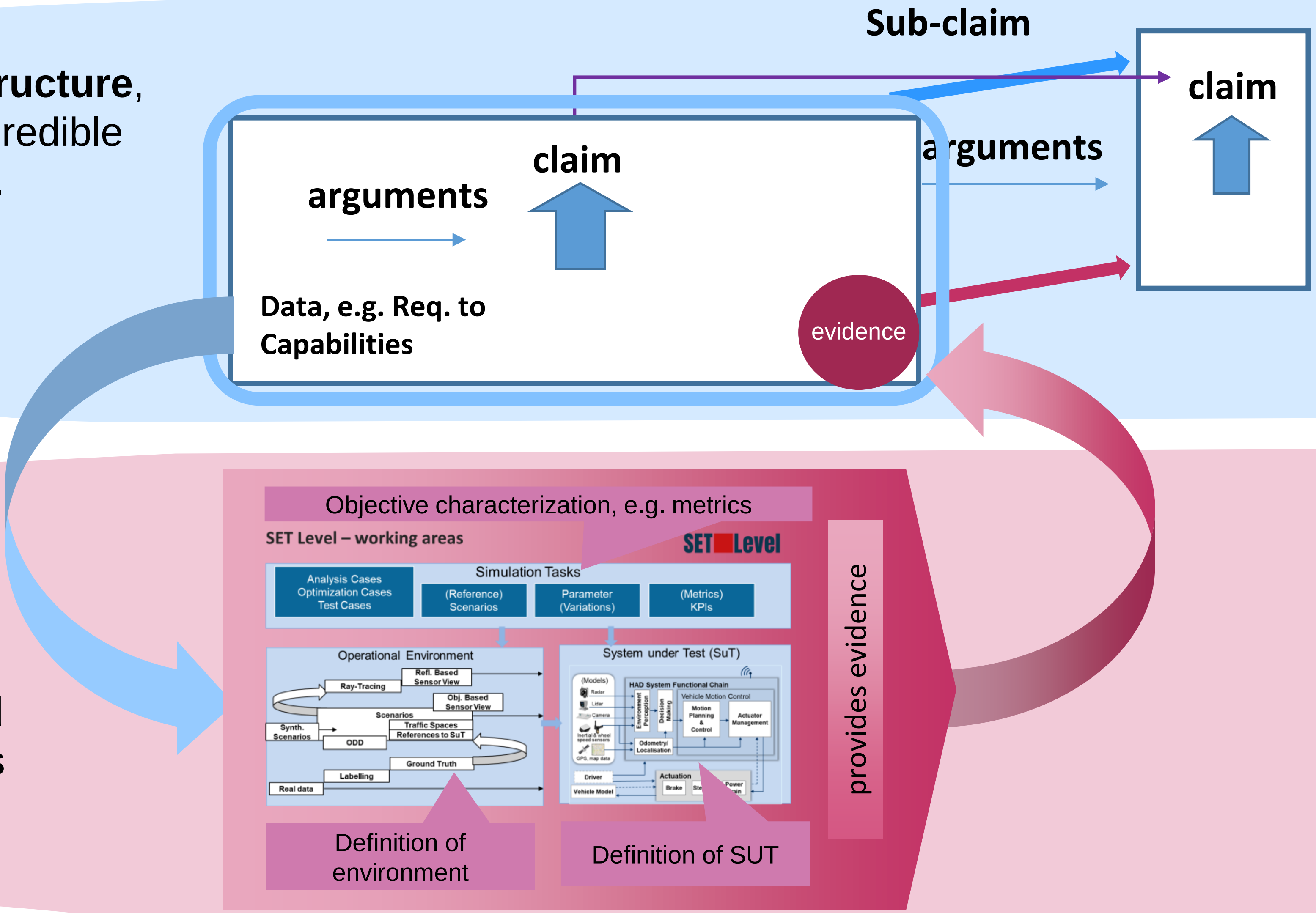


▶ Simulation Engineering Task can be directly assigned to the VVM safety argumentation layer structure.

SET Level - Processes Link to VVM

(2) Process Link: Credible Simulation / Modeling Process

→ Based on VVM **argumentation structure**, the **simulation task / goal** of the Credible Simulation Process can be defined.

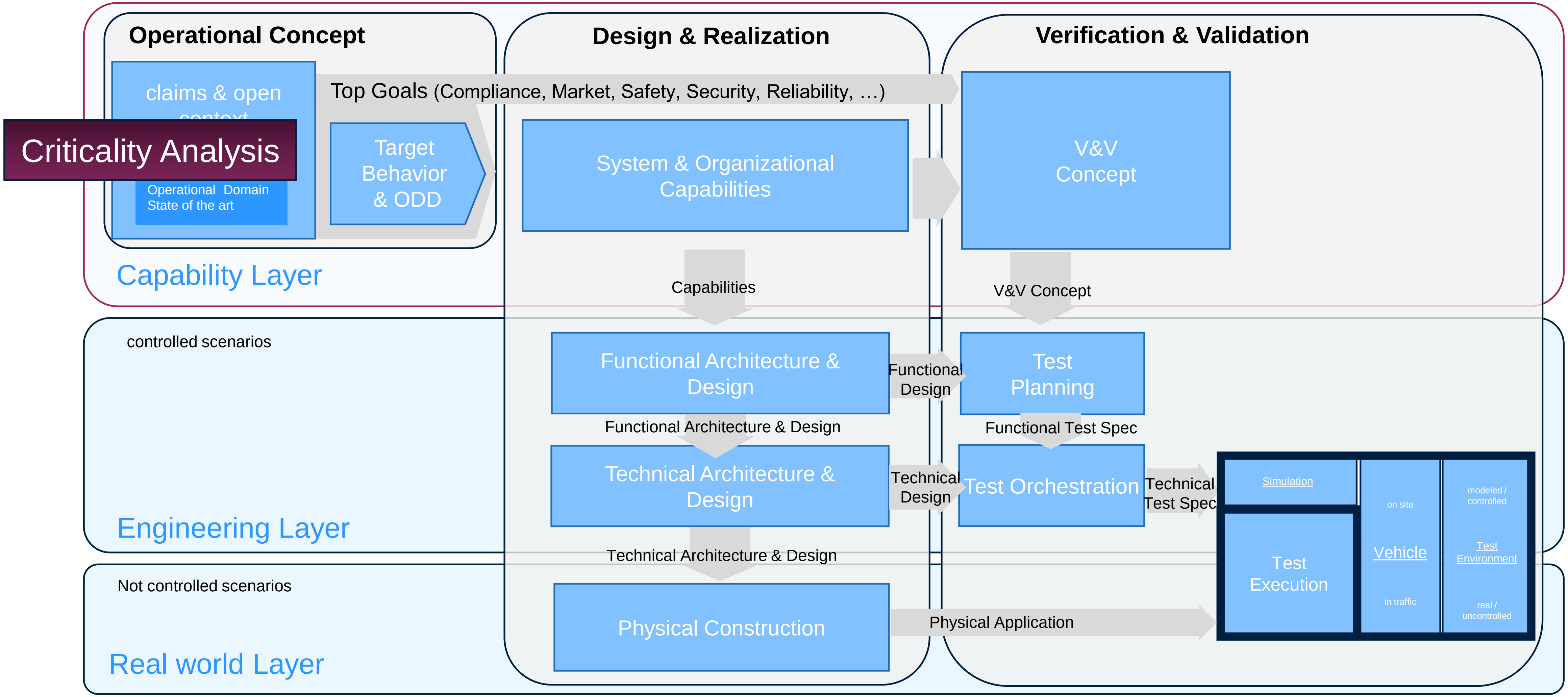


SET Level

→ Simulation objectives, environment and system under test can be derived by **claims**, **arguments** and **system data** as, thus requirements to models can also be derived.

VVM Assurance Framework

- Within the assurance framework, the criticality analysis contributes to structuring the operational domain.



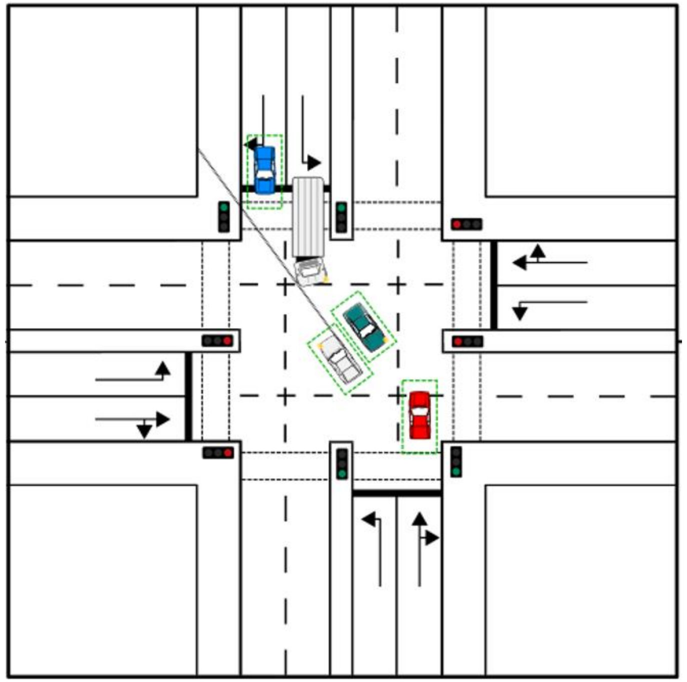
Criticality Analysis in VVM

VERIFICATION
VALIDATION
METHODS

- **Criticality** (of a traffic situation) is the combined risk of the involved actors when the situation is continued

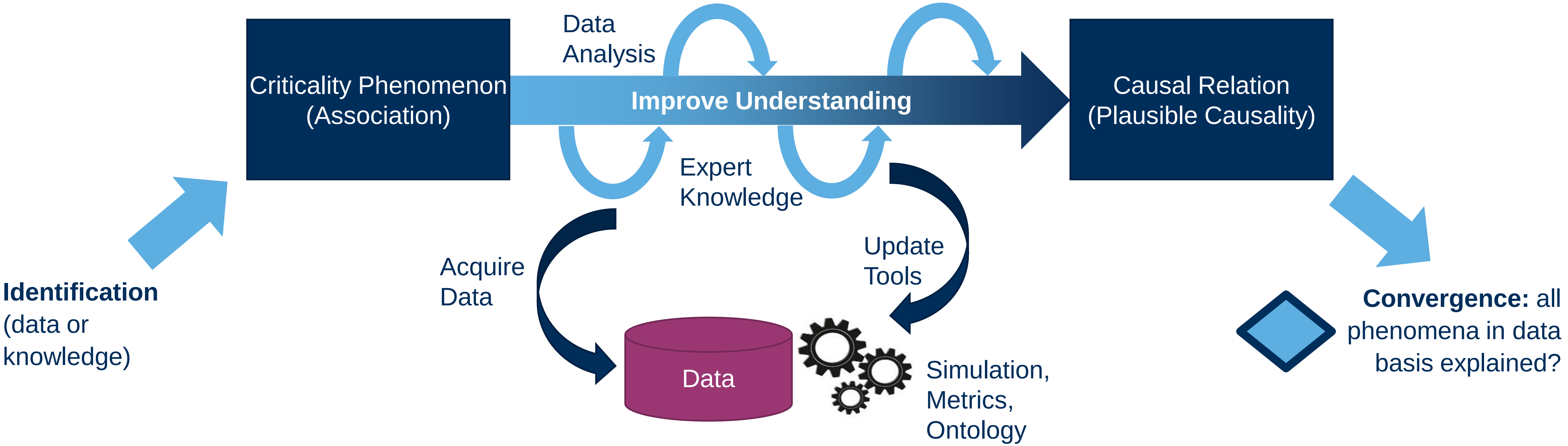
- **Main goal:** gain knowledge on the **open context** w.r.t. the emergence of criticality and its conditions → structuring of the **operational domain**
  - identification of influencing factors associated with increased criticality → **criticality phenomena**
  - improve understanding of criticality phenomena by analysis of underlying **causal relations** → derivation of **target behavior** and **safety principles**
  - specification of abstract scenarios featuring criticality phenomena and causal relations

    → **contribution** to **scenario-based verification & validation**



use case „urban intersection“

Criticality Analysis – Basic Concept



Assumptions:

- set of criticality phenomena is limited and manageable → finiteness (of artefacts)
- relevant phenomena leave traces in growing data basis → completeness (of artefacts)

Simulation-based Analysis within the VVM Criticality Analysis

VERIFICATION VALIDATION METHODS

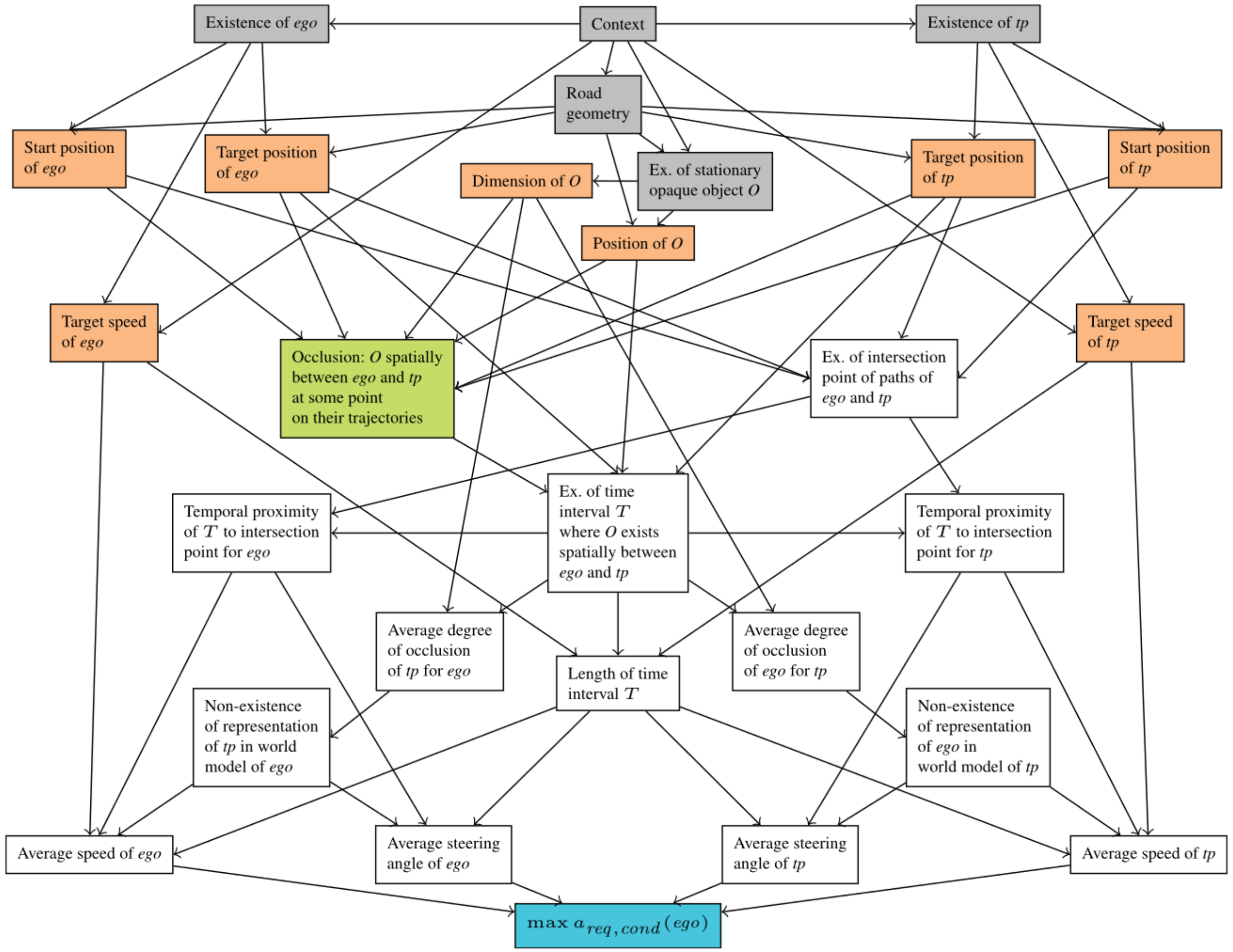
Minimal Required Functionality:

- representative sampling from large scenario classes
  - e.g. instantiation of logical scenarios using parameter variation
- execution of concrete scenarios
- evaluation of criticality metrics

→ Provided by **SET Level Simulation Use Case 1.**

Use of Simulation within the VVM Criticality Analysis:

- abstraction and refinement of criticality phenomena and causal relations
- engineering, calibration and comparison of criticality metrics
- plausibilization of causal relations → check implemented model against real-world data
- effectiveness of safety principles → check whether safety principles reduce the criticality in a causal relation



Causal relation for the criticality phenomenon „occlusion“

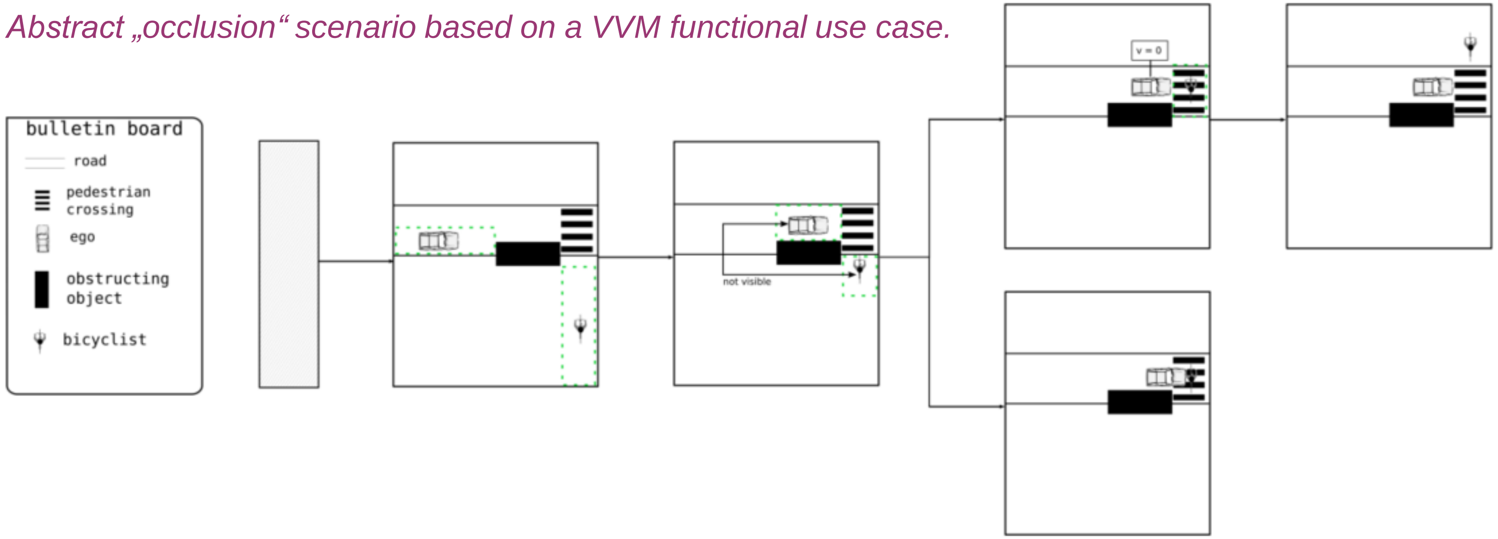
Plausibilization of Causal Relations using Simulation

VERIFICATION
VALIDATION
METHODS

Analysis Task: generate data for the relevant random variables of the causal relation „occlusion“

- based on adjustment variables (identified via graph analysis),
- evaluate the presence of the criticality phenomenon „occlusion“,
- and measure criticality with a suitable criticality metric.

Abstract „occlusion“ scenario based on a VVM functional use case.



Logical „occlusion“ scenario in CARLA.

Parameter	Range
ego start position (x, y)	$[-58, -33] \times [-29, -28]$
ego target position (x, y)	$[50, 55] \times [-29, -28]$
ego target speed (km/h)	$[25, 60]$
bicyclist start position (x, y)	$[31, 32] \times [3, 15]$
bicyclist target position (x, y)	$[-50, -45] \times [-34, -33]$
bicyclist target speed (km/h)	$[10, 25]$
Dimension of O (discretized as number of parking cars)	$\{0, 1, 2, 3, 4, 5, 6, 7\}$
Position of O (x, y)	$[2, 20] \times ([-35, -34] \cup [-26, -25])$

Approach: model the causal relation (including its context) as a logical scenaio for assessment in a simulation

- e.g. openPASS, CARLA, …

Evaluation of Causal Effects and Modeling Quality

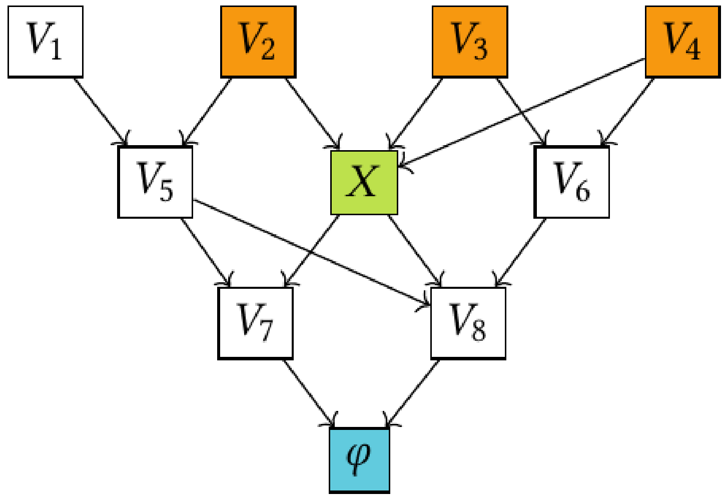
VERIFICATION
VALIDATION
METHODS

- **Evaluate Causal Effects**
  of a criticality phenomenon $cp \in Image(X)$ on a suitable criticality metric φ using the do-calculus, e.g.
  - Average Causal Effect

$$ACE(cp, \varphi) := E(\varphi \mid \mathrm{do}(X = cp)) - E(\varphi \mid \mathrm{do}(X = \neg cp))$$

  - Relative Causal Effect

$$RCE(cp, \varphi) := \frac{E(\varphi \mid \mathrm{do}(X = cp))}{E(\varphi \mid \mathrm{do}(X = \neg cp))}$$



- **Evaluate Modeling Quality:**
  - calculate the **extent of explanation** of measured criticality by a criticality phenomenon
  - calculate the distance between joint probability distributions to check **dependencies of X**

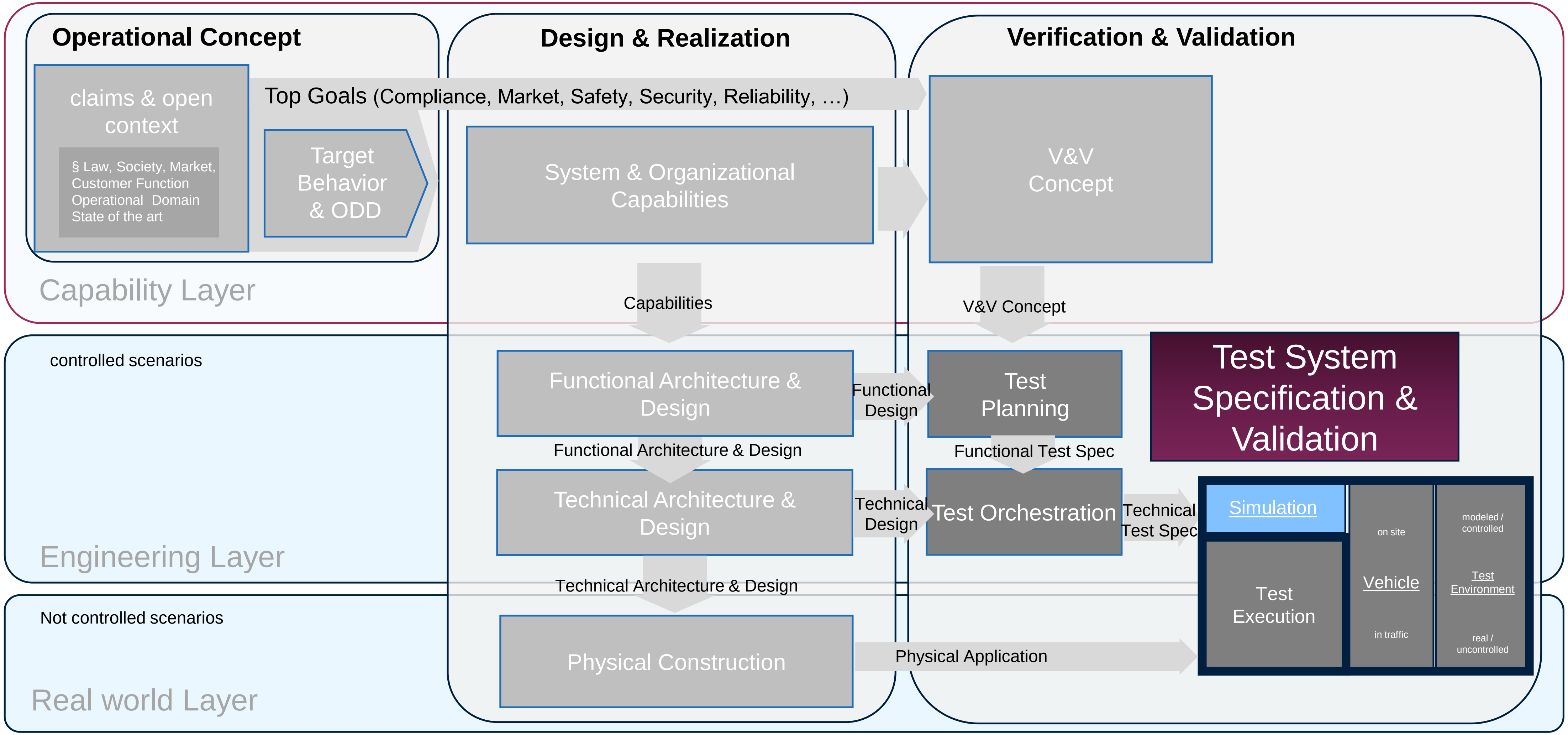
$$\sigma(cp, \varphi) := 1 - \frac{E(\varphi \mid \mathrm{do}(X = \neg cp))}{E(\varphi)}$$

$$\rho = D(P(V_2, V_3, V_4, X) \mid\mid P(V_2, V_3, V_4, X'))$$

Tjark Koopmann, Christian Neurohr, Lina Putze, Lukas Westhofen, Roman Gansch, Ahmad Adee. *Grasping Causality for the Explanation of Criticality for Automated Driving, to be submitted to ACM Transactions on Intelligent Systems and Technology, 2022*

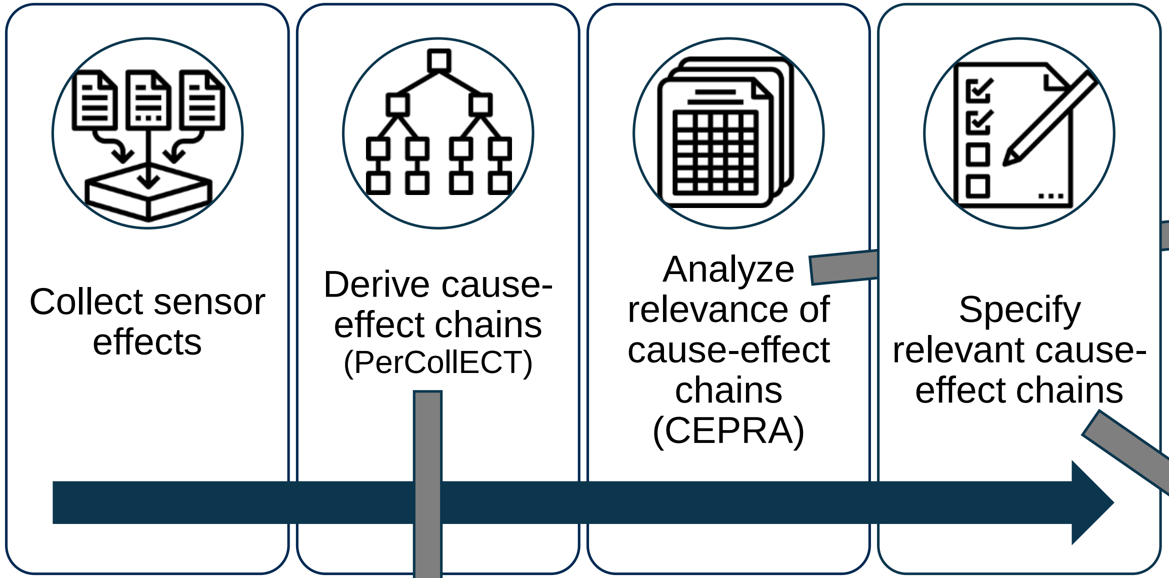
VVM Assurance Framework

▶ Within the assurance framework, the criticality analysis contributes to structuring the operational domain.



PerCollECT and CEPRA for Sensor Model Specification

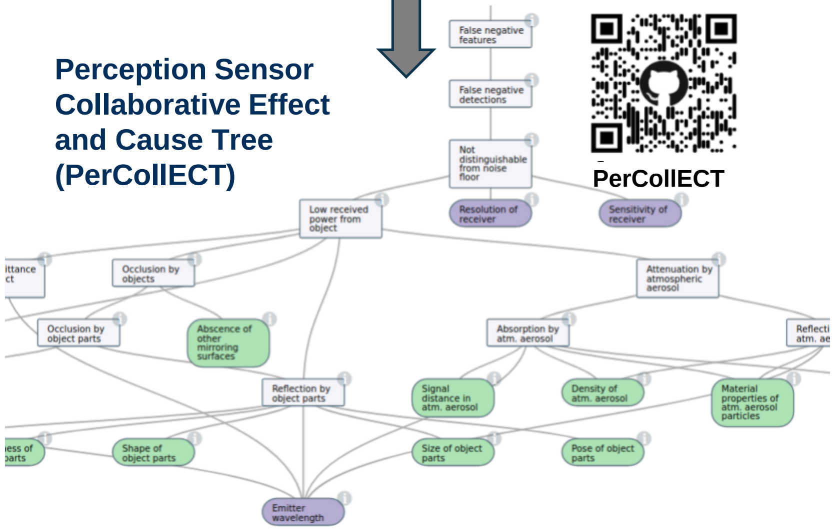
VERIFICATION
VALIDATION
METHODS



Cause, Effect, and Phenomenon Relevance Analysis (CEPRA)

CEPRA ID	Pheno menon (P)	Effect chain (EC) of phenomenon	Causes of effect chains		P&EC occurrence (O) in ODD		P&EC impact (I) on SUT in ODD		Relevance of P&EC
			Environmental causes	Design parameters	*[1, 10]*	*Rationale*	*[1, 10]*	*Rationale*	*O + I*
Lid_CEPRA_005	False negative in object list	→ FN features → FN detections → Not dist. from noise → Low rec. power from o. → Reflection by obj. parts	• Materials • Roughness • Shapes • Sizes • etc.	• Emitter wavelength	*9*	*filled by sensor expert*	*4*	*filled by SUT expert*	*13*
Lid_CEPRA_008	False negative in object list	→ FN features → FN detections → Not dist. from noise → Low rec. power from o. → Attenuation by atm. aer. → Absorption by atm. aer.	• Signal distance • Density of atmosph. • Material of particles • Size of particles • etc.	• Emitter wavelength	*8*	*filled by sensor expert*	*9*	*filled by SUT expert*	*17*
• • •									

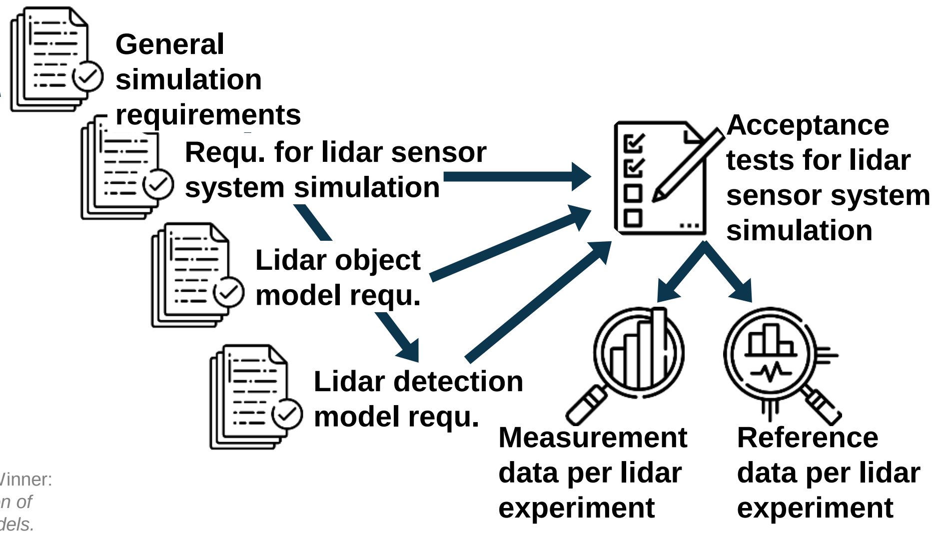
Perception Sensor Collaborative Effect and Cause Tree (PerCollECT)



PerCollECT

SET Level

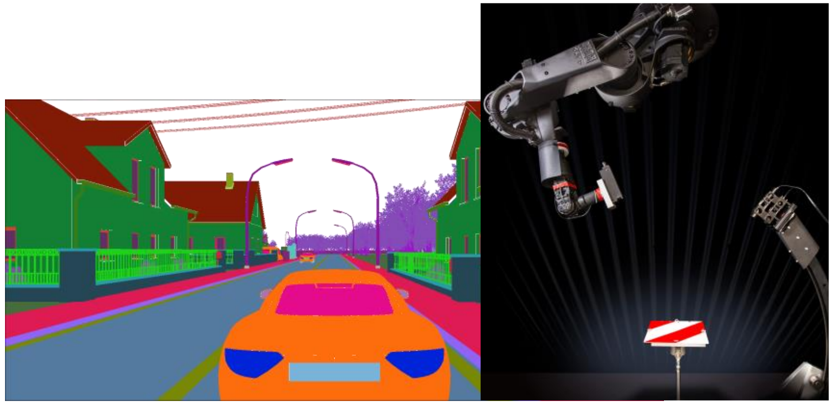
VERIFIKATION
VALIDIERUNG
METHODEN



C. Linnhoff, P. Rosenberger, S. Schmidt, L. Elster, R. Stark, and H. Winner: *Towards Serious Perception Sensor Simulation for Safety Validation of Automated Driving – A Collaborative Method to Specify Sensor Models.* 24th Conference on Intelligent Transportation Systems (ITSC), 2021

Validation of Test Infrastructure

- Exemplary validation of lidar simulation with Replay-to-Sim
- The dSPACE SIL Environment replicates the HIL-stations measurements
  - Open and standardized interfaces for model integration
  - Validated material database



Source: Fraunhofer IOSB

vehicle dynamic +

virtual 3D environment

sensor environment simulation

generic output

OSI*

sensor model

FMU*

SET Level

*Input from SET Level

Sample Validation

VVM Technical Test Specification

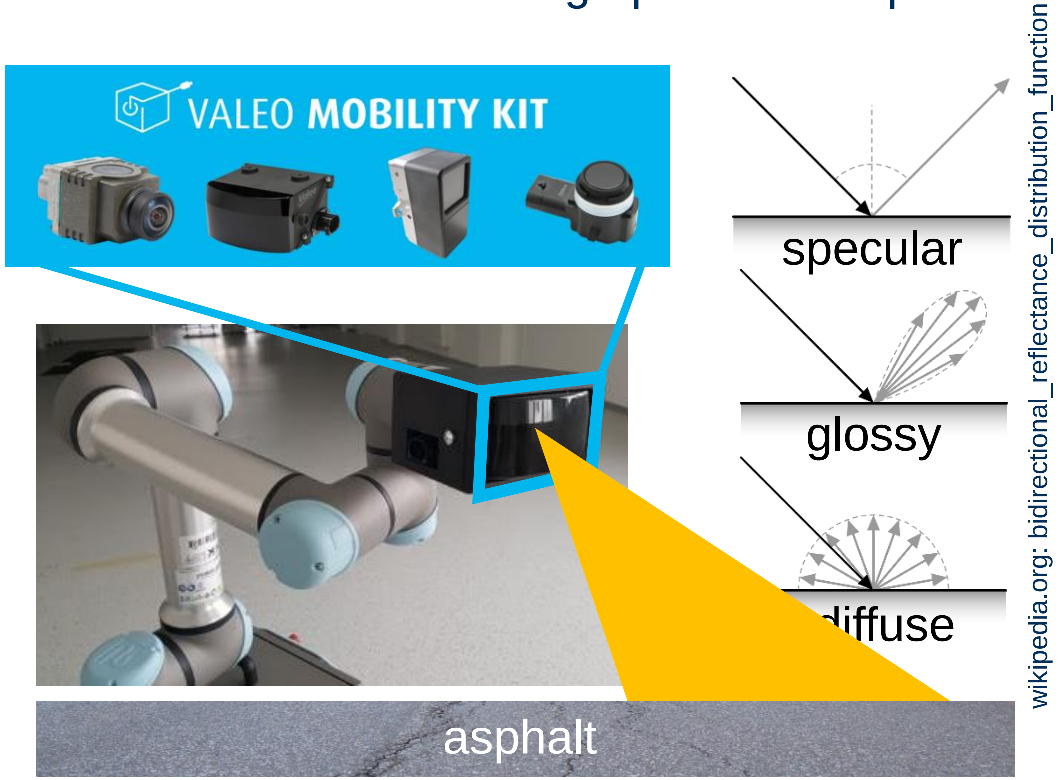
- The format of the technical test specification for **validating the test infrastructure** is the same as for **validating the AD system**
- Content of the VVM technical test specification
  1. Meta information
  2. Test infrastructure
  3. Test cases
  4. Test sequence
  5. First evaluation for the success of the test sequence

VERIFICATION VALIDATION METHODS

SET Level

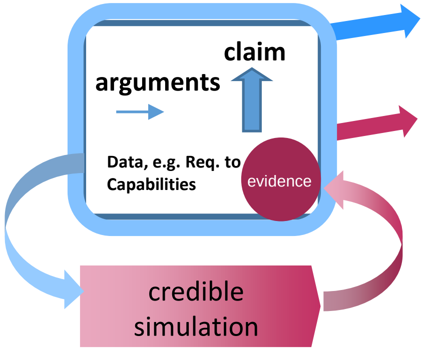
Lidar-HiL for reference measurements

- A collaborative robot (cobot) to collect lidar & reference data over a large parameter space



Summary

- **Assurance framework and argumentation build the basis for an efficient use of simulation**
  - Requirements and metrics for Credible Simulation can be derived by claims and its argumentation strategies.
  - The Simulation-based Analysis provided by SET Level has multiple applications within the methodical VVM criticality analysis
    - E.g. for plausibilization of causal relations or evaluation of safety principles



- **Cooperation between SET Level and VVMethods within PEGASUS Family**
- Successful alignment of test-specification and joint sensor model specification and validation.

The assurance framework supports simulation and data processes, so that exact fit evidences for the assurance argumentation can be provided.

VERIFICATION
VALIDATION
METHODS

Thank you!

Roland Galbas, Robert Bosch GmbH

Dr. Christian Neurohr, German Aerospce Center (DLR) e.V.

Philipp Rosenberger, FZD

Dr. Gerhard Schunk, Valeo

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