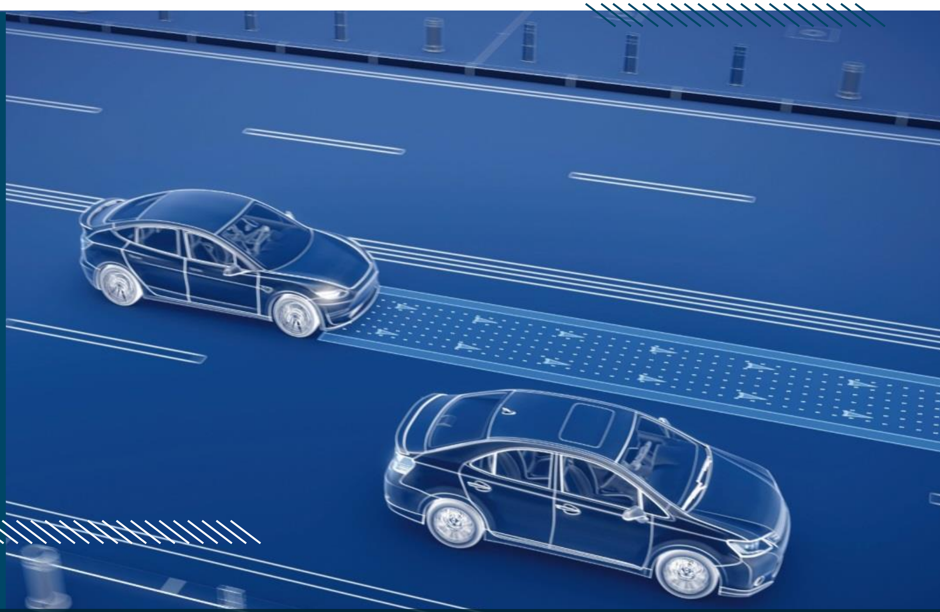
Wie weise ich dies nach?

How can we proof it?



PEGASUS

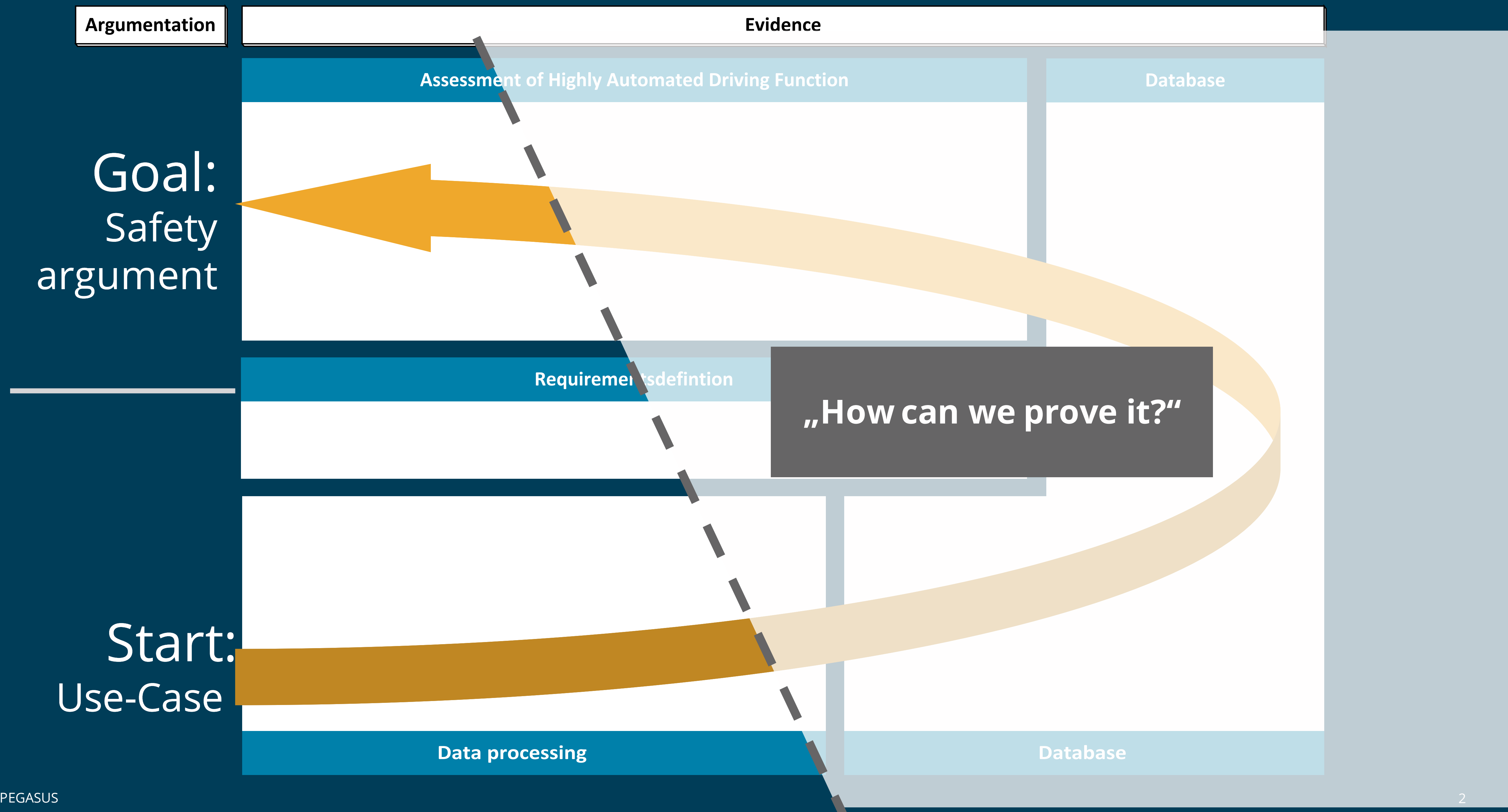
Dr. Helmut Schittenhelm | 13. Mai 2019

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

PEGASUS Method for Assessment of Highly Automated Driving Function (HAD-F)



What is in the scope of the prove?

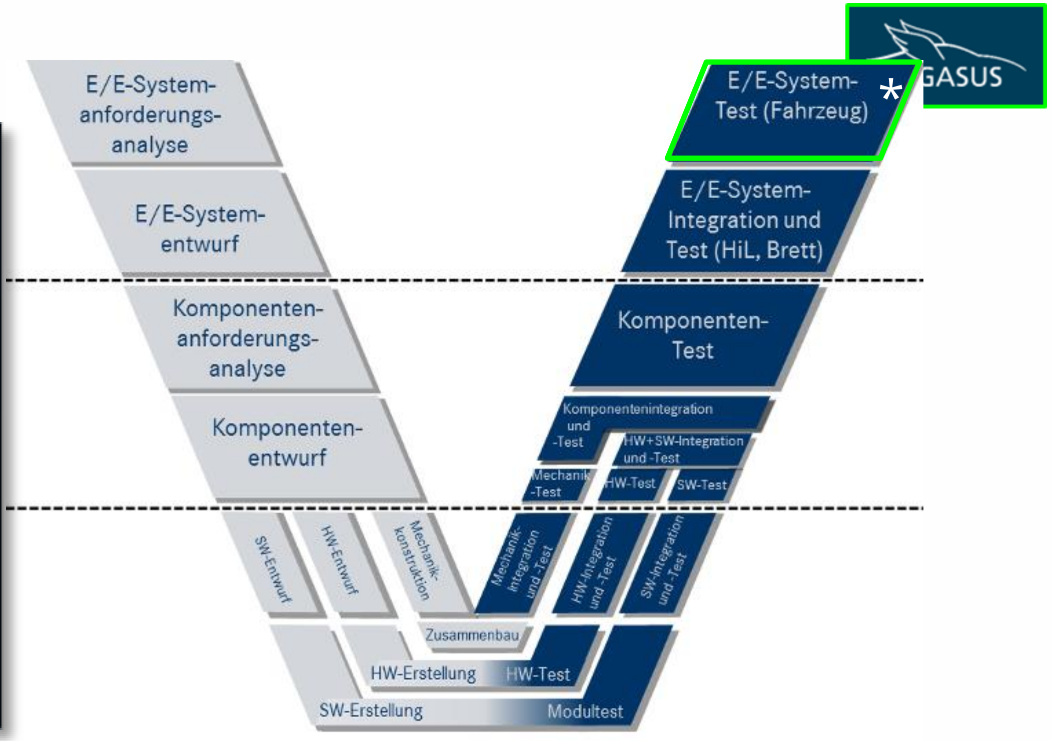
In the scope:

- Safeguarding of driving function in terms of collision-free driving within ODD*
- Sensor functionality as input for system performance

Not within the scope:

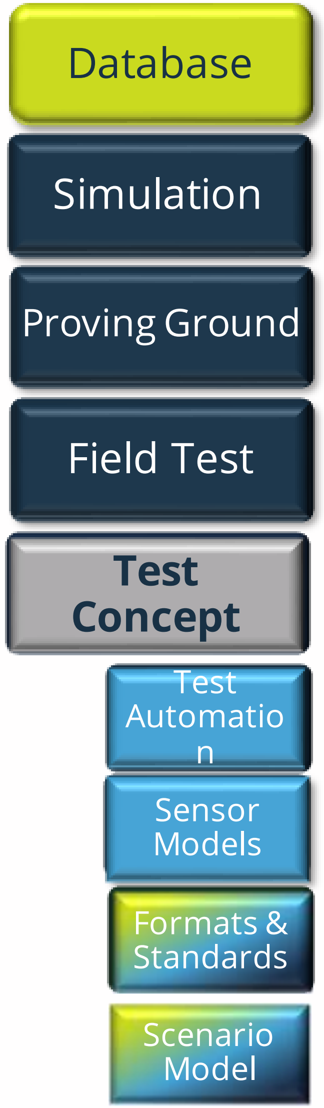
Further AF-relevant topics, covered by OEM / supplier / regulations: e.g.

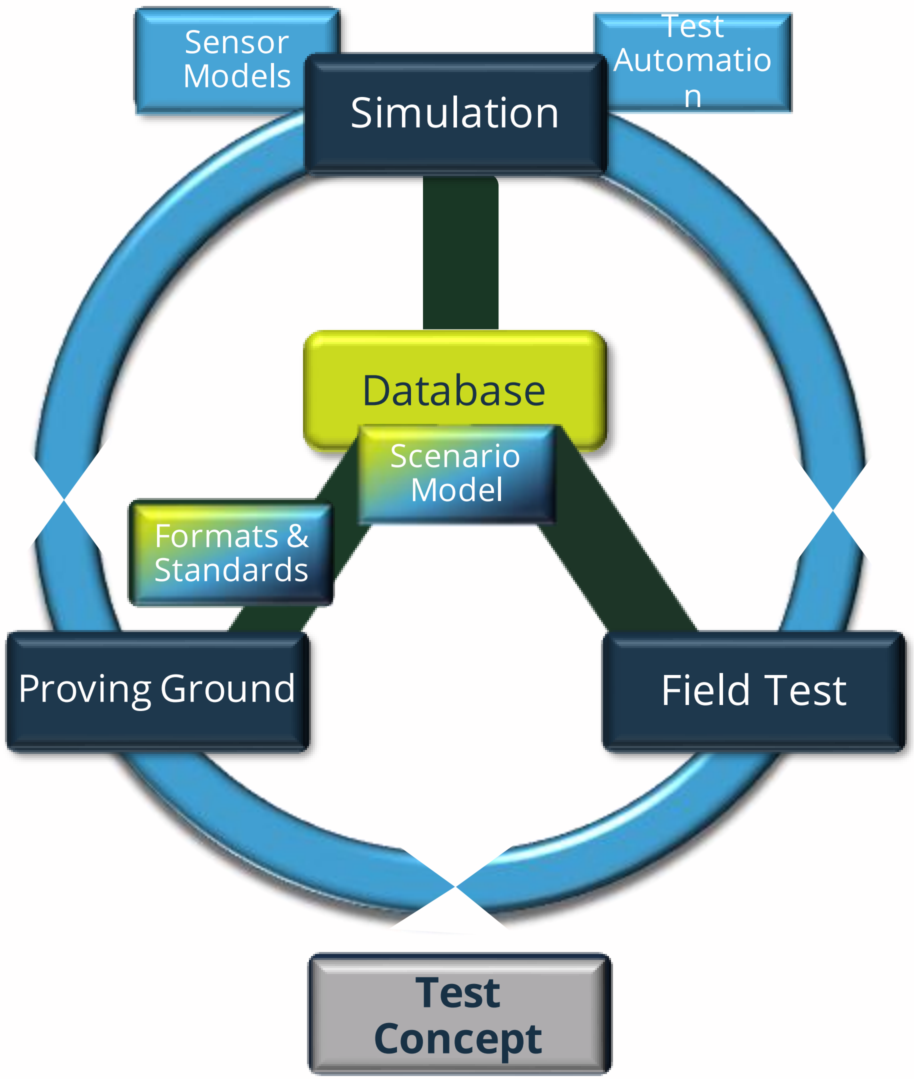
- Testing according to ISO26262
- Direct validation of sensor functionality
- Safeguarding driver interaction
- Compliance with traffic regulations
- …



*Objective of PEGASUS: Development of a methodology for the generating of a safety assessment for a Level 3 systems (SAE,definition, Highway Chauffeur, max 130km/h)

Who contributes ?

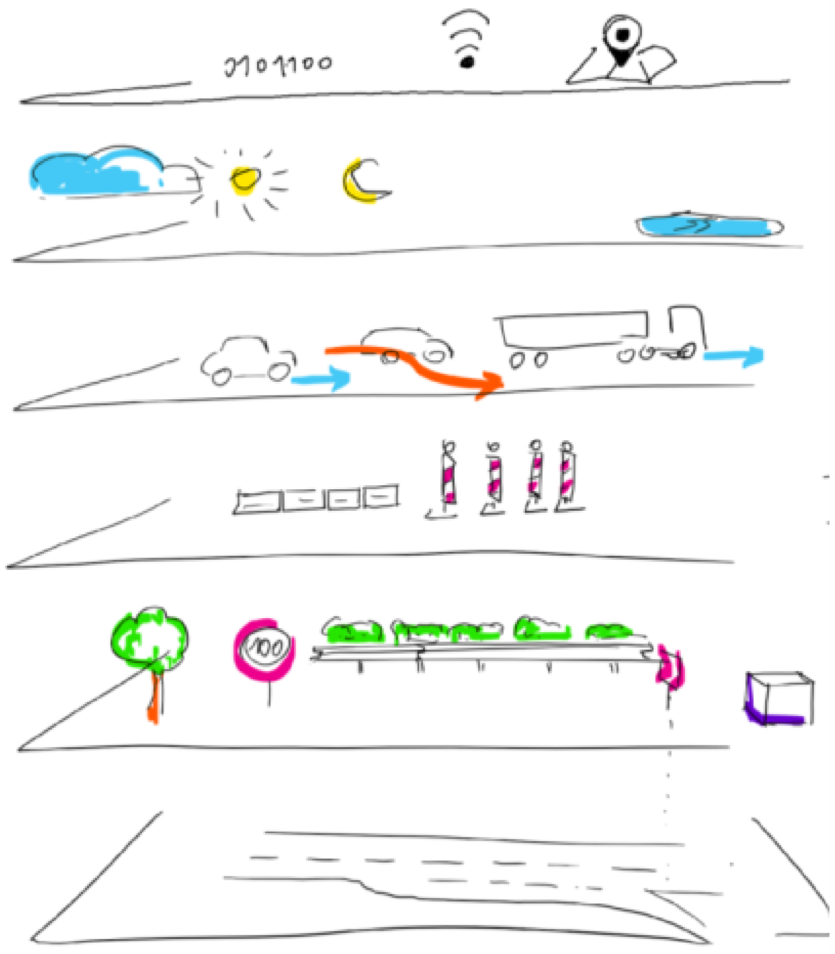




Modelling systematically and consistent the scenario space

6-Layer model, describing relevant factors and their geometric, temporal and/or logic relationship

according to [1], based [2], integration planned



Layer 6 — **Digital information:**
e.g. V2X information on traffic signals, digital map data
=> *Availability and quality of information communicated to ownship*

Layer 5 — **Environmental conditions**
Light situation, weather (rain, snow, fog…) temperature
=> *environmental influences on system performance*

Layer 4 — **Moving objects**
Vehicles, pedestrians moving relatively to ownship
=> *relevant traffic participants and their motion incl. dependencies*

Layer 3 — **Temporal modifications and events**
Road construction, lost cargo, fallen trees, dead animal
=> *temporary objects minimizing / influencing the driving space*

Layer 2 — **Road furniture and Rules**
traffic signs, railguards, lane markings, bot dots, police instructions
=> *including rules, where to drive how*

Layer 1 — **Road layer**
road geometry. Road uneveness (openCRG),
=> *physical description, no scenario logics*

[1] Bock et al. 2018: Data Basis for Scenario-Based Validation of HAD on Highways
[2] Bagschik et al. 2018: Ontology based Scene Creation for the Development of Automated Vehicles

Are there PEGASUS Standards for Scenario Description?

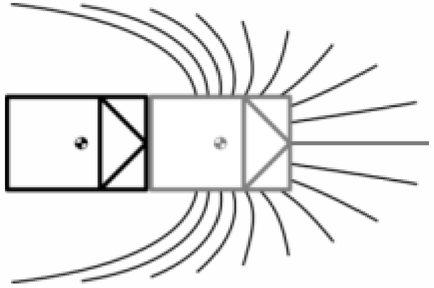
OpenSCENARIO, OpenDRIVE, and OpenCRG are currently subject of ASAM Transfer projects.

ASAM OpenSCENARIO 1.0.0 will be released in January 2020.

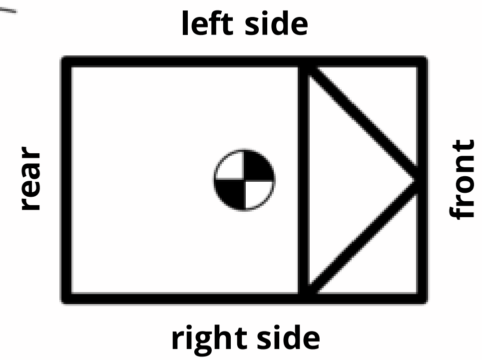
The goal of this transfer project is to create the first version of ASAM OpenSCENARIO on a quality- and completeness-level that is expected from a public standard and from ASAM members. This also includes work on a technical level to complete and enhance the currently existing specification documents, to clarify open issues and to fill specification gaps, which might be brought up by project group members during the project term.

Scenario concept

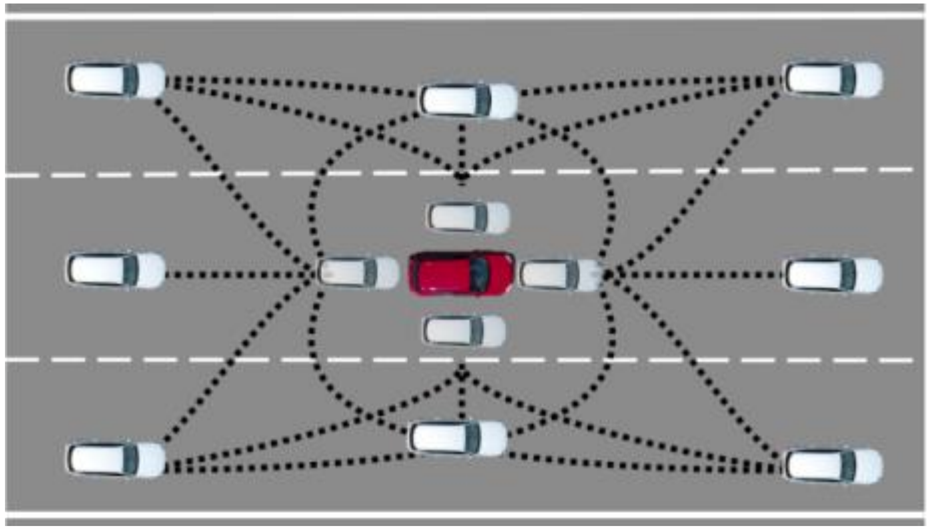
- **A challenging vehicle induces a reaction of the subject vehicle to prevent an accident [1]**
  - Description based on **accident reconstruction**
  - Relational description **from the subject vehicle perspective with relative paths**
  - Considering the **potential impact location** (front, side, rear) and the **initial position of a challenger vehicle**



Possible relative paths between challenger and subject vehicle

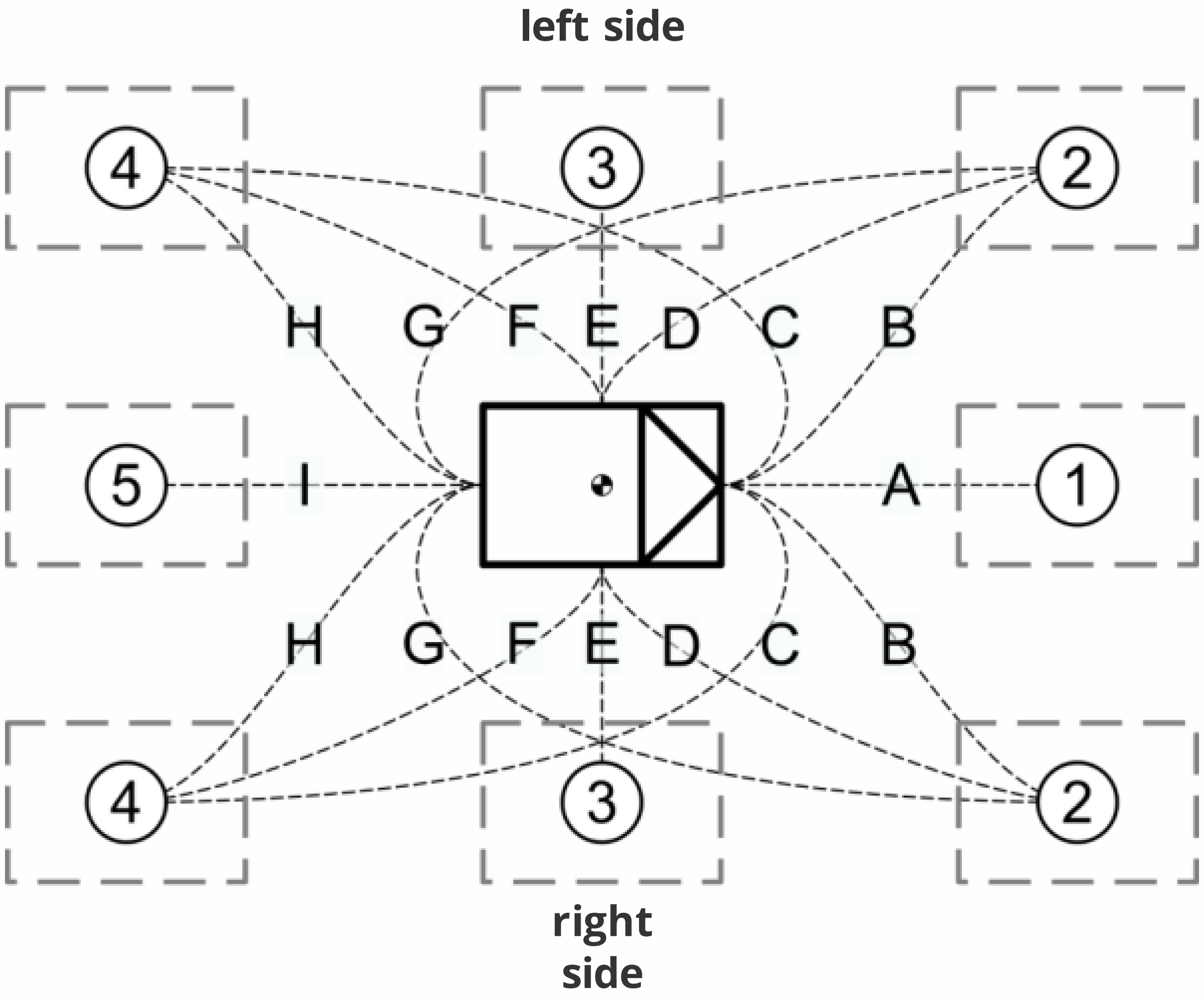


- **Challenger Vehicle**
  - 9 Scenario Types for influenced driving
  - 1 (non-) Scenario for uninfluenced driving
- **Further Vehicles:**
  - Occlude relevant information (“Dynamic occlusion”)
  - Constrain possible actions of subject vehicle (“action constraints”)
  - Challenge the subject vehicle at the same time
  - Cause the challenger´s action (“challenger cause”)
- **Every other vehicle is not relevant (enough) for scenario-description**



[1] Bock et al. 2018: Data Basis for Scenario-Based Validation of HAD on Highways

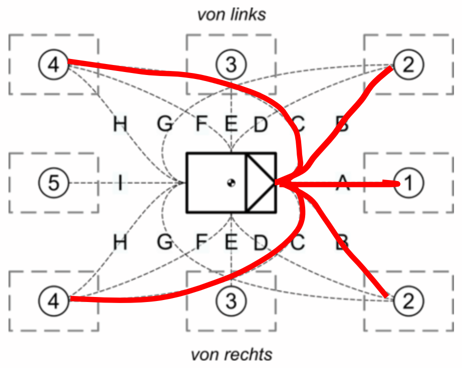
Scenario Types: Overview

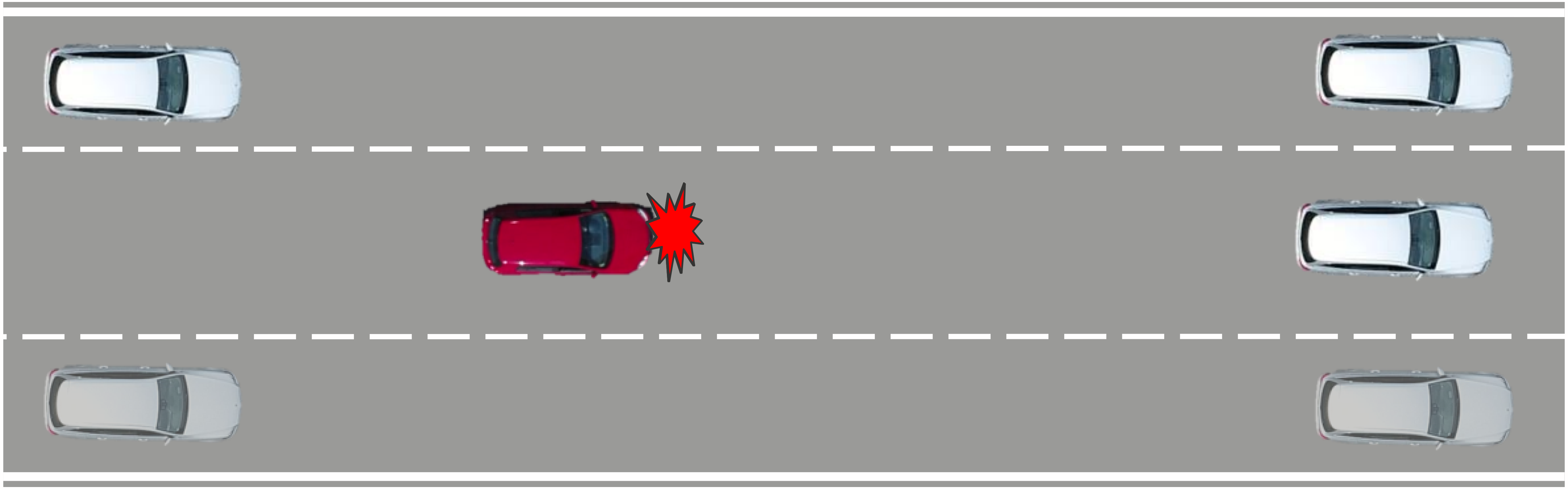


Impact	Initial position	Path	Indication
Front	1	A	Lead vehicle challenger
	2	B	Slower turn into path challenger
	4	C	Overtaking turn into path challenger
Side	2	D	Slower side swipe challenger
	3	E	Side swipe challenger
	4	F	Overtaking side swipe challenger
Rear	2	G	Slower Rear End Challenger
	4	H	Rear end turning into path challenger
	5	I	Rear end challenger
Non	-	-	Uninfluenced/Free driving

Scenario Types: (Potential) Frontal Impact

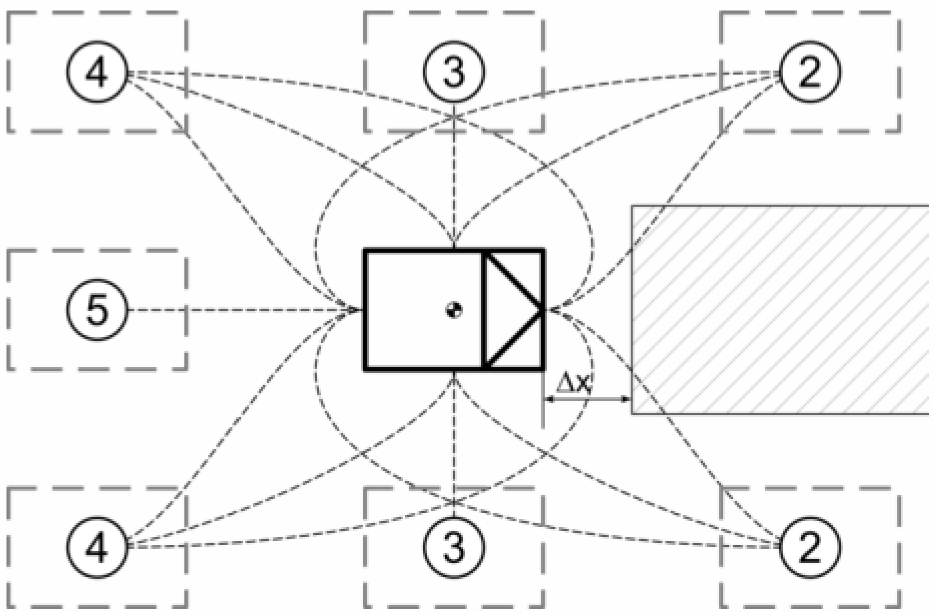
Impact	Initial position	Path	Indication
Front	1	A	Lead vehicle challenger
	2	B	Slower turn into path challenger
	4	C	Overtaking turn into path challenger



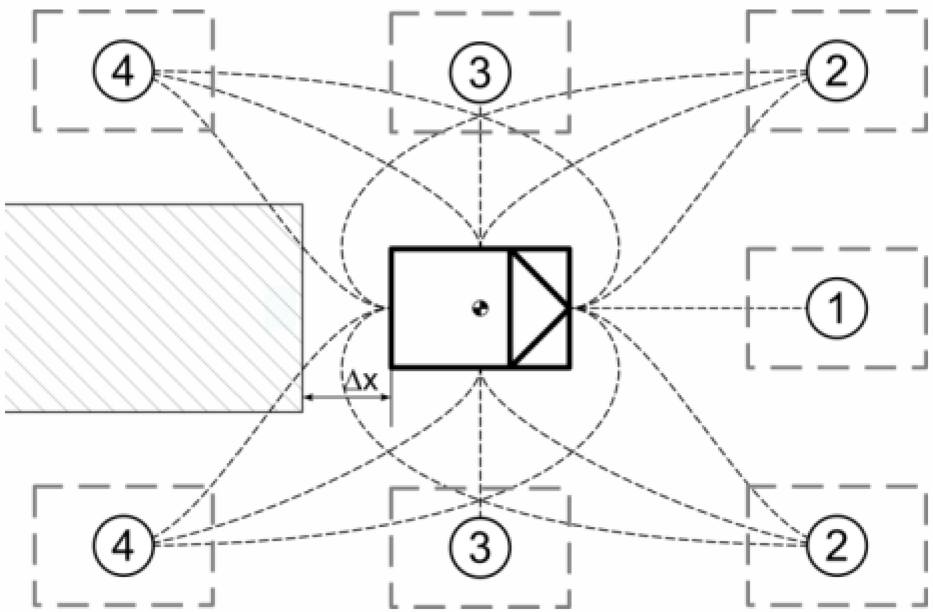


Action constraints (1/3)

- Beside the challenger also other vehicles can have an influence on the driving behavior of the subject vehicle
- Surrounding vehicles constraint the possibilities to act
- Distinguish between five different cases, which may be combined

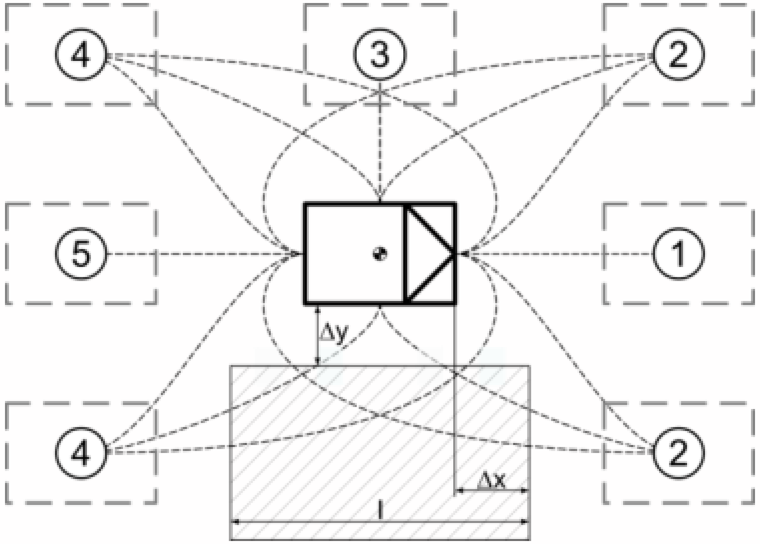


(1) Front



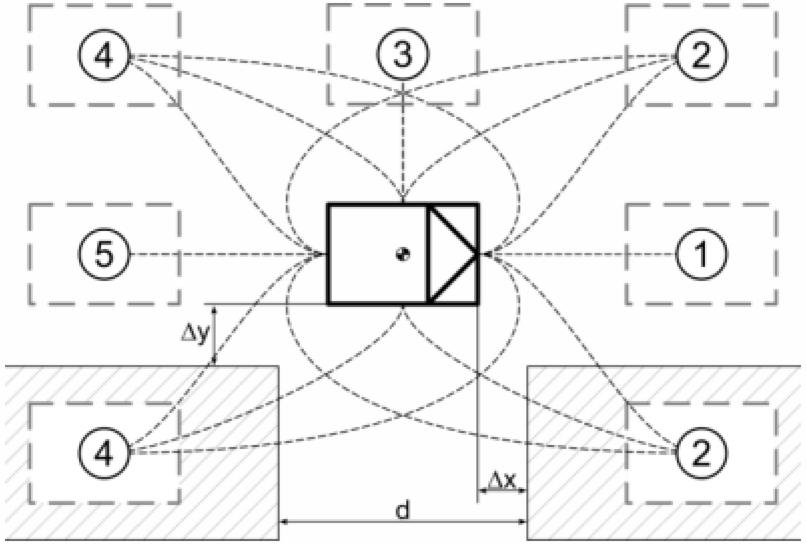
(2) Rear

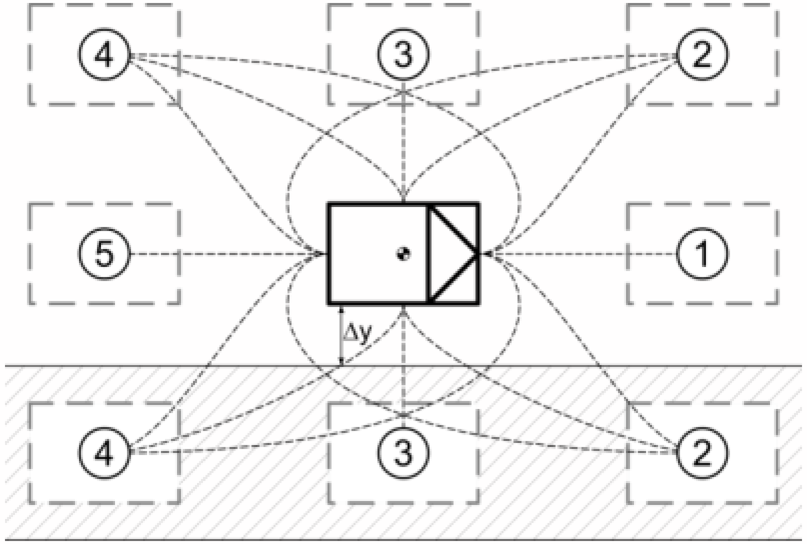
Action constraints (2/3)



(3) Object

(4) Gap

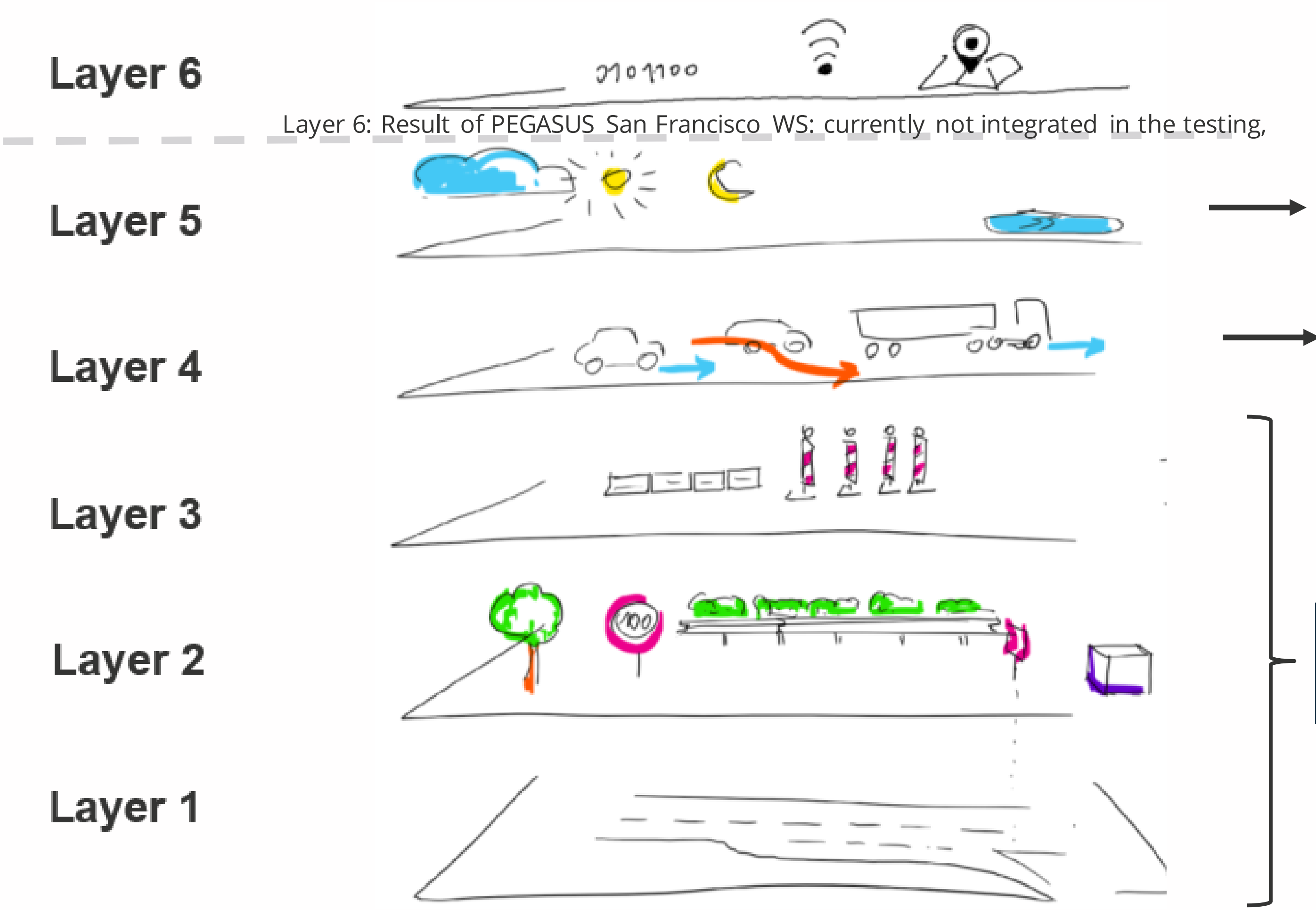




(5) Blockade

Simulation / Scenario: What is currently feasible?

6-level model for describing scenarios:



Current phenomenological* modeling possible (e.g. visibility, object not seen, ...) description in **Open*SCENARIO***

Description of the dynamic traffic situation in simulation via **Open*SCENARIO***

Description of the infrastructure in simulation via **Open*DRIVE***

Description of the road surface in simulation via **Open*CRG***

- → Focus Simulation in PEGASUS: Testing the system behavior of the highway driver in dynamic, variable traffic situations
- → *Outlook: Predictable environmental influences through improvements to sensor models, thus physical effects can also be simulated in future

Test-specification-database - expertise of the scenario approach. Initial basis for an international standard in this area

PEGASUS

Database

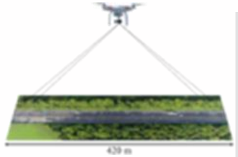
Goal: Representative collection of all relevant scenarios, metrics, pass criteria as basis for testing
Input: Data from field, derived test cases from knowledge, certification, automation risks ...
Output: Logical Scenario and parameters (incl. distributions), pass criteria, Metric

Data source

FOT/NDS with sensing of the driving environment

FOT with (L3) HAD systems

Accident data



Arial data

Real World test Driving proving ground

PEGASUS – database

harmonization

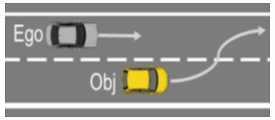
Input

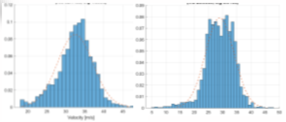
processing

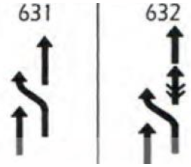
Output

Test space

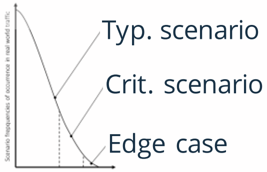
- Logical Scenario
- Parameter space
- Critcal Parameter Sets
- Metrics and pass criteria
- Relevance



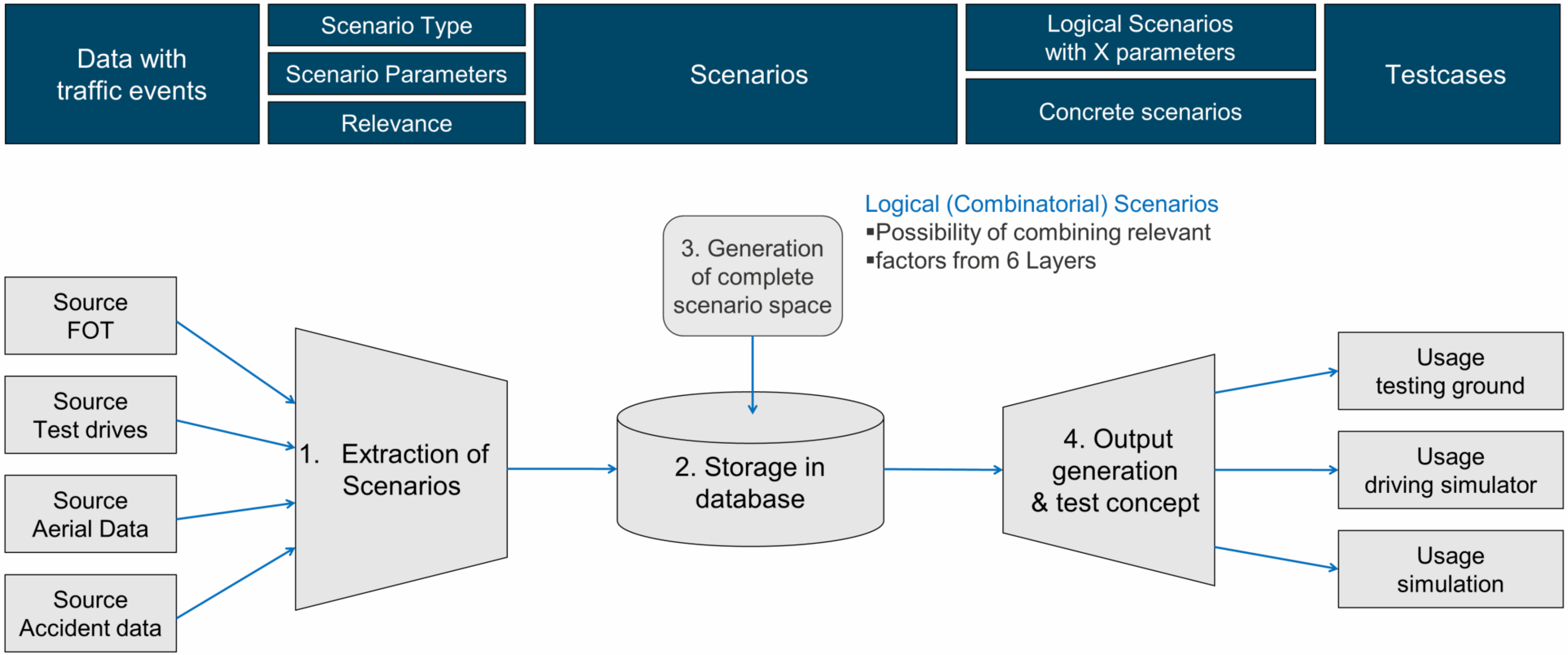




- **TTC**
- **No collision**



The Processing Chain is a Key Component of the Database.



<source> event
- FOT event
- Testdrive event
- …
- Accident event

<source> Scenario
- FOT scenario
- Testdrive scenario
- …
- Accident scenario

<instance> Testcase
- Proving ground testcase
- Driving simulator testcase
- Simulation testcase

What happens with the database after the end of the project?

- In discussion different options for organizing the operation of the PEGASUS database, concretization: second half of 2019
  - 1. step: agreement on a solution among the PEGASUS partners
  - 2. step: open it to the public on an international level

- independent non-profit Society, optionally as private / public partnership (model GIDAS)
- open to anyone who is interested in participating
- collection of representative scenario data of integrity
- Involvement of all important stakeholders such as national and international OEMs for joint filling of the database as well as relevant national and international authorities (typ-approval, traffic, homologation, certification)

How does the test case allocation take place?

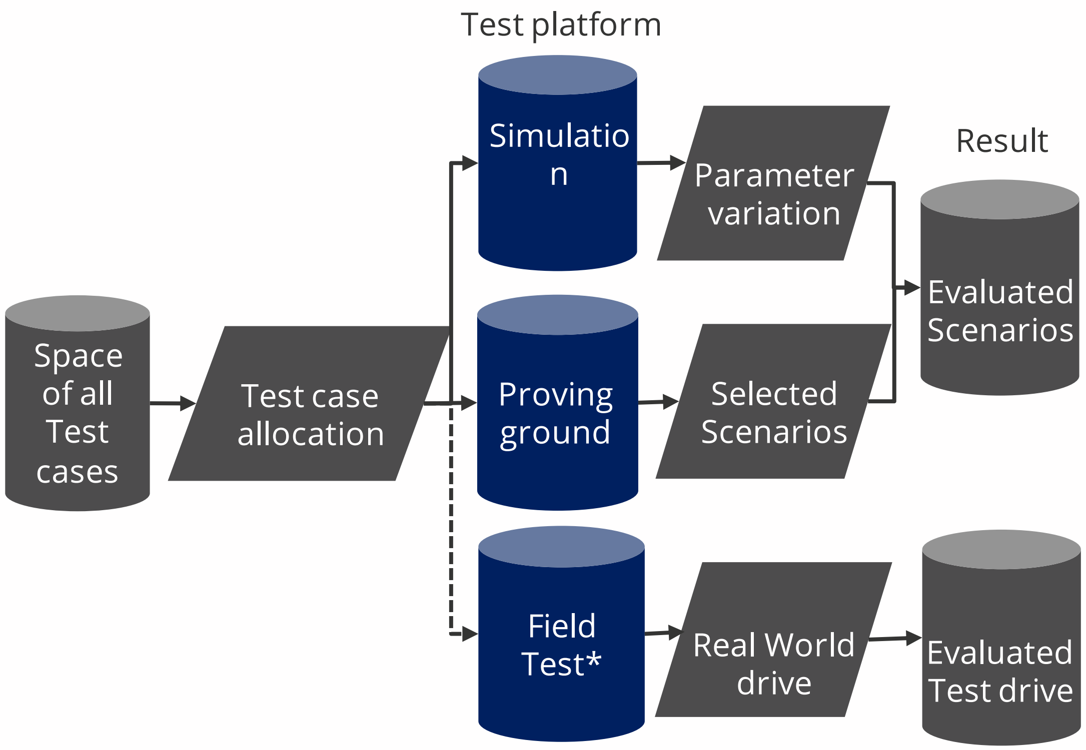
Test case allocation:
- **Simulation:**
  - All logical test cases regarding scenario based testing with a high number of scenarios but a low relevance regarding real sensor performance

Proving ground:
- Pre selected tests, e.g. certification tests
- Test with a high relevance regarding drive dynamics and real sensor performance
- Rare events which can hardly be seen in field tests

Field tests:
- Tests with a high relevance regarding real system performance under a high variation of surrounding conditions

Test result:
Based on Pass/Fail criteria evaluated concrete scenarios for simulation, test ground and field test Probability for accident scenarios

Test end criteria regarding simulation (suggestion):
- Create transfer function between scenario parameters (input) and test result (output, e.g.accident yes/no, distance between ego-vehicle and relevant target):
  Target value for quality of transfer function ≥ 80%*
- Calculate standard deviation σ of computed probability for accident scenarios: Target value for σ ≤ 20%*



*No direct coupling to testcases

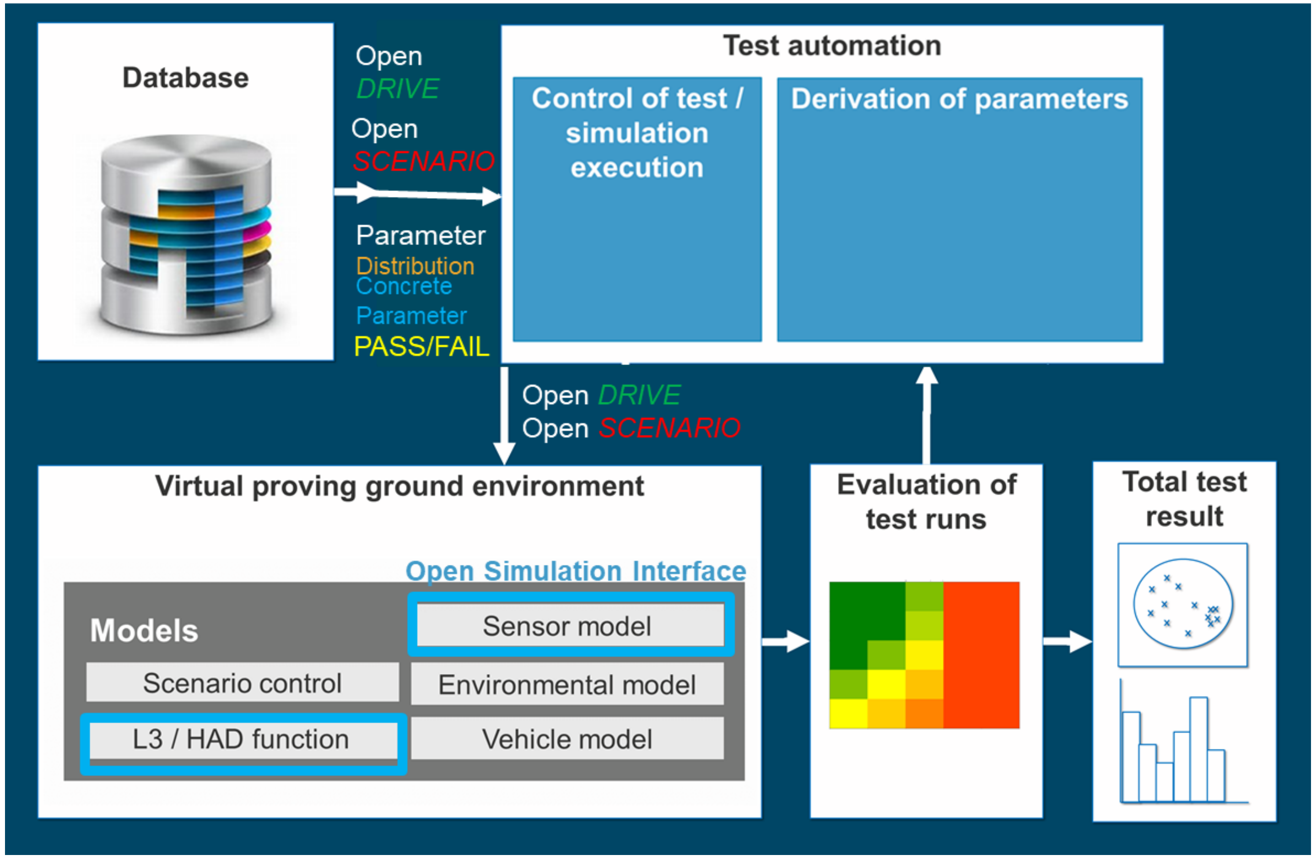
What ´s the role of Simulation in PEGASUS?

Simulation

Goal: Testing of all scenarios from the data base (scanning the parameter space for identification of scenarios with risk of collision)
Input: Scenarios, parameters, pass criteria/metrics, ECO-SW-Code as system under test
Output: Evaluated Scenarios and the probability for collision scenarios

Motivation:

- Using a common architecture for a toolchain for safeguarding makes it more easy to execute test cases.
- Standardized interfaces between and within the tools / test instances make it possible to exchange tools or modules within the proven tool chains.



Which sensor models were developed in Pegasus?

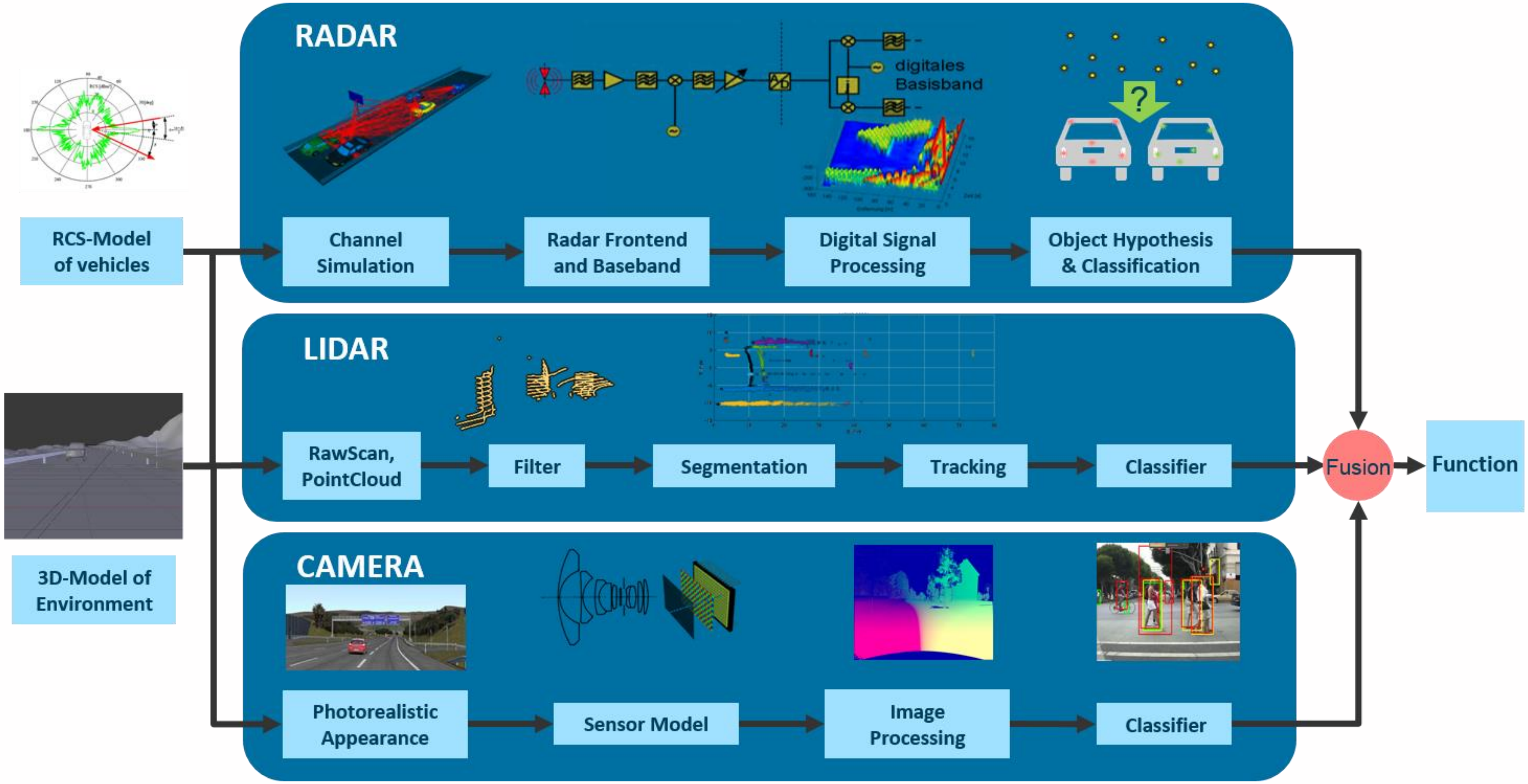
Simulation

Sensor Model

Phenomenological radar sensor model BOSCH Technik fürs Leben

Phenomenological lidar sensor model FZD FAHRZEUGTECHNIK TU DARMSTADT

Phenomenological camera sensor model BOSCH Technik fürs Leben CONTINENTAL



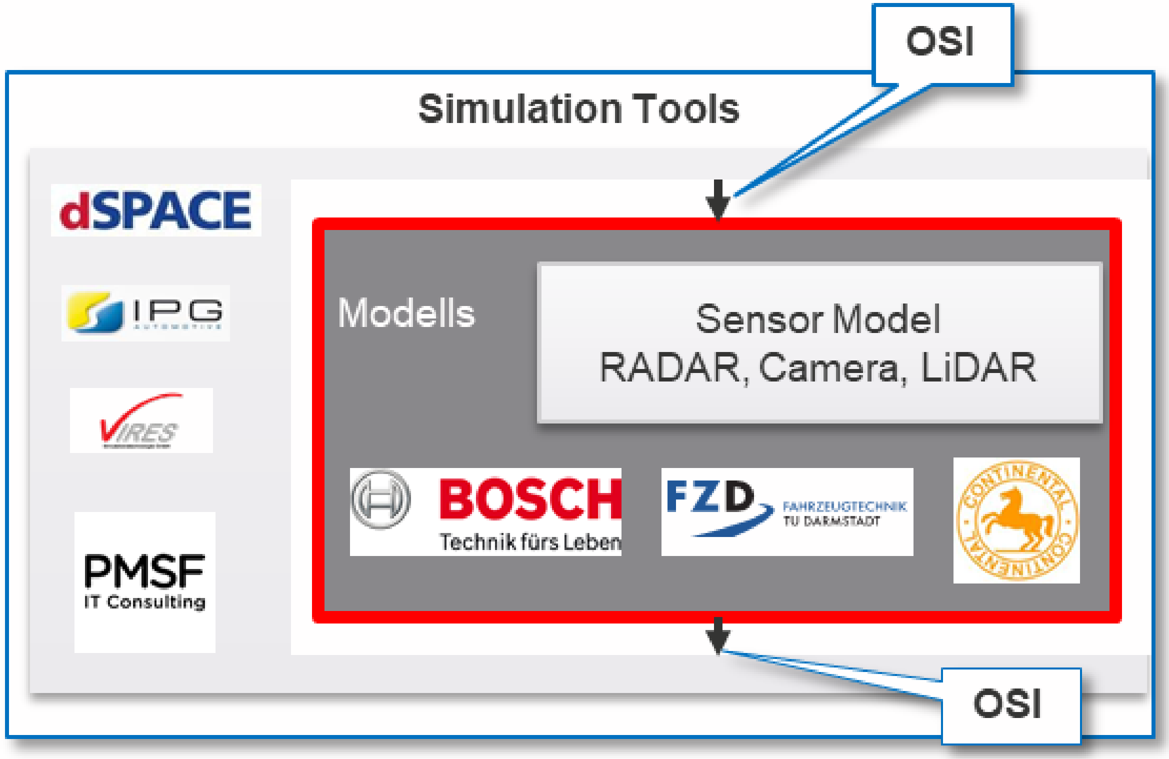
Components of the sensor models for radar, LiDAR and camera based on their physical setup. For radar and camera the effects are modelled phenomenologically, i.e. the result of the effect is modelled.

The radar-sensor model requires a polar representation of the RCS (Radar Cross Section) of all involved vehicles in simulation.

Which sensor phenomena were modelled?

- For radar-, camera- and LiDAR-sensors models have been developed, which reflect the properties of the respective sensors:

- **All sensors**
  - Distance
  - Field of View
  - Masking
- **Radar**
  - Antenna diagram
  - Attenuation (weather/coverage)
  - Resolution (angle/distance/velocity)
- **Camera**
  - Weather conditions
  - Time of day
  - Optical variations (distortion, blur, vignetting)
- **LiDAR**
  - Number of scan layers, range
  - Noise behaviour
  - Relevance of attributes for object recognition



Open Simulation Interface

OSI provides the standard for a generic interface that enables simple and uncomplicated linking of the numerous driving simulation frameworks for the development of automated driving functions.

What ´s the role of the Proving Ground in PEGASUS?

Simulation

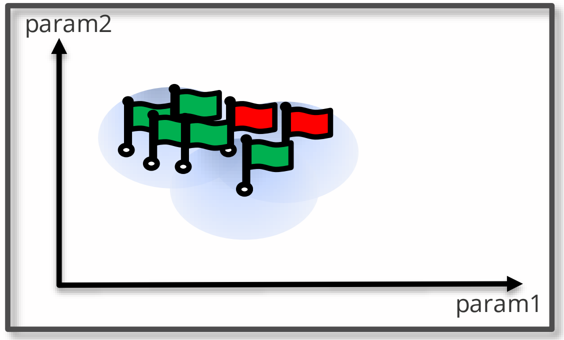
Test Automation

Goal: Based on stochastic variation within the parameter space of the logical scenario, concrete parameter sets are created automatically. The target is to execute a detailed search in the parameter space for sets of critical parameter. A variance/probability-based robustness analysis is performed in parallel.

Input: Logical scenario and parameters (incl. distributions), pass criteria/metrics

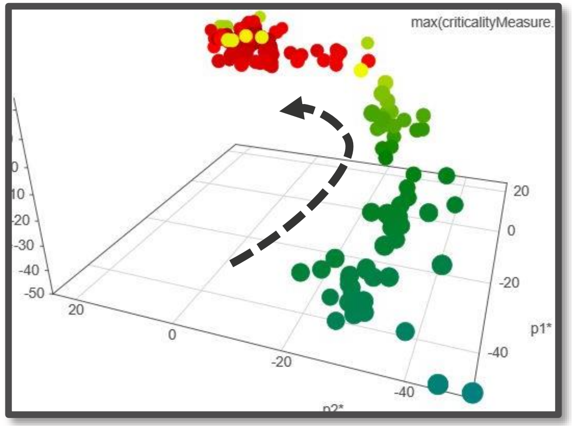
Output: Concrete scenario (parameter set for a logical scenario)

1. approach: Explore known critical scenarios, also with local variation of parameters.



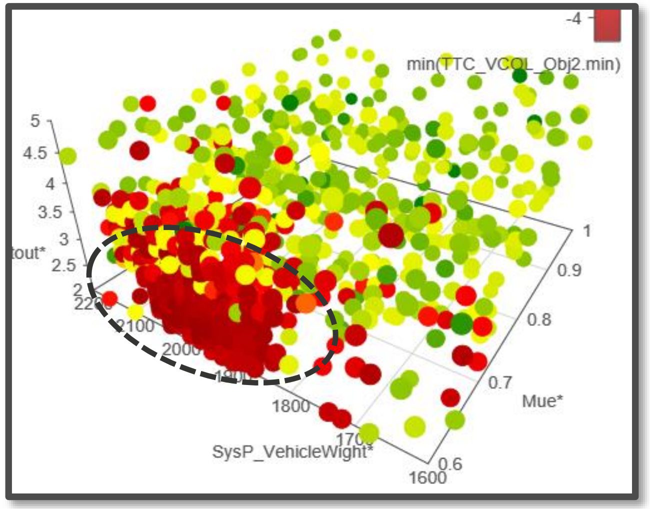
2. approach: Explore a given abstract parameter subspace (logical scenario) with optimization methods in order to find one or more worst cases of the safety metrics.

Starting points for iterative search may be chosen as known critical parameter subsets from real traffic data. (concrete parameter sets for representative accidents, particularly critical pre-crash constellations observed in reality for the logical scenario

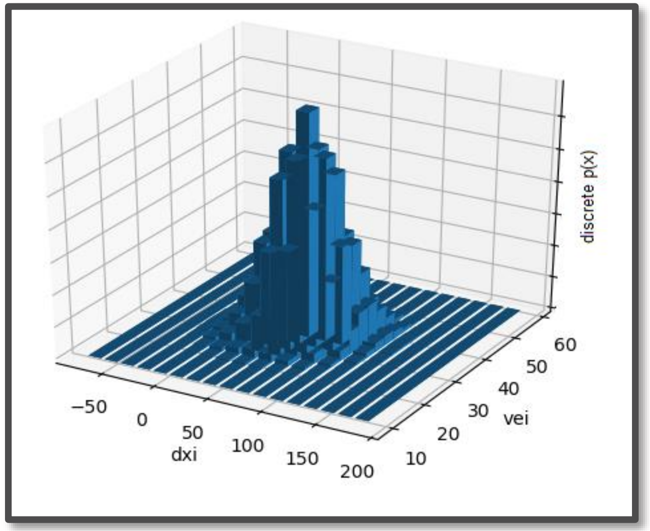


Stochastic Variation – Characterization.

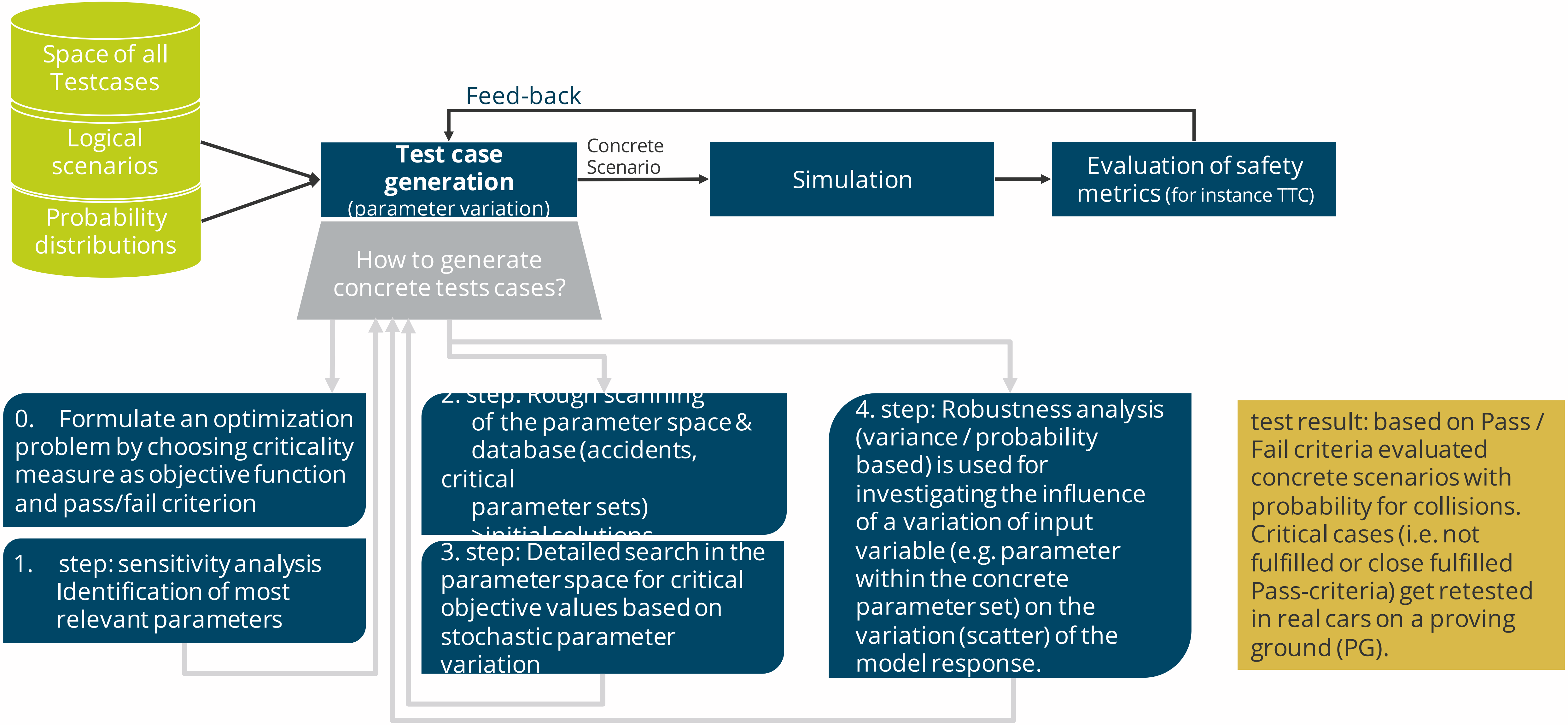
1. Characterization means assessing the probability of safety violations for a logical scenario space with a given confidence measure.



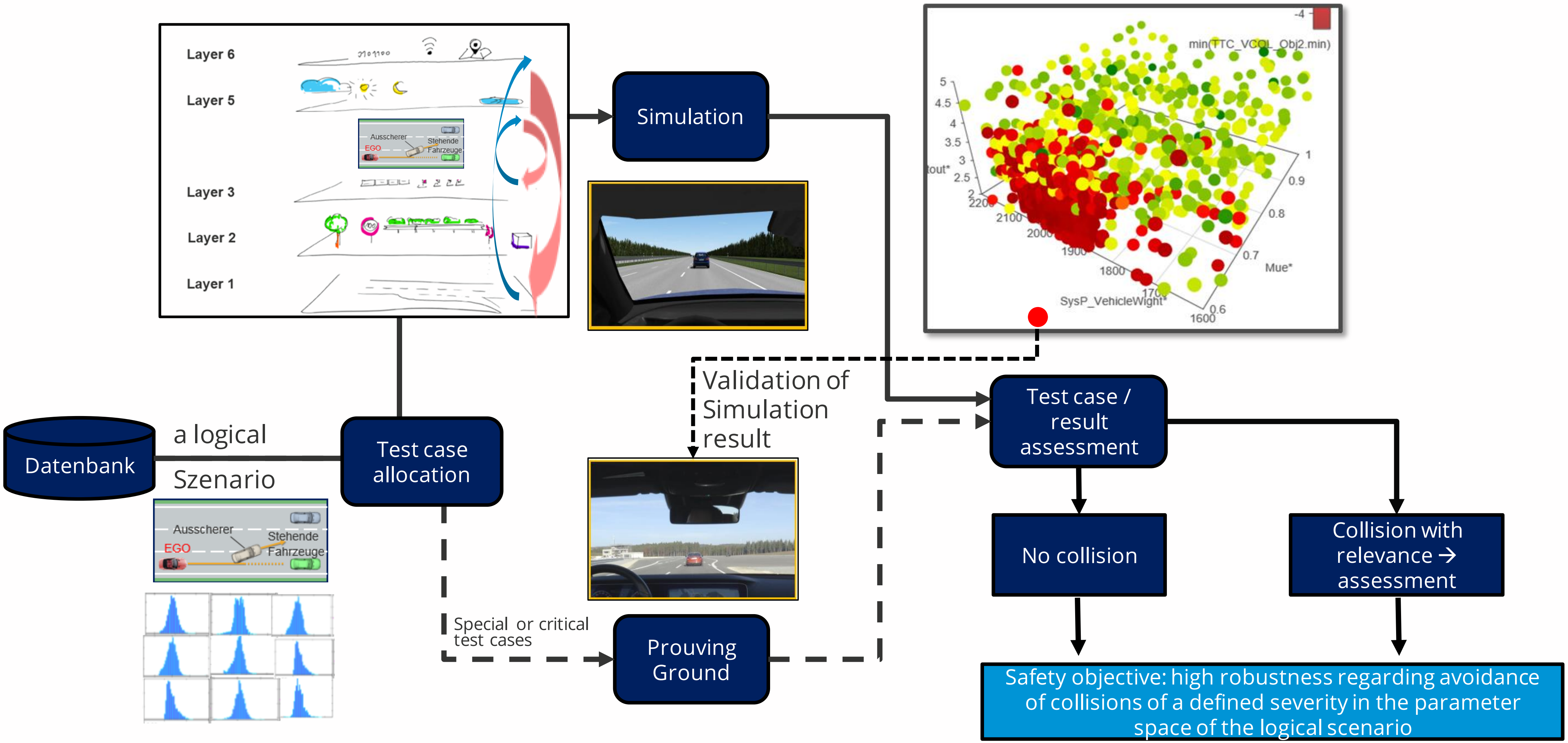
2. Test result is a description of the critical parameter subspace where a metric reports a safety violation including an approximation of probability.



How can concrete test cases be generated?



Pegasus-Prozess → Erweiterung auf „logisches Szenario“



What ´s the role of the Proving Ground in PEGASUS?

Proving Ground

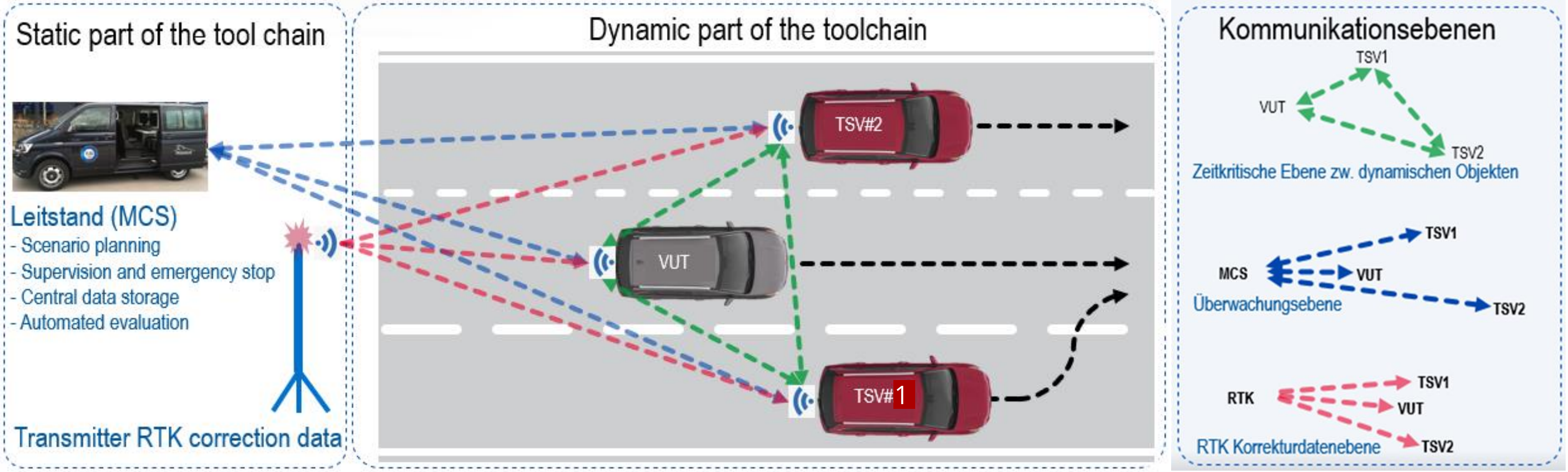
Goal: Test of selected scenarios:
A) Special or critical test cases, e.g. derived from certification
B) critical test cases identified in simulation to validate simulation results

Input: Vehicle Trajectories from scenarios (concrete scenario), pass criteria, original vehicle as system under test

Output Evaluated Scenarios and data for the validation of the simulation results (return flow to simulation)

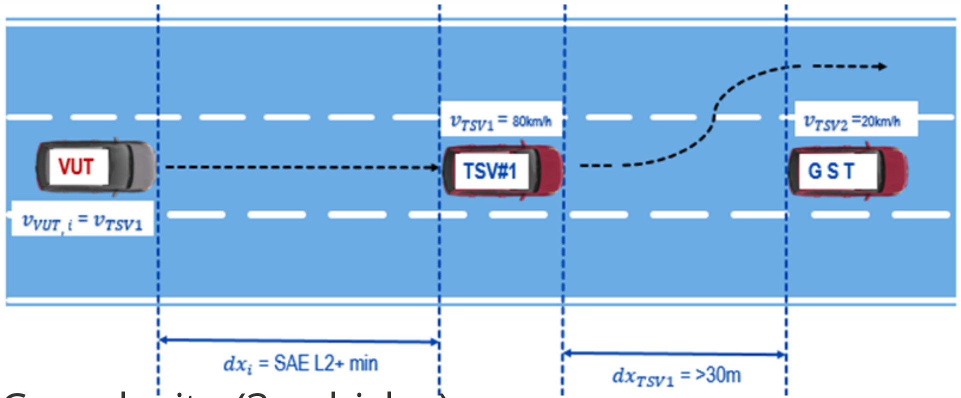
Requirements: high-precision implementation of the maneuver specifications, robust execution, exact repeatability, interchangeability of all scenario elements, complexity of scenarios (no. of in parallel controlled elements)

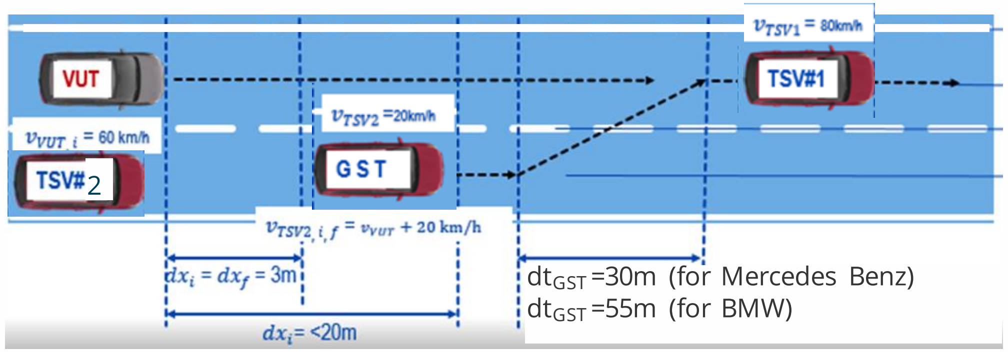
Approach (realized in PEGASUS with two different characteristics):



What could be achieved? (Proving Ground on the right side)

Examples shown outside: robust execution, exact repeatability, interchangeability of all scenario elements, complexity of scenarios (number of in parallel controlled/coordinated elements),



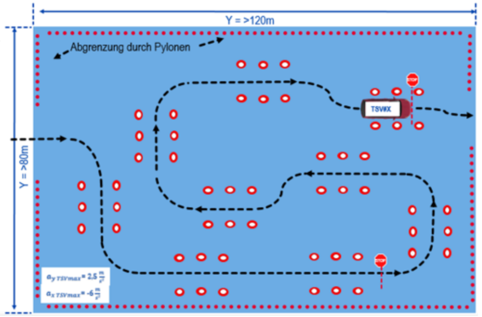


Complexity (3 vehicles):

- 1 TSV (1st round: MB-E-Class, 2nd round: KIA)
- 1 GST (Controlled Soft Crash Target)
- 1 VUT (1st run: BMW, 2nd Run MB GLE, 3rd run VW T-Cross)

Complexity (4 vehicles):

- 2 TSV (1xKIA,1x MB E-Class)
- 1 GST (Controlled Soft Crash Target)
- 1 VUT (1st run: BMW, 2nd Run MB GLE)

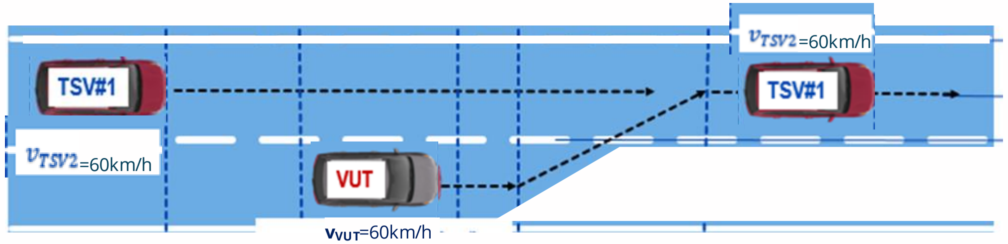


Complexity (1 vehicle):

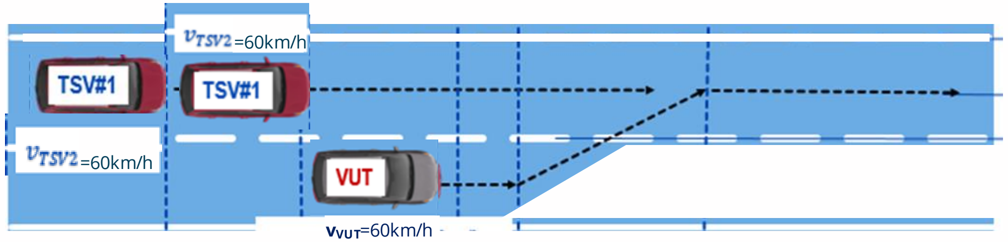
- 1 TSV (1st round: MB-E-Class, 2nd round: KIA)

What could be achieved? (Prouving Ground on the left side)

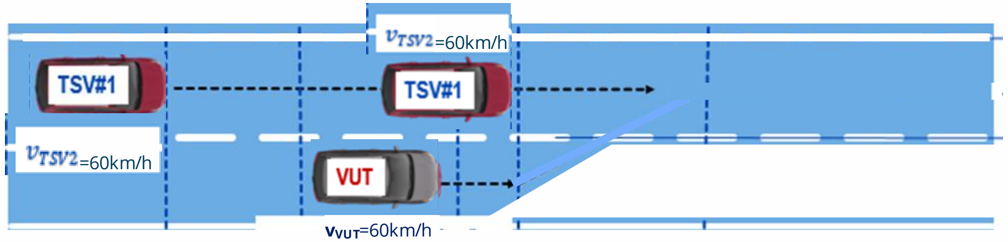
Examples shown outside: robust execution, exact repeatability, complexity of scenarios



Complexity (3 vehicles):
- 2 TSV (2xAudi)
- 1 VUT (Audi)



Complexity (3 vehicles):
- 2 TSV (2xAudi)
- 1 VUT (Audi)



Complexity (3 vehicles):
- 2 TSV (2xAudi)
- 1 VUT (Audi)

What´s the role of the Field Test in PEGASUS?

PEGASUS

Field Test

Goal: Test of the HAD-function in real world traffic (long term testing)
- identification of specific individual situations within the framework of event-based simulation
- Identification of faults/impairments of the system as a result of environmental influences cannot currently be simulated directly via models, as no suitable physical models are yet available.
- Perform special "*pass*" assessments (e.g. risk in passing or following other vehicles

Input: global guidance of conditions, pass criteria, original vehicle as system under test

Output Evaluated real world test drive, measurement data as input for database (return flow to database)

Examples for PASS-/FAIL-Criteria for Field Test

No Accident
- distance to surrounding traffic / objects on the road

Main criteria for Simulation / Proving ground in Pegasus

Correct distance to ahead or passing driving traffic

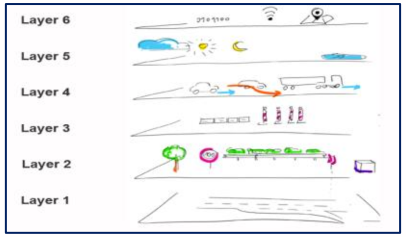
Not leaving the lane (except for a lane change)

Meet with speed limits or other traffic regulations

Additional criteria for field testing

Measurement guidelines

Guidelines (e.g.):
- Route
- Weather, Daytime
- Special environment



Real world test drive

Find „surprises"

Analysis of measured data on database

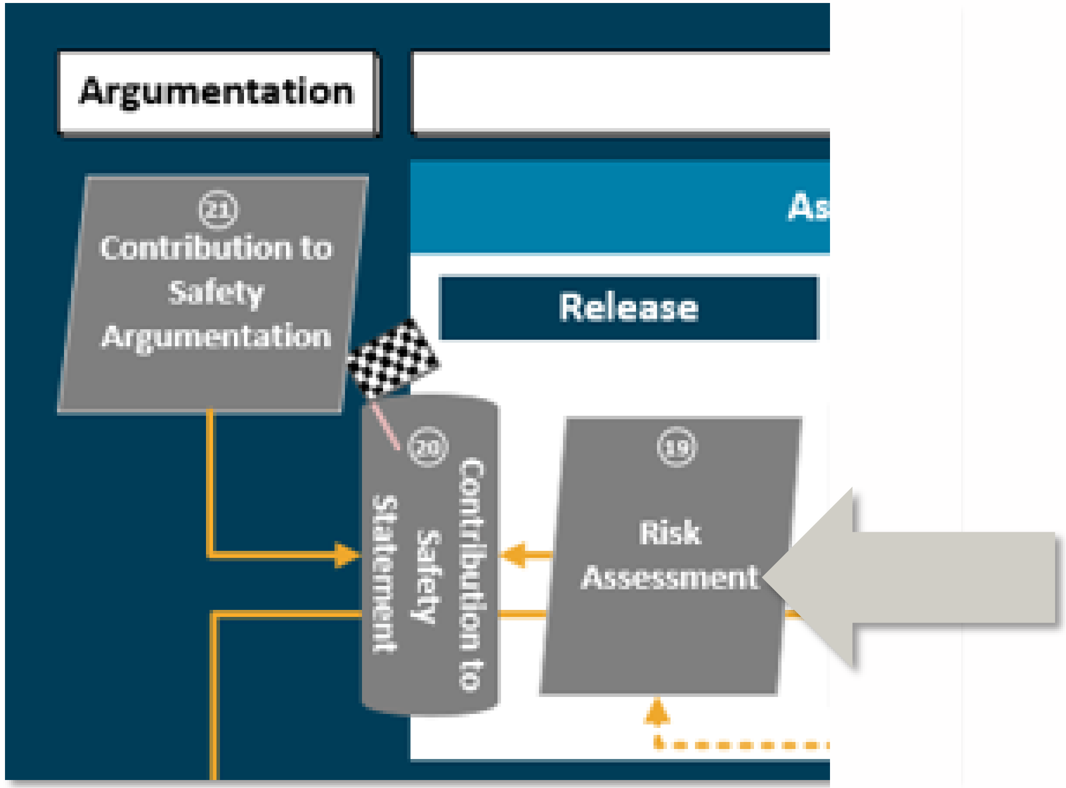
Pass-criteria met?

Calculation of criticality metrics

Scenario and parameter extraction

Input for Replay2Sim

Next Processing Step – Risk Assessment.



Test Results:
For each logical scenario:

- concrete tests & test results per critical scenario

or

- description of the parameter subspace where a metric reports a safety violation including an approximation of extension and probability.

Is there a PEGASUS list of test scenarios?

- Unfortunately, no.

- The scope of PEGASUS Testing / Safeguarding of driving function in terms of collision-free driving within ODD*.
- Each of the components of a HIGHLY Automated Driving Function such as ODD, function specification, sensor setup, architecture etc. has individual characteristics for each specific development.
- For this reason, the list of tests resulting from the process can only be individually tailored and not generally valid.

PEGASUS

Vielen Dank für Ihre Aufmerksamkeit!

Many thanks for your attention!