Integration of PEGASUS tools into certification Process?
What is in the scope of the PEGASUS testing method?

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

Goal: **Representative** base / 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

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**Database**

**Data source**
- FOT/NDS with sensing of the driving environment
- FOT with (L3) HAD systems
- Accident data
- Aerial data
- Real World test Driving proving ground

**PEGASUS - database**

**Test space**
- Logical Scenario
- Parameter space
- Critical Parameter Sets
- Metrics and pass criteria
- Relevance

- TTC
- No collision

**Harmonized Input**

**Harmonized Output**

**Goal:**
Representative base / 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
What’s the role of Simulation in PEGASUS?

**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 within the ODD

**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.
What’s the role of the Proving Ground in PEGASUS?

**Goal:**
- Test of (tool for) 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):**

- **Static part of the tool chain**
  - Leitstand (MCS):
    - Scenario planning
    - Supervision and emergency stop
    - Central data storage
    - Automated evaluation
  - Transmitter RTK correction data

- **Dynamic part of the toolchain**

- **Kommunikationsebenen**
  - VUT
  - TSV1
  - TSV2
  - MCS
  - Überwachungsebene
  - RTK
  - RTK Korrekturdatenebene
What’s the role of the Field Test in PEGASUS?

**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 for test 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)

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Examples for PASS-/FAIL-Criteria for Field Test:

- No Accident
  - distance to surrounding traffic / distance to ahead or passing driving traffic
- Correct distance to ahead or passing driving traffic
- Meet with speed limits or other traffic regulations
- Additional criteria for field testing

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**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**

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**Measurement guidelines**

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Use of components of the PEGASUS method

Assessment in the development process

Assessment in the certification process
## Comparison of PEGASUS components in relation to certification

<table>
<thead>
<tr>
<th>Test coverage (practicability / running numbers of test cases)</th>
<th>Simulation</th>
<th>Proving Ground</th>
<th>Field Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very High</strong> &gt;&gt; 10,000 simulation runs per scenario, especially critical scenarios</td>
<td><strong>Low:</strong> “30” scenarios, especially critical scenarios or scenarios with certification relevance</td>
<td><strong>NOT POSSIBLE:</strong> explicit scenarios pre-settable, depending on the real traffic</td>
<td></td>
</tr>
</tbody>
</table>

| Effort qualification of testing tools and methods | **High** effort for sim. model parametrization und validation (driving dynamics, sensor, actuators, traffic agents) as well as overall verification of the simulation chain with real driving data. | **High**, but only one time (exactness of execution control of targets) | **Low** due to purchase of already qualified standard measuring equipment |

| Effort for test setup and preparation | **Low**, but depending on the degree of test automation | **Very high**, as controllable vehicles, measurement technology and other proving ground infrastructure have to be measured individually for each test case. | **Very high**, Fleet of vehicles must be equipped with suitable measuring equipment, if necessary reference measuring equipment. |

| Effort for test enforcement | **Low**, "only" computing power necessary | **Medium**, depending on the number of tests and the available proving ground | **Very high**, since vehicles & test drivers are on the road in endurance tests |

| Standardization methodology and tools | **No or only conditional standardization** of manufacturer-specific simulation models and tools (methodology given by PEGASUS) | **No or only conditional standardization** as test equipment and infrastructure are OEM-specific implemented and qualified | **No**: measurement technology and implementation already OEM-specific established |

| Current Limitations | Ego vehicle, environment and sensors not yet fully modelled (a question of time for overcoming this lim.) | Test site not part of the ODD, HD card required in OEM-specific format Infrastructure must be suitable for L3. | No scenario selection possible, high risk of overlooking relevant but rare scenarios |
The multi pillar concept by OICA

The multi pillar concept for Certification of Automated Driving Functions (Certification Approach proposed by OICA)

- **Real-World-Test Drive**
  - Overall impression of system behavior on public roads
  - Assessment of system’s ability to cope with real world traffic situations with a standardized checklist
  - "Driving license test" for automated driving system
  - Guidance through given set of situations which shall be passed

- **Physical Certification Tests**
  - Matching of audit/assessment results with real world behavior
  - Assessment of system behavior in fixed set of challenging cases, which either aren’t testable on public roads or cannot be guaranteed to occur during the real world test drive.
  - Reproducibility of situations is given

- **Audit and Assessment**
  - Audit of development process (methods, standards)
  - Assessment of safety concept (functional safety, safety of use) and measures taken
  - Check of integration of general safety requirements and traffic rules
  - Use of simulation results (high mileage approval, capability to cope with critical situations, which aren’t testable on proving grounds or in public)
  - Assessment of development data/field testing, OEM-self-declarations

- Certification depends on all three pillars – partial assessment doesn’t have significance
- Scope of work should reduce with every step (audit/assessment: largest scope – real world test drive: final confirmation)
- Safety for test witnesses and other road users – no endangering tests on public roads

* in the sense of an inspection drive in real traffic

The pillars and their individual purpose

### PILLAR 1

**Audit/Assessment**

- Understand the system to be certified
- Assess that the applied processes and design/test methods for the overall system development (HW and SW) are effective, complete and consistent
- Assess system’s strategies/rest performance to address (multiple) fault-conditions and disturbances due to deteriorating external influences; vehicle behavior in variations of critical scenarios
- Simulation: Test parameter variations (e.g. distances, speeds) of scenarios and edge-cases that are difficult to test entirely on a test track

### PILLAR 2

**Physical Certification Tests**

- Assess critical scenarios that are technically difficult for the system, have a high injury severity and are representative for real traffic
- Compare with critical test cases derived from simulation and validate simulation tools

### PILLAR 3

**Real World Test Drive**

- Assess the overall system capabilities and behavior in non-simulated traffic on public roads and show that the system has not been optimized on specific test scenarios
- Assess system safety requirements like e.g. HMI and ODD
- Assess that the system achieves a performance comparable to an experienced driver

An adapted example*: the pillars and their individual purpose

* Adaption of an urban example to Autobahn-Chauffeur
PEGASUS simulation and field test data are used as subset in the **Audit/Assessment** column.

PEGASUS validation / simulation tools and special tests are used in the **Physical Certification Tests** column.

Column **Real-World-Test Drive** as certificate-specific proof with focus on safe traffic flow and compliance with traffic regulations.
Objective Simulation in the context of future certification

- Variants/variations of certain scenarios for an automated driving functions are extremely comprehensive/multifaceted and can not be reproduced completely/practically in a reasonable timeframe on the proving ground (e.g. different driving speeds, curve radii, environmental influences/weather, distances)
  - The objective of the simulation is therefore the identification of collision-relevant characteristics of scenarios on the basis of criticality metrics (e.g. residual distance) by parameter variation (scenario diversity).

- The assessment of individual components (e.g. sensors) should not be part of the simulation within the scope of certification, because individual requirements for components and their performance (even in the event of a fault) can vary greatly depending on the overall system.
  - The aim of the simulation should therefore be the evaluation of the overall system reaction/performance.

- Simulation does not have the aim of replacing the field test 1:1
  - Objective is the identification of specific individual situations within the framework of event-based simulation
  - Furthermore, 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.
The role of the database

- The database is a key element in the PEGASUS Method for Testing Highly Automated Driving Functions. It is the basis for testing variants/variations of relevant scenarios for an automated driving functions.

- PEGASUS Method needs
  - Generalized, systematical model for parameterizable scenarios
  - Data on relevance of scenarios
  - Data on relevance of scenario parameters
  - Data on relevance of criticality in scenarios

- PEGASUS specified in its work and discussed in workshops and bilateral meetings with international partners:
  - Common harmonized input format that could be applied to different data sources and measurement requirements
  - Common harmonized output formats

- PEGASUS implemented a robust database mechanics that processes data and executes data filtering.
  - Comparable with the necessity of having a representative data base with scenarios that automated vehicles could experience of the multi pillar approach for certification of automated vehicles.
PEGASUS database and the end of the PEGASUS project.

- what will happen with the database after the end of the project?
- In discussion different options for organizing the filling and the operation of the PEGASUS database, concretization: second half of 2019
  - independent non-profit Society, optionally as private / public partnership (model GIDAS)
  - 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
  - open to anyone who is interested in participating
  - collection of representative scenario data of integrity
  - integrity sharing, generalized scenario data

- contact: Helmut.Schittenhelm@Daimler.com
**PEGASUS components**: The use of simulation tools is a meaningful and necessary addition to the established components proving ground and field test.

**Target database**: Internationalisation in the sense of standardised interfaces and modelling language for scenarios, so that scenarios can be brought together, exchanged and compared in perspective.

**Objective Simulation**: Identification of collision-relevant characteristics of scenarios from database and system evaluation based on criticality characteristics (e.g. distances, speeds) by parameter variation (scenario diversity).

**Simulation challenges**: System failures/impairments due to environmental influences are currently not fully simulable via models. Supplementation via field tests makes sense thus also continuous improvement of environmental/sensor models.

**Standardization of simulation tool chain**: useful and possible in many areas. No or only conditional standardization of manufacturer-proprietary simulation models and tools for e.g. vehicle behavior, sensors and driving functions.

**Validation**: Simulation tool chain for certification purposes: In a first step possible through comparison with results of specific proving ground tests based on overall system reaction.

**Use of PEGASUS modules**: as a component for future certification of automated driving functions in the "Audit/Assessment" and "Proving Ground Tests" pillars.
Vielen Dank für Ihre Aufmerksamkeit!
Many thanks for your attention!