Testing of level-3 Systems

stepping through the current
PEGASUS approach
Up to now, system behavior in traffic is considered a purely stochastic process. This corresponds to the attempt of covering the state space representatively by pure driving.

Transferring the previous procedure to highly automated driving would require at least 240* million kilometers of driving instead of 1 million kilometers!

- „Absicherung automatisiertes Fahren“, Prof. Winner, 6. FAS-Tagung, München, 29.11.2013
- How Many Miles of Driving Would It Take to Demonstrate Autonomous Vehicle Reliability?, Kalra, Paddock
Approach to the solution

- **Enhanced virtualization of the testing and safeguarding process**
  - to handle the large test space and volume,
  - to identify relevant test scenarios.

- **Iterative determination of the relevant scenarios for the highly automated function by intelligent cross-linking of all test instances** such as simulation, proving ground and real world field tests. Comparison of the results with the contents of a central test specification database (scenario-based approach).

- **Simulative determination of functional limits** and carrying out of the **proof of controllability**.

**Challenge for simulation techniques / tools:**
- Close-to-reality models (sensor technologies, environmental representations)
- Verification and validation with proving ground and field tests

**Challenge for testing techniques / tools:**
- Reliable, reproducible and exact execution of the maneuvers
- Standardization of the interfaces with simulation
Scope of work of SP 3 „Testing“ –
Method development for testing and demonstration of the safeguarding process.

- Construction and filling of test-specification-database.
- Establishing and verification of testing methods, interfaces, tools in simulation, on proving grounds and in real traffic.
- Development and coordination of industrywide established models, tools and interfaces for the simulation.
- Compilation of a test catalog and requirements for lab, proving ground and field tests.
- Construction of reference elements for practical testing and demonstration of functions.
- Demonstration of an exemplary safeguarding by simulation, proving ground and in real world tests.
Standardization - a requirement for increasing virtualization

**OpenScenario:** For the (formal) description of the dynamic and static content (f.x. objects, traffic simulation vehicles (TSV)) of a scenario OPENSCEENARIO v 0.9.1 is used. Usage:

- Database (Test-Specification-Database)
- Scenario / maneuver control in simulation and on the proving ground

**OpenDRIVE:** For the (formal) description of roads and tracks OPENDRIVE v1.4 is used.

- Database (Test-Specification-Database)
- Scenario / maneuver control in simulation and on the proving ground

**OSI und FMU 2.0:** For the integration of sensor models and other modules, FMU 2.0 (Functional Mock Up) and OSI (Open Simulation Interface) are used as standard for co-simulation and communication.
Test-specification-database - expertise of the scenario approach.

Initial basis for an international standard in this area

Data source

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

Collect in a harmonized way, archive in a standardized manner, evaluate uniformly to ensure that standardized test specifications are derived!
Standardized Processing is a Key Component of the Database

Data base

1. Generation of common environment and traffic description
2. Data checks and administration
3. Generation of deduced signals
4. Determination of scenario affiliation
5. Merging of scenarios and determining of exposures
6. Definition of test specifications

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By data owner

Input data

Measurement Data Scenarios

Logical scenarios

Parameter space

Post processing of individual scenarios

Legend

Elements of the database

External elements
Tool chain „Testing on the Virtual Proving Ground“
Systematic qualification of the established and proven

PEGASUS enables the connection to existing proven tools / test instances.

**Motivation:**

- Using a common architecture for a toolchain for safeguarding makes it 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.
Example of proceeding in simulation with regard to the process

Test case control, Test space coverage

simplified parameterization!
Example: the irrelevant and relevant scenario

**Parameters of irrelevant case:**
\[ m = 1600 \text{ kg}; \ s = 5 \text{ s}; \ d_A = 20 \text{ m}; \ v = 50 \text{ km/h}; \ TT_{C_{\min}} = 1.892 \text{ s} \]

**Parameters of relevant case:**
\[ m = 2200 \text{ kg}; \ s = 2 \text{ s}; \ d_A = 0 \text{ m}; \ v = 80 \text{ km/h}; \ TT_{C_{\min}} = 0.676 \text{ s} \]
Formation of the test space
Linking of relevant, representative real word knowledge with technical requirements

*The previously defined cover “logical scenarios” is a complete coverage of real-world situations that were feasible in the system / functional boundaries.

Vehicle (VUT)
- vehicle dynamics
- driving environment sensor system

Sensors (phenomenological)
- radar
- lidar
- camera
- ultrasonic sensor

Environment
- Road / track parameter
- static objects
- dynamic objects
- environmental conditions

Driver

Function (L3)

Functional Safety (26262, SOTIF)
Interaction Test-Specification-Database und Test Instance

Test Concept and Test Case Allocation

- Test Specification Database
  - Logical Scenario
  - Parameter space
  - Metrics and pass criteria
  - Relevanz

Simulation (SiL, HiL, ViL, …, Driving Simulator)

- selecting test specification running test automation
- simulation (Identification of specific scenarios)
- automatic test evaluation and assessment

Proving Ground

- selecting concrete scenarios test planning and preparation
- test execution
- test evaluation and assessment

Field Test (Real World Testing)

- Identification of relevant case scenario in measurement data
- Replay2Sim (measurement data 2 concrete scenario)
Innovative test methods for reproducible testing – technologically at the same level as a HAD system

Mobile Control Center

Generic Approach for assembling test scenarios

Maneuver planning as input for maneuver control
Verification: Simulation results versus Proving Ground

Parameters of relevant case:

- $m = 2200 \text{ kg}$
- $s = 2 \text{ s}$
- $d_A = 0 \text{ m}$
- $v = 80 \text{ km/h}$
- $TTC_{\text{min}} = 0.676 \text{ s}$
Field test - a test platform for testing in real world environment

Guideline:
- Route
- Weather
- Time
- Special environment

Execution of real world test

Find "Surprises"

Guideline: Special environment
- Route
- Weather
- Time

Examples:
- Tunnel
- Traffic jam
- Low sun
- Bad road marking
- Drive through highway interchange
- If applicable, use guidelines Simulation / Proving ground

Highlight while test driving or investigation through data analyze

Guideline: Measurement Equipment
- Highly accurate timestamp
- GNSS-Position
- Reasonable sampling rate
- Data channels as defined by json-Files
- If applicable reference measurement equipment

Measurement Guidelines

Pass-criteria reached?

Execution of metrics of criticality

Scenario application and creation of new scenarios/parameters

Input for Replay2Sim

Analyze of measured data
Overview of the sub-project's exhibition stands of SP 3 „Testing“
Much has not been addressed, everything is shown in the exhibition!

Basics for Testing
10 Test Concept and Test Case Allocation
11 Scenario Formats
12 Test Specification Database
13 Test Case Generation, Test Space Coverage and Test Effort Reduction
14 Test Infrastructures / Maps

Testing & Safeguarding
15 Sensor Simulation Models
16 Software-in-the-Loop
17 Hardware-in-the-Loop
18 Proving Ground, Control and Generic
19 Tools for Proving Ground & Field Tests
   • Localization and Collision Avoidance
   • Mobile Traffic Acquisition
20 Wizard-of-Oz-Vehicle
21 Field Test Concept
Many thanks for your attention