Highly Automated Driving – Validation and Test

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Overall Methodology

- **Scenario Development**
  - HAD-SYSTEM
  - USE-CASES
  - BASE-SCENARIOS
  - GENERIC PARAMETERS

- **Test-Case Identification**
  - INFORMATION BASE
  - SPECIFIC PARAMETERS
  - MANEUVERS
  - TEST-CASES

- **Test Procedure**
  - TEST SPECIFICATION
  - TEST DISTRIBUTION, EXECUTION
  - ASSESSMENT AND EVALUATION
Scenario Development

HAD Systems

Use-Cases

Base-Scenarios

Test-Cases

examples:

Automated approach and merging

Test-Case 1-n

Driveway

Scenario-Catalog
Test-Case Identification

**INFORMATION BASE**

- **Stat. and Dyn. Parameters, Maneuvers**

**ANALYSIS**

**RATING**

- **Distributions, relevant characteristics**

**TEST-CASES**

**Graph:**
- **length of acceleration lanes**
- **frequency (Σ133)**

- Length in m:
  - 0
  - 100
  - 200
  - 300
  - 400
  - 500
  - 600
  - 700
  - 800
  - 900
  - 10...

- Frequency:
  - 0
  - 5
  - 10
  - 15
  - 20
  - 25

**Test-Case Catalog**

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Test Procedure

**Test-Cases**

**Assignment**

**Simulation-Framework**

**Proving Ground**

**Public Road, Test Field**

**Assessment**

[1] Variation

[2] Reference
Testspezifikation

Example from Test Catalog
Concept “TestAssist“ Software

- lane change to the right
- shortly deceleration to 85 kph
- 5 kph too slow
- planned position
- real position
- position 11m backwards
- Target

HMI „driver navi“

Slave 1

Master
Concept "TestAssist" Software

Target Master position 11m backwards shortly deceleration to 85 kph 5 kph too slow

Slave 1 planned position real position
Concept “TestAssist“ Hardware

WLAN - Router

“TestAssist” HMI

localization reference

car computer “TestAssist”
Tool “TestAssist”

- Planning scenarios for each vehicle (Target, Master, Slave 1 and 2)
- A high accurate map is used (OpenDrive)
- Simulation of planned scenarios with moving vehicles – useful for:
  - Briefing test drivers
  - Optimizing the test case
- Definition of the test case is saved in a “json” file
- Positioning & moving data from a test run are saved in a “Logging” file (10 to 20ms step)
- Replaying of test runs and comparison real vs. planned test cases
  ➔ Related to absolute positions based on topographical surroundings
Concept “Testmanager“ IfF TUBS

- Object1
  - $v_{\text{object1}}$ [km/h]
  - $x_{\text{object1}}$ [m]
  - i.a. observed parameters
- Object2
  - $v_{\text{object2}}$ [km/h]
  - $x_{\text{object2}}$ [m]
- $\Delta x$ [m]
- VuT$^{[1]}$ / Master
- LIDAR coverage
Tool “Testmanager“ IfF TUBS

- Tool-Chain for the observance of test parameters and precise test execution in reality
- Planning and Definition of complex highway scenarios
- Test Instructions for a high precise execution
- Evaluation of run test-cases [Quality-Index]
- Visualization via mobile device or Car-PC
- No additional hardware needed in object vehicles
- Based on LIDAR-Sensors and WLAN Communication

→ Related to relative positions of object vehicles
Simulation as a Tool

- The simulation environment consists of models that generate signals for input over time or receive them as output of the system under Test (SuT)
- Open loop vs. closed loop:
  - Closed loop considers feedback of the SuT
- Virtualization of the outer environment is utilized to test the SuT
Simulation as a Tool

- Continuous testing describes a method which aims to give early feedback about software development from source code level to product level.
- Automated execution of:
  - Software build
  - Tests
  - Analysis
  - Reporting to stakeholders
Simulation as a Tool

Continuous testing workflow

GitHub

Jenkins

Gate 1:
Compile

Gate 1: Static and Unit tests

Gate 1 successful?

Yes

No

New Code?

Jenkins

Observes for changes

Developer

Simulation Report

Gate 2:
Gate 2:
Integration ("smoke") test

Gate 2 successful?

No

Yes

Gate 3:
Gate 3:
System test

Gate 3 successful?

Yes

Regression test

No

Yes

Effort

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Simulation as a Tool

- By this approach early feedback could be given to developers
- Failures could be localized easier
- Real vehicle testing is done only with high mature software

- Check for functional failures at vehicle level
- Check for interface failures after integration of all software modules
- Check for failures at software module level
- Perform a complex regression test only with release candidates
Simulation: Sensor Modelling

- High-Level Sensor Models
  - Object Lists
  - Statistical Approach

- Low-Level Sensor Models
  - Sensor specific i.e. Point Cloud
  - Ray Tracing Approach
Simulation: Validation of Sensor Models

▪ Visit our Simulation Demo on the Main Floor
Simulation: Co-Simulation

Traffic

Vehicle Dynamics
Simulation: Prototype-in-the-Loop

Real-World Vehicle-under-Test

Virtual Traffic Participants
Assessment of Real World Data

1. Requirements Analysis
2. Definition of Evaluation Subjects
3. Modelling of Evaluation Criteria
4. Deduction of Parameters
5. Testing / Datalogging
6. Evaluation / Recommended Actions
Assessment of Real World Data

Which requirements are placed on the HAF?

- Requirements linked to Ko-HAF project goals
- HAF has to be...
  - ...safe
  - ...efficient
  - ...comfortable,
while performing functions at speed up to 130 km/h on highways.
Assessment of Real World Data

How to ensure that the HAF meets the requirements?

- Based on the Use-Cases and Base-Scenarios, a Scenario-Catalog had to be defined
- This led to a Test-Catalog with Test-Cases containing
  - Specific parameters
  - Maneuvers
  - Distributions
  - and relevant characteristics
- The Test-Cases were assigned to different test environments
  - Simulation
  - Proving ground
  - Public road
- Matching these Test-Cases and the Requirements, a variety of Evaluation Subjects were defined
Assessment of Real World Data

Which criteria to use for a HAF?

- A jointly agreed Logging was developed with all Partners involved
- Using a standardized “json” architecture
- Contents of the file are based on the Evaluation Subjects
- Since all Partners developing own HAF-Vehicles, focus on quality and quantity criteria
  - Technical maturity of the HAF
  - Reliability of the functions
  - No benchmark
Assessment of Real World Data

How to rate the HAF?

- The Ko-HAF Logfile contains a variety of parameters such as...
  - Local ID
  - Lane ID
  - Event time
  - GPS position (long; lat)
  - Event Message
  - Ego speed
  - Vehicle position around the Ego
  - etc...

### Deduction of Parameters

**Example from the Logfile**

<table>
<thead>
<tr>
<th>Werte - Eventeintrag</th>
<th>JSON Datei - Kurzname</th>
<th>Einheit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>EventName</td>
<td>Text</td>
</tr>
<tr>
<td>Zeistempel</td>
<td>EreignisZeit</td>
<td>YYYY-MM-DD-HH:MM:SS.mmm</td>
</tr>
<tr>
<td>Relativer km-Stand</td>
<td>RelativerKmStand</td>
<td>Meter</td>
</tr>
<tr>
<td>Spur-ID</td>
<td>SpurId</td>
<td>In Ko-HAF keine absolute, sondern relative Nummerierung der Spuren. Details in Dokument Ko-HAF_Spezifikation_Kommunikationsschnittstellen.docx: <a href="https://service.projectplace.com/pp/pp.cgi/r1232389708">https://service.projectplace.com/pp/pp.cgi/r1232389708</a> Seite 19 (siehe oberer Abschnitt)</td>
</tr>
<tr>
<td>Position</td>
<td>GpsPositionLat</td>
<td>ms arc</td>
</tr>
<tr>
<td></td>
<td>GpsPositionLong</td>
<td>ms arc</td>
</tr>
<tr>
<td>Message</td>
<td>EventMessage</td>
<td>Freitext</td>
</tr>
</tbody>
</table>
Assessment of Real World Data

Which test environment fits best to HAF?

- After the assignment of the Test-Cases, testing took place in simulation, on proving ground and on public road

  - With conclusion of the testing, each partner is providing their logfiles for evaluation

  - The logging data of each test environment is concentrated at the Ko-HAF Safety Server

Ko-HAF Test area on public road
Assessment of Real World Data

Has the HAF met the requirements?

- After completing the development and testing in Ko-HAF, the Evaluation will take place following the final presentation
- As determined by the assessment process, the evaluation is performed on the basis of the jointly agreed logging data

→ The aim of the Evaluation is to prove whether the HAF was able to fulfill all requirements and to recommend actions for further developments
Thank you for your attention!

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