Introduction and Overview of 3.5 Years of PEGASUS
The PEGASUS-history

Mid 2014: First Discussion about a Common Proving Center for AD

Autumn 2014: Focusing on a Method for Safeguarding

January 2015: Project Outline

September 2015: Project Description
The PEGASUS-history

January 2016:
Project start with 17 partners
OEM: Audi, BMW, Daimler, Opel, Volkswagen
Tier 1: ADC, Bosch, Continental
Test Lab: TÜV SÜD
SMB: fka, iMAR, IPG, QTronic, TraceTronic, VIRES
Scientific institutes: DLR, TU Darmstadt
Subcontracts: IFR, ika, OFFIS

Mid 2016:
Convention of an Advisory Board
• Federal Ministry for Economic Affairs and Energy
• Federal Ministry of Transport and Digital Infrastructure
• Federal Ministry of Justice and Consumer Protection
• German Association of the Automotive Industry (VDA)
• German Road Safety Council (DVR)
• ADAC

Key-facts:
42 Months Term
1.791 man-month or 149 man-years
34.5 Mio. EUR Budget
4 Sub-Projects
13 Workpackages
38 Sub-Workpackages

Associated Partner:
Federal Highway Research Institute (BASt)
dSPACE
The PEGASUS-history

November 2017:
PEGASUS-Half-Time-Event in Aachen

For the first time: Presentation of the PEGASUS-Approach

PEGASUS becomes International
The PEGASUS-history

Germany: BMVI, BMWi, BMJV, KBA, BASt, DVR, ADAC, Ethics commission (Prof. Hilgendorf)

Europe:
- OICA \rightarrow UN-ECE Horizontale Initiative;
- EU-Comission, EU Strategic Transport and Innovation Agenda

Japan:
- METI, JAMA, Toyota, Honda, Nissan

China: CATARC

US: NHTSA, US DOT, AutoAlliance, RAND

World wide:
- DIN SAE: Spec Project Terms and definitions

Addtl. Cooperation Requests & bilateral Exchange:
- FP Nouvelle France Industrielle, AutoAlliance, Jaguar LandRover, Hyundai, Volvo, RDW, etc.
The statement that we all need

YOU ARE GOOD ENOUGH
With **PEGASUS**, we contribute to answer the question...

How safe is safe enough and how can we verify that it achieves the desired performance consistently?

...by introducing a

**Scenario Based Method** to
Assess Highly Automated Driving Functions
PEGASUS Method for Assessment of Highly Automated Driving Function (HAD-F)

<table>
<thead>
<tr>
<th>Argumentation</th>
<th>Evidence</th>
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</thead>
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**Safety argumentation**

**Safety evidence**

**Data / Content**

**Procedure**

**Workflow**

**Process Instruction**

Preprocessing / Reconstruction

Systematic Identification of Scenarios

Source of Information

Evaluation & Conversion

Scenarios

V1.4 Status 21.09.2018

central decentral

Use Case, Knowledge, Data

Requirements Analysis

Process Guidelines + Metrics for HAD Assessment

Space of Logical Test Cases

Test Cases

Test Data

Test Results

Evaluation and Classification

Risk Assessment

Release

Test Evaluation

Test Execution

Test Case Derivation
Goal: Safety argument

Start: Use-Case
Goal: Safety argument
Start: Use-Case
Use Case

- Safeguarding of Level 3 (Highly Automated Driving) function
- Based on an application-oriented example, highway chauffeur
  - Basic function:
    - Highways or highway-like roads incl. road markings
    - Speed 0 - 130 km/h
    - Automated following in stop & go traffic jams
    - Automated lane changing
    - Automated emergency braking and collision avoidance
  - Construction sites
  - Automated exiting off the highway
  - Extreme weather conditions

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

Assessment of Highly Automated Driving Function

Requirements definition

Knowledge:
Laws, Standards, Guidelines, ...

Requirements Analysis

Process Guidelines + Metrics for HAD Assessment

Data processing

Database

central
decentral

Data / Content
Procedure
Workflow
Process Instruction

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Application of different risk acceptance principles

Individual mortality risk per person per year

-10 -9 -8 -7 -6 -5 -4 -3 -2

Major technology
Involuntary
Job-related
Voluntary

acceptable

inacceptable

ALARP lower limit
ALARP upper limit
MEM/20
MEM
GAMAB

ALARP = As Low As Reasonably Practicable
MEM = Minimum Endogenous Mortality
GAMAB = Globalement Au Moins Aussi Bon

Method Gap

How do we use test results with regard to an approval recommendation?

The challenge is to map single test results to global acceptance criteria.
PEGSUS Method for Assessment of Highly Automated Driving Function (HAD-F)

Assessment of Highly Automated Driving Function

Requirements definition

1. Knowledge: Laws, Standards, Guidelines, ...
2. Data: Use Case, Knowledge, Data
3. Requirements Analysis
4. Process Guidelines + Metrics for HAD Assessment

Source of Information

Data processing

Use Case, Knowledge, Data

Central, Decentral

Data / Content
Procedure
Workflow
Process Instruction

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1.5 Status
14.02.2019

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Input data

NDS / FOT

Real world

Simulation

Simulator

source: UDRIVE, IPG, Audi, DLR
PEGASUS Method for Assessment of Highly Automated Driving Function (HAD-F)

**Assessment of Highly Automated Driving Function**

**Source of Information**

1. Knowledge: Laws, Standards, Guidelines, ...
2. Data: Test Drive Simulation Simulator FOT/NDS Accident

**Data processing**

3. Systematic Identification of Scenarios
4. Preprocessing / Reconstruction
5. Data in PEGASUS-Format

**Evaluation & Conversion**

6. Process Guidelines + Metrics for HAD Assessment

**Requirements definition**

7. Requirements Analysis

**Database**

8. Space of Logical Test Cases
9. Logical Scenarios + Parameter Space

**Integration**

10. Pass Criteria

**Scenarios**

11. Application of Metrics + Mapping to Logical Scenarios

**Use Case, Knowledge, Data**

- Central
decentral

- Data / Content
- Procedure
- Workflow
- Process Instruction

**Argumentation**

**Evidence**

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Scenarios and possibilities for description – Layer model

Layer 1: Road-Level
- Geometry, topology
- Quality, boundaries

Layer 2: Traffic Infrastructure
- Boundaries (structural)
- Traffic signs, elevated barriers

Layer 3: Temporary manipulation of Layer 1 and 2
- Geometry, topology (overlaid)
- Time frame > 1 day

Layer 4: Objects
- Static, dynamic, movable
- Interactions, maneuvers

Layer 5: Environment
- Weather, lighting and other surrounding conditions

Layer 6: Digital Information
- (e.g.) V2X information, digital map

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### Functional scenarios

**Base road network:**
- Three-lane motorway in a curve, 100 km/h speed limit indicated by traffic signs

**Stationary objects:**
- 

**Moveable objects:**
- Ego vehicle, Traffic jam;
- Interaction: Ego in maneuver „approaching“ on the middle lane, traffic jam moves slowly

**Environment:**
- Summer, rain

### Logical scenarios

**Base road network:**
- Lane width: [2..4] m
- Curve radius: [0,6..0,9] km
- Position traffic sign: [0..200] m

**Stationary objects:**
- 

**Moveable objects:**
- End of traffic jam: [10..200] m
- Traffic jam speed: [0..30] km/h
- Ego distance: [50..300] m
- Ego speed: [80..130] km/h

**Environment:**
- Temperature: [10..40] °C
- Droplet size: [20..100] µm
- Rainfall: [0,1..10] mm/h

### Concrete scenarios

**Base road network:**
- Lane width: 3
- Curve radius: 0,7 km
- Position traffic sign: 150 m

**Stationary objects:**
- 

**Moveable objects:**
- End of traffic jam: 40 m
- Traffic jam speed: 30 km/h
- Ego distance: 200 m
- Ego speed: 100 km/h

**Environment:**
- Temperature: 20 °C
- Droplet size: 30 µm
- Rainfall: 2 mm/h

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**Level of abstraction**

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**Number of scenarios**
From logical to concrete Scenario

Logical Scenario

Import of a Logical Scenario

Scenario Concretization

Parameters:
- Lane Width
- Speed Limit
- Velocity Actor
- Initial Distance Ego-Actor
- Sheer-off Point in Time

Concrete Scenarios

Export of concrete scenarios
Test Objectives

- Search for safety violations / worst case(s)

- Characterize the regions with safety violations, e.g. find their borders

- Deliver coverage reports for one or for a suite of experiments

→ Assessment result for concrete sample Scenario depending on multiple parameters. Color range form green (not critical) to red
Test concept

- Test object: Functional implementation of highway chauffeur
  - Test level: Functional Test
  - Test platform: Simulation

- Automatized variation of parameter

- Critical cases

- Test execution looking for critical cases (e.g. accidents)

- Specific scenarios

- Feedback

- Test platform
  - Simulation
  - Replay 2Sim

- Space of logical test cases

- Test cases to test platform

- Allocations

- Scenarios

- Test platform
  - Test ground
  - Test ground/

- Parameter space

- Exposure of parameter

- Logical scenario

- No direct link to space of logical test cases

- Test object: Overall system highway chauffeur including vehicle behavior
  - Test level: Vehicle test
  - Test platform: Test ground/field

- Test execution of real world drive with guidelines:
  - Route
  - Weather
  - Time
  - Specific features

- Evaluated concrete scenarios (Pass/Fail)

- „Surprises“

- Measured data for database

- Measured data for Replay 2Sim
Software in the Loop – Standardized Interfaces as Key-Success-Factor
The overall rating of a test-case is currently derived by aggregating the time-discrete results of the multiple stages.

The contribution of the different stages to the overall test-case result differs depending on their character.

Further knowledge about exposure and significance will improve strength of argument.
Automated Driving Systems (ADS) are widely accepted in the public.

There is an understanding of what factors foster acceptance of ADS.

Top level goals are set to be met in order to achieve acceptance of ADS.

Logical structure of the Safety Argumentation links top level goals with methods & tools and their results.

The Safety Argumentation is implemented using methods & tools.

Results become evident when they can be traced back to the achievement of a goal.
Many thanks for your attention!