Public relations
- Public & politic reactions in case of accidents
- Customer acceptance
- Cyber security
- Ethic

Technical
- Functional safety & Reliability in all conditions (Traffic, Weather & Road)
- Infinite high number of test cases
- Complex and new technology
- Time & Cost pressure during development

Legislative
- Homologation criteria
- Responsibility in case of accident

The rocky road to ADAS/AD
Development, Validation and Homologation
Responsibility

Driver's License

Regulations

Now

Level 5 Future

? ? ? ?
A lot of progress concerning the TECHNOLOGY is visible, but:

“The critical path to introduce autonomous driving vehicles will not be the technology but the development of a metric which empowers for an approval”

Prof. Dr. rer. nat. H. Winner, November 2013

... and the next question will be how to execute scenarios, test cases etc. of this metric in a limited time
“The biggest hurdle is validation to confirm that the system does not cause failures. One has to execute 250 million test kilometers”

Bosch Executive Director.

Same approaches as 36 years ago?

Mercedes-Benz 190 E (1982) - Demonstration and advantages of ABS

New and Innovative Approaches in Testing and Validation are necessary!
Facing the Challenges of Development and Homologation of Autonomous Driving Using Virtual Approaches

Vehicle Validation and Self Driving Vehicle

Driving Software and Digital Driver

Legislation, Regulations and Conformity
Regulation for Homologation and Approval of AV

Dr. Houssem Abdellatif
Global Head Autonomous Driving and ADAS
HOMOLOGATION

Qu'est-ce que c'est?

**Definition**
Homologation refers to the certification process of a product (vehicle) granting that it complies with all local standards and legal regulations such as safety and environmental regulation.

No homologation → No CoC → No sales

**Self certification vs. type approval 3rd party principle**

- European Union: Directive 2007/46/EC Type approval, tests are based on United Nations Economic Commission for Europe (UN/ECE) procedures;
- North America: Federal Motor Vehicle Safety Standards (FMVSS) regulations released by the NHTSA;
- Australian Design Rules (ADR) regulations;
- Japan follows UN/ECE regulations and their own Test Requirements and Instructions for Automobile Standards (TRIAS) regulations;
- Other countries that accept or base their own regulation on those mentioned above, following the latest release or previous versions of the regulations.
Take a **SIMPLE IDEA** ...

Maneuver / scenario data base
- description
- parameters
- fail/pass criteria (KPI)

A 6 Points Approach to realize this Idea to empower for Approval

results: \( m \) vehicle variants \( \times \) 
\( n \) scenario variants \( \times \) ...

subset for physical testing

subset for homologation

subset for simulation testing

test track

real vehicle

virtual vehicle

simulation

results: \( m \) vehicle variants \( \times \) 
\( n \) scenario variants \( \times \) ...
1 Establish SCENARIO-BASED TESTING as State of the Art

A scenario is a description of a driving situation

- a) Left turn in road junction
- b) Overtaking on a dual carriageway

Using scenarios from concept to approval

- Concept Stage
  - system
  - subsystem
  - components
  - software

- Type Approval
  - system validation
  - subsystem integration tests
  - component integration tests
  - software integration tests
Show Me The

Data Base!!

Availability and access
- Data base should be hosted by a neutral instance and made accessible by public (by everyone!)

Scenario Definition
- A uniform definition of scenarios and their respective abstraction layers is needed
- A universal scenario description should be provided and supervised

Pass/Fail Criteria
- Multiple criteria to be defined and associated to each scenario
- Relevance of pass/fail criteria to be defined by the use case (safety, comfort, customer experience, country & cultural relevance)

Monitoring and Supervision
- A committee and/or organization is to be defined that is responsible for updating and grooming the data base: increase, precise, delete, correct scenarios and pass/fail criteria
What is enough?

The **CRITICALITY COVERAGE**

- **Criticality Coverage**
  - Define a criticality selection method
  - Define a criticality threshold for validation and for verification

- **Criticality Metrics**
  - A uniform definition of criticality metrics with respect to pass/fail criteria and the respective use case
  - What are the most critical scenarios?

- **Functional Scenarios**
  - Critical parameter combinations

- **Critical Scenarios**

---

**p1**

**p2**
Use **SIMULATION** for Approval

**Using simulation**
- Enable the use of simulation in the homologation process, e.g.
  - UN/ECE R140 for the approval of Electronic Stability Control
  - UN/ECE R79 (new Release) for the approval of (automatic) steering
  - Next?
- Extend the purpose of simulation use to more than just variants verification to enable scale-out effects

**Using the right simulation**
- Obligate the validation of simulation tool and its trustworthiness as an integral part of the homologation process
- Define how to demonstrate the trustworthiness in
  - Perception (e.g. Sensor simulation)
  - Interpretation (e.g. sensor fusion)
  - Reasoning (e.g. decision algorithms)
  - Acting (e.g. E/E and control algorithms)
  - Executing (e.g. Vehicle Dynamics)
- Enforce standards for simulation and simulation interfaces, enforce affordable and/or open-source solution
Consider

5

FUNCTIONAL SAFETY Assessment

Industry

International Standards

DO-178B/C EN 50128 EN 50129 ISO 26262 IEC 62304 IEC 60880

Mandatory Submission of Documents to Regulator

Change This!
Close the Loop by

REAL-WORLD DRIVING

Event Data Recorder
- Obligate the integration of Event Data Recorder in automated vehicles
- Define the set of necessary data to be logged for safety monitoring and accident reconstruction

Feedback into Homologation
- All approval related and relevant field tests to be documented and to be submitted with logged data
- Submit data to scenario supervision committee (see Point 1)

Real-World Driving (Field Tests)
- Define categories, e.g. highway, city center, suburbs, rural areas, etc..
- Manufacturers conduct supervised/witnessed real-world driving tests

Critical Issues
- In case of critical issue, consider this in the product correction
- Provide proof of consideration with test results, e.g. simulation, real vehicle testing
Combining Tools (Tool Chain) for Concise Approval

Scenario data base
- description
- parameters
- fail/pass criteria (KPI)

subset for approval

subset for testbench testing

subset for physical testing

subset for simulation testing

results: $m$ vehicle variants $X$ $n$ scenario variants $X$ ...

real vehicle

virtual vehicle

test track

test bench

simulation

Combining Tools (Tool Chain) for Concise Approval
Virtual Testing & The Toolchain

Dr. Tobias Dueser
Department Manager
Advanced Solution Lab
A seamless but open toolchain with new approaches is necessary

The most efficient validation will be done by those who will use the best combination...
Insights: Approach for the best combination...

Simulation

Scale Testing of Variants (Vehicle Configurations and Scenarios)

Virtual TESTING

Integrate, Analyze and Improve

Optimize/Improve

+ specific test cases which cannot be done in simulation

Proving Ground

Finalize and Confirm

Real World

+ specific test cases which cannot be done in simulation and/or Virtual Testing

Remark:
Focus of this slide is system (vehicle) validation. In addition there will be component test beds like HiL, Sensor Test Beds, etc.
"The validity of the applied modelling and simulation tool shall be verified by means of comparisons with practical vehicle tests. The tests utilized for the validation shall be the dynamic maneuvers (...)"

Source: Uniform provisions concerning the approval of passenger cars with regard to Electronic Stability Control (ESC) Systems, ECE R140
Toolchain Validation
Example Vehicle Dynamics

Vehicle prototypes

Virtual prototype
Boundary Conditions:

In the area of simulation there is not only ONE tool or ONE model. Different tools have different advantages, different models are for different use cases (e.g. dynamic scenarios require complex vehicle dynamics)

Example bandwidth based on customer use cases

<table>
<thead>
<tr>
<th>#</th>
<th>Powertrain</th>
<th>Vehicle Dynamics</th>
<th>Environment</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CUS Simulink</td>
<td>MSC ADAMS</td>
<td>VIRES VTD</td>
<td>CUS FMU</td>
</tr>
<tr>
<td>2</td>
<td>AVL VSM</td>
<td>AVL VSM</td>
<td>CUS Tool</td>
<td>ROS1 Node</td>
</tr>
<tr>
<td>3</td>
<td>Real on Test Bed</td>
<td>Real on Test Bed</td>
<td>VIRES VTD</td>
<td>On control unit</td>
</tr>
<tr>
<td>4</td>
<td>CUS Simulink</td>
<td>CUS Simulink</td>
<td>IPG CarMaker</td>
<td>ROS2 Node</td>
</tr>
</tbody>
</table>

... and the landscape is broad!

Requirements and Challenges (Overview):

An open integration platform is crucial!

The platform need to combine simulation and real components up to the real vehicle

Integration on simulation level is more the exchanging signals!
Challenge Co-Simulation (2)

Requirements and Challenges (Details):

Technical View:
- Multi-domain development
- Multi-tool approach
- Multi-vendor
- Dynamic coupling
  - Virtual prototype representation

Mathematical View:
- Multi-method
- Multi-solver
- Multi-rate
- Dynamic coupling
  - Coupling error

Example:

AEB Scenario:
“Full braking after acceleration to 100 km/h”

Significantly longer braking distance (~1.9 m) due to coupling error!

Correct (co-)simulation result with NEPCE*) in Model.CONNECT™

*) NEPCE … Nearly Energy Preserving Coupling Element
Implementation with NVIDIA Tools
Reference: Proving Ground

- Methodology, Test Catalogue and KPIs for AD Function
- AVL DRIVE for ADAS
- NVIDIA DRIVE
- SC
- Vehicle Interface
- Real Vehicle on Real Proving Ground

**Proving Ground**
+ very close to the real operation
- expensive, high effort, less repeatability
Implementation with NVIDIA Tools
Virtual Testing @ the AVL DRIVINGCUBE™

Virtual Testing
+ close to real operation, chassis dynos are already established for homologation (emissions)
- limited in terms of lateral dynamics
The AVL DRIVINGCUBE™…

...as vehicle integration lab

Different functions and perceptions must be evaluated at a certain time in the vehicle.

The DRIVINGCUBE is the only test environment for reproducible and repeatable test on vehicle level!

... for security testing

Hacking attacks to evaluate the security of the vehicle must also be performed during operation of the vehicle.

Do you want to try an attack on a highway at high speed?

... to reproduce critical scenarios and tests

Critical Scenarios (in general or determined out of simulation) must be analyzed on vehicle level in a reproducible way.

... as most efficient test instance for a lot of use cases

Different use cases in validation and also homologation can not be executed efficiently in other test instances (e.g. ECE 79: LKA above 130km/h)
DRIVINGCUBE as vehicle integration lab

...as vehicle integration lab: Details
...as vehicle integration lab:
Details

The AV functions must always be validated in combination with the vehicle (dynamics, performance, behavior).

Not each detail can be modelled and provided for simulation.
...as vehicle integration lab: Use Case / Example

Evaluation of a Lane Keep Assist:

KPI: Curve-Cutting-Gradient (CCG)

- Calculate Distance to centerline (D2L) by using Ground-Truth-Maps
- Evaluate (de)position of VUT during driving with LKAS

In a study with one of our research partners we figured out that even in one model series (so nearly the same vehicle – Vehicle T and D) a LKA function behaves completely different and the calibration of this function had to be adapted.
Implementation with NVIDIA Tools
Architecture Simulation

- fast, flexible and cheap in operation, there are already ESC homologation processes in simulation is only as good as the model(s)
First Results / First Comparison

Scenario 1:
From standstill follow-up with 50 km/h reducing to 30 km/h back up to 50 km/h and 30 km/h again

Scenario 2:
From standstill follow-up with 80 km/h reducing to 60 km/h back up to 80 km/h

Scenario 3:
From standstill follow up with 60 km/h, TSV pull out left, VUT accelerate to 80 km/h

Scenario 4:
From standstill follow up with 60 km/h, TSV pull out right, VUT accelerate to 80 km/h

Validation and Homologation of Autonomous Driving will be a challenge.

Partnering is extremely important to join the forces.

The most efficient validation and homologation will be done by those who will use the best combination of different test environments.

NVIDIA, TUEV SUED AND AVL will push this topic together.