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Use of Simulation for the Homologation of Automated Driving Functions

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Virtual tests are essential for the homologation of increasingly complex automated driving functions. In this article, TÜV Süd shows how simulation can be established as a legitimate and regulatory valid test and homologation tool.

INTERNATIONAL CONDITIONS

During the development of homologation and type approval regulations for future automated vehicles, international understanding has established itself that simulation should be used in official approval of automated vehicles. Both the NHTSA in the USA, the UN/ECE in Europe and the CCA in China will release regulations that provide for this. Scaling of the tests becomes possible only with simulation and this is the only way how the complexity and the enormous variety of the validation and homologation task as well as the associated scenarios can be mastered. This raises a new central question: which requirements must the simulation tool meet to deliver reliable and legally binding results?

In homologation, UN/ECE-R140 [1] already contains approaches using simulation for homologation. If the manufacturer has successfully completed the homologation tests for a vehicle variant on the proving ground, he can release further vehicle variants to the satisfaction of the Technical Service using simulation with regard to ESP [2]. The regulation already specifies a minimum accuracy for the simulation. The proof of accuracy is a binding part of the homologation report. This approach must be pursued further and extended to the far more complex systems of automated driving.

SIMULATION-BASED AND VIRTUAL HOMOLOGATION

Reliability of simulation for the release of automated driving functions is significantly more complex and layered than for the release of ESP systems. The associated requirements are explained in the following based on the single simulation steps. It is important to emphasize that homologation is not a repetition of the validation performed by the manufacturer in product development and manufacturing. Homologation is a test which is limited to providing sufficient proof of the validity, safety and roadworthiness of the automated driving function [3]. Part of the type approval is always a test catalogue defined depending on the driving function. The tests depict driving situations in which the driving function must fulfill the specified characteristics. The parameters and criteria to be evaluated for these so-called scenarios are also defined. If part of the test scope is performed virtually, all steps must be performed as shown in **FIGURE 1**.

The result of the virtual tests is the validation report. It is included in the overall test report of the technical service. Since it is used by the responsible approval authority for the homologation of the driving function, results of the simulation are of decisive importance and must therefore be generated with the necessary care and according to the current state of the art.

SCENARIO DEFINITION AND MANAGEMENT

The simulation environment must provide that basic scenarios are implemented or imported unambiguously, that variation and parameterization of the scenarios are clearly defined and can always be repeated identically, and that all necessary process steps are mapped by a correct and robust automated procedure.

The description of the scenario is available in the appendix of the corresponding regulations, must be transferred exactly into the simulation environment and must be executable there as described, **FIGURE 2**. A standardization of scenarios as well as a description of the components is currently the subject of various committees (e.g. OpenDrive [3] and OpenScenario [4]). Automated processes minimize potential sources of error and this is the only way to ensure reliable scalability of the scenarios. After the transfer, it must be proven that all components of the scenario correspond to the specifications and - in the case of dynamic components - behave in this way throughout the entire duration of the virtual test. If necessary, variations of the individual scenario parameters must be defined. These variations are often not precisely specified within the regulation and must be defined to the satisfaction of the technical service.

SIMULATION MODELS AND COMPONENTS

The actual simulation environment must have four unique and separable domains:
- Vehicle models (without automated driving function)
- sensor model(s)
- environment models
- the driving function to be homologated.

This clear separation must be made to ensure the universality of the method, to protect the IP of the vehicle manufacturer and suppliers and to categorize any fault finding in executing the tests. **FIGURE 3** shows a high-level structure of the virtual environment.

The vehicle model provides a digital twin of the vehicle, which may consist of different sub models from various manufacturers and suppliers. Regardless of the modelling depth, the following properties must be verified:
- The automation of the model parameterization: it must be ensured that a vehicle variant can be created and parameterized unambiguously and repeatable.
- A model validation with help of real measurement data as part of the simulation environment.

Sensor models must represent the required sensor types, such as camera, radar, lidar or ultrasound, and in particular meet two requirements: Firstly, the generation of the necessary information for the sensors of the driving function is carried out analogously to the interface

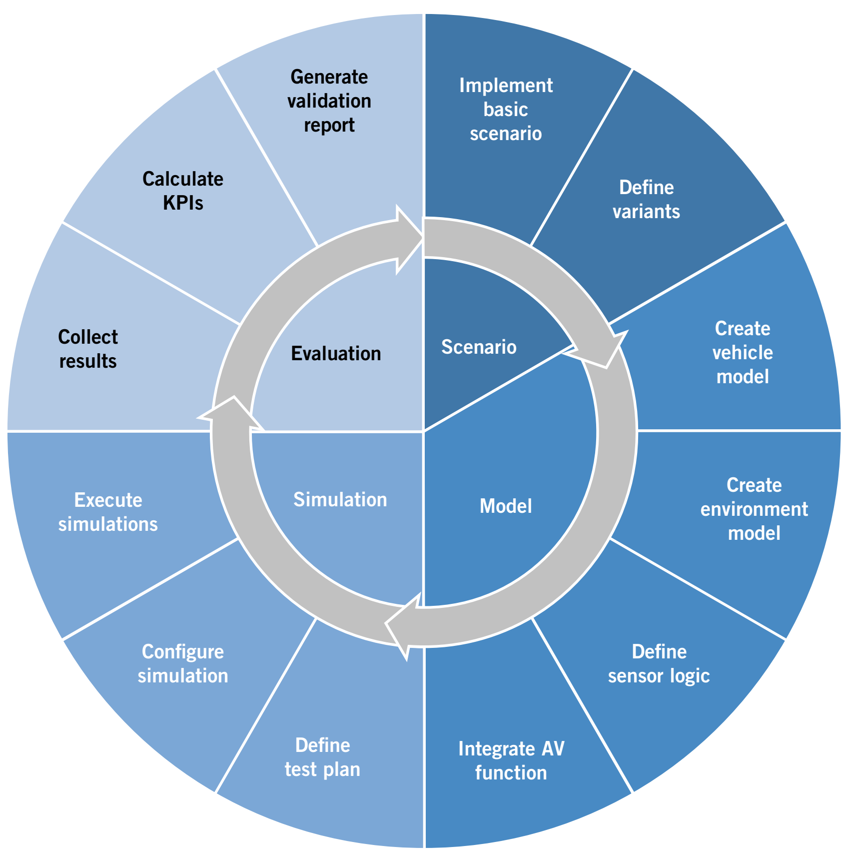

FIGURE 1 Virtual validation process for automated driving functions (© TÜV SÜD)

FIGURE 2 All elements, their behavior and environmental conditions of the virtual world must be mapped analogously according to the scenario description (© TÜV SÜD)

description. Secondly, the validation of the individual sensor type models with parameterization analogous to manufacturer specifications with the aid of real measurement data is part of the simulation environment. Sensor and vehicle model validation is necessary to prove the validity of the simulation as test medium. Depending on the model component, the model validation takes place in different ways [5], [6], [7]. If corresponding specifications are missing, they must be developed and released by the technical service. Verification of model validity is a binding part of the overall homologation report.

The environment model depicts all components of the virtual world outside the vehicle and must meet the following requirements: All specifications from the scenario description must be fulfilled and basic physical laws must be adhered to, and the transmission of the resulting information via dedicated interfaces must be guaranteed over the entire time period within the overall model. It is particularly important to pass on the information to the sensors. Depending on the sensor type, different stimulation signals are required. Effects such as overlapping at intersections with poor visibility must be ensured.

There are different valid X-in-the-Loop (XiL) procedures [9] for the integration of the driving function. The following requirements need to be fulfilled:

- The driving function must be linked to the rest of the model in a traceable and verifiable manner, analogous to interface definition.
- Model signals required for the validation of the driving function must be recorded accurately and unambiguously and must be available after the simulation has been carried out.

An open and documented model architecture is mandatory. In order to ensure interface conformity and clear signal conventions, established standards such as OSI (Open Simulation Interface [10]) and FMI (Functional Mockup Interface [11]) are to be preferred. For the validation of the driving function, the so-called ground-truth information is also required and must be available transparently and correctly within the architecture. Models do not have to be open white-box models. If the model interfaces and signals are documented and freely accessible in such a way that a correct model validation can be proven clearly, black box models can be used. This is preferred not only to protect the IP of the authors, but also to unambiguously decouple the suitability of the simulation for homologation from the model contents.

SIMULATION EXECUTION AND EVALUATION

When executing the actual simulation, the following specifications must be fulfilled:

- Definition of the test plan (scenarios, parameter variation and characteristic values) analogous to the specifications from the used regulation
- clear, comprehensible and reproducible assignment of the applied model environment, including parameterization of the individual test cases
- clear assignment of simulation results to individual simulation runs.

For each individual simulation, it must be verified that it was carried out with exactly predefined contents from the test plan, that the required results were generated and that these can then be uniquely assigned to this test case.

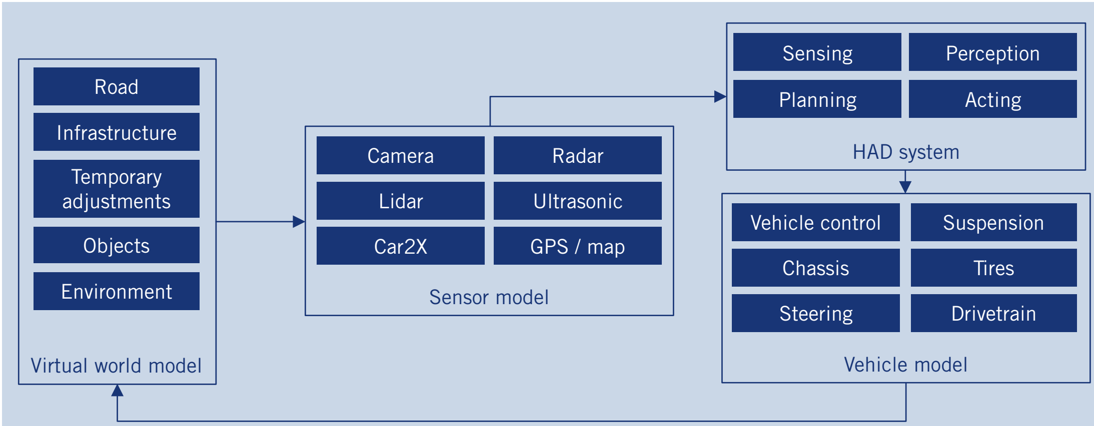

FIGURE 3 Modular model structure guarantees universality of the method (© TÜV SÜD)

As a last step, all results are collected within the evaluation and the characteristic values are calculated for each test case. Within the validation report, these are compared with the limit values specified in the regulation and the result relevant for the type approval is listed. The calculation of the characteristic values must comply with the requirements of the regulations, be well-defined and transparent. In addition, the validation report must contain not only the calculated characteristic values but also all details about the tests performed that are relevant for traceability (metainformation).

SIMULATION DATA MANAGEMENT

The data used within the simulation play an essential role for the trustworthiness of the results of the validation report. The simulation environment must therefore meet further additional requirements: On the one hand, all data used for the process steps shown in **FIGURE 1** must be managed in a comprehensible manner with the aid of a suitable data management system, including version control. On the other hand it must be possible to reproduce the results of the function validation even after some time.

In addition to the data and functions for scenario, modeling, simulation and evaluation, this also includes information about the software used and its version or specific customization. The proof that the simulation data management meets the requirements is also a binding part of the homologation report.

SUMMARY

To be able to realize the homologation of increasingly complex automated driving functions, virtual tests must be carried out as part of the overall type approval. For this it is necessary to define requirements for the trustworthiness of simulation. It is essential that vehicle manufacturers, suppliers, manufacturers of the necessary tools and independent technical services work closely with the authorities. By testing the performed model validation and qualification of the simulation environment by an independent testing authority, the simulation can be established as a legitimate and regulatory valid testing and homologation method.

REFERENCES

[1] UNECE (Hg.): Addendum 139 – Regulation No. 140: Uniform provisions concerning the approval of passenger cars with regard to Electronic Stability Control (ESC) Systems, 2017. Online: https://www.unece.org/trans/main/wp29/wp29regs121-140.html, aufgerufen am 22.10.2019

[2] Holzmann, H.; Hahn, K.M.; Webb, J.; Mies, O.: Simulation-Based ESC Homologation for Passenger Cars.In: ATZ worldwide 114 (2012), No. 9, S. 40 - 43

[3] ASAM e.V. (Hg.): ASAM OpenDRIVE, 2015. Online: https://www.asam.net/standards/detail/opendrive/, aufgerufen am 22.10.2019

[4] ASAM e.V. (Hg.): OpenSCENARIO, 2017. Online: https://www.asam.net/standards/detail/openscenario/, aufgerufen am 22.10.2019

[5] International Organization for Standardization: ISO 4138:2012 Passenger cars – Steady-state circular driving behaviour – Open-loop test methods. Geneva, 2012

[6] International Organization for Standardization (Hg.): ISO 19365:2016 Passenger cars – Validation of vehicle dynamic simulation – Sine with dwell stability control testing. Geneva, 2012

[7] Düser, T.; Abdellatif, H.; Gutenkunst, C.; Gnandt, C.: Approaches for the Homologation of Automated Driving. In: ATZelectronics worldwide 14 (2019), No. 10, S. 48 - 53

[8] UNECE (Hg.): Addendum 65 – Regulation No. 66: Uniform technical prescriptions concerning the approval of large passenger vehicles with regard to the strength of their superstructure. Geneva, 1995. Online: https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/r066r1e.pdf, aufgerufen am 22.10.2019

[9] Riedmaier, S. ; Nesensohn, J.; Gutenkunst, C.; Düser, T.; Schick, B.; Abdellatif, H.: Validation of X-in-the-Loop Approaches for Virtual Homologation of Automated Driving Functions. GSVF-Symposium. Graz, 2018

[10] Open Simulation Interface OSI, https://github.com/OpenSimulationInterface, aufgerufen am 22.10.2019

[11] Functional Mockup Interface FMI, http://fmi-standard.org/, aufgerufen am 22.10.2019