Validation of Highly Automated Driving Functions with Cloud-based Simulation

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If additional vehicle functions are activated after the regular start of production, validation and verification of highly automated driving functions according to SAE level 4 and 5 must be able to be repeated. Etas shows how this high system complexity can be managed securely in software architecture and real test drives can be saved by using cloud computing.

EXPONENTIALLY GROWING NUMBER OF TEST CASES

The validation and verification of Highly Automated Driving (HAD) functions according to SAE level 4 and 5 require numerous test kilometers. It is widely accepted that the required test scope cannot be covered within feasible amounts of time and money by exclusively using real test drives [1]. **FIGURE 1** demonstrates this situation in an exemplary manner: By changing various parameters such as driver types, weather conditions, altitude profiles, etc., an exponentially growing number of test cases is created. Moreover, if additional vehicle functions are provided and activated after the regular start of production, validation and verification must be able to be repeated. In addition, the HAD functionality is usually implemented via distributed systems with several subsystems. Consequently, when validating and verifying an overall system, the interaction and communication of these subsystems must be taken into account. This leads to a high system complexity.

These factors suggest that HAD testing requires intelligent validation and verification strategies [2-4] that work with different methods (also in combination). In addition to real test drives and Hardware-in-the-Loop (HiL) tests, this includes in particular Software-in-the-Loop (SiL) tests [5]. With SiL systems, HAD functions can also be tested without risk in dangerous driving maneuvers, at physical limits of driving dynamics, in the event of failure of system components, and in accidents. This would not be possible in real test drives. Cloud computing is a key technology for the required large-scale use of SiL tests. Most current tools for system development and testing in the automotive sector are designed for execution on single computers. They are therefore poorly suited for implementing smooth workflows in the cloud. Etas offers automotive developers a way to economically utilize existing, powerful cloud resources.

EXTENSIVE SIL SIMULATIONS FOR AUTOMATED DRIVING

The SiL simulation is a core element of the HAD validation and validation strategy. It links single or multiple virtual Electronic Control Units (ECUs) with simulation models of the real vehicle and its environment. The bus communication between the ECUs is also simulated.

HAD development requires the cooperation of many stakeholders. Similar to the design of the real vehicle, suppliers provide digital twins of their real components. These are integrated into a virtual vehicle and used for SiL validation and verification. Thus, virtual ECUs must be provided by the ECU suppliers, sensor models by the sensor suppliers and vehicle models by the vehicle engineers. Tools from Etas support this integration process of heterogeneously developed components from different domains, **FIGURE 2**, by consistently following a modular, standard-based tool architecture and by providing powerful APIs.

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SCALABLE SIL: FROM DESKTOP TO CLOUD COMPUTING

SiL simulations are usually set up incrementally so that effort and complexity can be controlled carefully. First, a small user group creates a limited setup on PCs. As soon as this setup works successfully, further details are added, such as test cases, parameters, further simulation models, etc. Over time, the complexity of the SiL setup and the number of required simulations increase. The demand for computing power increases accordingly. To secure a HAD vehicle in such a scenario requires the simulation of a test drive over several million kilometers, which can only be carried out within a reasonable time on a server cluster or cloud infrastructure.

REALIZATION OF AN SIL SIMULATION SOLUTION FOR HAD

The core idea of SiL validation and verification is to couple virtual ECUs with controlled route models, thast means, a virtual vehicle and its environment. The resulting system simulation is executed on a simulation target. On this target, the functional behavior of the test objects in a virtual environment is observed. The simulation and coupling of the controlled route models and virtual ECUs is carried out via an integration and co-simulation environment. Since the ECUs in the real vehicle are connected via data buses, the simulation of vehicle buses is also required for the SiL overall solution. In addition, there are tools such as test automation for endurance tests or the automated search for special driving situations.

The Etas Cosym integration and simulation tool chain, for example, enables simulation models (for instance in the form of Functional Mock-ups (FMUs)) and virtual ECUs based on different

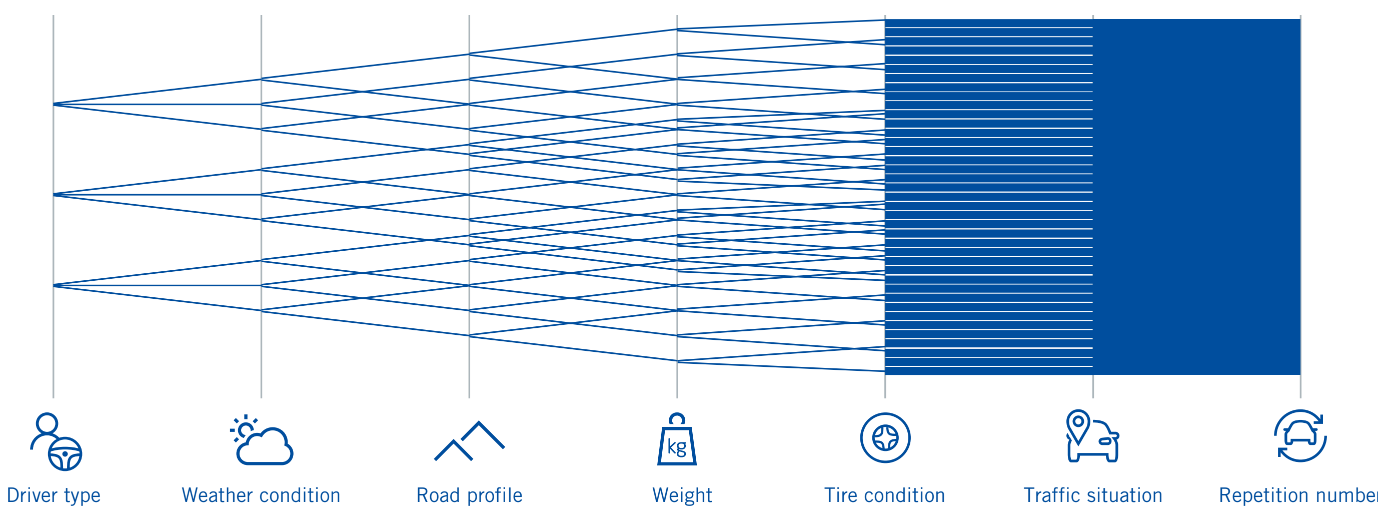

FIGURE 1 The combination of all parameters to be considered leads to an unmanageable number of test cases (© Etas)

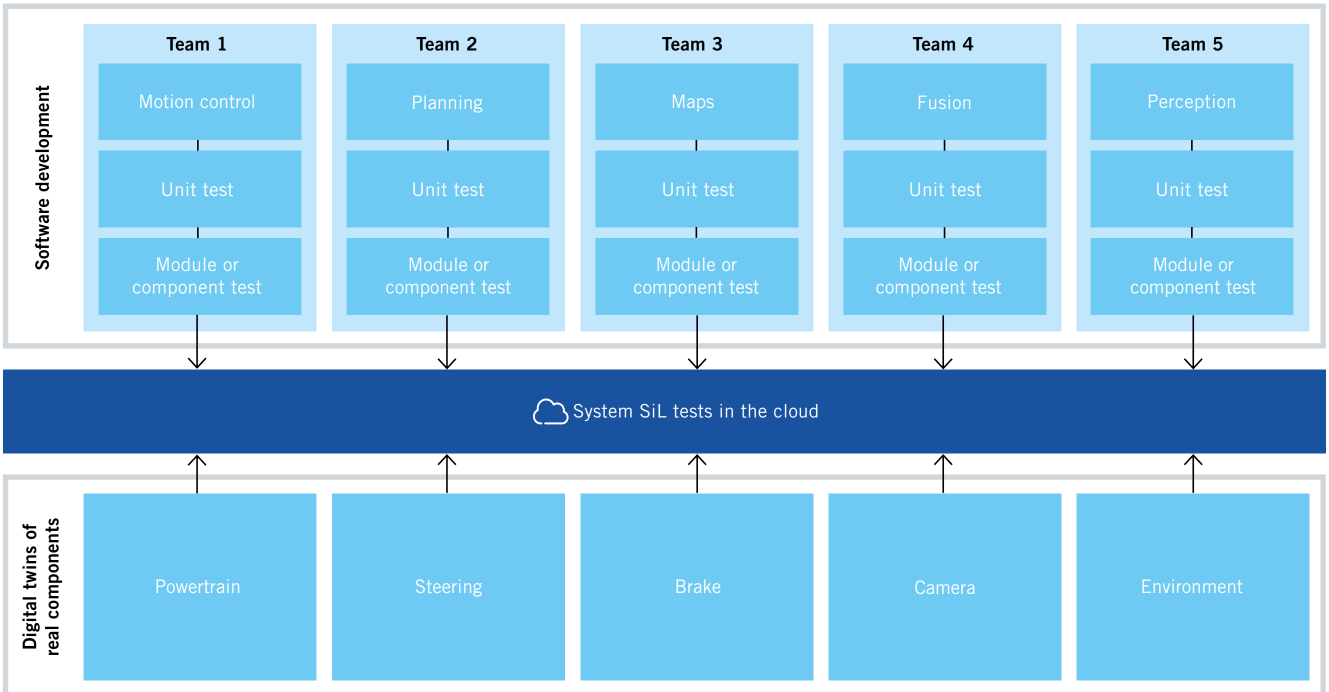

FIGURE 2 Cloud computing enables cross-domain collaboration and system SiL tests in the cloud (© Etas)

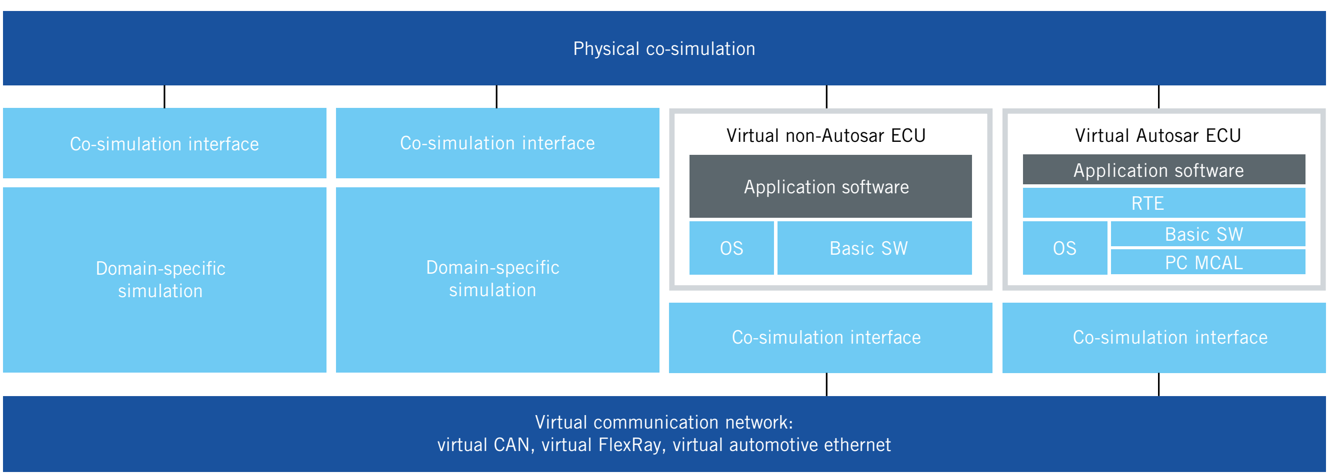

FIGURE 3 Virtual networks are essential for a simulation of the overall vehicle system (© Etas)

technologies to be integrated and connected. In this way, the (virtual) HAD vehicle can be simulated in its environment. The platform can be used either as a complete installation for interactive use on a PC or as a simulation backend. It can be accessed via micro services in a continuous integration toolchain and in the cloud.

OPEN AND MODULAR ARCHITECTURE

In order to support the cooperation models described, a modular and open tool architecture with standard interfaces such as FMI and ASAM is adhered to. All functions can be controlled via API so that the tool can be adapted as required and integrated into existing tool chains.

Through the cloud, access to fully scalable parallel computing resources is enabled. Cosym integrates with all leading commercial cloud infrastructure providers as well as enterprise-internal cloud solutions. The simulation results are independent of the computing platform. In addition, the SiL simulations can even be reused for an HiL system.

The functionality for autonomous driving is usually distributed over ECU networks. The ECUs are connected via communication networks and buses, **FIGURE 3**. To integrate virtual ECUs into virtual vehicles, SiL environments must offer the possibility of replacing these buses with simulations. The simulation of buses is an integral part of Cosym. This allows, for example, investigation of system behavior under the influence of communication latencies or high bus loads, as well as system stability in the event of component failures.

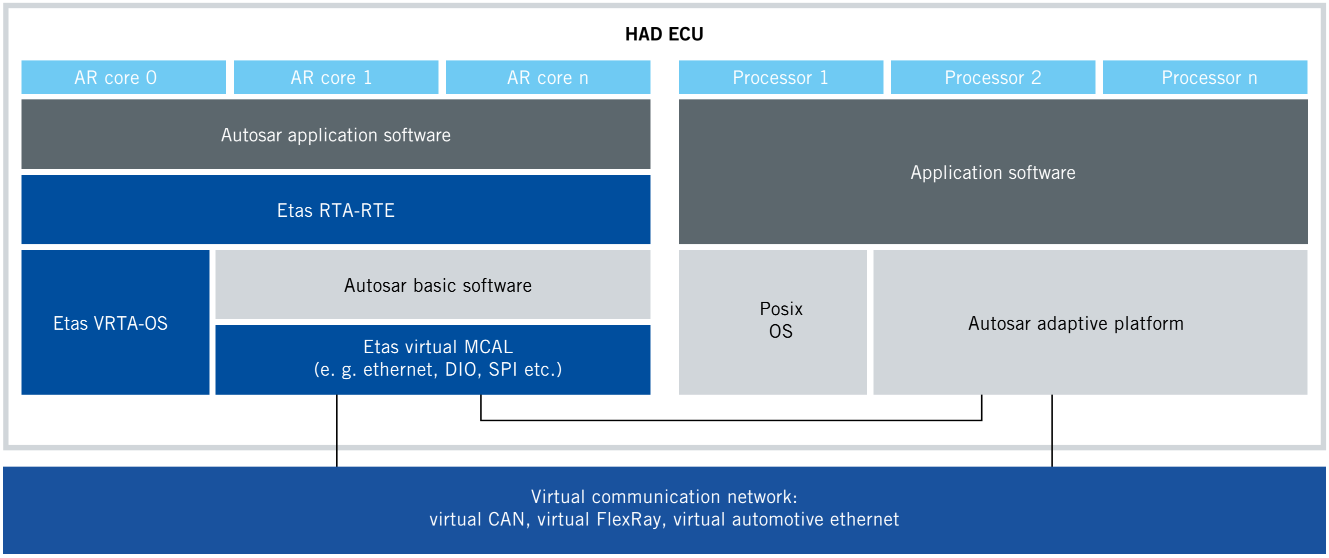

FIGURE 4 Possible heterogeneous HAD ECU architecture (© Etas)

VIRTUAL ECUS

HAD ECUs fulfill both safety tasks as well as demanding functional requirements. Therefore, they often consist of microcontrollers and microprocessors which are implementing the Autosar Classic Platform or are based on it [6]. For the virtualization of such ECUs, microcontrollers and microprocessors are considered separately. The Autosar Adaptive Platform defines a Posix-based architecture for the microprocessors. There are standard solutions for their virtualization, which are not discussed here.

The virtualization of microcontrollers is a major challenge. Microcontrollers are fundamentally different from PCs or servers. For their virtualization, Etas offers a solution that minimizes and overcomes these differences. With the Isolar-EVE development tool for virtual ECUs, virtualization takes into account special features such as scheduling, multi-core execution, memory access, hardware interfaces, etc. Virtualization does not only include the Application Software (ASW), but also almost the entire basic software and the Etas operating system, **FIGURE 4** – proven on the road in millions of production vehicles.

Communication between the various ECUs is an essential aspect of virtualizing the overall system. Therefore, each individual virtual ECU can be configured to support the relevant communication stacks for interaction with the virtual buses of Cosym. This enables a realistic SiL setup with network communication. It is also possible to create simpler virtual ECU setups. For example, with a focus on purely functional aspects of ASW and system integration on the level of physical signals using FMI. Standardized SiL architectures will play an important role for the interfaces of virtual ECUs in the future. The Isolar-EVE solution supports continuous integration processes. It enables the creation of virtual ECUs for execution on laptops and desktop PCs, server clusters, cloud architectures and also for real-time operation.

CONCLUSION

The cloud-based SiL validation and verification of HAD vehicles enables the collaboration of many persons involved while satisfying the need for high computing power to perform extensive testing. The proven and tested simulation and integration tool chain Cosym as well as Isolar-EVE from Etas, the development tool for virtual ECUs, meet this need with a consistent cloud-oriented concept. The use of micro services enables continuous integration and testing approaches. The collaboration between several engineers at different locations and the flexible use of the tools is also possible. As all leading cloud infrastructure providers are supported, companies can select their desired platform in the competitive, growing cloud market and benefit from price cuts.

The consistent orientation of the tools on cloud operation enables seamless workflows for HAD developers, so that they can focus on their core tasks such as system design and function development instead of having to deal with the complexity of the technical cloud infrastructure.

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