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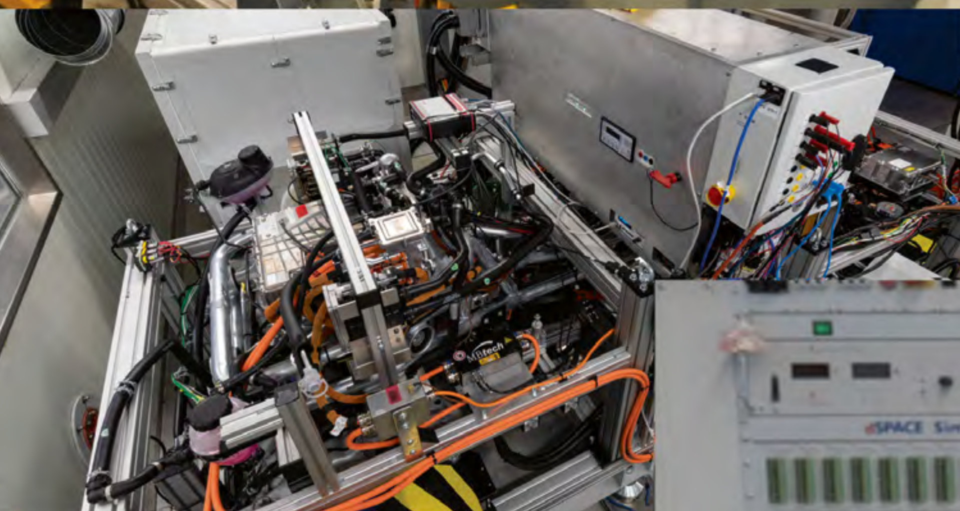
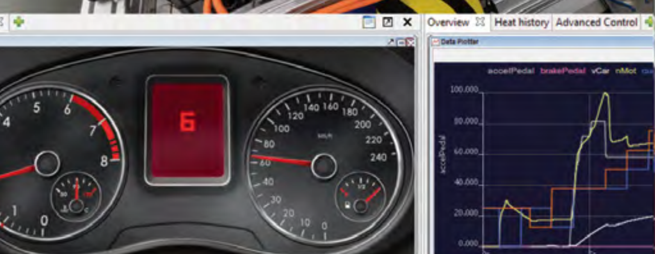
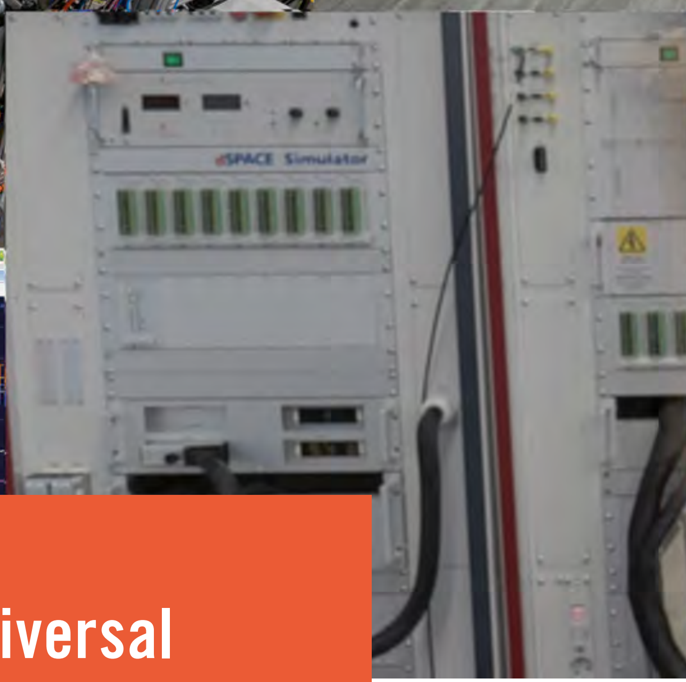
X-IN-THE-LOOP

Used as a Continuous Testing Method







X-in-the-Loop – A Universal Testing Methodology

Increasing complexity due to digitization and electrification and shorter development times for testing vehicle powertrains present challenges that need to be overcome. At Mercedes-Benz, a concept for an end-to-end testing methodology with generic tests has been developed that leverages synergies of different test platforms and thus makes a significant contribution to efficient product development.

In the field of vehicle testing, a large number of tools for test automation, diagnostics and fault analysis are state of the art. Since they differ, existing test cases from a particular testing environment cannot be easily reused on another platform. In developing a universal methodology, generic test cases were defined for the following testing environments:

– Software-in-the-Loop (SiL)
– Hardware-in-the-Loop (HiL)
– test benches (for example component, system or vehicle test benches)
– vehicle on the road.

The methodology allows tests to be exchanged between test environments without manually adjusting the test script. The effort required to create test-case descriptions is reduced, and consistency across all test environments is ensured. Duplication of work is prevented, and easy comparability of results from identical test cases on different test platforms is possible.

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DEFINITION OF XIL AND SYSTEM TESTS

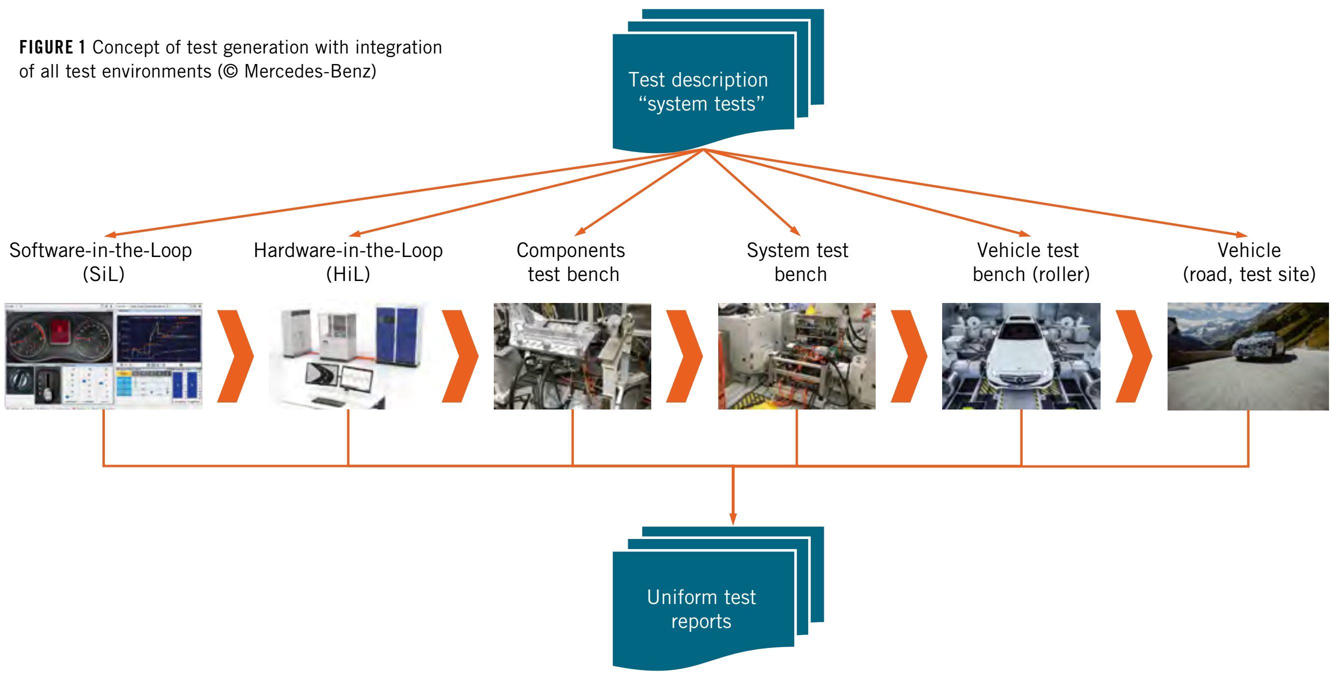
The X-in-the-Loop (XiL) approach is based on the system engineering theory of target, action and object system (the so-called ZHO model). It pursues the idea of validation of the different product detailing levels along the development process, with continuous involvement of the system "user" (driver) and the system "environment" [1], and extends from components and subsystems to the overall system. In the ZHO model, the validation constitutes the central activity of the product development, generating new knowledge [2, 3]. Dedicated test environments are provided for different system detailing levels. For the "vehicle" level, real road traffic, test sites and vehicle test benches are used (Vehicle-in-the-Loop, ViL). Powertrain test benches are available for the "system" level, HiL test benches for the "ECU" level and SiL simulations for the "software" level. The XiL approach combines these test environments with an overarching methodology, whereby "X" stands for the abstraction level of the test object to be examined [1]. Depending on the test environment, the systems of driver, environment and test object vary. Each requires a test flow description, **FIGURE 1**, which should ideally be applicable regardless of the implementation and the automation technology of the environments.

In particular, the approach adds value to system tests – tests from the driver's point of view, which are intended to validate the system`s defined product requirements of the system: detect errors, build trust in the system, provide proof of the functionality of the system and achieve a predefined test coverage [4]. The level of detail of the test object usually increases from the SiL simulation to the overall system vehicle on the road. Therefore, module, component and integration tests are usually predestined for a specific test platform and rarely transferable due to special constraints. System tests, on the other hand, can be carried out across all test platforms if an overall "drivable" system is available. This applies even if only certain components are actually present and the rest is simulated. Test platforms that were originally predestined for other test types are thus more versatile.

CONCEPT

The consistency of the test description for all platforms is achieved by generically presenting the dependencies between the driver and the test object systems – the Human-machine Interface (HMI). The driver's actions and the feedback to him or her are defined as the smallest generic functions and common intersection of the various test platforms. These include, but are not limited to, controls in which the driver

FIGURE 1 Concept of test generation with integration of all test environments (© Mercedes-Benz)



operates something, or feedback in which the driver checks a value or a condition. The control (Set) functions represent an active influence on the test object, the setting of a value (write access), changing the vehicle state or injecting an error. The feedback (Get) functions are, for example, values that are read by a control unit or bus system (read access) or prompt the tester to evaluate a certain vehicle action or state (for example charging plug inserted). The generic Set and Get functions are combined in a function library, **FIGURE 2**. Generic in this context means that the functions are independent of the vehicle and the test environment and describe the perspective as seen by the driver. To perform the system test, the generic functions must be executed on the specific platforms. Consequently, the generic functions must define how the controls specific to each test environment are triggered. Which platform-specific function is used automatically differs, depending on the test environment in which the test is carried out. An example of a platform-specific control can be the actuation of the accelerator pedal. In the vehicle, this actuation is carried out by an instruction to the driver, on the test bench by controlling a driving robot and in an SiL/HiL environment by presetting a simulation signal. The platform-specific implementation of a single function is independent of other platforms and detached from the generic level. This allows a centralized management of generic functions and a decentralized management of platform-specific functions.

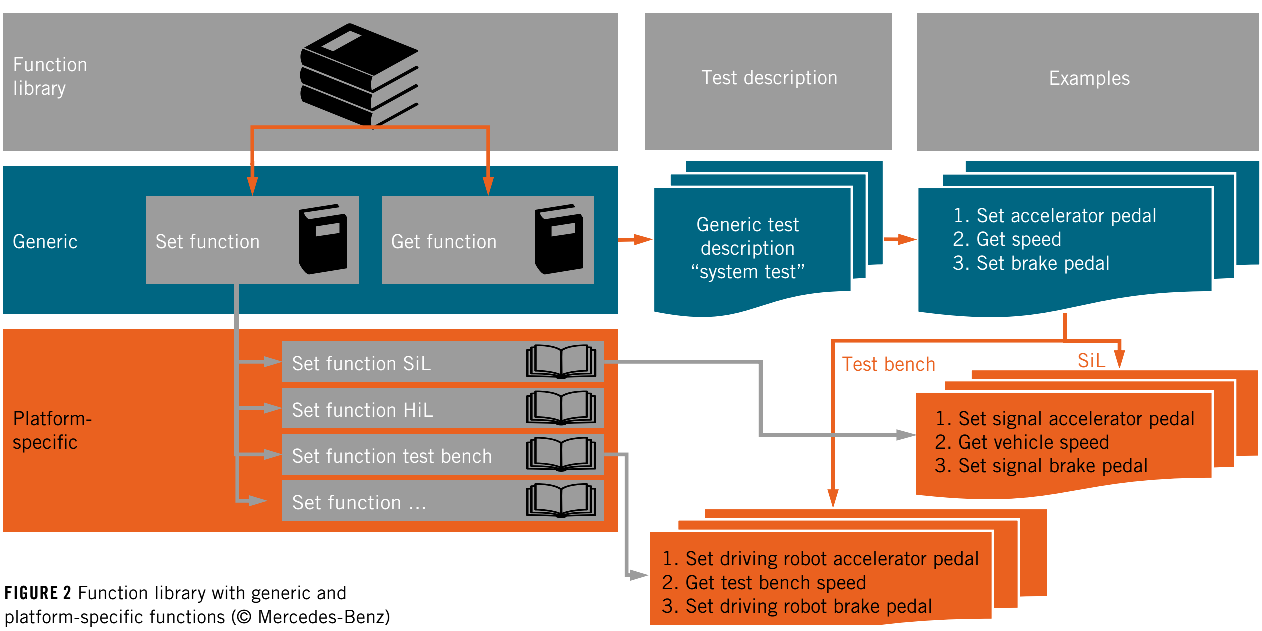
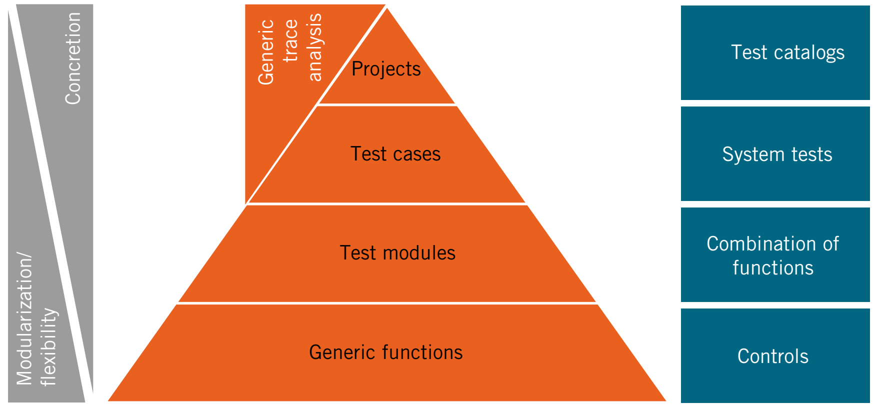


FIGURE 2 Function library with generic and platform-specific functions (© Mercedes-Benz)

FIGURE 3 Building blocks and hierarchies for system tests (© Mercedes-Benz)



The Set and Get functions represent the completely reduced components of a generic test, similar to machine elements in construction design. They perform the same or similar functions in the same or similar form for different test cases. The functions are parameterized so that they can trigger similar actions. Based on these, the lowest level of a test concept can be defined, **FIGURE 3**. A test module is a combination of several functions.
A test case is defined from functions and modules, which can be merged into comprehensive test catalogs/projects. Test catalogs can cover various validation areas. The lowest level of a test case is composed of generic functions, so the whole test case itself is generic. This creates a modular concept which is extendable to any test environment. This ensures that a test definition is only implemented once and can be used on all test platforms independently of the vehicle.

The concept shown in **FIGURE 3** also facilitates modularized, generic trace analysis to check the specified requirements. This refers to an automated evaluation of measurement data, which provides information about the system behavior and the fulfillment of requirements, based on the recorded signals. The evaluations can be created independently of the test platform. The combination of test cases and trace analysis is done in projects and is modular. For instance, an evaluation of the peak performance of the electric motor can be developed once and added modularly to each test case. A standardized reporting is thereby possible. This concept was developed in the studies [5–7] using the test automation tool ECU-Test from Tracetronic. This tool is based on the ASAM XIL API standard and enables the coupling to diverse test platforms.

IMPACT ON THE PRODUCT DEVELOPMENT

The consistency makes it possible, for example, to develop tests with a virtual SiL simulation and then apply them to the overall system on a test bench. The tests can therefore be co-developed in the course of the development process. This results in frontloading, **FIGURE 4** – the time required for testing is shifted from the end of the development process, from cost-intensive test environments, to the beginning in more cost-effective test environments. New tests can thus be used on all test environments during the development of the vehicle, and changes to test cases are immediately incorporated into all test environments.

The concept is also used in reverse engineering, **FIGURE 4**. If, for example, a software error is detected in the vehi-

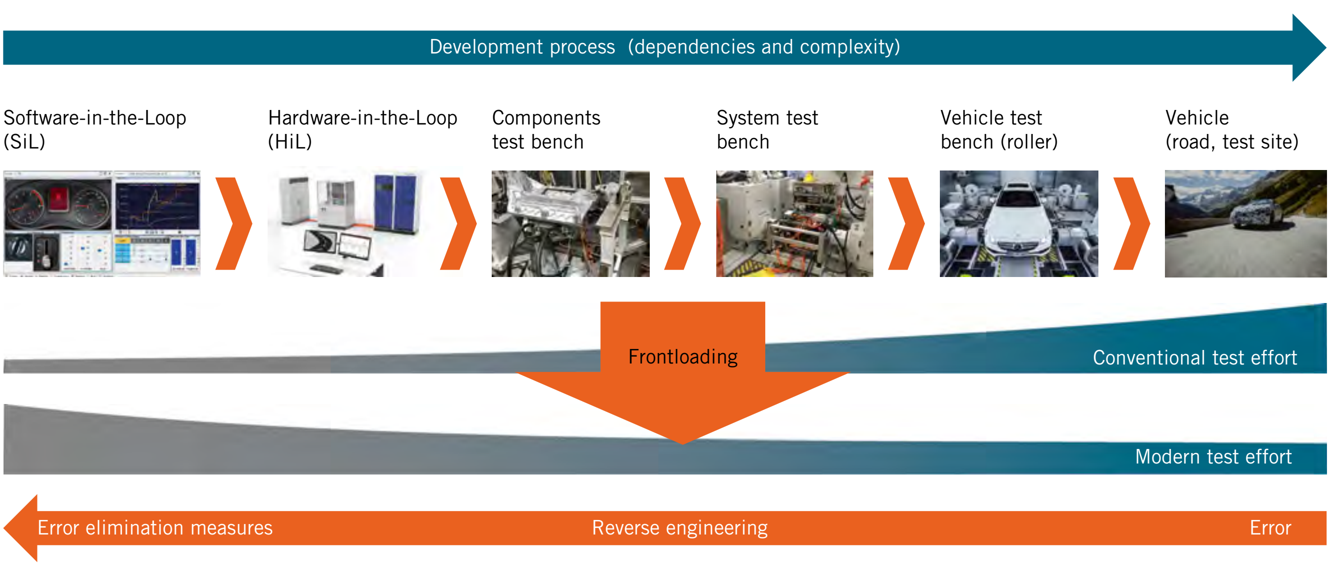


FIGURE 4 Frontloading and reverse engineering in the product development and testing process (© Mercedes-Benz)

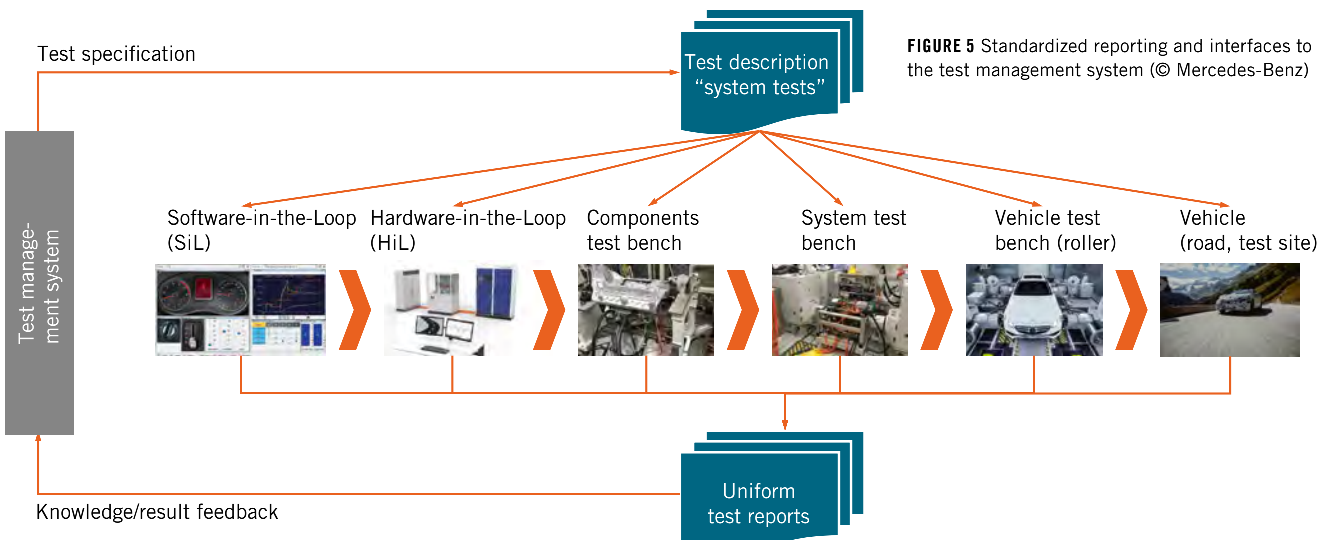


FIGURE 5 Standardized reporting and interfaces to the test management system (© Mercedes-Benz)

cle, a test case reproducing this malfunction can be developed and tested automatically in a suitable platform (for example SiL/HiL environment) and analyzed in more detail. Thanks to the transferability of the test cases, the effect of the error elimination measures defined from this can be tested and their effectiveness subsequently demonstrated in a reproducible and comparable manner on the test bench. The comparability of the test procedures is the basis for comparability of results and thus also for a validation of the plant models used by the different test platforms.

The methodology enables optimized networking with test management through two interfaces: a uniform test specification and the knowledge/result feedback by means of standardized reporting, **FIGURE 5**. Here, the test specification defines which knowledge is necessary for the testing, and the knowledge/result feedback documents which knowledge is gained from the testing [3].

SUMMARY AND OUTLOOK

The presented concept has been evaluated with different tests in all participating test platforms with identical test objects. The results prove that the use of centrally managed generic system tests work on different test platforms and comparable test procedures are provided. This enables consistency in vehicle testing, resulting in the following advantages: test reuse, test comparability, facilitated collaboration between product development and testing, frontloading during test-case creation, reverse engineering to support failure analysis, validation of the plant modeling and test management optimization.

Future investigations will focus primarily on the increased use of digital test environments with the aim of being able to test at an early stage under the most realistic boundary conditions possible. In order to unburden the real test in a targeted manner, it must be evaluated in detail which use cases are expediently feasible in which test platform. This test concept already enables a much more efficient validation of vehicles with shorter development cycles and makes a valuable contribution to product development.

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