VIRTUAL TEST DRIVING
HARDWARE-INDEPENDENT INTEGRATION OF SERIES SOFTWARE

For the verification of Electronic control unit (ECU) software independently of the target hardware, the BMW Group relies on the Virtual verification platform (VAP). To operate intensively interlinked components in the comprehensive interaction with the vehicle and the environment, the concept has been combined with virtual test driving. In conjunction with the open integration and test platform CarMaker, the series software can be integrated into the virtual vehicle without the need for real target hardware.Therefore, the software can be experienced live in the simulated driving situation at the developer's workstation.

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MOTIVATION

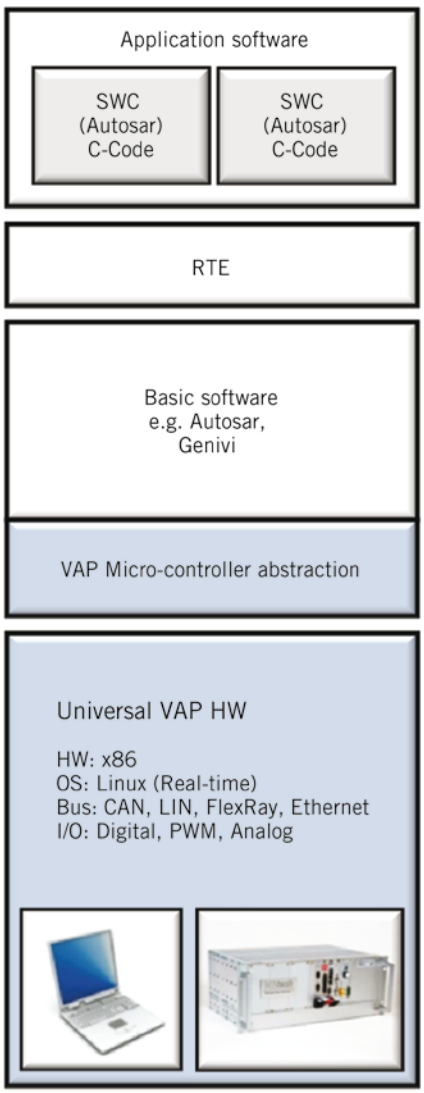
Frontloading in the software development process and re-usability are central factors of success for high-quality software in the vehicle. This is driven by the objectives of achieving efficient development, early detection of errors, a significant increase of the degree of maturity and avoidance of duplicate work. For this purpose, the BMW Group relies on rigorous standardisation in the software development process based on Autosar and Genivi as well as the use of intelligent development methods. The virtual verification platform VAP is an example of this. It allows series software to be developed in the original Autosar workflow and testing it independently of the ECU hardware by using the Software-in-the-Loop method (SiL). Furthermore, in collaboration with IPG Automotive, the existing VAP concept has been combined with virtual test driving. This has resulted in a powerful development environment that makes standard software a tangible experience in the virtual world, including a guaranteed 'fun factor' for the developer.

VIRTUAL VERIFICATION PLATFORM VAP FOR SOFTWARE INTEGRATION

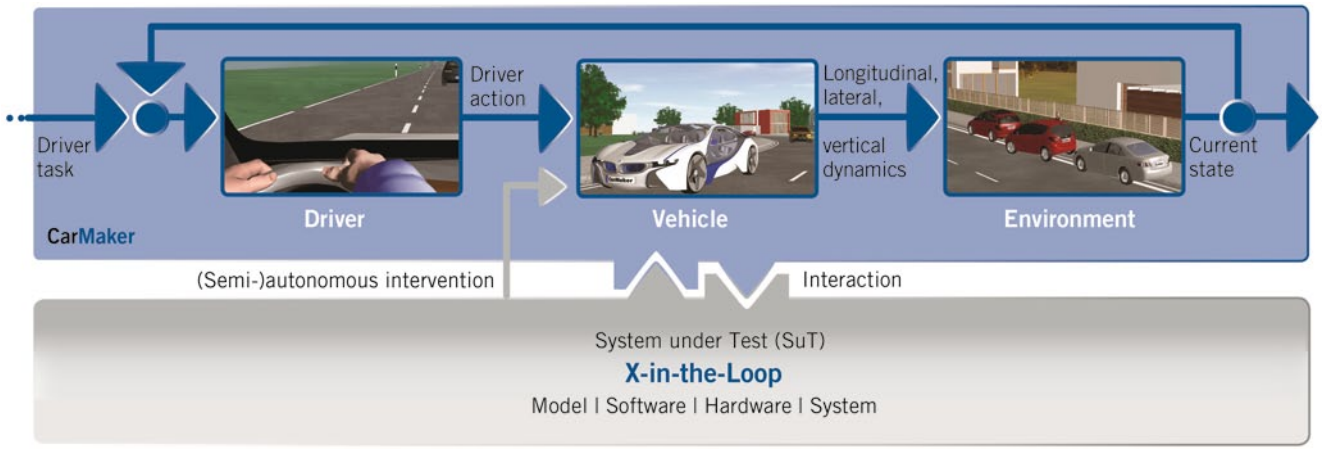
The VAP is a PC system featuring x86 architecture, which allows a modular extension by all interfaces commonly used in the automotive sector to be achieved using CompactPCI cards. The structure of the platform is depicted in ❶, [1]. Real-time capable Linux is used as the operating system. For external access to the interfaces, a micro-controller abstraction layer that has been specifically adapted to the VAP is used. Located above it is a full Autosar stack with the associated runtime environment (RTE). The top level accommodates the functional software, which is divided into individual software components. The functional software can be integrated and tested in the original condition, as it would be deployed on the target platform. This is done by using the same workflow as on the target hardware.

At the BMW Group, the platform is already successfully being used for the following use cases [2]:

: Qualification of basic software: The VAP is used as a reference platform for integrating various Autosar basic software stacks. This makes it possible to evaluate and compare different stacks under defined conditions.
: Accompanying the development: Use of the VAP in the early development stage as a contribution to frontloading. ECU software can be tested early on a hardware platform with real-world basic software and complete communications, which makes it possible to detect and locate errors at an earlier stage of the development process.
: Reusability: Verification of the reusability of ECU software on different types of hardware. This serves to test the configurability, portability, compilability and completeness of the software.



❶ Schematic structure of the VAP with system-under-test (white) and VAP specific components (blue)



❷ XiL allows early verification and validation of systems; CarMaker offers the corresponding interfaces to integrate all relevant components and systems into the virtual vehicle

The application at the BMW Group takes place in ECU projects from standard production development, spread across all vehicle domains, such as the instrument cluster, safety electronics, engine control or driver assistance functions. This has made it possible to detect and correct errors in the entire development workflow, such as incompatibilities with the Autosar standard, faulty configurations of the basic software and customer-relevant implementation errors [3, 4].

VEHICLE DYNAMICS AND ENVIRONMENTAL SIMULATION

In order to create the link from the VAP as the system-under-test to the whole vehicle, it must be possible to connect plausible models of vehicle physics and the vehicle environment. In CarMaker, the seamless "X-in-the-Loop" (XiL) approach has been consistently implemented, ❷. The XiL method allows a very early integration and comprehensive validation of all relevant system components, as models, software or hardware, in the whole vehicle [5].

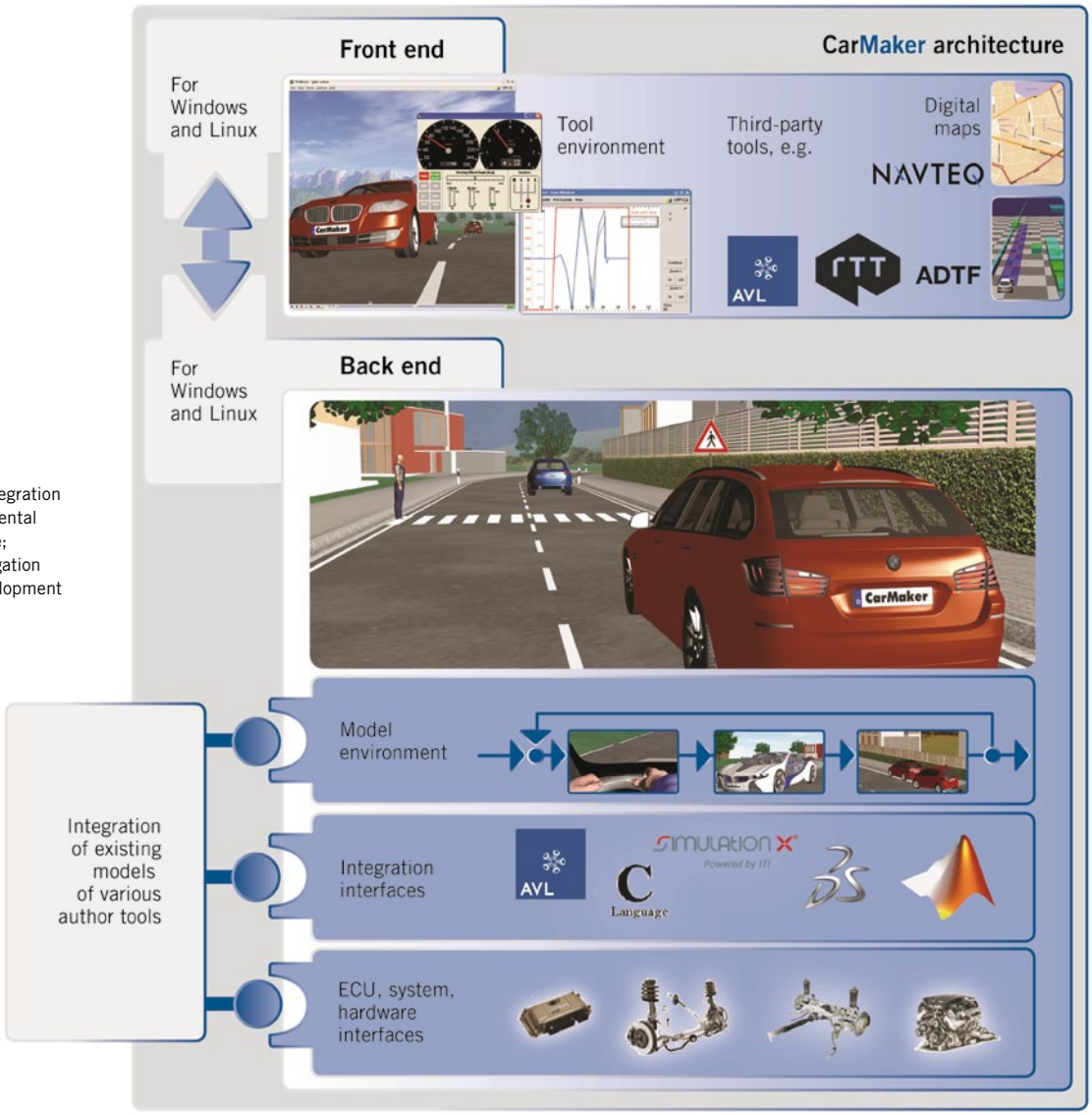
As an open integration platform, CarMaker offers an interface architecture that is attuned to vehicle development. By mouse click, models, software components and real-world vehicle components are integrated into so-called digital prototypes – from the single component to interlinked systems. The powertrain, chassis/suspension, assistance and control systems etc. as well as display and control concepts can be integrated as needed, ❸ [6]. The virtual integration creates the prerequisites for checking the impacts of the components under test on the performance and behavior of the whole vehicle. Errors can thus be detected at an earlier stage [7].

The digital prototypes can be verified in virtual test driving as a total system. In addition to the vehicle and driver model, CarMaker encompasses a complete environmental simulation consisting of roads (with corners, signage etc.), moving traffic with environment sensors plus digital maps (e.g. Navteq, Google Earth). This results in modeling the test environment at a very high level of realism. Furthermore, as a test platform, CarMaker offers a maneuver description that is based on the principles of real-world road testing. Complex open- and closed-loop tests are executed as maneuver instructions as well. The virtual test drive is reproducible and easily modifiable as needed, and the test results are valid all the way up to the physical limit. This makes it possible to evaluate new developments in virtual test driving and making them tangible experiences in realistic driving situations [8].

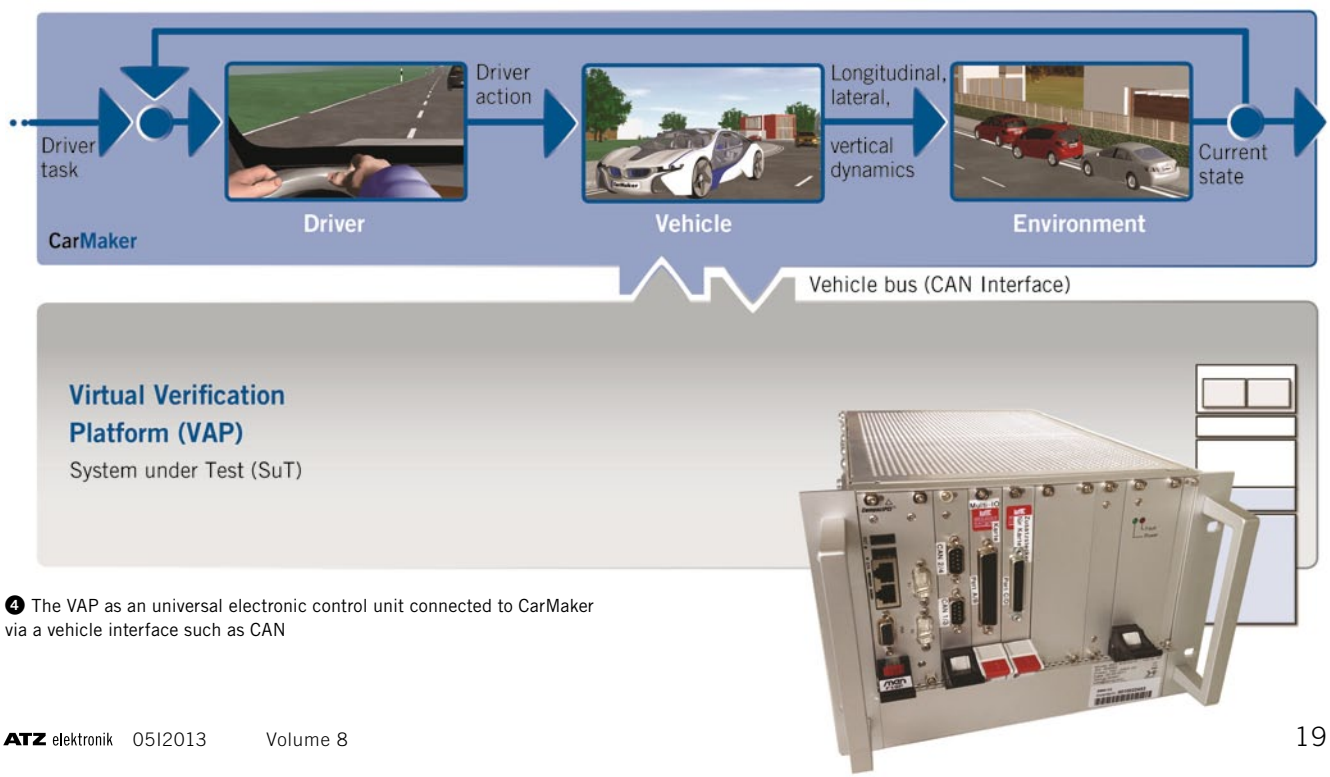
INTEGRATION OF SERIES SOFTWARE IN VIRTUAL TEST DRIVING

The new approach aims to combine the VAP as a universal control unit with the simulation environment of virtual test driving, ❹. To do so, the VAP including the application software that is integrated on the Autosar basic software stack, is interconnected with real-time hardware for CarMaker via the required vehicle buses and/or I/O. The software (system-under-test) is stimulated in the relevant driving situation of the virtual test drive with the corresponding realistic signals and/or parameters. Thus, the approach equals the hardware-in-the-loop method but does not require any expensive control unit prototypes. The technical architecture of the software functions under test can be modeled on the VAP. If necessary, functions distributed in the control unit network can be partitioned to several logical instances and tested. The resulting development environment enables the hardware-independent development of software in the series production development process, supported by a virtual, test drive-based and visualising test environment. The major advantages are:

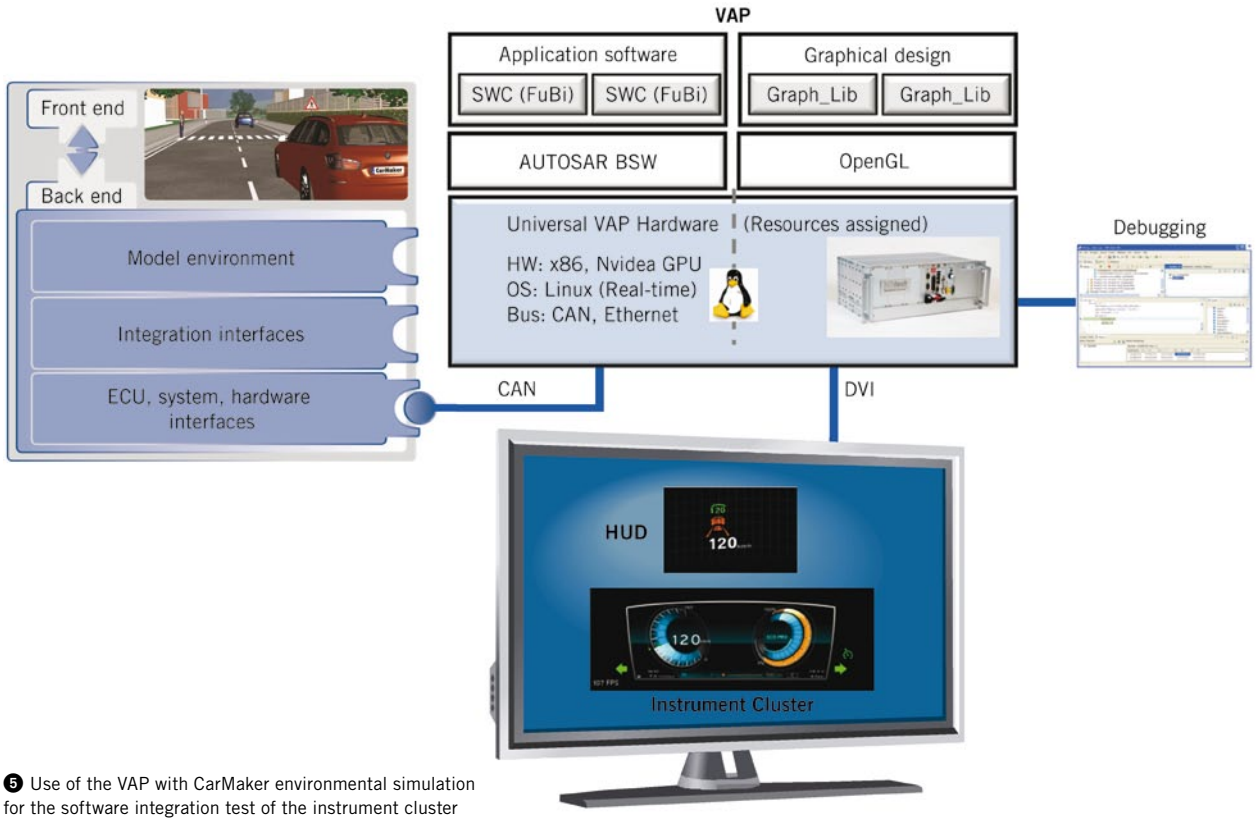
- integration/configuration of the series software in the original Autosar workflow with original Autosar basic software and tooling, analogous to the electronic control unit
- open state-of-the-art development environment based on Linux, including standard tools for analysis, coding, debugging and profiling of the software
- closed-loop test operations by feeding back the vehicle signals and HiL interface
- real-time interface for communications with other electronic control units (HiL) including test automation



❸ CarMaker allows the integration of functional and environmental models as well as hardware; interconnections with navigation systems and software development tools are possible as well



❹ The VAP as an universal electronic control unit connected to CarMaker via a vehicle interface such as CAN



❺ Use of the VAP with CarMaker environmental simulation for the software integration test of the instrument cluster

: ability to visually experience the software in realistic driving scenarios with direct feedback to the developer/tester
: wide range of driving scenarios: from the simple maneuver to highly complex scenarios of various traffic situations, with the capability of the virtual driver executing significant customer situations
: possible interactive override of the simulation as well as intervention options for the tester
: possibility to configure driver profiles, driving scenarios, vehicle and environmental models as needed.

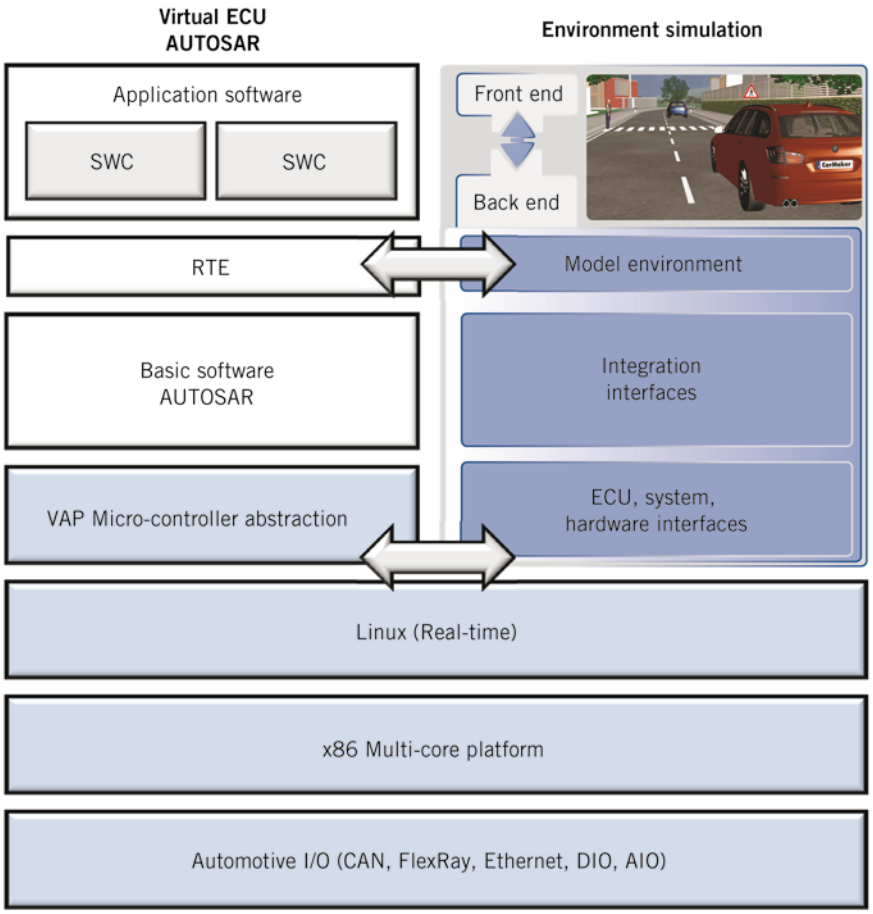
The new method can be used on the left-hand side of the V-Model to accompany the development process through to the electronic control unit integration test on the right-hand side. For example, modern display and operator control concepts which are interlinked with driver assistance and vehicle dynamics functions can be evaluated at an early development stage in the whole vehicle and/or tested using regression tests for software implementations shortly before deployment to the hardware.

APPLICATION EXAMPLE: INSTRUMENT CLUSTER AND HEAD-UP-DISPLAY

The VAP use cases "Assurance of Software Reusability" and "Frontloading in the Software Development Process" are piloted and rolled out in several electronic control unit projects of the BMW Group. In the component project for the instrument cluster/head-up-display (IC/HUD) the software development for calculation and display of the instruments is performed in-house at the BMW Group. The VAP in this case serves as a reference integration platform for software delivered to the electronic control unit supplier by the BMW Group. The integration of the proprietary software on the VAP is used to assure the reusability and quality of the software. ❺ depicts the schematic test configuration of the IC/HUD project for which the hardware was substituted by the VAP.

The software architecture of the instrument cluster is divided into an Autosar part with a microcontroller for parameter calculation, state machines and on-board network communications in the electronic control unit network and an OpenGL part for the graphical 3D representation on the displays of the instrument cluster and the HUD. Both parts are integrated with the original series software on the VAP and communicate internally via inter-processor communications, analogous to the communications in the real-world ECU. The graphic output of the IC/HUD occurs via a standard monitor and serves as feedback to the developer.

In the evolution stage, this approach was combined with CarMaker virtual test driving in order to make the tangible experience of the software functions possible. The stimulation occurs via a real-time simulation system (HiL) with a 3D vehicle model, with body, suspensions, steering, tires, brakes, powertrain, aerodynamics, sensors and dynamic residual bus simulation. Additionally, the behavioral models and/or software ECUs required for the stimulation of the display instruments are integrated – in this case, the logic of the Adaptive Cruise Control (ACC). The vehicle signals required for the instrument cluster are generated in the dynamic rest-bus simulation and communicated using the



❻ Outlook for the next technical evolution stage with combination of VAP and CarMaker on x86-hardware

original on-board network data via the CAN bus.

The developer has the opportunity to execute automated runs of predefined drive cycles in the regression test and/or to override the simulated driver through interaction. In the test cycle, for example, the preceding traffic is recognised via the simulated radar sensor and the default setting of the minimum gap is adjusted via the soft-ECU of the ACC. The developer can thus conclusively test, evaluate and realistically experience his series software for the displays in the instrument cluster in the selected driving scenarios. The evaluation criteria in this case relate to the situational correctness, the representation context and the optical quality of the displays of the IC/HUD in the virtual vehicle.

OUTLOOK

As the architecture of the VAP and the CarMaker XiL solution are based on the same hardware and software platforms, it is planned to fuse both methods in an integrated hardware solution in a subsequent evolutionary stage, ❻. The development environment will thus become even more practicable, economical, manageable and flexible for the software developer.

REFERENCES

[1] Martinus, M.; Cutura, Z.; Würz, T.: Virtuelle Absicherungsplattform – Integration und Wiederverwendung von Software. In: ATZelektronik 7 (2012), No. 1, pp. 56-61

[2] Fuchs, M.; Jurchen, S.; Martinus, M.: Virtuelle Absicherung von E/E-Umfängen. In: 3. AutoTest – Fachkonferenz zum Thema Test von Hard- und Software in der Automobilentwicklung, Stuttgart 2010

[3] Deicke, M.; Hardt, W.; Martinus, M.: VAP 2.0 – Die nächste Generation der virtuellen Absicherungsplattform. In 4. AutoTest – Fachkonferenz zum Thema Test von Hard- und Software in der Automobilentwicklung, Stuttgart 2012

[4] Piasecki, T.; Weber, M.; Martinus, M.; Schmid, H.: Virtuelle Absicherung zur Beherrschung der Komplexität und Varianz von E/E Systemen. In 16. Internationaler Fachkongress Fortschritte in der Automobil-Elektronik, Ludwigsburg 2012.

[5] Schick, B.: Mission V-Process enhancement by integrated vehicle performance evaluation within an entire X-in-the-Loop process, Keynote SIAT ARAI 2013

[6] Schick, B.; Leonhard, V.; Lange, S.: Vorausschauendes Energiemanagement im virtuellen Fahrversuch. In: ATZ 114 (2012), pp. 328-333

[7] Schneider, S.-A.; Schick, B.; Palm, H.: Virtualisation, Integration, and Simulation in the Context of Vehicle Systems Engineering, embedded world 2012, Nürnberg 2012

[8] Palm, H.; Holzmann, J.; Schneider, A.-S.; Koegeler, H.-M.: Die Zukunft im Fahrzeugentwurf, Systems-Engineering-basierte Optimierung. In: ATZ 115 (2013), No. 6, pp. 512-517