Data Management in the Development of Automated Driving Functions

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The importance of data management systems in vehicle development is increasing because the systematic provision of content is crucial for efficient and agile development processes. In order to meet new demands, ZF, together with PDTec and IPG Automotive, is implementing a data management solution for virtual test driving on a global basis.

MOVING TOWARD VIRTUAL DEVELOPMENT

Digitalization in general as well as automated driving in particular poses great challenges for the automotive industry. Moving toward an increase in virtual development is a pivotal factor for success that requires new methods and infrastructures at the same time. Automated vehicles are complex and safety-relevant systems for which an ideal interaction of sensors, actuators and software is of major importance. An efficient, cross-domain and safe system development in this area necessitates a high degree of simulation [1, 2].

As a result, the number of people working regularly with simulation programs is growing continuously, and workflows need to be integrated sustainably into superordinate development processes. A systematic management and an intelligent, distributed use of models, simulation data and test scenarios are playing a key role [3, 4]. The same applies to the integration of scalable computing infrastructures. To meet these and further requirements, ZF has implemented a data management solution for virtual test driving with the support from PDTec and IPG Automotive. The following article is going to elaborate on this solution.

AREAS OF DATA MANAGEMENT

A modern enterprise Simulation Data Management (SDM) covers the entire CAE range: from providing data from Product Data Management (PDM) systems like CAD systems to comprehensive

support of CAE processes as well as post-processing and correlation of results. Consequently, some of the hereafter discussed requirements did not necessarily arise in the context of automated driving as they are already met by existing SDM solutions. This being the case, the solution presented here is an extension of the established SDM solution by PDTec [5], which meets the requirements of automated driving in conjunction with the use of the integration and test platform CarMaker from IPG Automotive. The approach is based on centrally providing virtual full vehicles for functional system testing, **FIGURE 1**.

The platform offers a comprehensive and scalable simulation environment for the development of automated driving functions including vehicle, sensor and environment simulation [6]. In the following, the SDM areas which are of particular relevance are described in more detail.

SIMULATION PREPARATION AND PROCESSING

The simulation preparation comprises the parameterization, the validation and the distributed use of vehicle models, which include the different subsystem models (for example wheel suspension, steering, brake, sensor technology, powertrain) – known as virtual vehicle prototypes – as well as the provision of suitable test scenarios. Both in simulated driving and in real world, these scenarios include static elements (road, traffic signs and 3-D environment), dynamic elements (vehicles, pedestrians and other dynamic objects) and the impact from environmental conditions (weather, time of day, etc.). All components of virtual testing have to be available in adequate detail for the application purpose.

During the simulation processing, contents have to be used seamlessly over development stages and domains on the desktop computers, on real-time systems in the Hardware-in-the-Loop (HiL) laboratory and on the test benches as well as on high-performance computers or in the cloud. The integration of scalable solutions for automation is as important as registering manual simulation runs.

STORAGE AND EVALUATION OF RESULT DATA

In addition to managing great amounts of result data from various simulations, the targeted search for data sets and the complete traceability of their creation history play a vital role. Moreover, the systematic, holistic management of simulation data has great potential to serve as a source for data analysis processes. Taking into account further data sources, the areas of application include for example model validation or the (systematic) comparison of different test methods, for example Software-in-the-Loop (SiL) and HiL tests.

DATA MANAGEMENT SYSTEM REQUIREMENTS

The significance of data management systems in virtual vehicle development is continuously increasing because providing and reusing contents systematically is essential for an efficient and agile development. Whereas consistent data management in collecting and processing measurement data is well established with OEMs and suppliers, in the context of virtual test driving, many do not use comprehensive solutions yet.

Especially when developing automated driving functions – and working in interdisciplinary and international teams of developers – a global and likewise relia-

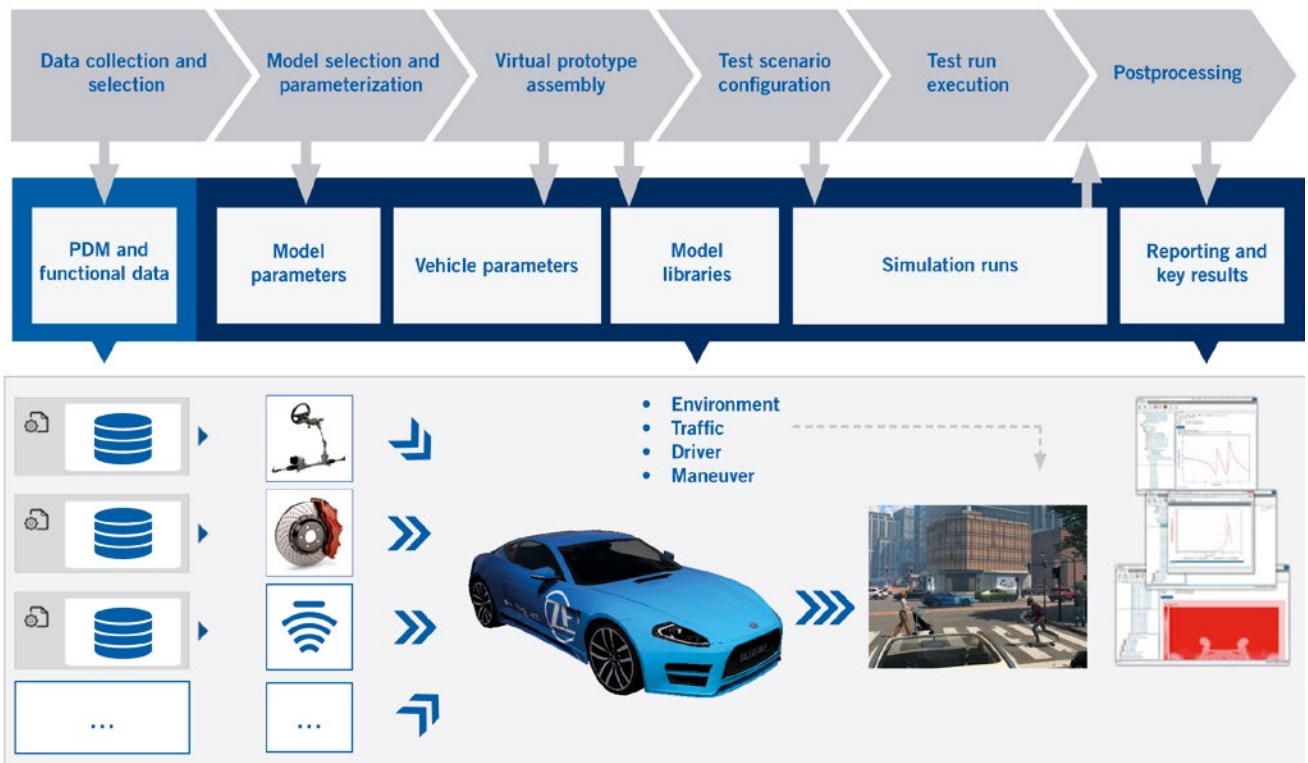

FIGURE 1 Workflows for functional testing of software and hardware components in real driving scenarios of virtual full vehicles (© ZF | PDTec | IPG Automotive)

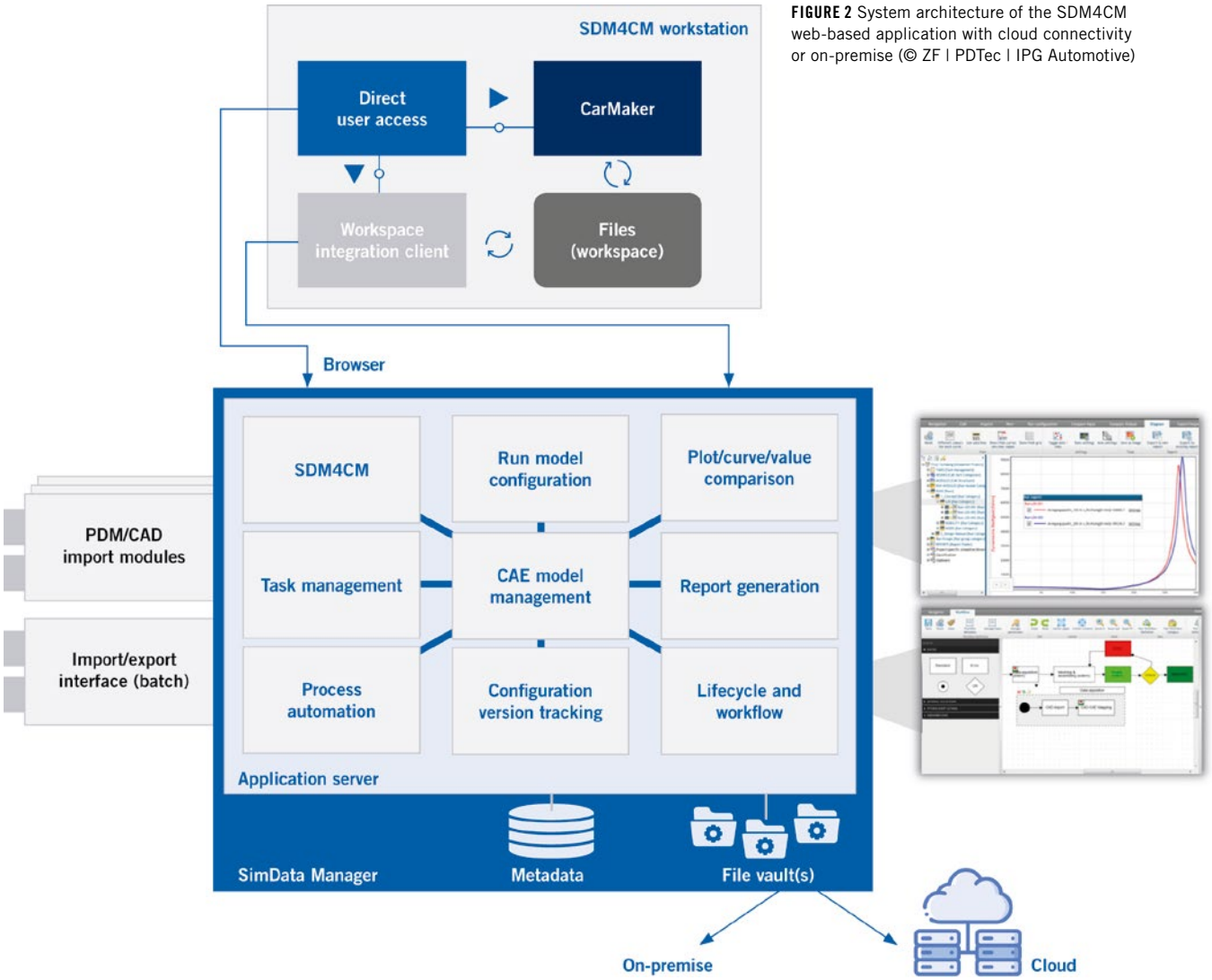

FIGURE 2 System architecture of the SDM4CM web-based application with cloud connectivity or on-premise (© ZF | PDTec | IPG Automotive)

ble collaboration is necessary. A centralized management of all simulation artifacts and related processes is vital to this end. In the following, the requirements on a data management system are therefore of utmost importance.

SYSTEMATIC PROVISION AND EASY ACCESS

Many models of subcomponents and suitable driving scenarios are required to perform efficient full vehicle simulations employing virtual prototypes (digital twins). As reusability represents a goal for both models and scenarios independently, providing corresponding libraries is essential. Processing and contribution functions for these contents are administered by relevant experts. In addition, an extensive use and adaptability of meta-information is necessary since it is the only solution to make libraries accessible to a wide user community.

In today's world, simulations need to be globally accessible for interdisciplinary teams. Therefore, a high degree of process reliability is required. On the one hand, simulation processes have to produce the same result, no matter who the editor is. On the other hand, complex simulation processes have to be available in a robust solution for users with little simulation expertise as well as for automated workflows. For individual upscaling in addition to process reliability, there is no alternative to the consistent integration of high-performance computering clusters and/or cloud infrastructures, especially in the context of automated driving.

GLOBAL COLLABORATION

The necessity for worldwide collaboration implies numerous administrative requirements. On one side, they demand a comprehensive role, user and access rights management which, among other things, provides reusable components centrally and enables the encapsulation of specific contents in projects. At the same time, limited bandwidths between development sites need to be addressed with intelligent, distributed storage mechanisms for (larger amounts of) user data. This way, users can access the entire knowledge at all times, while important data transfers between the sites solely take place in a controlled manner or in case of need.

DATA MANAGEMENT SOLUTIONS FOR VIRTUAL TEST DRIVING

The Simulation Data Management for CarMaker (SDM4CM) from PDTec is a web-based application provided centrally using a server with a global user access via the internet browser. **FIGURE 2** presents the overview on the system architecture. All simulation data are stored centrally. The SDM system can be configured with multiple so-called vaults if necessary. Vaults are installed at the relevant premises or in the cloud to organize big data amounts locally, minimize network traffic and increase user friendliness. With a comprehensive role and access rights management, the effective control of globally operating teams becomes a reality.

The use of web technologies facilitates handling the heterogeneous client landscape of different users which results from interdisciplinary teams and the broad application of simulation. The SDM4CM can be used modularly in combination with the regular SDM system SimData Manager from PDTec for simulation based on geometry data. Within the PDTec product family SE-Data Manager for Systems Engineering, SDM4CM can also be extended by other modules.

In the context of automated driving, many elements beyond the tested object need to be modeled and hence covered by data management. The decisive step forward to enable the evolution from a regular SDM solution to a data management solution for virtual test driving was to break down the underlying simulation workspaces into their logical components on the client and server side. When using black box approaches to manage data sets, the logical contents of the workspace artifacts are not interpreted. In contrast, this approach enables a solid versioning and connection of logical components. The complete decomposition of complex virtual test scenarios into all individual parts can therefore be managed transparently, **FIGURE 3**. This step allows for the application of existing mechanisms to create general-purpose libraries for example for simulation models, driving scenarios or 3-D content. The necessary meta-information inside these libraries can be adapted individually.

The development of automated driving involves the extensive use of SiL and HiL

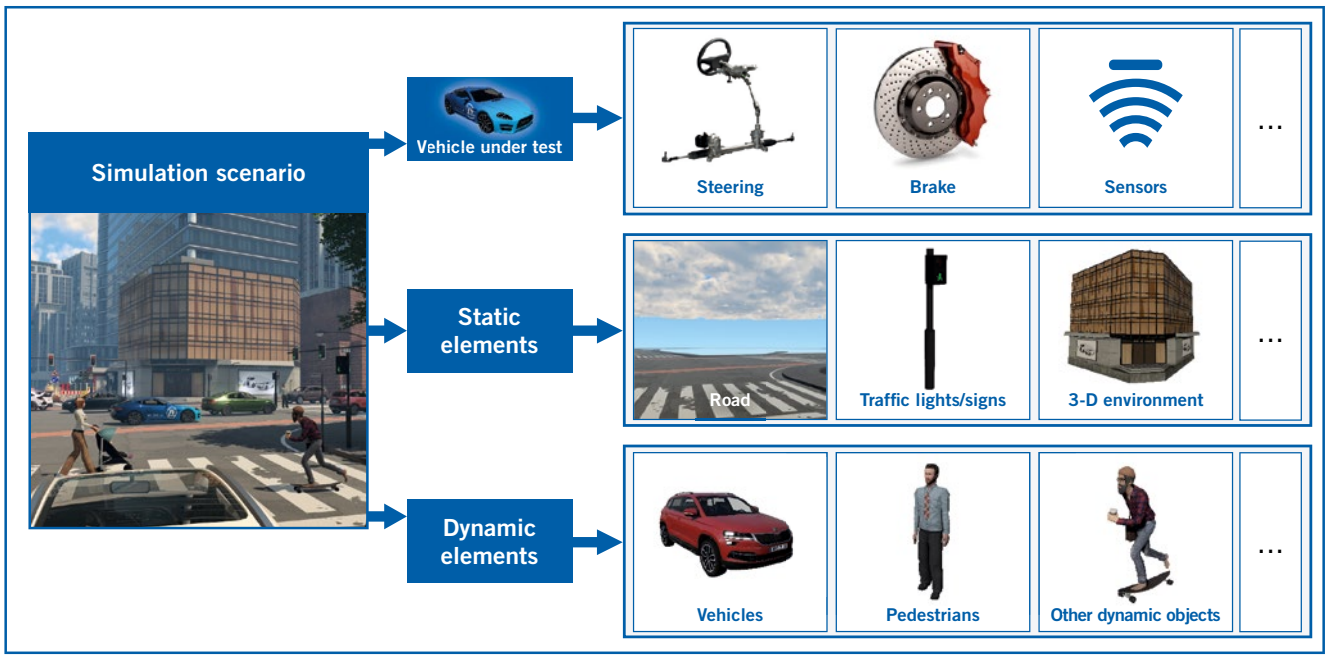

FIGURE 3 Braking down a simulation scenario into artifacts for data management systems (© ZF | PDTec | IPG Automotive)

tests which, in case of seamless application of the CarMaker platform, underlie the same test constraints. Depending on the test and the required modeling depth, input data from the individual subsystems can be variable, meaning that it is available in different levels of detail. The resulting possibilities of consistent referencing with regard to identical logical contents in data management systems enables the systematic connection of the two test approaches that are usually operated in different sub-organizations. To this end, possibilities for bidirectional traceability of virtual test driving and its components were created. Mechanisms for continuous fixing of data sets were adapted to guarantee the necessary overall reproducibility of virtual test driving.

Especially in the context of SiL tests, there is a colossal need for automated simulation that seamlessly fits into current software development processes. It is consequently not only necessary to connect the data management with scalable computing resources but also to provide complex simulations as easily usable "Services" so that simulation runs can be integrated into overriding workflows (for example continuous integration and KPI-based testing). Thanks to the implemented system architecture, **FIGURE 2**, both requirements were effortlessly accomplished.

SUMMARY AND OUTLOOK

Here, ZF, PDTec and IPG Automotive describe the importance of data management systems for an effective use of simulated driving in the development of automated driving functions. Based on the numerous requirements in this area, it is illustrated how these requirements were addressed and how a comprehensive, complete solution based on a regular SDM system was designed and implemented at ZF. The system enables a large user community to use models, simulation data and test scenarios in an intelligent and distributed way.

The consistent coupling of regular CAE simulation domains and system simulations bears a great potential for the future, as they allow for example to derive reduced models for system simulation from complex models. Traditional domains as vehicle dynamics but also more recent disciplines such as sensor simulation require these processes. Furthermore, the systematic management of virtual vehicle prototypes and test drives can improve collaboration between OEMs and their suppliers.

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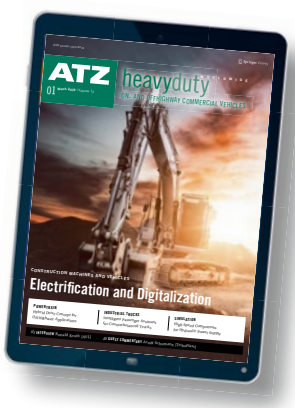

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