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Connected Car Challenges Digital Loop –
Data-Driven Development of Driving Functions

C³ White Paper: Digital Loop – Data-Driven Development of Driving Functions

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Radical changes in the automobile industry require continuous, data-driven development

An Increase in Functions Requires New Development Methods

As in many other industries, the automotive sector is facing challenges related to the development, validation, and homologation of the growing number of digital and networked products. Previously based on standards and the classic V-model, software-based automated systems now require data-driven as well as iterative and agile development methods. More than ever before, selling a traditionally discrete product also involves rendering regular services for the operation, maintenance, and continued development of vehicle systems that have already been delivered. Due to the growing range of functions in modern vehicles and the resulting complexity of the E/E architectures, the number of software updates for vehicles in operation will continue to increase. This increasing overlap between various phases and their further development within the product life cycle poses a great challenge for car manufacturers. Mastering this challenge requires innovative approaches for the continued advancement of highly complex digital systems. Achieving highly automated driving is a prime example of this. In this case, the car as a physical product takes a backseat and is replaced by a cyber-physical system, which is called an "automated driving system (ADS)" by leading standardization committees such as the Society of Automotive Engineers (SAE).A significant change resonates in this name: Although modern vehicles already represent highly complex systems, they are self-contained to a great extent and are therefore perceived as a clearly delineated unit after being produced. In contrast, an ADS is a much more open and modifiable system, which can sometimes be part of a networked or distributed system. An ADS is a key component of its environment and must be able to perceive the surrounding objects on its own. It has to estimate their reactions and movements in real time in order to respond independently within the scope of its defined limits and targets.

Data-Driven Solutions for Volatile Problems

These new characteristics essentially result from the complexity of the problems. In contrast to the basic physical operation of a vehicle – that is to say, its propulsion along a certain trajectory using the various steering and control devices – this is a challenge that can likely be overcome only by means of data-driven, continuously optimized solutions (based on artificial intelligence and machine learning). Traditional rule-based systems are quickly reaching their limits due to the many different influencing factors and each of their distinct characteristics and correlations. Logically, the existing sets of training and validation data will determine the success of these data-driven solutions. The more comprehensive and representative this data is, the better the quality of the resulting algorithms. However, because modern traffic environments are not only highly complex and dynamic but also volatile – for example, due to new modes of transport, changes to urban areas, or amended traffic regu-

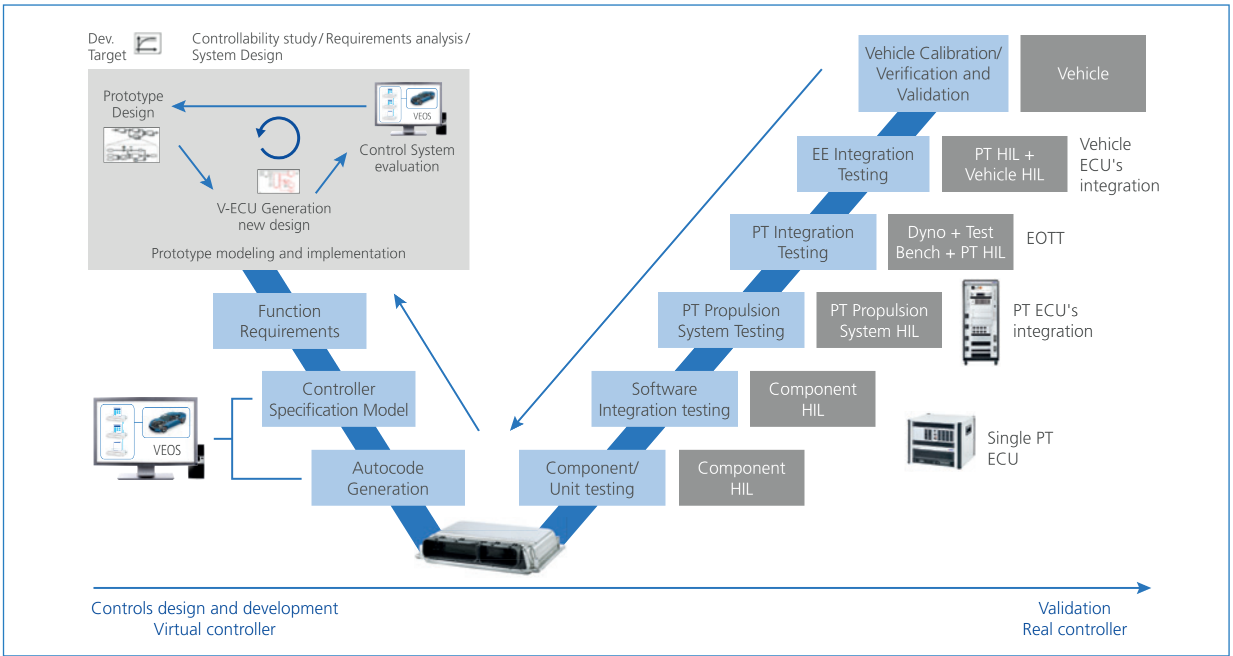

Fig. 1: A typical process for developing algorithms.

Established Development Approaches Limited by Speed and Flexibility

lations – there is not a set point in time at which all relevant data can be collected to find consistently valid input parameters for developing algorithms. Instead, it can be assumed that existing algorithms have to be adjusted on a regular basis as a result of new and changing functional requirements. Likewise, it is necessary to take into account the qualitative development of existing algorithms. If possible, these adjustments should be made available to all ADS currently in use. As described at the beginning, this is necessary because the boundaries between development and operation are becoming increasingly blurred. This blurriness has to be covered by a completely integrated, fast, and especially reliable process.

Paradigm Shift Due to Data-Driven Development

Where earlier most people worked with closed loops for developing (prototyping) and validating (closed-loop XIL), data-driven development has led to a paradigm shift: The data is also used to stimulate the interfaces and for the final evaluation. This requires test methods and systems that reproduce recorded and enriched data from test drives or from simulation to validate the behavior of AI algorithms and AI-based control units. This can be done purely as a simulation on the basis of software and AI algorithms or under strict real-time requirements directly with the ECU hardware. Ultimately, testing functional and structural requirements by using collected, synthesized, and enriched data leads to new challenges in validation. To make this data process as secure as possible and to link it efficiently to the established integration stages along the E/E development process, the new technologies and methods must be integrated into an overall process. This process covers all aspects equally, from data processing and AI training to system integration, and relies on continuously repeating processes that also improve the system maturity with additional data.

Current Processes for Developing Algorithms

Taking a look at the current processes used to develop algorithms can help illustrate the amount of adjustments and modifications required for this. In the case of data-driven development, this process begins in the vehicle itself. Within the scope of test drives, large amounts of sensor data (up to 10 terabytes per day and vehicle) are recorded to specific storage devices. After completing the range of test drives, these storage devices are removed and read with the help of specially provided docking stations, and the data they collected is fed into the appropriate systems for further processing. In view of the large amounts of data, typically no mobile data connections are used for transferring relevant raw data sets within the framework of prototypes and preproduction series tests. The data sets are then exported from the test vehicles either via WLAN or a plug-in solution at the edge (test location) and then processed further there (code to data). In the case of plug-in solutions, there is a great deal of logistical effort involved because the hard drives and the data sets they contain have to be processed via plug-in solutions. Especially in remote test locations, this can lead to significant delays. For the continued further development based on fleets (vehicles that have already been delivered to customers), this approach is not sufficient since, on the one hand, the hardware costs per vehicle would increase considerably and, on the other hand, the data would only be removed and exported in extremely inadequate intervals, for example, as part of agreed maintenance intervals.

Limitations of Established Development Approaches

After the data has been collected, the data sets flow into a lengthy development process. This process is divided into different development units, which verify and validate the gradual progress of their development tasks by means of simulations and even real test drives. Both rule-based and data-driven development approaches are used here. Typically, these are lengthy processes with very little automation that consume a lot of resources. Furthermore, interorganizational coordination and planning, deliveries, test drives (in many different situations over thousands of kilometers), and dependencies on other development areas (especially hardware development) result in process steps that last months or even years. Therefore, requirements are missing here to ensure continuous development in short cycles, although the basic development methods being used certainly correspond to the state of technology. Delays caused by physical testing and approval processes limit the speed of the process too much, making it impossible to use it as a flexible solution to solve problems that arise at short notice.

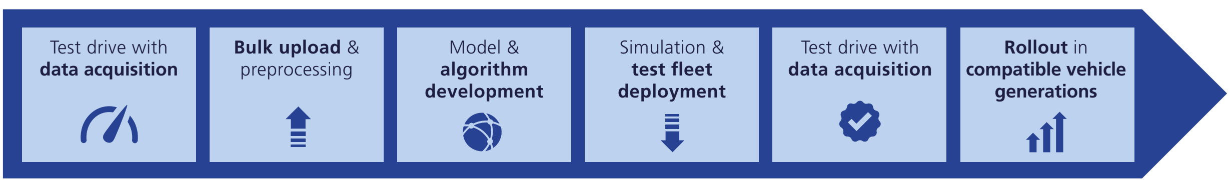

Fig. 2: Status quo process chain for functional development.

The Structured Use of Swarm Intelligence Is Revolutionizing Functional Development

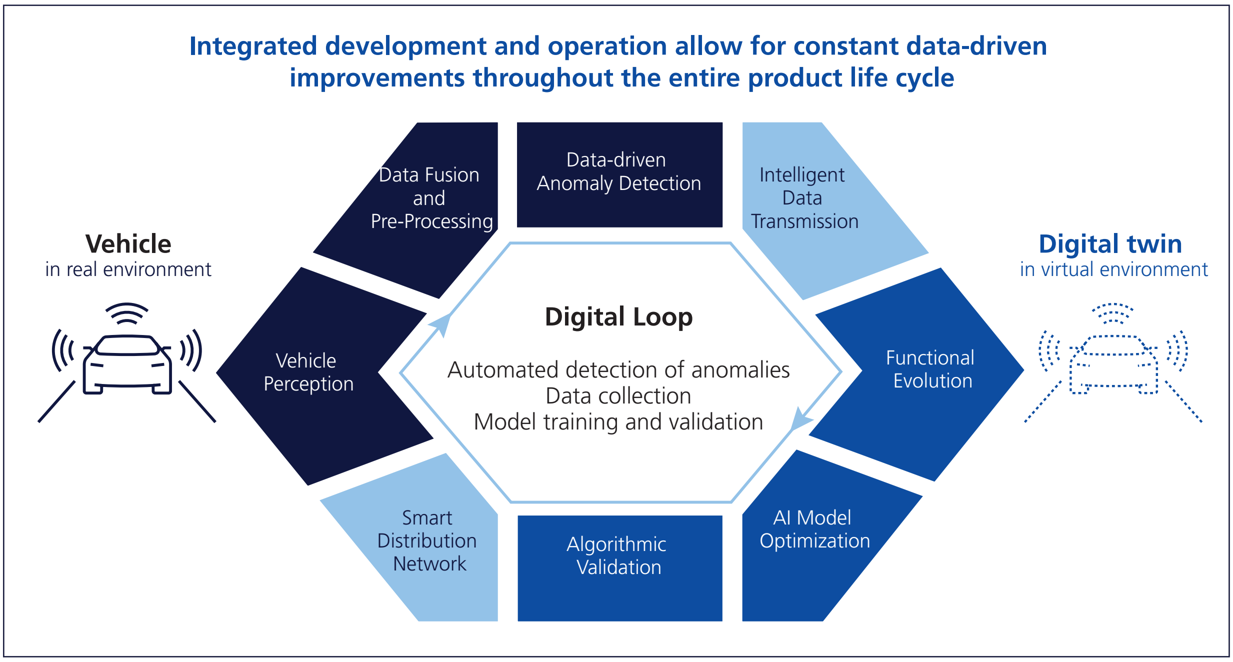

Fig. 3: Development system components are run one after the other as digital loops.

Delivering Newly Implemented Functional Components

If the development and test process was carried out in accordance with regulations, the question arises as to how the development results can be provided to the vehicle systems that have already been delivered. This is only possible to a limited extent for the majority of the relevant vehicle fleets because vehicles are currently inspected and approved as a unit consisting of hardware and software components. Therefore, any later modifications to the vehicle software have to be evaluated to determine whether they are relevant for homologation. If so, the modifications require subsequent approval. At the same time, safety concerns arise regarding changes to safety-relevant vehicle components as a result of over-the-air (OTA) updates. As a consequence, software updates for safety-critical components are typically provided only as part of recall campaigns and workshop visits. Apart from that, development progress is intended only for new generations of vehicles, which then stay on the market for an average of ten years. Therefore, current processes allow for the sustained development of infotainment functions at best. However, new regulations, such as UN ECE R156, are aimed at changes in this area that will increasingly make safety-relevant function updates possible.

Using the Data Collected from Vehicle Fleets

It is conceivable that the widely practiced approach to data collection, algorithm development, and algorithm distribution will represent a serious barrier to innovation. Due to limited capacities and high costs, dedicated test methods can cover only a comparatively low share of relevant traffic situations. As a result, this is not a sufficient basis for data-driven algorithm development. Simulations and synthetically generated data sets can compensate for these deficiencies, but they are subject to a certain degree of uncertainty with regard to their representativity and authenticity. For an effective and efficient solution, making use of the growing vehicle fleets in operation is essential. This potential resource is not yet being used sufficiently by the majority of established car manufacturers, although doing so would result in a clear competitive edge in the mid to long term. Therefore, a systematic approach will be outlined below with the aim of taking advantage of this previously untapped potential and achieving the associated competitive advantages by means of a consistently automated process. To set up such a system, it would be necessary to implement various individual solutions one after the other. These include components within the individual vehicle systems in a fleet, an intelligently orchestrated data transfer, validation and homologation components in the back end, and a channel for safety-relevant over-the-air updates as a feedback loop to the fleet.

Modern vehicles allow for a continuous collection of data sets for defined situations

In the Vehicle: Collecting, Merging, and Selecting Data

Modern vehicles are equipped with a wide range of environment sensors. In addition, you can count on enhanced built-in sensors for the higher levels of automation. As part of continuous environment scans, large volumes of raw data are collected, especially camera feeds as well as lidar and radar measurements. At the same time, data for the vehicle system functions themselves is generated on a number of data channels as different ECUs and application, such as a head unit and other computing units, are used. Merging all data results in a dynamic environment simulation of the current situation. The system uses this basis to automatically make decisions and plan actions. All this data is relevant to an extent, but not all of it can be processed due to the sheer volume. Therefore, data sets are currently discarded right after they are used for productive operation to avoid memory overloads in the vehicle. Conversely, test drives are used to collect as much data as possible over a longer period of time, albeit with a relatively limited number of vehicles compared to productive operation. This means that test drives are samples at best. In reality, the majority of the collected data is only of little value for the further development of vehicle algorithms, because the data usually represents traffic situations that are already contained in existing data sets, which can therefore be used to solve most traffic situations. The question arising for development is how to collect data specifically for unusual driving situations or situations that have not been solved yet.

Situation-Based Data Collection

It is important to identify the relevant situations, put them into the appropriate context, and index them accordingly. In practice, this means that out of 24h of sensor data recording, only a few seconds are actually relevant. For example, if a vehicle was maneuvered through a complex traffic situation at an intersection. The only way to filter for these scenes on a large scale with economic efficiency is automation. One possible solution is to set certain flags for relevant situations during algorithm development. The flags are then collected as protocol anomalies in later operation, saved, and transferred for use in a backend machine learning process. Some examples for such flags can be found in object detection. Certain combinations of factors point to rare or highly complex situations that can be relevant for later development stages, such as a high number of pedestrians in an intersection combined with rain and partial road blocks. If a fleet vehicle faces such a situation, the relevant data sets are automatically collected by a smart data logger. The data logger is directly integrated into the processes for sensor data processing, fusion, and analysis. This way, it can record the data sets for later use. Rolling storage processes can cover times before and after a flag is set. This ensures that the required context is stored with the scene. Generating the meta data for each situation and the underlying flags and/or protocol anomalies ensures that the data can be processed in a structured manner later on.

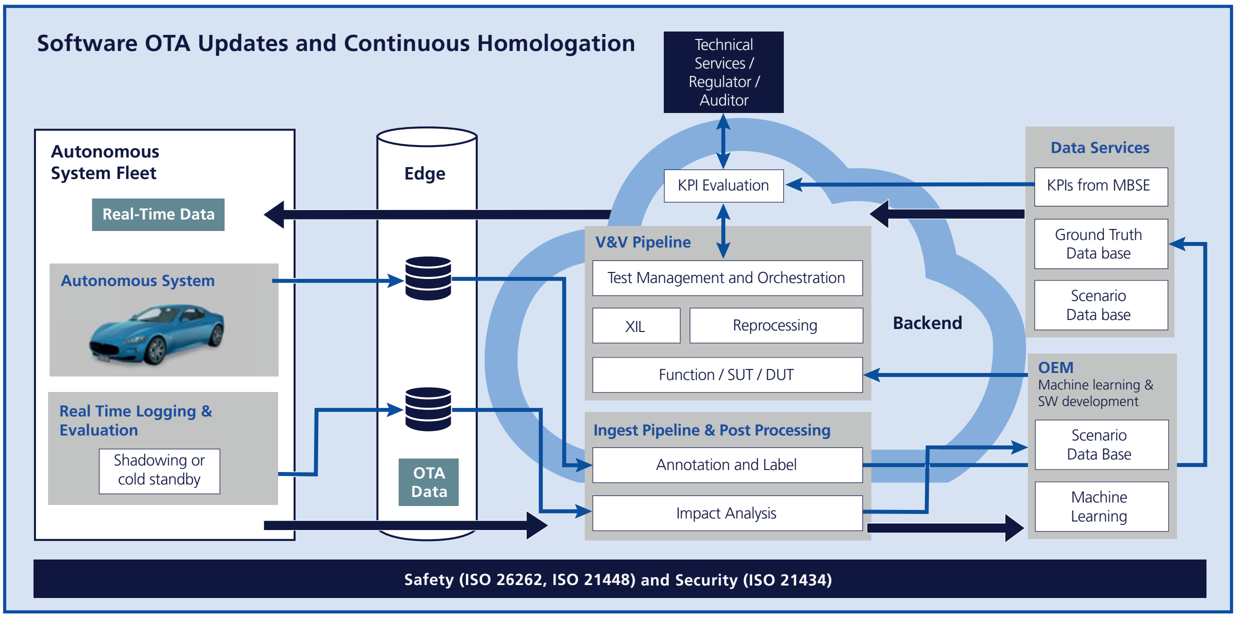

Fig. 4: Software OTA updates and continuous homologation.

Intelligent data transmission allows for faster development and validation on the back end

Intelligent Data Transmission

The collected data is coded as required. It is then directly transmitted via mobile communication or saved via dedicated edge devices or WLAN hot spots for later bulk uploads. Currently, data is predominantly read using edge devices. In the long term, however, hybrid methods will become possible that reduce the required data volume and allow for the prioritization of the collected data sets so that data transmission can be better orchestrated. The basis for orchestration is an intelligent data flow that covers the entire process chain, from vehicle sensors and onboard data processing to edge devices and back end instances. In this data flow, data from different sources is processed on the basis of its context. Data processing is based on logical groups which are based either on the specific traffic situation, as described above, or on characteristics such as the data source (e.g., a specific vehicle system, external traffic infrastructure like traffic lights or traffic management hubs, locality with different source systems, etc.). This can result in a large number of logical groups, depending on each use case.

Optimized Data Distribution and Analysis

Meta data and logical groups allow for continuous monitoring of the overall data flow. Anomalies are logged with a reference to the relevant data packet. They are subsequently analyzed to avoid processing potentially corrupted data sets. This approach also makes it possible to control further data processing. For example, in latency-critical data streaming, performing an analysis in mobile edge nodes is useful, i.e., in the computation instances that are closer to the data source in the network architecture, thereby allowing for smaller latencies. Longer-term analyses, on the other hand, can be completed in subsequent cloud back end instances. Orchestration in the data flow can also be used to handle redundancy. For example, if multiple vehicles encounter a certain complex traffic situation, the data volume can be minimized if only the difference between the sensor measurements is processed further. This means the system uses the most effective and efficient transmission channel to implement structured n:n communication between different data sources and data sinks.

Virtual Validation

In the back end, transferred data enters an ingest pipeline in which the back-end-based preprocessing is performed, including labeling and, if required, transcoding. In this case, it is important that the incoming data sets were already analyzed and annotated with meta data by the onboard data logger and in the intelligent data flow. The meta data is used to identify similar historical real data sets in comprehensive scenario repositories. The combination of new and historic real data sets form the basis for synthetic data sets, which are used to extend the training data base. The synthetic data sets are created for the algorithm tests that are required later on. However, the real data can be used for model training only to a certain extent. Therefore, the real data is complemented with synthetic data sets for the further development process, e.g., by adding rain or light and shadows to a scene. This makes it possible to improve the models as required in open- and closed-loop testing. Synthesis algorithms play an important role here, because they are used to create the data.

Simulations and XIL Tests

Simulations that are based on synthetic data are used to test and improve models. The system uses relevant use case catalogs that comply with current safety standards, such as SOTIF (ISO/PAS 21448) in the automotive sector. These use cases contain complex driving scenarios which define the requirements catalog for each algorithm component. For example, an object detection component is checked to see if pedestrians are correctly identified in different scenarios. If this is the case, the current model configuration does not have to be changed. If this is not the case, the model is adjusted until the defined minimum performance threshold is reached. In order to correctly measure performance, the test object has to be integrated in known simulation scenarios and XIL tests have to be performed, i.e., a combination of model-in-the-loop (MIL), software-in-the-loop (SIL), and hardware-in-the-loop (HIL) testing. As the HIL tests entail greater effort, they can only be included in specific points in the process. However, they are absolutely necessary in light of the cyber-physical nature of the vehicle systems. This is the only way to achieve meaningful results for later use in production vehicle systems.

Digital Validation Methods Offer Valuable Support for Validation and Homologation

Iterative Simulation and Validation

Co-simulation proves to be particularly valuable to ensure a targeted and seamless use of the test hardware, whose availability is strictly limited, in hybrid simulation scenarios. A more efficient separation into test scenarios results in an acceleration of the entire product life cycle.

Therefore, the entire validation process becomes an iterative sequence of simulation, model training, and the generation of KPIs on model performance, distributed across the individual algorithm components and different XIL test categories. It is important to understand the entire existing basis of real data, which can be provided using digital twins for the relevant fleet systems and other data sources involved, such as the infrastructure. In turn, the synthesis process has to be monitored. This process is a core component of the overall system, but it always has to be analyzed and questioned at a very detailed level because it always involves a deviation from ground truth. As with any tool, knowing the limits of a system is of utmost importance for virtual validation. This can be achieved by establishing safety margins for error rates, for example. At the same time, it is becoming clear that certain model versions can only by covered by dedicated test drives.

Digital Loop as Homologation Support

After model improvements and virtual validation are completed, it has to be checked whether they affect vehicle type approval according to EU regulation 2017/858. This has to be verified before the modifications can be passed to production vehicles systems. This means that covering and automating an entire end-to-end process requires a solution for homologation. In general, these vehicle functions can be separated into homologation-neutral and homologation-relevant functions. The new UN-ECE regulation R156 formulates requirements for OEM's software update management system (SUMS) and the vehicle types. OEMs have to use the processes in the SUMS to implement measures that can be used to identify whether software updates on target vehicles are relevant for homologation.

Technical Integration of Auditors

If a modification is relevant for homologation, an extension of designation is required. The required process speed can be implemented only by integrating auditors into the overall process. This calls for the introduction of the necessary interfaces between development and test systems as well as homologation processes so that independent auditors can directly access the subsystems to be tested. The audits can focus on different areas. The main result of the continuous development and validation processes is data-driven models. The auditors can subject the models to specific test cases. For example, they can use their own audit scenarios with relevant driving situations and use cases.

Standardized Validation Software

This requires the creation of a suitable validation component that represents the final step in the continuous validation process and can be used as a part of type approval. Auditing activities would therefore be extended to the creation and validation of simulation results. By extending audits from mere checks of real vehicle types to also include simulation-based validation, it becomes possible to check complex vehicle functions and accelerate the processes in the long term.

It is a known fact that the current auditing methods will lead to bottlenecks in data-driven development for safety-relevant functions in the short and medium term. It is therefore essential to find alternative solutions quickly, test them, and turn them into products or standards. The close cooperation between development partners and auditors is of particular value in this regard.

New Software Components Are Delivered Using Flexibly Scalable Update Campaigns

Structured Fleet Updates

After the successful check and seamlessly integrated homologation, the improved algorithms have to integrated into the respective fleet vehicles. The typical OEM fleet size, which is usually several million vehicles, poses certain logistical challenges, which are best solved by distributing updates on a data network. A multimodel approach is beneficial here, similar to the intelligent data collection. Updates are passed to content delivery networks (CDN), which can then be controlled by vehicle systems via mobile communications, WLAN hot spots, and other data connections. A few prerequisites have to be fulfilled to execute this step. First, in the vehicle itself: It has to be ensured that the vehicle architecture is generally able to receive updates, process them, and provide a success or error message, depending on the result. This means that a completely software-defined vehicle would be ideal to reap the full potential of continuous, data-driven development. Naturally, interim solutions can also be used, where only specific vehicle components are integrated into the system. The target architecture has to meet the regulations specified in relevant standards and rules, such as UN ECE R156. In addition to the vehicle, the back end components also have to be adjusted to the system requirements. The focus here is on device and remote update management systems of the individual OEMs, where the software components that were improved using virtual validation are stored in a central software repository. The repository provides a complete version history of the developed software component.

Update Campaign for Heterogeneous Vehicle Clusters

If significant errors occur, rollbacks to stable earlier versions can be implemented this way. In addition to this software repository, the update component has to provide clearly structured device management options that can be used to check which software version is installed in each fleet vehicle system. It also has to be possible to classify the vehicle systems into logical groups in order to steer the update process according to compatibility, priorities, network availability, etc. This input is used to provide updates to the vehicle clusters in an overall campaign management process.

Automating Update Workflows

It is important that the systems can access the vehicle clusters by means of flexible processes, similar to accessing the software-defined components in the vehicle. Therefore, the relevant protocols and interfaces have to be documented and available. At the same time, the processes must be as powerful and efficient as possible. Otherwise, the high vehicle volumes can cause shipment delays. If critical software updates are required, this could have fatal consequences for productive operation. Furthermore, the update processes should be automated to a high degree and be based on robust, error-resistant workflows. As with the previously mentioned partial processes, the required processing speed can be achieved only by using automated workflows that have to be checked and adjusted by experts only in occasional, exceptional cases.

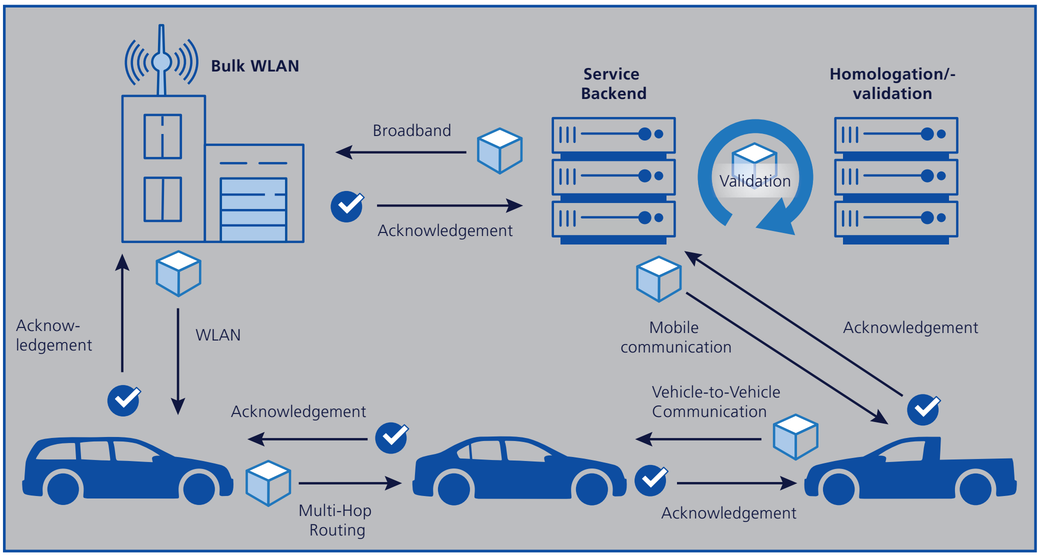

Fig. 5: Updates can be provided and orchestrated on a range of network media.

The Core Principles of the Digital Loop Increase Development Speed and Shorten Time to Market

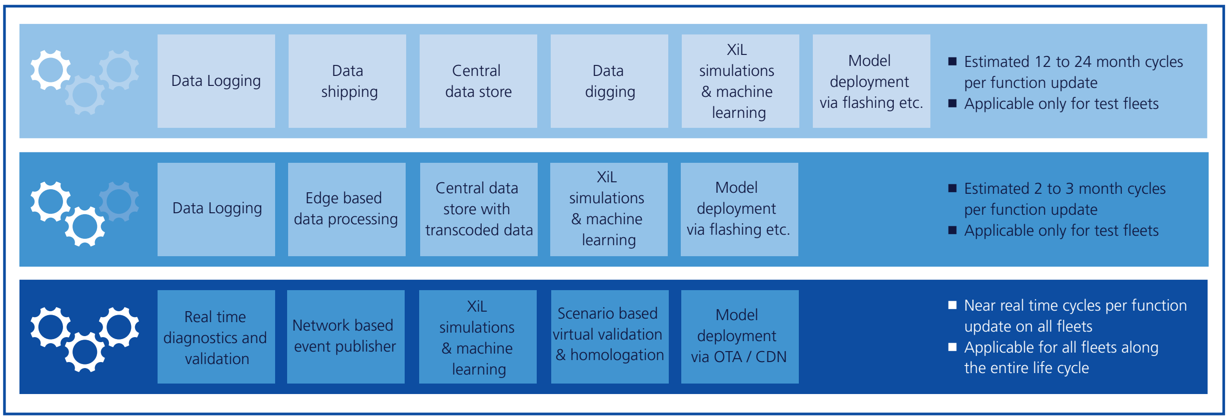

Fig. 6: The setup of digital loop components improves quality and time to market.

Digital Loop – Basic Principles

In summary, it can be noted that the described concept aims to implement a range of principles in the context of function development. The system covers the entire development and validation process from end to end. Continued iterations of the process allow for continuous improvements to the specific software component. These improvements are based on data-driven development, making the process suitable for a number of domains. Data is collected in the manner of swarm intelligence by intelligently networked fleets. The entire process is automated to a large extent to achieve the speed required for productive operation.

Advantages for End Customers and Manufacturers

Implementing such a system provides a range of benefits for manufacturers and end customers. It not only allows for faster approval of new vehicles and functions. It also addresses their continued development so that the product's software, data-driven automation, and control functions can also be kept up to date, making it an attractive long-term investment for vehicle users. A continuous stream of new features is not the only benefit for customers: Potential errors are resolved immediately and any subpar customer experience configurations can be corrected swiftly. The described process is therefore an essential tool for securing one's market position despite ever shorter product life cycles. In addition to the functional improvements, this approach improves traffic safety by means of continuous development and validation. The flexible handling of different data sources enables interoperability between traffic participants and infrastructure elements even in early phases of development. The incurred development costs are consistently reduced because the collected data is used efficiently and existing fleets are used. A functional separation into building blocks that can be used independently of each other ensures the uncomplicated integration of existing solution parts into the overall system.

Conclusion

New challenges call for new solutions. This statement is particularly true for the automotive industry in view of the many new and converging challenges. Data is certainly not the be-all and end-all in this matter, but it does play an increasingly important role by paving the way to environmentally friendly and integrated mobility. Data is also an important driver of highly automated and connected driving. Competence in data handling is therefore indispensable. This means that development departments are facing a host of requirements that are difficult to fulfill with conventional methods. To achieve higher levels of automation even in complex traffic environments, efforts in data acquisition, model development, and validation are required, which previously entailed unreasonable investments in conventional development resources. The approach to continuous development and validation in this paper presents an efficient alternative.

Strong Network of Partners Drives the Design and Implementation of Digital Loops

Consistently automating and structuring complex process steps saves time and resources, making it possible to achieve high-quality, safe solutions even with relatively little development effort. The advancement of algorithms for highly automated driving is certainly one of the more promising use cases. At the same time, only minor modifications make the model usable for numerous other industries and software components (building general autonomous systems). Any data-driven application with strict validation requirements could benefit from such a system. Even though industry-specific factors do play a role, the underlying technological questions are very similar for all autonomous systems. Whether these systems are used in the automotive industry, intelligent manufacturing, or medical diagnostics – The seamless automation of the underlying process chain remains an important prerequisite for future-proof delivery models for digital products and services. Some questions on implementation and automation remain unanswered. Considering the increasing degree of networking that will be required in the future because vehicle ecosystems will span multiple organizations, it would not be wise to rely on in-house developments. Rather, the use of standardized building blocks and, if available, modular platform-as-a-service (PaaS) components is advisable. In addition to addressing functional requirements for validation and homologation, open platforms and multi-partner ecosystems are most suitable to efficiently cover topics such as scalability, interoperability, and general regulatory compliance.

Authors and Partners

The design and implementation of the digital loop requires broad expertise in industry and technology. Together with our partners, we therefore push research projects and reference implementations to make the design a reality.

dSPACE: Partner in Simulation and Validation

Every day, people around the world use means of transportation that were developed, tested, and validated with dSPACE solutions. They can trust that their vehicle's propulsion system is energy-efficient, that intelligent assistance systems make driving more comfortable, and that the plane they are on is safely guided to its destination. Even today, dSPACE is working with leading technology providers worldwide to make the vision of autonomous driving a reality.

T-Systems: Integration and Networking

With building blocks for intelligent connectivity, connected services as well as platform setup and transformation, T-Systems offers a broad range of solutions for the data-driven development of tomorrow. These solution components for networked, automated, and integrated mobility are already being used in globally connected car fleets encompassing millions of vehicles. The advancement of the T-System building block portfolio is continuously pursued in a number of research projects.

TÜV Nord Mobilität

TÜV Nord Mobilität is one of the major technical service providers for technical monitoring. Its core values include independence, neutrality, and integrity. TÜV Nord Mobilität is home to the Institute for Vehicle Technology and Mobility (Institut für Fahrzeugtechnik und Mobilität, IFM). The IFM is an accredited and independent engineering and audit service provider in the automotive sector, working for industrial companies and government authorities in Germany, Europe, and worldwide. As a designated technical service provider of various approval authorities, the IFM is active in the homologation of road vehicles worldwide.

Detecon International GmbH

Detecon is a leading, international management and technology advisory firm with headquarters in Germany. It has combined classical management consulting with competence in technology for over 40 years. The company focuses on digital transformation: Detecon supports companies from all industries in using state-of-the-art communication and information technology to align their business models and operative processes with the competitive environment and customer requirements in a digitalized, globalized economy. The expertise of Detecon combines the knowledge gained in successful consulting projects in over 160 countries. ■

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