Images: Softing

E/E in the Vehicle Manufacturing of the Future

Software-Driven Vehicle Engineering

For a number of years, electronics and software have played an increasingly important role in vehicles. In particular, a wide range of assistance functions together with the fields of autonomous drive, electrification and the connected car & V2X have expanded the importance and scope of software-based solutions in vehicles. From approx. 10 million lines of code (LOC) in the 2010s, this figure has now risen – in certain cases – to well over 100 million LOC. And it is not stopping there. This is made possible, and driven forward, by the greatly enhanced performance of the hardware installed in present-day vehicles. In addition to conventional ECUs, domain controllers with a high processing power and, in some cases, specialized processor cores have also been adopted in recent years. This has led to a massive increase in the need for software engineering, accounting for a significant proportion of the development costs. The next step along the road to zonal high performance clusters will accelerate this development even further.

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In light of these factors, the importance of expertise in the field of software engineering has grown immeasurably in recent years among almost all vehicle manufacturers. Greater cooperation and an increased number of joint ventures between vehicle manufacturers (Argo AI, Cruise, Motional) and with technology companies such as Amazon, Microsoft and Google underscores the long-term nature of this change. With modern vehicle and backend architectures increasingly converging on IoT architectures that have already existed for a number of years, noticeably more established IT standards and technologies are finding their way into vehicle engineering. It is therefore no surprise that modern vehicles have in recent years become known as “"smartphones on wheels".

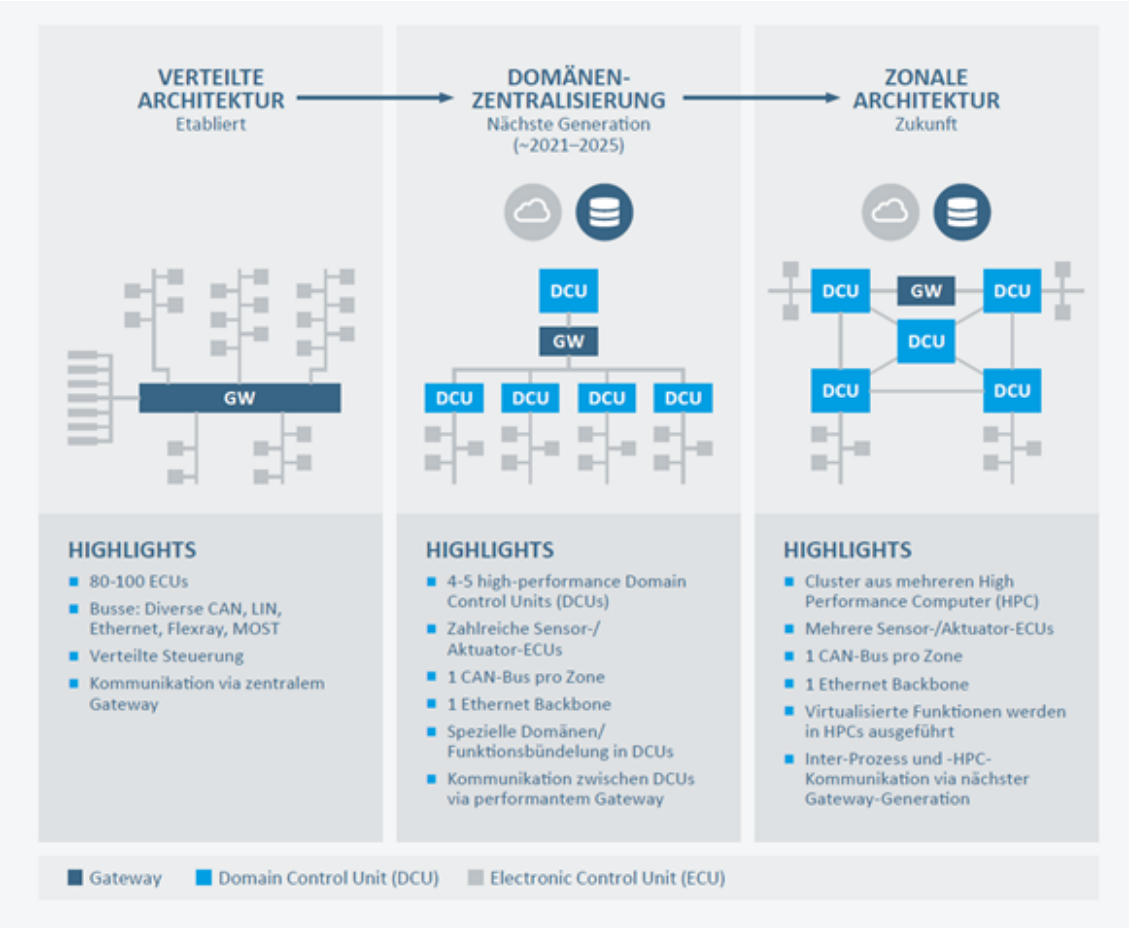

Figure 1: Changes in E/E Vehicle Architectures over Time (Schematic Diagram)

Software Update Challenge

The automotive industry nevertheless demonstrates certain sector-specific particularities. In vehicles, these include the numerous different bus systems, interfaces and transmission protocols. More particularly, the heterogeneous E/E architecture and the various bus systems make it difficult to transfer mobile device & cloud IT approaches in full because while a DCU or HPC can certainly be updated by means of proven software update methods, this is not the case for downstream ECUs on the CAN bus. Here, the flash procedures established in automotive standards are to be used for an ECU update. Other bus systems, such as FlexRay, LIN and occasionally even MOST, do not make the situation any clearer. Even in modern vehicles, this often results in a distorted picture at the OBDII port:

In addition to high-performance, modern onboard computers reached via fast Ethernet connections, there are also numerous CAN and CAN FD connections. While data rates of up to 100 Mbit/s (100Base-TX) or even 1 Gbit/s (1000Base-T1) can be achieved with Ethernet connections, a maximum of 1 Mbit/s (CAN HS) or up to a maximum of 8 Mbit/s (CAN FD) are possible with CAN or CAN FD connections. In terms of the number of ECUs installed, CAN-FD vehicle access is still predominant in new vehicles. The switch to Ethernet is nevertheless already in full swing. The type of bus system is therefore key to determining the duration of a software update procedure. Currently, the size of software packages for flashing all ECUs in a vehicle is typically between 50 and 500 MB. If you nevertheless consider that the size of software packages for future vehicle generations will be over 1GB, the importance of the bus system becomes all too clear, because in the automotive industry in particular, time is money!

Current Situation in Series Production

This is especially true in vehicle manufacturing, because nowhere else are the efforts to optimize each process sequence more intensive. And the unit in question is seconds. So it is not surprising that the rapidly increasing software package sizes represent a massive challenge in the field of vehicle manufacturing. Even though every manufacturer has their own production strategy, numerous parallels can be drawn in the following simplified summary: The assembly line is divided into different production line sections, linked by

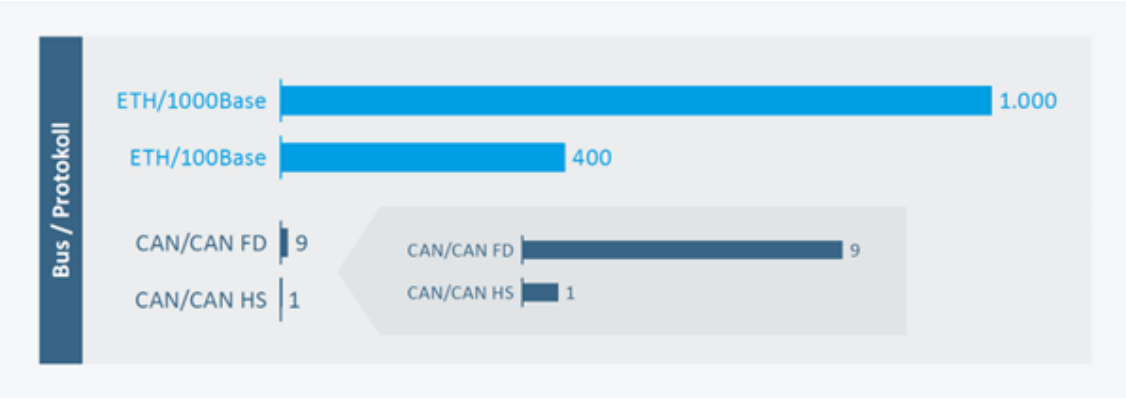

Figure 2: Relative Data Throughout per Unit of Time with Different Bus Systems for Large Volumes of Data

means of conveyor technology, for the different manufacturing and engineering phases up to the finished vehicle. The scopes of the E/E development as well as the subsequent flashes and tests are spread across different production line sections. The associated work is performed automatically and/or manually by workers at the workstations along the line. The initial installation of the relevant electronic components and their electrical connection to the vehicle access by being connected to the vehicle electrical system is a prerequisite for conducting flash and test processes at the subsequent workstations. The working time at the workstations is controlled by the speed of the assembly line conveyor technology. The period of time between arriving in and leaving the workstation area corresponds to the cycle time. Nowadays, once a central ECU has been installed (often the engine ECU, gateway or head unit), a Wi-Fi connection is usually established between the testers and the vehicle's E/E systems by inserting a vehicle communication interface (VCI). Test, flash and coding processes are initiated for the relevant vehicle, controlled by the manufacturing system and adapted to the current state of construction or the work content at the respective workstations. The number and distribution of these E/E process steps differ considerably depending on the vehicle manufacturer and model. While some manufacturers only carry out E/E process steps on certain production line sections, others use almost the entire length of the assembly line.

Because every vehicle is configured individually for the buyer, the specific versions of the work content differ from one vehicle to another. The progression of the vehicles and their adaptation to the assembly cycle correspond to the manufacturing program. Tailored specifically to each vehicle, the associated construction scopes and working steps together with data for flashing, testing and coding, in the case of E/E scopes, are recorded in production orders. The so-called manufacturing system, which is a

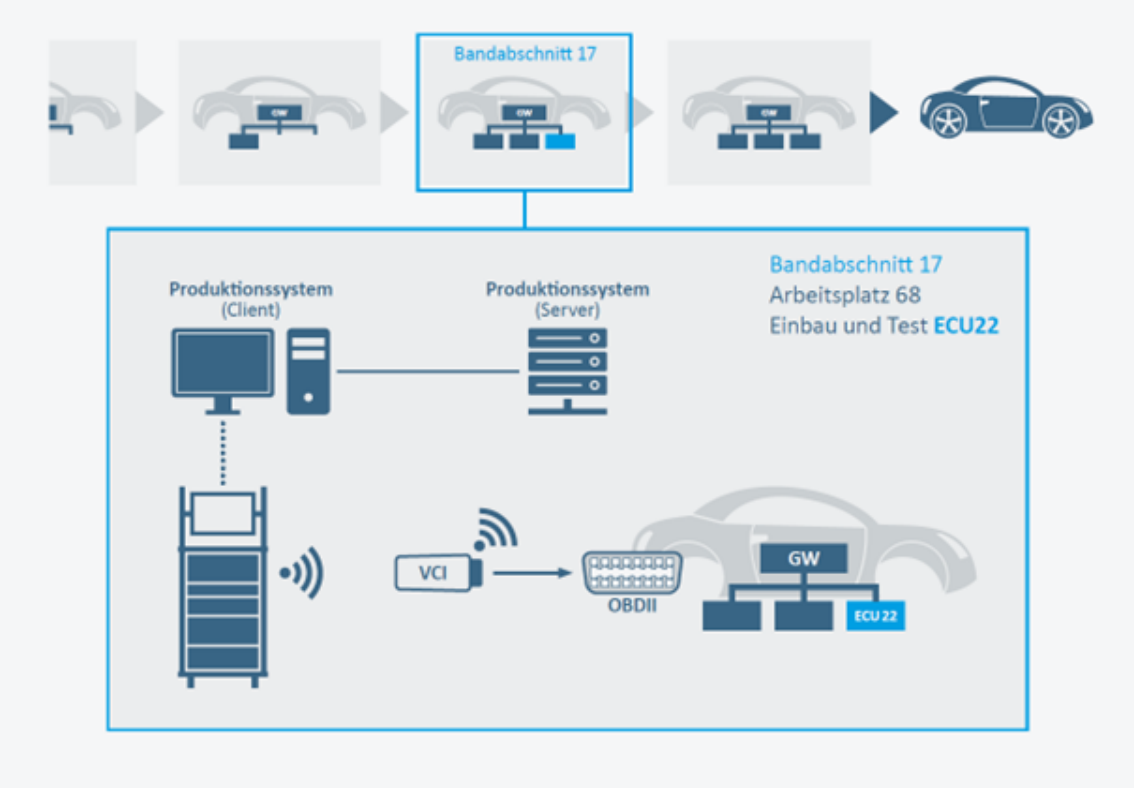

Figure 3: Overview of the "Vehicle Flash" in Modern-Day Vehicle Manufacturing Lines

specialized ERP system, is tasked with controlling this. Even though the core of a manufacturing system of almost all vehicle manufacturers is a standard commercial software, there are often additional tools developed in-house which provide vehicle-specific data. Accordingly, the relevant manufacturing system must incorporate different data sources. In this respect, action is often still required to ensure that there is a generally-valid single point of truth (SPOT) for vehicle manufacture. This is another stumbling block with regard to the direct transfer of mobile device & cloud IT approaches.

New approaches

Naturally, these challenges are already recognized in the automotive industry, with huge efforts being made and countless projects implemented to achieve "digitized vehicle production". In many cases, this involves creating the data-related basis, in the sense of a SPOT, and adopting the future manufacturing infrastructure for the provision of data on the assembly line. In light of the large and extremely heterogeneous data sources, cloud technologies are often used as SPOTs. The major advantage of this is that they can draw on proven processes, methods and tools from the IoT for the purposes of

- Version management as well as the distribution and updating of software and data,
- Compliance with performance, availability, backup and security requirements,
- Scalability and automation capacity, and
- Flexible extension and migration options.

The course already embarked upon towards cloud computing will be extended by means of new data transmission technologies such as Wi-Fi 6 and 5G. These enable transmission speeds of 10 Gbit/s and more (5G). While Wi-Fi can already be found in numerous manufacturing facilities, 5G campus networks have only been tested in Europe in recent years. Which technology offers the greater benefits depends on the specific application, the actual environmental conditions and the place of use. As the respective 5G licenses are awarded by national or regional authorities, there are differences in the frequency bands that can be used in campus networks – even resulting in the restriction of campus networks in general. It is currently too early to say which technology will prevail in the medium-term in the field of vehicle manufacturing. One thing is nevertheless clear: Vehicle manufacturing in the future will be cloud-based and will use high-performance, wireless data transmission technology.

On the vehicle side too, development is progressing rapidly. Current vehicle projects implement new architectural concepts, use HPCs and plan high-performance vehicle access. While new vehicles can be "connected" via 5G technology immediately after delivery using corresponding connectivity DCUs or HPCs, this possibility is not yet available on the many vehicle manufacturing workstations because DCUs and HPCs often do not yet work completely without a complete E/E environment. This means that in the future, they are unlikely to be able to undertake initial tasks until half the assembly line has been completed. In this respect, transmission paths to vehicles will remain the time-determining bottleneck in the coming years. It is therefore necessary to optimize this. Assuming that fast Ethernet "Gigabit" buses & protocols, such as 1000Base-T and 10GBase-x/T, are implemented on the onboard side and already have to be used in manufacturing, for example for flash procedures, vehicle interfaces and VCIs will also need to be equipped with corresponding capacities in future. While vehicle access via the OBDII port is currently set at a maximum 100 Mbit/s (100Base-TX) with Diagnostics over IP (DoIP), some manufacturers are already testing separate high-speed access via BroadR-Reach for vehicles. This would allow transmission speeds of 1,000 Mbit/s and more. In contrast, current VCIs connected at the OBDII port are often much slower. With CAN FD, a maximum speed of only 8 Mbit/s is achieved, with a maximum of 100 Mbit/s via DoIP. This raises the question of how these transmission speeds can be noticeably increased. And the answer is, through more high-performance hardware!

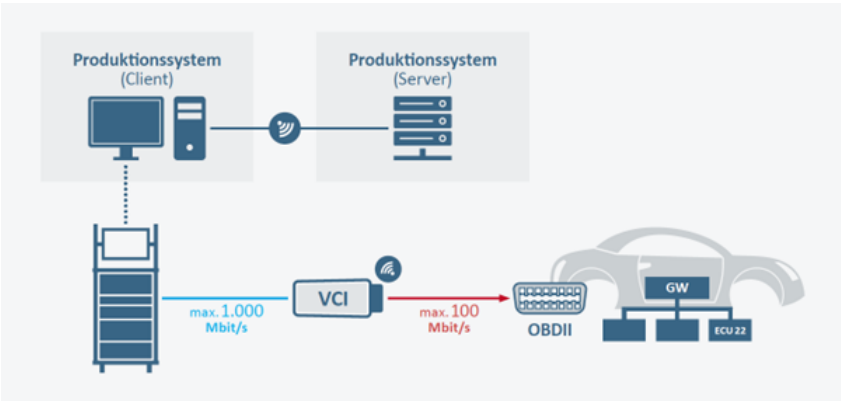

Figure 4: Bottleneck in Data Transmission to the Vehicle (Actual Situation)

Implementation

More high-performance hardware is nevertheless only one necessary condition for the speed actually achieved when conducting test, flash and coding processes. As already described, the suitability of DCUs and HPCs as independent "on-board master computers" to control these E/E process steps is very limited. Even though manufacturing systems monitor and control the entire process and the provision of data, basic offboard capacities are necessary at the vehicle access due to the (time) criticality of certain process steps (such as flashing) in order to complete and close them successfully. At the same time, such offboard capacities are a key means of controlling the decentralization and thus the flexibilization of E/E process steps during the assembly process. In this respect, the hardware- and software-based capacities of a VCI are certainly a crucial factor of vehicle manufacture, as they not only transport data but also carry out predefined process steps independently, react to messages from the vehicle ECUs and report the status back to the manufacturing system. In doing so, they facilitate not only data transmission, but also process control. And as data volumes increase, the need also increases to be able to carry out E/E process steps as locally as possible along the entire assembly line.

Current VCI implementations involve manufacturer-specific hardware as well as specific instrument software implementation. Due to the development times and subsequent lifecycles of five or more years, the resources available in the devices are often only up-to-date for a short period of time. Software functions differ considerably depending on the manufacturer and the device type. High-quality Wi-Fi VCIs in particular, such as those currently used in manufacturing, generally have the capacity to perform sequence logic procedures. . A few devices can also buffer data and be used locally. The development and qualification of this type of devices are very complex and, due to the relatively small quantities involved, lead to high equipment costs. Maintenance of the device software as well as the configuration and operating software involves additional costs in the life cycle. One alternative is systems similar to industrial computers that can be operated with standard software, thereby reducing software costs in the life cycle. . Industrial PC systems (IPC) incur only hardware engineering costs for adaption and integration into a complete device. The available hardware is nevertheless limited and the required transmission speeds are only available at a relatively high device price. So how can high performance be achieved at an affordable price for small and medium quantities? It helps to take a look at the mobile device & cloud sector already mentioned: by using smartphones. These have high-performance CPUs, large working memories, rapid hardware interfaces and cutting-edge wireless data transmission technology that has been tried and tested a hundred million times over. Furthermore, despite their outstanding performance levels, they are relatively small and are available at a calculable cost. So a "small smartphone (VCI) provides a large smartphone on wheels (car) with data"? The idea has a certain charm. But how could mobile device platforms, such as those currently found in smartphones, be used for the application of VCIs in vehicle manufacture? By fitting them with a peripheral for connection to the existing CAN/FD bus systems and interfaces for automotive Ethernet and DoIP. And by upgrading them to a small offboard HPC using the available tools of the operating system that serves as a connectivity platform, data memory and master computer.

This approach makes it possible to create a cutting-edge, high-performance data transmission system that is already approved and ready for use. This significantly simplifies the incorporation into current and future production infrastructures with Wi-Fi and/or 5G. In addition to developing a peripheral boasting a small form factor and incorporating it into the actual mobile platform, the particular challenge lies in implementing protocol and control software and in creating application software on the mobile platform. To this end, tried-and-tested tool chains are available for engineering and test purposes as well as complete software management in the life cycle. Furthermore, mobile platforms already have a large number of helpful and useful libraries and applications that can easily be integrated – a true El Dorado for software developers!

Initial implementations by Softing show that it works and that – after ruggedizing a managed operating system core and transferring protocol implementations – the speed of software engineering can be considerably increased. From the standpoint of an automotive company, the greatest challenge is nevertheless adapting to the cycles, trends and practices in the mobile communications industry. On the

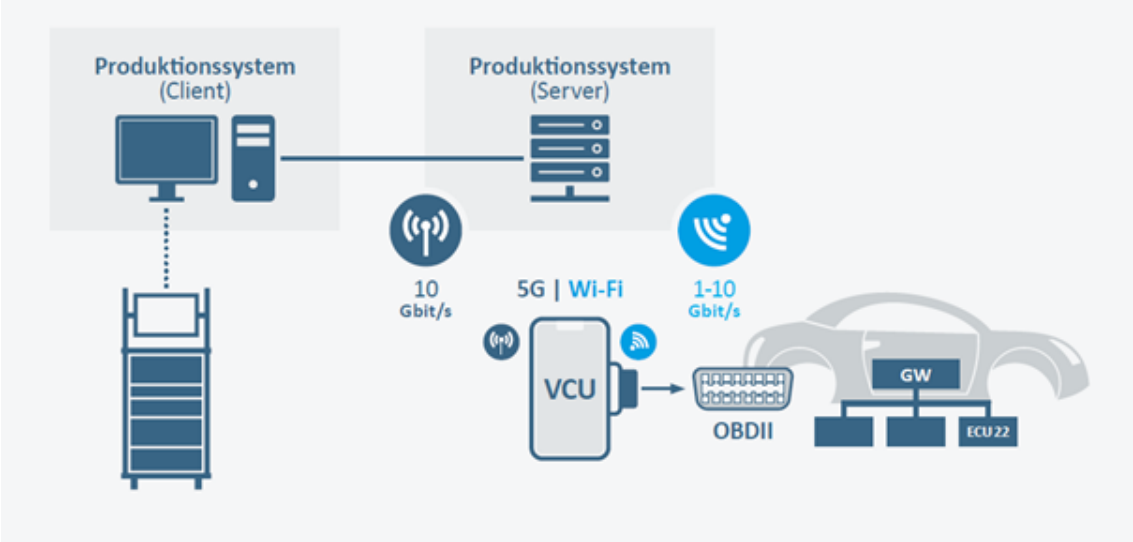

Figure 5: The Next Step: Mobile Platforms as a Bridge between IoT Backends and New Vehicle Generations

software side, numerous methods and technologies have been tried and tested in the automotive industry for a number years, such as continuous integration and delivery, microservices, containerization as well as configuration and version management. The technological leap is often no longer all that big and the rapid further development of mobile devices opens up entirely new dimensions in the medium and long term, so that conventional VCIs can be transformed into a vehicle communication unit (VCU)!

The digitized production of the future

In the future, a mobile platform will probably have more computing power than the computers used along the production line. Entirely new, highly flexible and decentralized E/E process sequences will be possible through vehicle-related VCUs. To a large extent, they will be able to carry out all E/E process steps autonomously. It will be possible to focus the backend infrastructure on the provision of data and its wireless transmission to the VCUs. It will merely be necessary to adjust the workstations along the production line to the construction progress of the vehicle – operations relating to E/E process steps will largely be eliminated.

In the long term, would it not be possible to replace offboard resources, such as a VCU, by onboard systems? In the vision, all test, flash and coding processes are possible via connectivity DCUs or HPCs if a complete electrical system is present initially and all (mechanical) peripherals follow. This is conceivable, but involves a paradigm shift in vehicle manufacturing: Cars would have to be built “from the inside out”. Each manufacturer must decide whether achieving this vision makes business sense, because the accompanying high degree of automation comes at a price. One thing is nevertheless certain: Manufacturers that want to go down this road must rethink the vehicle assembly process! This solution might still be a very long way off for most volume models, but specialized series production of niche models could soon take further steps in this direction. In contrast, it is highly likely that one of the next steps taken by most vehicle manufacturers will be to install a VCU.

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