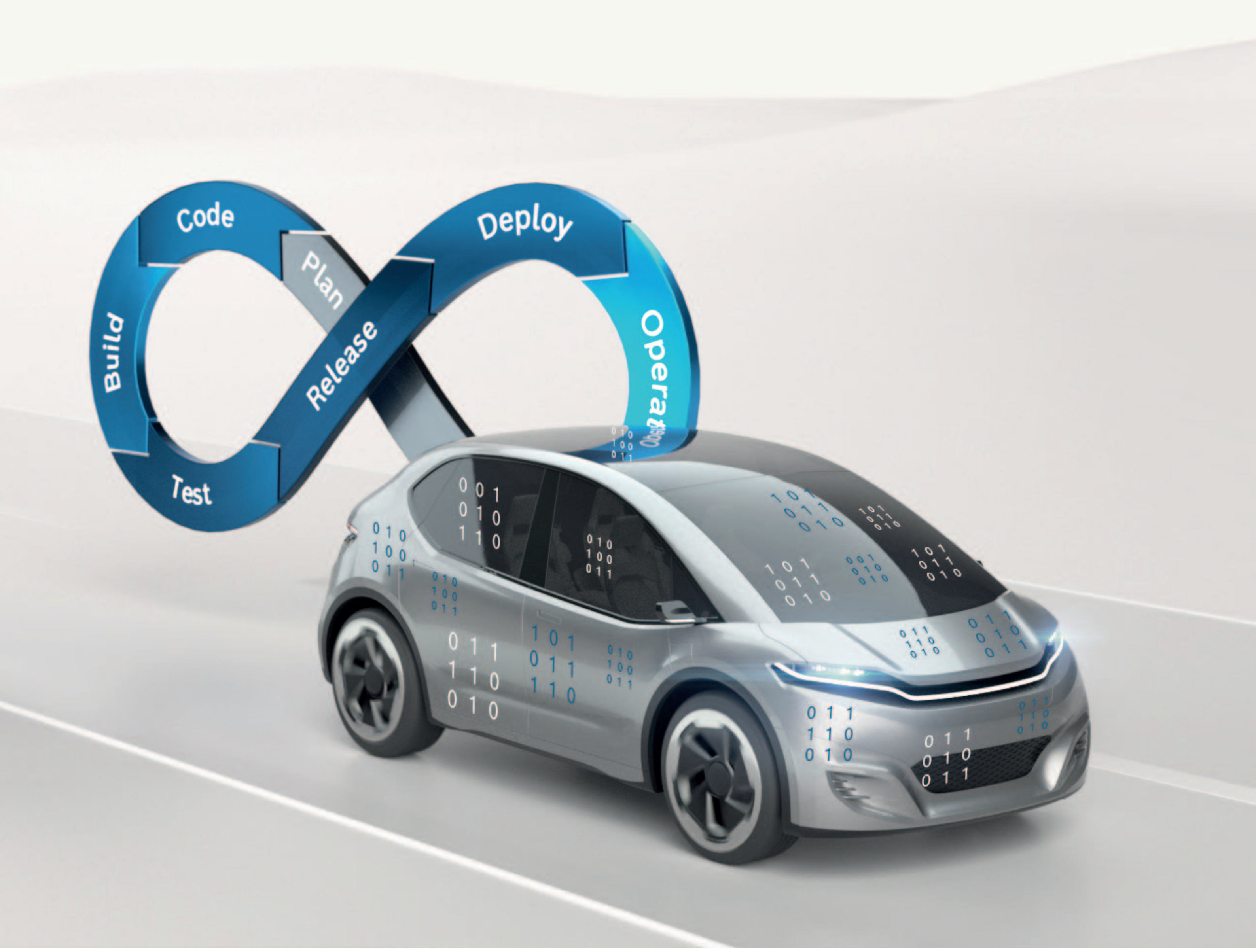



**Whitepaper**

# Driving innovation: collaborating to unlock the full technical potential of software-defined vehicles

The move from hardware with embedded software to software-defined vehicles and services will shape the mobility of the future. Over-the-air updates and upgrades throughout the vehicle lifecycle will take customer satisfaction to the next level. At the same time, these developments present new business opportunities for manufacturers and suppliers that extend beyond vehicle and component sales.

# Preface

The mobility sector is in the midst of a paradigm shift, with software becoming the defining factor. Coupled with artificial intelligence, innovation cycles are accelerating, placing user experience at the forefront. As a result, vehicles are increasingly connected, intelligent, and becoming integral parts of broader ecosystems.

While this transformation presents significant opportunities for the automotive industry, it also calls for fundamental changes that mobility players must respond to. Over-the-air updates and upgrades, for example, open up new business opportunities throughout the vehicle lifecycle, extending beyond traditional vehicle and component sales while at the same time disrupting classical value chains. Competition in these emerging fields of business is fierce, and the market is changing rapidly, also as a result of continuous developments in AI.

Excellence in software engineering is crucial for adapting to evolving user requirements and delivering timely updates and upgrades. By centralizing in-vehicle intelligence and decoupling hardware from software, hardware can be standardized effectively, transforming software itself into a valuable, independent product. Achieving market success hinges on rapid scalability, which in turn calls for strategic partnerships. Our objective is to bring foundational products and technologies to users swiftly and at affordable prices. Through DevOps cycles – creating closed loops between development and operations – both products and user experience can be improved quickly and continuously.

With our combined expertise in multiple domains and regions, we are creating integrated and innovative hardware and software solutions for software-defined vehicles. This document showcases our broad and modular portfolio and discusses the technical enablers that deliver tangible benefits to manufacturers.

**We invite you to join us in shaping the future of mobility.**

**Mathias Pillin**
Head of Technology
of Bosch Mobility

# Table of contents

# 01
# Management summary

Based on a precise definition of "software-defined vehicles" (SDVs), this whitepaper identifies five decisive enablers for the transition to the SDV era. These enablers correspond to the five main chapters of this document:

1. Decoupling the application software from hardware with middleware and the operating system
2. Standardized interfaces
3. Modular design of the Bosch portfolio
4. Continuous upgrades, updates and integration
5. SDV-ready hardware

Each chapter describes the challenges involved and details how Bosch Mobility offers comprehensive solutions in software, services, and hardware components for the SDV. These solutions bridge the past to the future of car development and production. Many TIERs come from the embedded world, where the application software (ASW) is directly embedded into the hardware (HW). Now, SDVs offer microprocessors (μP) with a new software stack based on an operating system (OS). The OS and the middleware (MW) enable the decoupling of the ASW from the hardware and increase flexibility. This allows the ASW to continuously be improved over the air, even in the field.

Bosch's extensive product offerings across most of the vehicle domains enable us to provide comprehensive support to OEMs. This ranges from the seamless integration of foundational components such as the electronic stability program (ESP) with our "Vehicle Motion Management" software product, to sophisticated cloud services such as vehicle health diagnostics. This whitepaper details how our portfolio is structured and relies on standardized interfaces. With future SDV features increasingly requiring cross-domain capabilities, the breadth and modularity of our portfolio are major assets. Additionally, by collaborating with ETAS, we ensure continuous integration and state-of-the-art cybersecurity for SDVs – both of which are critical requirements.

Given the complexity of the transition to the SDV era, we have prepared a second whitepaper that addresses the business implications of this paradigm shift. Using case studies, it assesses the impact of generative artificial intelligence (GenAI) on products and organizations. It also provides clear guidance on how to successfully navigate the transformation.

# 02
# Introduction

Future generations of vehicles will be software-defined, and this will fundamentally change the automotive supply chain. SDVs will spark a groundbreaking transformation by separating the application software from the hardware. This shift calls for new development paradigms that encompass both technical and organizational modifications. Bosch is committed to collaborating with OEMs to facilitate this transition.
We present our insights in two separate whitepapers:

- → a business-focused paper that addresses the impact of SDV and GenAI on the automotive industry

- → a technology-focused paper that discusses the impact of SDV on the Bosch portfolio

This technology-focused whitepaper is intended for OEMs and technical trade media, shedding light on the technical enablers that will allow OEMs to benefit from transitioning to SDV. The business-focused whitepaper provides a detailed analysis of the business implications of the SDV for the automotive industry.

This technology-focused whitepaper presents a collaborative approach to unlock the full potential of SDVs. It addresses the trends driving the transition to SDV and their benefits. It also describes five key enablers within the SDV ecosystem, which are as follows:

1. Decoupling the application software from HW with middleware and the operating system
2. Standardized interfaces
3. Modular design
4. Continuous upgrades, updates, and integration
5. SDV-ready hardware

This paper also offers insights into the Bosch portfolio and sheds light on the areas in which the company is collaborating with partners in the SDV ecosystem.
It includes detailed examples of ongoing standardization efforts and important open-source communities. In brief, the Bosch portfolio is preparing a modular end-to-end SDV architecture. Bosch is a trusted provider of hardware, middleware, and application software products, offering comprehensive solutions for a wide range of business needs. The whitepaper provides a detailed overview of the embedded, compute, and cloud layers.
Moreover, it not only shows how the increasing complexity of the SDV software stack can be modularized, but also how the Bosch hardware portfolio is already prepared for the SDV era.

# 03
# Three pillars of SDV opportunity

What sets SDVs apart is that the software – not the hardware – enables the vehicle's key features and USPs. This shift allows car manufacturers to quickly innovate, improve user experience, personalize services, and generate continuous revenue through regular feature extensions and digital services. In turn, this makes the SDV more attractive than a "hardware-defined vehicle", as it performs better in the three following areas.

## Better user experience

As a result of over-the-air updates and upgrades, the SDV's value for the customer can keep increasing after they've bought the car.
**Example:** Bosch has contributed to improving features and user experience by providing upgrades for the end-to-end assisted driving stack in China every 3–4 months.
In addition to updating the software via over-the-air updates, it is also possible to complement vehicle functions with cloud-based capabilities. This approach offers the two key advantages of high computation performance in the cloud and consistently updated functions that do not require over-the-air updates.

## Shorter time to market

OEMs can roll out new features, especially cross-domain features, faster, as well receive faster feedback from users. At the same time, closer cooperation between OEMs and Tier 1 suppliers enables more rapid development cycles and the effective delivery of new features to customers.
**Example:** Bosch successfully launched the complete eAxle just only 12 months after project start. The product was developed in close cooperation with the OEM within the required timeframe, despite a shift in the HV supply voltage from 400 V to 800 V midway through the project. Working with a pre-configured standard package of the eAxle software was decisive. These modular SW building blocks for the electrified powertrain are described in more detail below.

## Cost reduction and standardization

Development is less expensive and standardized interfaces increase software sustainability. The harmonized interfaces of software and hardware components allow for pre-configuration, thus reducing adaptation efforts.
**Example:** The Bosch portable Vehicle Motion Management software product can be flexibly and easily integrated into the OEM's SW infrastructure. Its standardized API stack is designed to significantly minimize adaption efforts.
Vehicle Motion Management offers a complete ecosystem to support OEMs in effectively managing the growing complexity of software, including integration and calibration services.

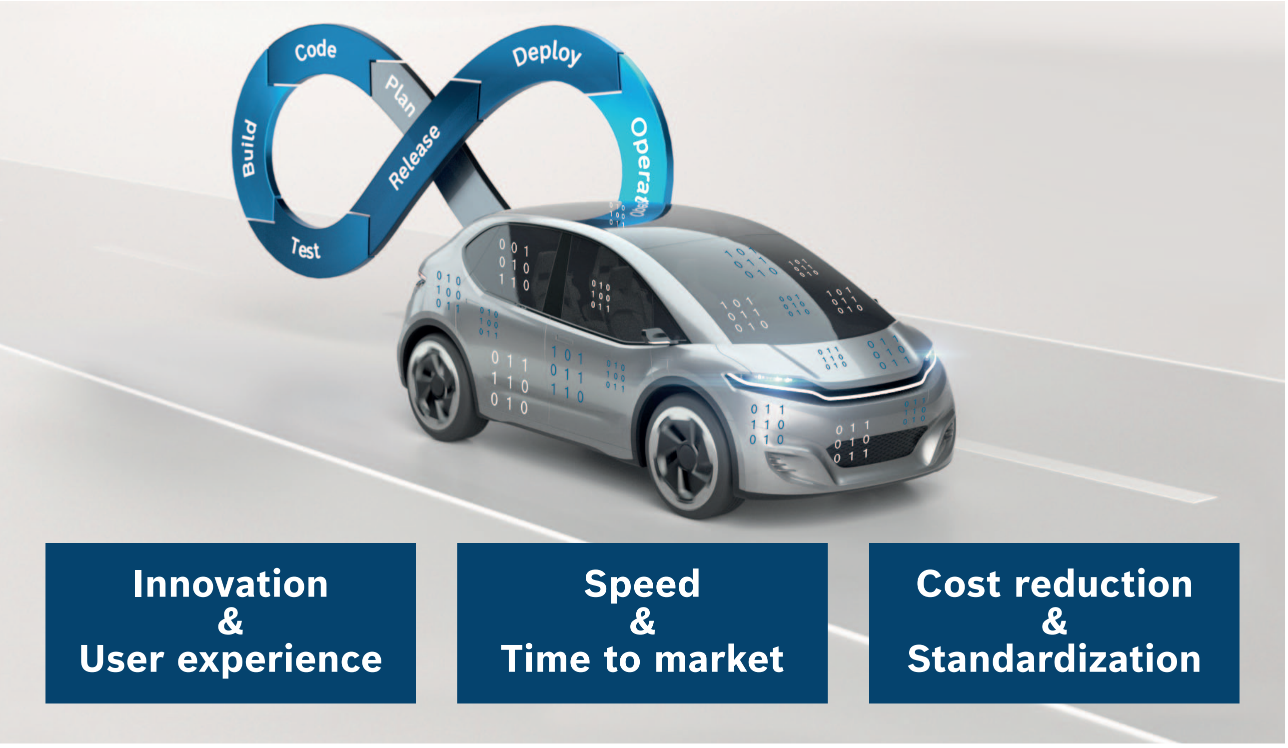



Figure 1: Benefits of SDV: Innovation & UX, speed & time to market, cost reduction & standardization

**Three major challenges must be addressed in the transition to SDV development paradigms.[1]**

- The traditional organizational structure is based on vehicle domains: body, chassis, powertrain, ADAS, and infotainment. However, cross-domain development is becoming essential as new features increasingly extend across domains. This poses a clear challenge in terms of making organizations SDV ready. Chinese manufacturers are currently leading the way, particularly with regard to rapid feature deployment and digital user experience.

- Offering products and services that are tailored to regional customer and user preferences is becoming a central success factor. The “one-world-vehicle-approach” is giving way to regionalized solutions. To meet target costs, new technical approaches with segment-specific and regional vehicle architectures are needed.

- It is important for manufacturers and TIERs to engage in collaborative efforts with the aim of enhancing reusability and promoting industry-wide scaling. This can be achieved by avoiding the use of proprietary, non-differentiating layers of software stacks and fostering the adoption of open-source software solutions. As a result of this, the automotive industry will adopt business approaches involving software products combined with long-term maintenance. A certain portion of the business will shift from project-driven business towards product-driven software business, particularly in non-differentiating areas.

[1] https://www.bosch-mobility.com/en/mobility-topics/software-and-services/download-automotive-transformation/

# 04
# Enabling the software-defined vehicle: definition and key principles

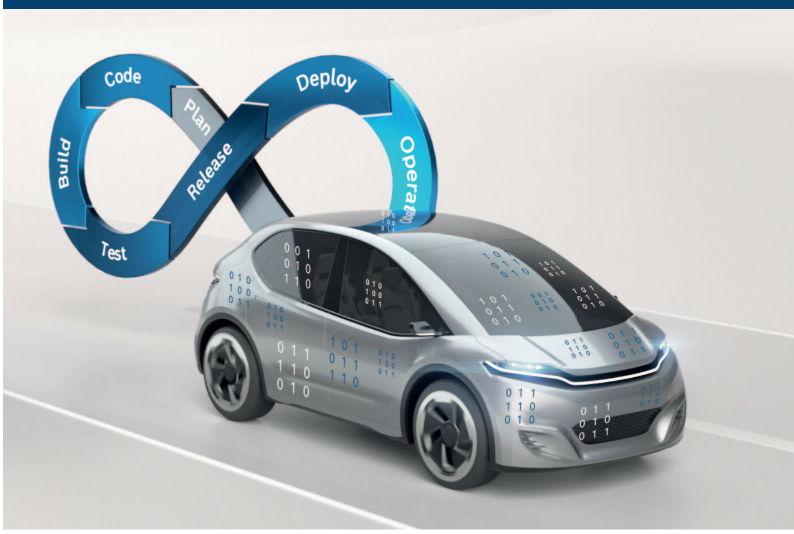
Given that there are currently many different ideas associated with the term “software-defined vehicle” we have defined SDV as follows for the purpose of this technical whitepaper:

**DEFINITION:**
**A software-defined vehicle** evolves throughout its life cycle: its key features change with both onboard and offboard software changes.

The traditional V-model can be combined with the dynamic DevOps cycle, which is driven by user and field data. The advantage of the DevOps cycle is that its features can be upgraded throughout the vehicle’s lifetime through cloud downloads. The cloud back-end is playing a growing role for SDV here. Over-the-air updates enable fast rollouts. The features that are relevant for quality management and functional safety are designed and tested largely in the cloud. This approach ensures that users receive updates and bug fixes more quickly. A standard software update during maintenance at the garage is enhanced by a wireless download when the SDV is connected to the internet. This approach enables significantly faster rollout times for improved features.

As outlined in figure 2, there are five key enablers. The following five chapters present the Bosch perspective on each of them.

**A software-defined vehicle can evolve throughout its life cycle:**
it changes its key features by changing software onboard or offboard.




**SDVs needs five main enablers**

1. Decoupling of ASW from HW
2. Standardized interfaces
3. Modular design
4. Continuous updates & integration
5. SDV-ready HW

Figure 2: SDV definition and its five main characteristics

## 4.1
## Decoupling the ASW from HW with middleware and the operating system

The key SDV challenge lies in decoupling the application software (ASW) from the underlying hardware. This is achieved by introducing abstraction layers, namely middleware (MW) and an operating system (OS), which provide standardized interfaces for the ASW. A key element of this abstraction is the new "signal-to-service" API (S2S-API) on the compute layer.[2]

A harmonized middleware solution on top of the operating system helps to reduce the complexity of the new cross-domain features. As one of the possible middleware providers, ETAS offers a combined abstraction based on AUTOSAR adaptive, the deterministic middleware for ADAS & AD, and a LINUX-based API with the Eclipse KUKSA data broker. Most of the middleware functions are non-differentiating for an OEM brand. Drivers do not generally make vehicle purchasing decisions solely on the basis of a car's middleware. While customers expect over-the-air updates in all future vehicles, the adoption of proprietary development for middleware can impose a significant financial burden on OEMs. At the same time, OEMs would not likely be able to resell their proprietary OEM.OS to other OEMs, which are reluctant to become dependent on one particular OEM.OS. The most effective approach may thus involve cooperating to share the costs and reduce the maintenance effort over the vehicle lifetime.

## 4.2
## Standardized interfaces

Standardizing interfaces and APIs enables the cost-efficient scaling of software across the industry. At the same time, aligned interfaces minimize the effort required to adapt the software. Standardized APIs also enable the flexible redeployment of application software. Each ecosystem generally tends to minimize its development effort for new features, as development resources are expensive and limited. In the current landscape of the smartphone industry, two prominent western APIs have established a dominant presence in the substantial software market, effectively attracting software developers to their advanced toolchains. In the eastern market, some additional APIs have emerged, and tech giants provide solutions tailored to the local context. A similar trend is expected in the automotive industry.

**To sum up: standardization may become the key for sustainable software. This is why Bosch is engaged in the ISO working groups to set interface standards for the complex AD stack (e.g., ISO 23150).**

[2] https://www.bosch-mobility.com/en/solutions/software-and-services/open-in-vehicle-api/

In other domains, COVESA provides a suitable data model, creating a common data basis for the cross-domain application software. Recently, the Vehicle Motion Management team contributed ASIL-D relevant interfaces to COVESA. This includes signal specifications for actuators such as braking, steering or powertrain, with further signal definitions forthcoming. A dataset is also required to facilitate the development process, enabling the creation of new features in a more efficient and rapid manner.

A first experience with COVESA APIs can be gained through digital.auto, which provides an open prototyping platform for SDV. The platform supports service-oriented application development using COVESA APIs and open-source projects such as the Eclipse Velocitas SDV project. Development and testing are assisted by Generative AI, which has been trained to understand the structure and semantics of the COVESA APIs. Here, applications can be deployed to both virtual test environments and prepared target hardware. As a result, the entire cycle – from development and testing to deployment of a new SDV feature – can be completed in minutes rather than hours or days. This dramatically accelerates the development speed for OEMs.

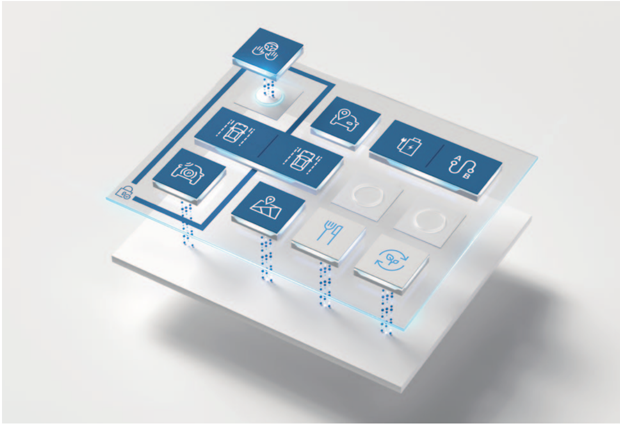


Figure 3: An API abstracts the application software from the middleware & operating system

Additional aspects of internationally standardized APIs are as follows:

- They can be provided to students at no cost, which has the added benefit of fostering the development of new talent for the automotive sector.[3]

- The increasing complexity of the computer middleware and operating system will enhance cooperation between tech leaders.

**To sum up: complementary collaboration models are needed to create cross-industry standards. To this end, Bosch contributes to Open-Source. In the Eclipse SDV group, we pursue the “code first” approach and publish code implementing the COVESA vehicle signal specification (VSS) data model (e.g. KUKSA project).**

[3] https://www.sdv.guide/

The industry needs to agree on a small number of base platforms to make the SDV financially attractive and to establish a viable basis for largescale application development/deployment. We thus support and drive activities such as the Eclipse S-CORE project and are willing to contribute key parts of our IP to these projects. We intend to make this core know-how available under open-source licenses. To foster this goal, Bosch is engaging in initial discussions with partners and customers on how to extend S-CORE into a “SDV.OS” approach. This would include integration into several POSIX-OS and domain-specific solutions with their toolchains. This approach would shape the foundation for simplified automotive application development.

S-CORE’s code-first, open-source approach is transforming the way the automotive industry collaborates. This shift calls for new methods for co-innovation, contribution processes, and agreements on standards for both OEMs and Tier suppliers. Concurrently, traditional license-based business models are being transformed into new commercial models, such as subscription-based distributions, which will also alter the scope of delivery and integration. As OEMs and new distributors progress towards series production in 2030, an alignment on a commercial model is needed that is viable for all parties. The business models present the major challenge to the adoption of open-source solutions. There is a high degree of consensus among relevant parties on the specific roles required (maintainer, several distributors) from the OEM perspective. However, the same level of certainty has not yet been reached from the supplier’s perspective. While it is understandable that OEMs want to realize all potential advantages of OSS-business models, the suppliers also need a viable and sustainable business model. As such a model is not yet in place, Bosch sees the risk of OSS initiatives losing momentum. This alignment is important for the sustainable growth of the entire ecosystem.

Our strategy combines the best of both worlds: to foster a broad ecosystem, we leverage open-source solutions such as Eclipse KUKSA for service-oriented, non-safety-critical applications. For safety-critical and hard real-time functions on microcontrollers, we continue to rely on our robust and proven AUTOSAR portfolio, while ensuring seamless integration between these layers via standardized APIs.

## Vehicle Motion Management

Bosch's Vehicle Motion Management (VMM) is an example of such software. It is portable and based on COVESA interfaces, where a new standardization activity is being planned under the umbrella of the German Association of the Automotive Industry (VDA). In collaboration with OEMs and partners, the motion management architecture is being addressed, and the functional distribution with the actuators may be harmonized. By integrating all motion actuators (braking, steering, powertrain, and suspension), it enables the transition from isolated to centralized and cross-domain solutions.

Our Vehicle Motion Management ecosystem comprises three categories:

- Portable software products with motion features
- System integration solutions to increase Dev-Ops efficiency
- Data-based services

(s. figure 4)

A variety of available motion features help reach new levels of driving performance by using multi-actuator control, taking information from the outside such as driver requests or environment data. To implement these features as efficiently as possible, system integration provides automated solutions.

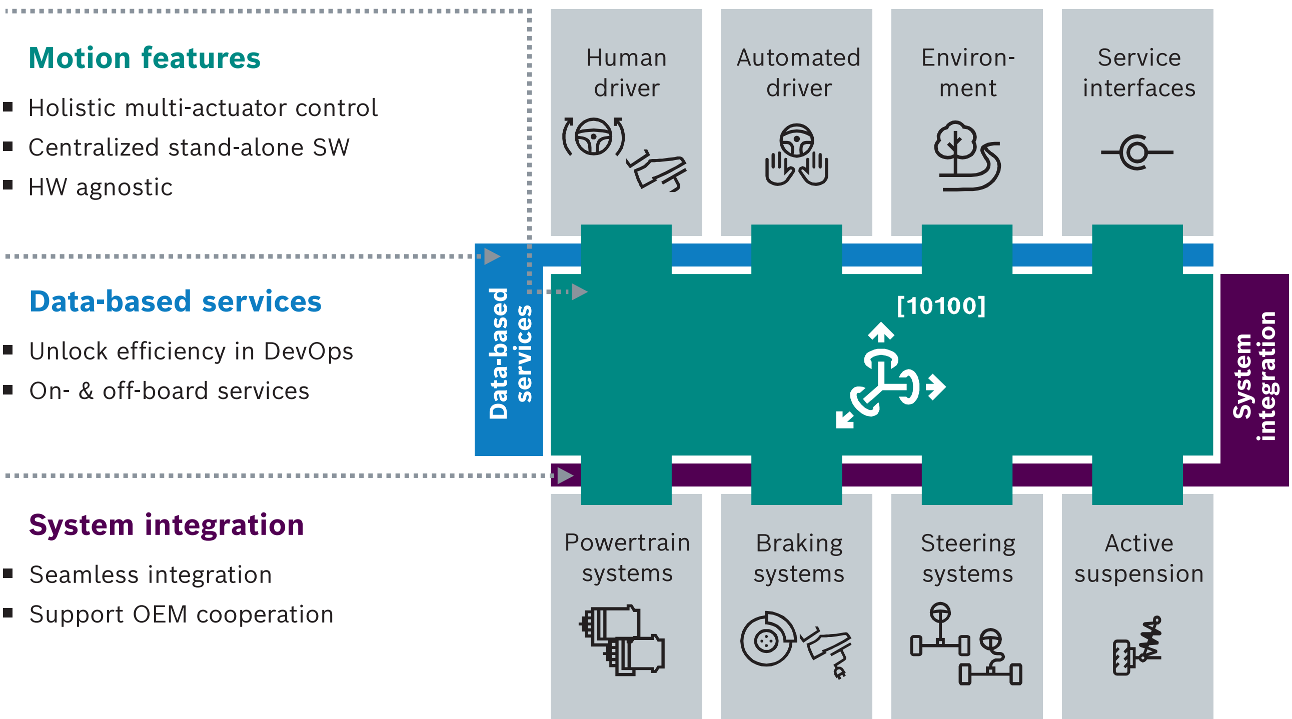



Figure 4: Vehicle Motion Management with data-based services and system integration services

Vehicle Motion Management software features can offer a flexible deployment option that is suitable for a variety of vehicles, including internal combustion engines (ICE), hybrid electric vehicles (HEVs) and battery electric vehicles (BEVs), as well as to different E/E architectures. Many different types of actuators can be controlled and exchanged to achieve the best performance for each use case. For example, in powertrain systems, 1–2 eAxle/s or 3–4 eMachines can be used. In braking systems, integrated power brake or electromechanical brake systems can be used, as well as a combination of ESP with e.g. an iBooster or a brake-by-wire actuator. In steering systems, either electric power steering, rear-wheel steering, or steer-by-wire can be used.

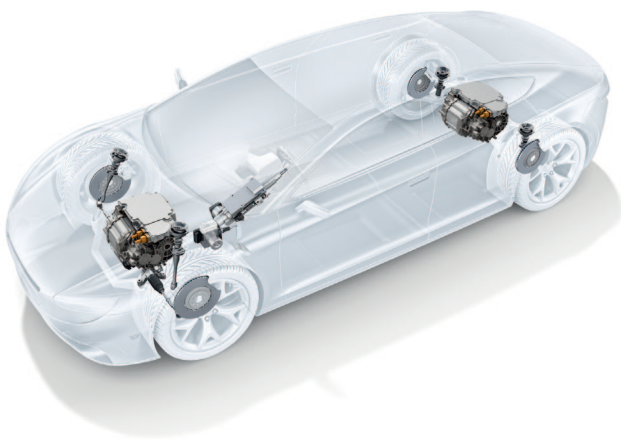


Figure 5: Transparent view on components managed by the vehicle motion control

**To sum up: standardization is a key success factor for a hardware-agnostic solution that works both with Bosch and with third-party hardware. Bosch is thus actively promoting industry-wide standardization through various initiatives, including recent efforts to standardize actuator signals in COVESA, VDA, and/or ISO.**

Bosch's advanced electronic suspension control hardware solutions are also included in the standardized interfaces. These solutions complement Vehicle Motion Management with SDV-ready mechatronic products for semi-active damping and air suspension. Here, the suspension characteristics are not fixed by the suspension hardware, but they can be adjusted by software und integrated into overall motion control.

The suspension portfolio includes high-performance solenoids for damper and air suspension stiffness control, suspension control units, and highly integrated module solutions to operate the air suspension system efficiently. The electronically controlled air suspension module is a closed-loop module that combines air dryer, compressor, air distribution block, and integrated electronics. This offers benefits in terms of performance, weight, and packaging. Both the module and the standalone suspension control units are available in different variants. These variants are optimized to support OTA readiness and various E/E architectures.

## 4.3
## Modular design

SDVs require modular software design. This simplifies the re-deployment of features from entry-class to premium vehicles. Customer expectations vary, both in terms of vehicle class and regional preferences. For example,  expectations in China are different than in Europe, Japan, or the United States. In the United States, for instance, trailer solutions are in high demand.

Given its interplay with hardware, migration, development, and feature costs, the E/E architecture presents a multifaceted challenge when it comes to optimization. Several years ago, the harmonization of E/E architectures across all vehicles was the predominant trend. The centralization of E/E architectures seemed to be the optimal approach. Meanwhile, it appears that a vehicle-centralized architecture is best suited for upper and premium vehicles, while the domain-centralized architecture is more prevalent at the mid- and entry level. For this reason, we draw on our experience with all major OEMs and offer individual consulting to determine the optimal solution for individual OEMs.[4]

Enabling vehicle hardware and choosing the right E/E architecture components are thus of central importance when it comes to the SDV. There are three different E/E architecture layers to be considered:

- **Cloud layer**
- **Compute layer**
- **Embedded layer**

Each layer will be supported by a standardized interface/API, which enables software migration and reduces the software adaptation effort. As SDVs are much more than software, figure 6 shows all three elements per layer:

- **Application software (ASW)**
- **Middleware (MW)** and **Operation System (OS)**
- **Hardware (HW)**

[4] https://www.bosch-mobility.com/en/mobility-topics/ee-architecture/download-ee-architecture/

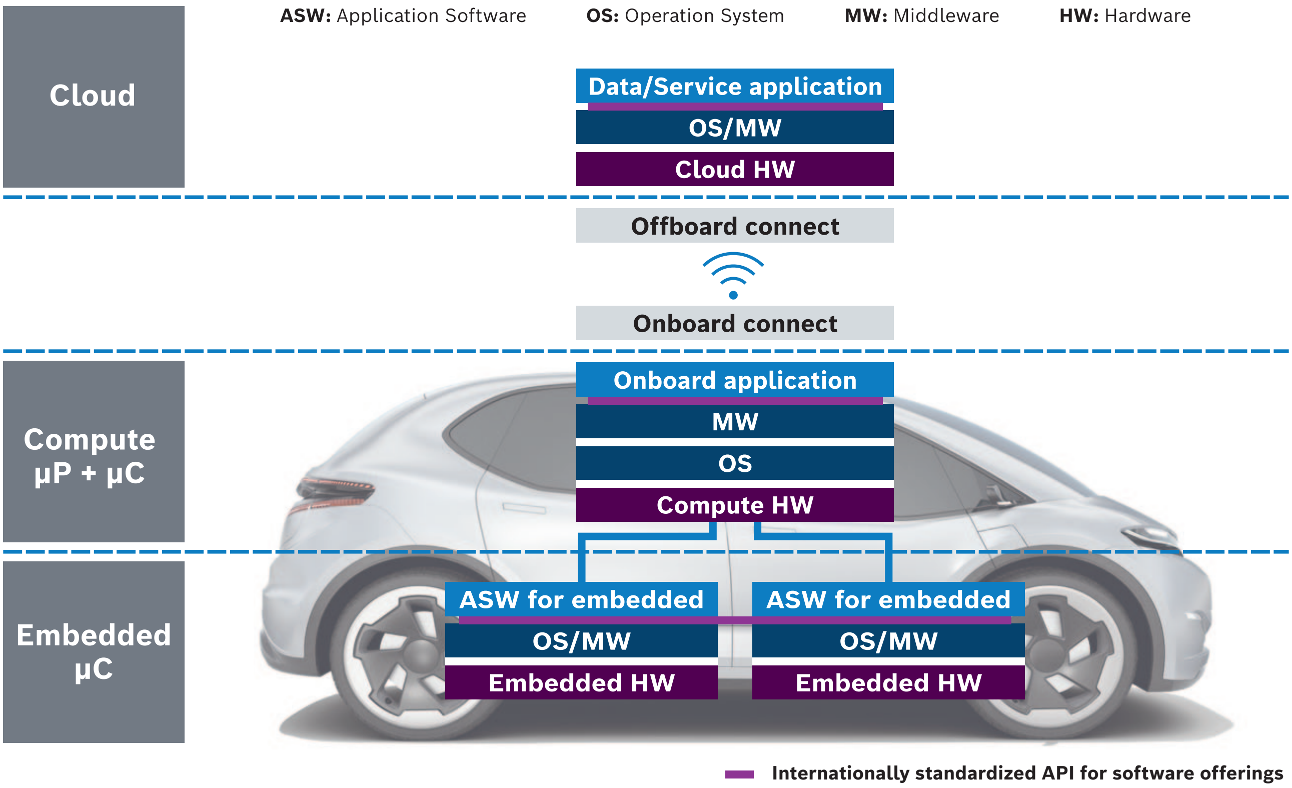



Figure 6: The API-based end-to-end software stack from embedded to cloud

Each layer needs specific middleware solutions and optimized hardware (HW). The application software will then make the difference for the driver's experience.

On the **embedded layer,** our motion application software package has also integrated a middleware abstraction layer. This means that Vehicle Motion Management can be offered as a modular SW product. A dedicated toolchain is designed to integrate Vehicle Motion Management into other µC-based ECUs. This toolchain allows for the modular integration of specific OEM software.

Recent advancements in technology and market trends, such as personalization, connectivity, electrification, and centralization in E/E architectures, present a significant opportunity for the development of innovative, cross-domain software products in the Vehicle Motion domain. Furthermore, end user demands for comfort, safety, agility, and individualization are becoming increasingly important.

The modularity of the software stack for electrified motion was a key factor in the successful launch of a complete eAxle within 12 months (see above). While Vehicle Motion Management focuses on SW modules for multi-actuator features, the modularity of the software stack within the powertrain portfolio is crucial for the success of software-enhanced actuator systems such as our eAxle.

On the **compute layer,** the flexible permission module (FPM) is one example of modular functions. This software solution is hardware-agnostic, redefining vehicle security and extending the capabilities of traditional immobilizers. It combines advanced cryptographic protection with multi-factor authentication (MFA) via smartphone, fingerprint, or facial recognition, delivering a flexible and user-friendly approach to securing connected vehicles. FPM is designed for seamless integration across all vehicle types and powertrains, including electric, hybrid, fuel cell and combustion, regardless of the ECU supplier. Its modular, plug-and-play architecture allows for deployment on any platform without the need for hardware changes. Features such as geofencing, alcohol detection, valet mode and racetrack mode can be added or updated post-SOP via secure OTA updates. In contrast to conventional immobilizers, which are fixed to specific hardware and do not have update capabilities, FPM centralizes all logic into one adaptable module. This reduces system complexity, minimizes integration effort and supports customer-specific configurations. The FPM offers a cost-effective solution for OEMs seeking to streamline architecture and enhanced flexibility thanks to its modular design.

For the **cloud layer,** a modular design and abstraction from underlying data sources is also required to develop truly interoperable and portable cloud services. Bosch is committed to the COVESA data model both within the vehicle and in the cloud. The process of standardizing incoming heterogeneous data from multiple data providers (e.g. different OEMs, third-party data providers, and data marketplaces) involves transforming the data into the COVESA VSS data model. The standardized data is then offered to cloud services via COVESA VSS-compliant APIs. These APIs enable the development of services for multiple heterogeneous data providers without having to change the service logic. A sophisticated access management system that is multi-tenant aware ensures that the data is accessible only to authorized data consumers who provide the correct credentials and have permission. Our API framework is based on open-source technology, enabling efficient COVESA VSS-compliant definition and the implementation of cloud service APIs. They can be deployed in multiple public clouds and on different tech stacks.

**To sum up: seamless modularity is decisive for our cloud services, which are facilitated by a common application programming interface (API). We are committed to the COVESA data model (defining the semantics of the vehicle signal specification (VSS)) as the basis for our cloud APIs. Standardized REST calls further streamline this process, enhancing modularity and enabling powerful data synergies across services. Access management protocols ensure robust data security, granting access only with the appropriate permissions.**

This cohesive API strategy powers our cloud service portfolio. For instance, the "vehicle health" leverages real-time vehicle data, which is accessible via this unified API. This empowers customers to proactively schedule maintenance, swiftly address incidents, and minimize downtime – a major benefit especially in fleet management scenarios. This approach offers substantial cost savings for OEMs, reduces development time, and minimizes lifecycle maintenance expenses. OEMs are not only monitoring data but also enabling predictive and preventative actions to improve the vehicle's uptime and to reduce costs over its lifetime.

Similarly, "ride care", our interior condition monitoring service, benefits from this shared API foundation. Ride care assists fleet companies in preserving their vehicles' value and maximizing resale potential by continuously tracking and managing wear and tear. It actively ensures that a vehicle maintains its quality and appeal throughout its operational lifespan.

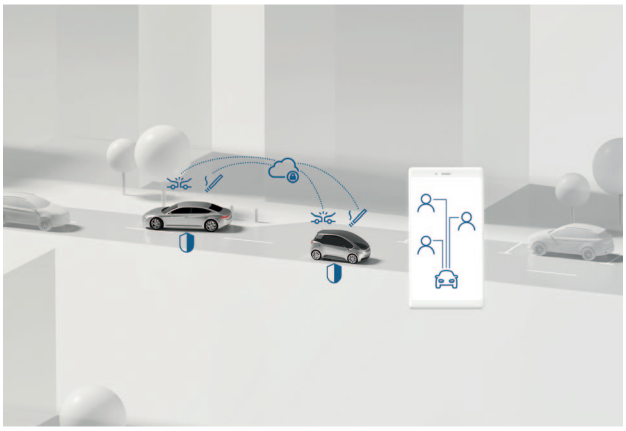


Figure 7: The ride-care service collects data during the trips and provides it to the fleet manager

The advantages extend to "connected vehicle energy management", which also leverages the COVESA VSS semantics through this common API. This holistic approach to managing the vehicle's energy systems empowers OEMs to develop features that actively reduce energy consumption and enhance the overall user experience. It is not only about tracking energy usage, but also about actively optimizing performance and efficiency for both environmental and user benefits.

Our commitment to an API-based design extends to cloud deployment via a robust cloud abstraction layer. This design choice enables deployment across various cloud providers, accommodating OEM-specific preferences and ensuring flexibility and scalability. This approach is driven by a deep understanding of our customers' evolving needs. Our objective is to provide innovative, interoperable solutions that offer continuous improvements, seamless integration across different domains, and flexible business models to best suit our partners and customers' specific requirements. To achieve this, Bosch Mobility has consolidated the development and operation of state-of-the-art software & services infrastructure. This allows us to provide our customers with maximum synergies, lower operational costs, and minimized maintenance requirements.

## 4.4
## Continuous updates, upgrades and integration

Integrating all the software blocks into the vehicle system is a challenging task. The integration efforts should be automated as much as possible. However, different versions and interactions must be managed, and fast deployment to the target hardware are key success factors for continuous integration. Our system is based on a distributed E/E architecture, where updates can be handled by the relevant ECU. In a SDV, upgrades are also provided for cross-domain features, which means that an update might concern several ECUs. While updates for single ECUs are straightforward, this distributed approach is a challenge for new cross-domain features that affect multiple ECUs simultaneously. Therefore, a coordinated update process across several ECUs considers also their different update cycles.

When updating different software components in a vehicle system, it is important to ensure that they do not cause each other any harm. They must thus be isolated from each other. This concept is referred to as "freedom from interference" (FFI), the central concept of ISO 26262. This objective can be achieved with virtualization technologies such as hypervisors, which provide protected run-time environments for different applications. To ensure the hypervisor's optimal performance, we partner with QNX whose Operating System and Hypervisor are safety certified to the highest level, ASIL D, and deliver robust isolation, real-time performance, and streamlined consolidation of mixed-criticality systems. Hypervisors play a pivotal role in the software's modular architecture, as it supports different partitions in parallel on one microprocessor. This enables parallel development. Finally, app-1 can be deployed to partition-1 and app-2 to partition-2 without interfering with each other.

QNX is also committed to facilitating easy access to complex software frameworks, for example, the company recently launched its QNX Everywhere initiative which provides a free, non-commercial version of the QNX® Software Development Platform (SDP) 8.0 which includes the latest QNX OS 8.0, making innovation more accessible than ever.

A key success factor for efficient and reliable continuous integration is the deliberate alignment of all parties involved on interfaces, signals, tools, and the operating model. The integration and testing environment will be set up in a modular way to avoid lock-ins to specific tools and definitions. A professional, cost-efficient operations service can ensure the management and maintenance of the integration pipeline over the vehicle's lifetime.

Virtualization of vehicle electronics and their load profiles is a major step forward in the setup for continuous integration, and it enables faster time to market. It might be scalable with respect to different levels

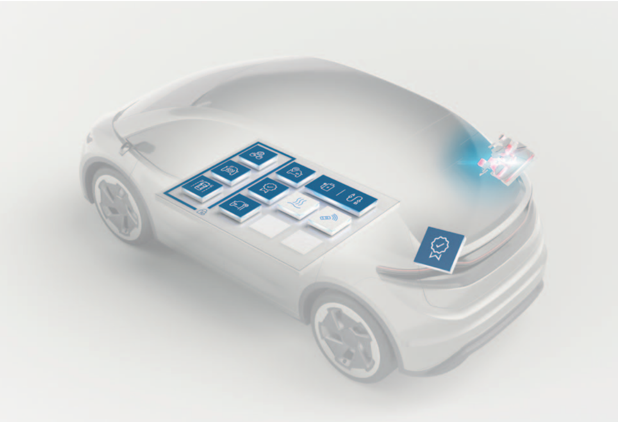


Figure 8: SDV requires continuous integration and state-of-the-art cybersecurity

of granularity. Different types of virtual ECU models are used in relation to the scope of the simulation. As the scope increases, the granularity decreases. Continuous integration requires cloud-based virtualization. State of the art is “bit-parity” where the code is undergoing virtual testing. One of the challenges we face is the management of the timing behavior. There, deterministic middleware solutions can help reduce release and validation efforts.

Security is a fundamental success factor for the SDV, which is a highly connected and complex system of systems that could be susceptible to a broad range of attacks. The SDV’s connectivity and its integration into the larger (software) ecosystem introduces new cybersecurity challenges that call for new security concepts. The SDV will see an increase in the multi-tenancy of software and increased requirements for isolating software, with mixed criticality. Effective key management is paramount in the SDV, as robust approaches for the authenticity and integrity of software and communication are crucial to ensure safe vehicle operation. At the same time, it creates opportunities for new approaches to securing the vehicle thanks to its connectivity and the decoupling of hardware and software. This includes, among other things, intrusion detection systems and a vehicle security operations center for continuous monitoring.[5] Detecting security vulnerabilities promptly and fixing them as quickly as possible is imperative. The process of detection can be automated, for example by implementing fuzz testing, and expanded to include fieldwork. Security monitoring of new threats coming from the darknet is a key driver for developing security patches. Each new software release must comply with international standards. In addition to conducting open-source software screenings, IP screening and security tests are also mandatory. The vehicle is becoming an interconnected part of the internet that will also benefit from the established internet security concepts.

ETAS provides a suite of consulting and cybersecurity solutions, such as security-enhanced comprehensive lifecycle diagnostics, code hardening, fuzz-testing, security tests, and field observation of security risks.

[5] https://www.etas.com/ww/en/products-services/cybersecurity-products/escrypt-vehicle-security-operations-center-vsoc/

## 4.5
## SDV-ready hardware

**SDV-ready computers:** with their performant systems-on-chip (SoCs), high-performance computers host the new SDV features. Given the high complexity of these computers, Bosch cooperates with multiple SoC providers to ensure cost-effective solutions.

In an ultimate step, two SoCs are merged into one “fusion SoC”. While this may be an optimal solution from a hardware perspective, it should be balanced carefully due to the tighter coupling of technologies and processes/workflows across domains. This tight integration increases complexity, but it also significantly reduces hardware costs and physical space, making the “fusion SoC” an attractive and cost-effective hardware solution, particularly for entry- and mid-class E/E architectures where bill-of-material costs are of critical importance. We support SoC portability and offer one software solution for different SoCs. On this foundation, we handle SoC-specific characteristics (e.g. in our video perception) and enable the application software on a variety of different SoCs. With our video perception, our customers can combine their high-level SW without major SoC-specific constraints. This enhances flexibility and efficiency.

The automotive industry is under constant pressure to reduce costs. As cutting-edge ADAS technology relies on large neural networks, the challenge lies in shrinking the neural network to fit into an automotive SoC. To reduce the footprint of the neural networks, Bosch provides a new tooling, compressing neural networks to smaller SoCs, and this saves costs for the OEM.

As a result of cost-related constraints, Bosch also offers the option of enhancing in-vehicle implemented functions by running external functions in the cloud. This allows OEMs to enhance a given feature after SOP without being limited by the vehicle architecture and compute platform. The basic functionality is still running in the vehicle and can be enhanced by additional functionality running in the cloud, leveraging superior computing capabilities and additional data, such as weather information.

Figure 9: Features are extend to the cloud and the vehicle is securely linked to the cloud-feature

**SDV-ready actuators:** when carefully optimizing the vehicle as a whole, 48V power distribution can be more cost-effective than 12V power distribution. A comprehensive system approach is needed to optimize and compare costs. This approach includes eFuses, wiring harness and 48V components. Bosch offers this holistic approach as a support service and has integrated the required 48V components in the roadmap (e.g., cooling fan, ESP®, "by-wire brake actuator"). Additionally, power distribution must be optimized from the perspective of functional safety.

SDV-ready hardware also means a modular component kit with an adjusted software kit. Building on a modular electric powertrain architecture maximizes re-use of standard software modules while continuously adding value-creating software modules that make a difference. To get the best out of our actuator systems for our customers, we aim to offer a holistic, modular hardware and software stack for all our electrified powertrain actuators.

Maximizing re-use also saves cost: our Electrified Motion division utilizes standardized software modules to enhance synergies across all actuators. For instance, communication stacks or cybersecurity modules can be re-used across our actuators, ranging from cutting-edge 48V comfort drives to highly performant 800V eAxles. Furthermore, we are standardizing our complete development toolchain to align with the future SDV development environment (e.g. CI/CD). Incorporating AI into our development methodologies has led to a significant reduction in costs. Making a difference in terms of add-on value lies in understanding the needs of our customers and delivering exceptional solutions that exceed their expectations: Bosch develops cutting-edge software features that create added value for our customers by reducing system costs, increasing efficiency, ensuring safety and enhancing driving comfort to maximize personalized driving experiences. Saving time while also enabling faster charging with a pre-conditioned battery increases performance. In the event of sensor failures, we enhance availability and reliability through a safe limp-home strategy. Driving comfort is optimized through smoother electric braking without jolts in stop-and-go traffic and with a faster warm-up of the driver´s cabin in cold weather. Bidirectional charging enables additional financial benefits for drivers.

The flexibility of SDV-ready hardware for 400V and 800V powertrains was the key enabler in keeping even demanding timelines (see example above).

**SDV-ready powernet:** in the evolving automotive technology landscape, the powernet remains a pivotal element in the design and functionality of vehicles.

The transition to SDV brings the powernet design to the next level. As the power demand of central computing units continues to surge, manufacturers must adapt their powernet architectures accordingly. Additionally, the introduction of innovative features such as steer-by-wire and brake-by-wire systems imposes higher safety requirements. To address these challenges, new design paradigms, such as zonal architectures, are being explored. Furthermore, technological advancements, including the adoption of 48V systems, might reduce copper demand, minimize weight, and support high-power components.

To effectively meet the dynamic requirements of SDV, new powernet solutions must be seamlessly integrated into the overall vehicle architecture. This integration provides the flexibility needed to accommodate increased dynamics while ensuring the reliability and safety required to incorporate new electronic functions. Enhanced monitoring and diagnostics capabilities, along with remote management features enable optimal performance. Additionally, innovative powernet designs with electronic fuses enable greater flexibility in vehicle architecture, making it possible to place the components responsible for power distribution in challenging locations. As power and current demands steadily increase, only the right powernet design can exploit the full potential of future E/E architectures (s. figure 10)

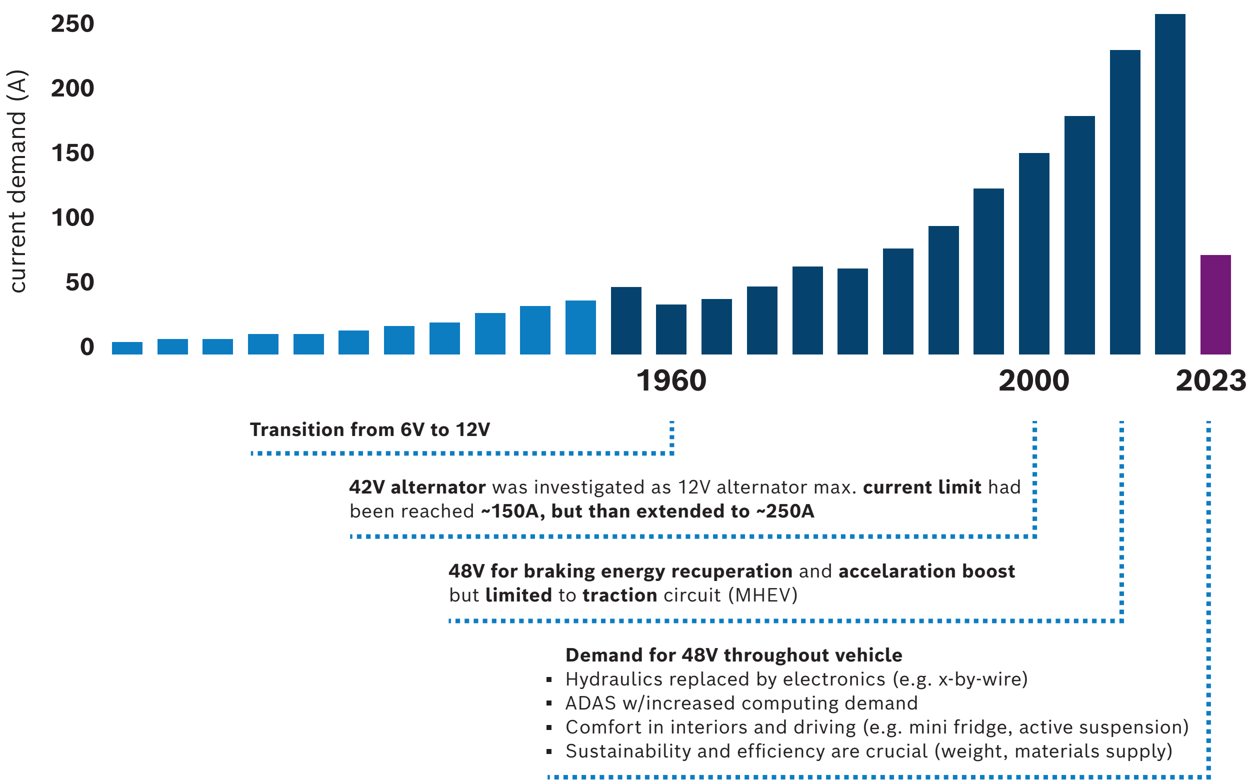



Figure 10: Increasing current demand over the years. Source: Tesla Investor Day 2023

Bosch offers a comprehensive portfolio of SDV-ready powernet solutions designed to meet the automotive industry's evolving needs. These solutions include the Powernet Guardian[6], a central power distribution device designed to protect safety-critical loads from interference. Additionally, Bosch provides Zone ECUs with integrated power distribution capabilities, as well as advanced energy management solutions that enhance controllability and optimize powernet performance.

However, Bosch's contribution extends beyond merely supplying components for SDV-ready powernet[7]. As a trusted partner, Bosch collaborates closely with OEMs throughout the product development lifecycle to address critical design challenges and helps deliver innovative solutions, such as the implementation of 48V systems.

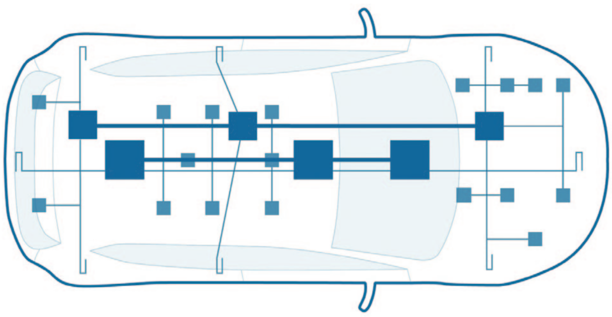


Figure 11: In-vehicle-network suitable for IEEE1722 communication between 3 big vehicle computers and 3 zone ECUs.

**SDV-ready communication network:** automotive ASW is frequently relevant in real-time situations.  Optimal performance thus requires minimizing latency and jitter across the signal chain, from the sensor, through the vehicle computer, to the actuator. Since most actuators are based on LIN, CAN, and Flexray-signals, these signals must be transferred to the service-oriented vehicle computer. The better the data link between the actuators/sensors and the vehicle computers, the better the performance of the new features in the computer. End-to-end latency is a critical factor for distributed control loops. Together with AUTOSAR, the new technology allows the encapsulation of CAN, LIN, or video messages into an ethernet frame. The tunneling is a low-latency link, as it is based on a very low ethernet layer (OSI-layer 2). Recently, AUTOSAR published an IEEE1722-compliant signal forwarding in the release R24-11. (s. figure 11)

A performant signal transmission via the zone ECU is the biggest challenge for this low-latency link. We thus propose a IEEE1722-compliant encapsulation of the signals in the zone-ECU on AUTOSAR classic and an "unpacking" in the computer based on AUTOSAR adaptive. Using our automotive safety and real-time capable AUTOSAR stack, we demonstrate an end-to-end latency of a single digit millisecond. An open-source version for LINUX is also available in "Open1722" and aligned with the COVESA community.

[6] https://www.bosch-mobility.com/en/solutions/driving-safety/powernet-guardian/
[7] https://www.bosch-mobility.com/en/mobility-topics/powernets/

Bosch Mobility focuses on deriving proposals for redesigning SDV-ready networks. The aim is to align with the evolving demands of modern vehicles, which are increasingly characterized by centralized control logic. As co-leaders of the Open Alliance's "remote control protocol" (RCP) working group TC18, we are actively involved in developing communication protocols specifically designed for SDV-ready components, such as vehicle sensors and actuators. The primary objective of this working group is to standardize communication at low protocol levels, thereby enabling the remote control of devices connected through interfaces such as SPI, UART, $I^2C$, and analogous protocols.

By reducing complexity and standardizing device management, this initiative could lead to the creation of more affordable edge devices. Our vision is a shift of complex control logic from microcontrollers to central computers. This will allow for significantly smaller and more specialized microcontrollers at the edge, reducing complexity and streamlining development. This aligns with our concept of SDV-ready hardware, where the control logic can be centralized and managed collectively. Instead of merely reducing the number of devices, we aim to minimize the integration points within a vehicle, which will streamline the development process.

The potential applications for these advancements are extensive, including interior and exterior lighting, switches, door and seat electronic control units (ECUs), and many more. These efforts reflect our commitment to enhancing the efficiency and manageability of automotive systems, ultimately contributing to a more integrated automotive ecosystem.

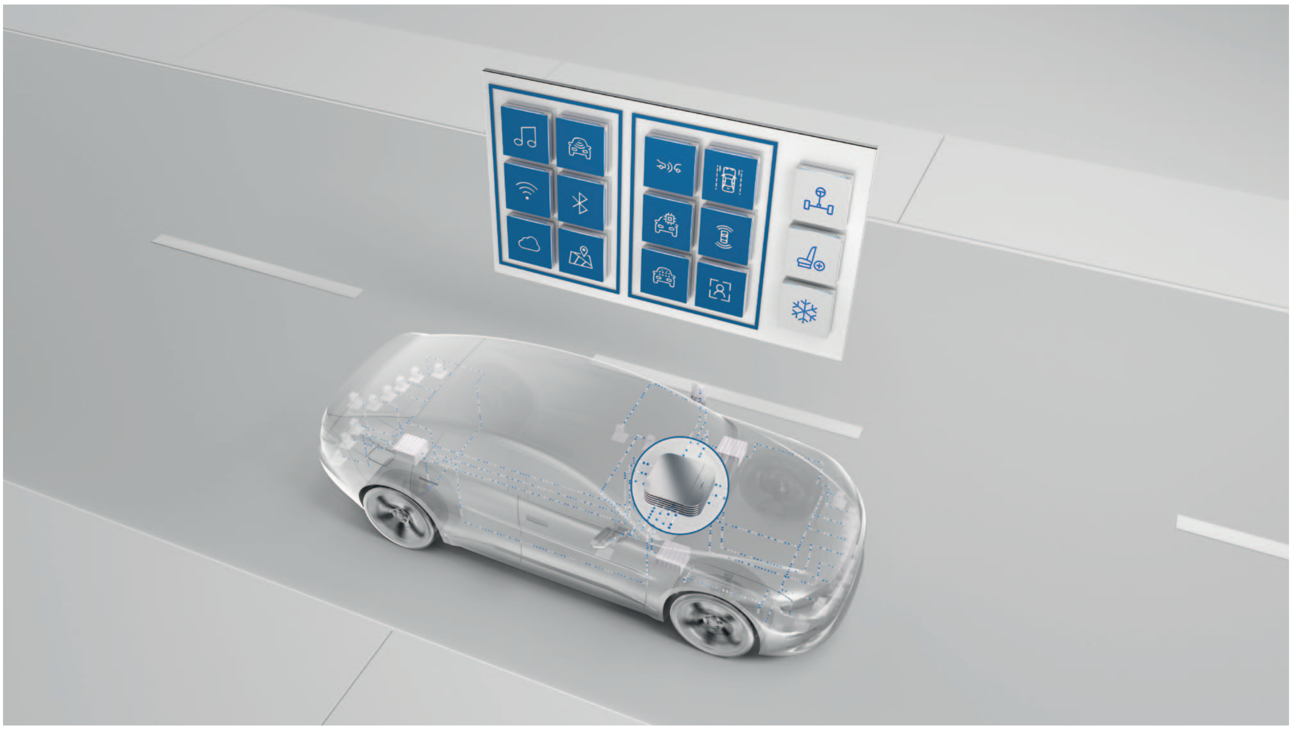


Figure 12: Centralized apps in the vehicle computer with high speed access to the sensors and actuators.

# 05
# Summary and overview of the Bosch SDV portfolio

Bosch Mobility is driving the transition to the SDV era, as Bosch offers solutions at all three levels (embedded µC ECU, Computers on µC&µP, and cloud, as seen in the figure below). Given the complexity of the SDV ecosystem, standardizing interfaces/APIs will be the key for the future technology stack.

The figure below shows the alignment of the offerings across all three SW layers, along with an adjusted portfolio for hardware, operating system/middleware (OS/MW), and specific application software.

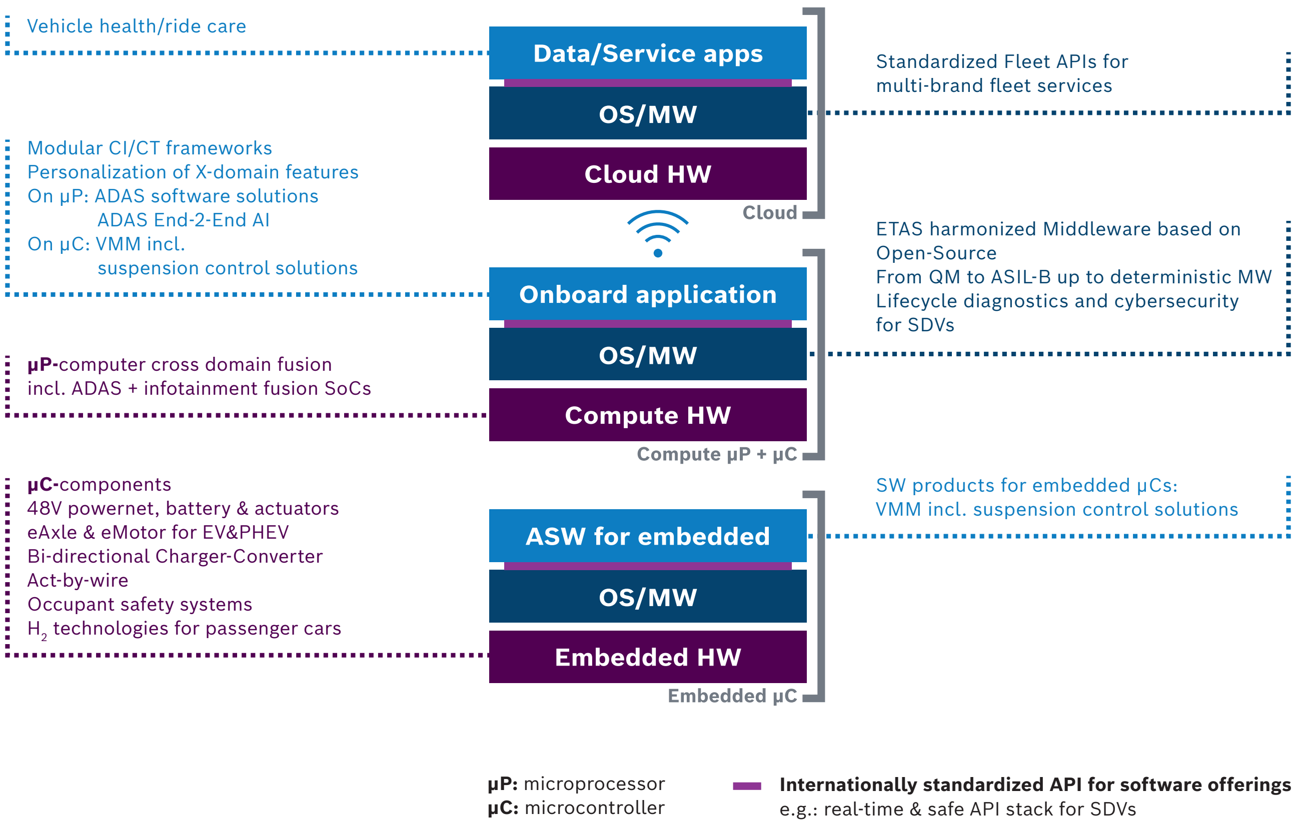



Figure 13: Bosch’s modular end-to-end portfolio based on internationally standardized APIs

Bosch addresses the SDV with a cross-domain approach and an end-to-end view, which includes all three layers (embedded, compute, and cloud).

### BOSCH offers

- Comprehensive software expertise for E/E architectures for personalized driving experiences, automation, electrification, and connectivity
- Tailored end-to-end solutions for everything from individual bits in sensors to cloud-based analytics – encompassing the entire tech stack throughout the vehicle life cycle
- A globally partner network with a detailed understanding of local conditions and market access
- A business culture based on shared leadership responsibilities, radical OEM-TIER1 collaboration, and the empowerment of dedicated cross-domain teams.

Designing and rolling out SDVs requires expertise in both the IT and automotive domains. The task presents tremendous challenges for all companies entering this market. While OEMs and TIER1 suppliers have successfully worked on real-time capabilities and functional safety for years, they must now expand their competencies in complex software systems and efficient software building processes – including tool chains – to achieve high and competitive software productivity. The automotive sector comprises multiple functional domains, including infotainment, body, motion, and ADAS, each of which has its own characteristics and challenges.

The required functional safety levels contribute to increased complexity. For decades, Bosch has successfully rolled out safety-relevant features. Only a few manufacturers and TIERs cover most or all functional domains. Bosch is well-positioned to meet these requirements and to provide solutions in all domains making OEMs successful in the SDV era.

# 06
# Closing remarks

While the vehicle has traditionally been a hardware-driven mass product, the SDV can be adapted to the driver's preferences. Pre-defined driving parameters will give way to adaptable features than can be tailored to the brand or even to the driver's way of life.

Enabling the SDV requires standardized interfaces, while APIs will make it possible to deploy individual settings flexibly on different vehicle platforms (e.g. for the Vehicle Motion Management). The software-defined vehicles of the future will be based on a modular software platform, and the complex automotive hardware will be decoupled from the application software. Safety, real time, and a state-of-the-art security concept that is updated at regular intervals will be decisive characteristics for the automotive software platform's performance. Given that security updates and software maintenance must be reliable for many years after the vehicle has been sold, these updates will rely on a highly automated CI/CD pipeline. A modular software architecture can reduce software variance, and development partnerships will help ease cost pressure in a complex mobility ecosystem. For this reason, we have joined forces with AUTOSAR, Eclipse, and COVESA.

Importantly, the automotive hardware must be "SDV ready". This means that it must be prepared for future updates, and this requires sufficient compute power. The vehicle powernet and communication network should thus be designed to accommodate growing power demands (e.g. on 48V) or even be fail operational.

By putting the driver at the heart of automotive design, SDVs bring us closer to end users and their personal preferences, turning vehicles into personalized products. As this whitepaper has shown, we at Bosch Mobility are well-positioned to support our customers in seizing the resulting opportunities and shaping the SDV era.

Please do also read our whitepaper:

**Beyond the hype:
turning automotive disruption
into opportunity**

# Imprint

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## Contact us now

Get in touch with our expert team. We are looking forward to support you with our expertise to find out more about the future of mobility.

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