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European **Software-Defined Vehicle of the Future** (SDVoF) Initiative

Vision and Roadmap V2.0

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Executive Summary

The European Commission's Directorate-General for Communications Networks, Content, and Technology initiated a consultation process in late 2022, leading to the establishment of the "**Software Defined Vehicle of the Future (SDVoF) initiative**". As the automotive industry shifts toward autonomous, electric, connected, and service-oriented vehicles, the significance of both hardware and software is growing. Software now drives value creation, serving functions and services both within vehicles (on board) and in the cloud (off board) as well as the infrastructure around the vehicle, which will provide mobility services. Customers prioritize "software freshness," seeking new applications and services related to infotainment, connectivity, and ADAS/AD functionality. Regular over-the-air updates enhance cyber-security, safety, and innovation during the vehicle's operational lifespan. This transition fuels demand for next-generation system-on-chip designs and high-performance processors, fundamentally reshaping software development and integration, and opens the opportunity to re-think and re-design the vehicle software stack to match the need of the future.

However, the European automotive industry faces intensified global competition due to non-EU manufacturers' early adoption of software-driven strategies. Large tech companies and hyper-scalers, leveraging substantial software budgets and indirect business models, are already dominating specific domains. Additionally, significant state aid in East Asia facilitates rapid market entry for new companies.

The SDVoF initiative specifically emphasizes collaboration across European Original Equipment Manufacturers (OEMs) and suppliers. It takes a **system-level approach** and focuses on **non-differentiating elements** (also known as building blocks) within the vehicle software stack. By fostering coordination among existing alliances and establishing **close ties with EU initiatives related to an open automotive hardware platform**, as well as initiatives **on connected and automated vehicles** or **zero emission mobility**, the SDVoF initiative aims to create a robust ecosystem. Additionally, where appropriate, **Open-Source software** initiatives will be seamlessly integrated.

Two critical approaches drive the SDVoF initiative:

- The first approach is driven by the concepts of **code-first and bottom-Up Integration**: This approach involves assembling the building blocks into OEM-specific SDV software stacks. Starting from the foundational components, such as communication protocols, security modules, and basic functionalities, the integration process gradually constructs a comprehensive software stack tailored to individual OEM's requirements.
- The second approach focuses on the **top-down development of an automotive-grade SDV middleware software stack**: In this approach, the focus shifts to the middle layer of software architecture. Here, the SDVoF initiative aims to develop a standardized, high-quality middleware software stack that abstracts and hides the technological details between the hardware and application layers. This middleware stack ensures seamless communication, safety, and reliability across various vehicle functions.

By combining these two approaches, the SDVoF initiative strives to strengthen EU strategic autonomy and leadership in the automotive value chain, positioning European actors at the forefront of future vehicle technology.

The SDVoF initiative envisions a comprehensive development process, organized into three distinct phases:

1. **HW/SW Abstraction**: In this initial phase, the focus lies on creating a clear separation between hardware (HW) and software (SW) components. By abstracting hardware functionalities, the initiative aims to facilitate interoperability and flexibility. This abstraction layer allows for efficient integration of various hardware platforms while ensuring compatibility with the evolving software stack.
2. **Middleware and API Framework**: The second phase centers around building a robust

middleware layer that acts as the bridge between the hardware/OS and application layers. This standardized middleware stack provides essential services such as communication protocols, security mechanisms, and data management. Additionally, an API framework ensures seamless interaction between different software modules, enabling efficient development and integration.

3. **Automated DevOps Tool Chain**: The final phase emphasizes automation throughout the software development lifecycle. An integrated DevOps toolchain simplifies the adoption/use of the new software layers and streamlines processes, including continuous integration, testing, deployment, and monitoring. By automating these steps, the SDVoF initiative accelerates development cycles, enhances quality, and ensures timely updates.

To achieve these goals, the initiative will engage in collaborative Research, Development, and Innovation (RDI) projects. These projects will focus on creating essential building blocks, defining the overall structure, and establishing standardized interfaces. Furthermore, a coordination and governance concept will guide decision-making, foster collaboration, and ensure alignment with European actors' strategic objectives.

The next step in SDVoF: European Automotive Connected and Autonomous Vehicle Alliance - ECAVA

The European Commission acknowledged that the automotive industry remains a cornerstone of Europe's economic strength and industrial identity. To stay globally competitive despite the undergoing rapid and far-reaching transformation driven by digitalisation, artificial intelligence, and the shift toward connected and autonomous mobility, Europe must regain technological leadership in software- defined, AI-enabled vehicle systems.

Therefore, the European Commission together with European automotive industry association created the European Connected and Autonomous Vehicle Alliance (ECAVA) in October 2025. It brings together leading stakeholders from across the entire automotive value chain—vehicle manufacturers, suppliers, technology providers, and innovative SMEs—to jointly accelerate Europe's transition toward next-generation mobility.

ECAVA will concentrate on concrete, near-term actions to advance cross-border innovation and support the deployment of connected and autonomous vehicles across the EU. The Alliance will also formulate regulatory recommendations and provide strategic input for future automotive partnerships and European innovation agendas.

ECAVA's work is structured around the five technological pillars of the EU's Automotive Action Plan:

- Modular software platform for Software-Defined Vehicles
- Advanced in-vehicle computing architecture
- Automotive-grade AI solutions
- Large-scale distributed testing and pilot facilities
- Roadmaps and expert guidance for scaling high-impact autonomous driving use cases

The Alliance will drive collaboration in software-defined vehicles, computing and electronics, AI models, and autonomous driving development, testing, and validation - including contributions to European and global standardisation.

ECAVA's mandate translates into four core responsibilities:

- Strengthening collaboration across technologies, industry actors, and EU programmes

- Identifying investment synergies to support strategic industrial competitiveness
- Benchmarking Europe's technological progress against other global regions
- Advising on regulatory frameworks for software-enabled, AI-powered connected and autonomous vehicles

ECAVA is designed as a lean, results-driven structure that builds on existing European initiatives while accelerating progress where coordination is currently fragmented. Governance will be ensured by a Steering Committee reflecting industry priorities, with the European Commission participating and providing a secretariat to support Working Groups and the Alliance Forum. The ECAVA Alliance Forum is globally open to disseminate the ECAVA results.

ECAVA is industry driven, the EC provided a defined space for industry collaboration in non-differentiating areas of in the important automotive industry sector of SDV and autonomous driving and a very welcomed startup support.

Table of Contents

1 State of play

1.1 The Transition to Software-defined-Vehicles

As the automotive industry moves towards autonomous, electric, connected, and service-oriented vehicles, hardware and software are becoming increasingly important in managing their operations and enabling new features. In the future, “software-defined vehicles” will be more valuable than traditional vehicles based mainly on mechanical parts, with electronics and software playing a key role in this new paradigm. Customers value new software applications such as infotainment, connectivity, ADAS/AD functionality, and regular over-the-air updates for new or improved functionality during the operational phase of the vehicles, automatically or on-demand. New apps are also combining clouds with vehicle functionalities to increase the comfort and safety of the driver for day-to-day operations such as charging, parking, and driving. Customers are willing to switch brands for these better applications and features.

The software platform, which includes virtualization, operating systems, middleware, and integration with the cloud, plays a key role in this new paradigm. By raising attention to software and hardware, manufacturers can create more value for their customers and stay ahead of the competition.

Embedded computing hardware and software are therefore becoming increasingly important for the original equipment manufacturers (OEMs) in complete lifecycles of the vehicles and enabling new features of vehicles at customers. But enabling new functions through over-the-air software updates raises new challenges.

The electronic architectures of vehicles are becoming more centralized, fueling the demand for next-generation system-on-chip designs and high-performance processors, and redefining how software is designed, integrated, and maintained. The software layers between hardware and applications, including interfacing with the cloud, play a key role in this paradigm shift.

Automotive players are transforming themselves into software-defined companies, but they are facing difficulties with software development. Software complexity is rising sharply, with lines of code in a vehicle expected to grow from 100 million today to a billion by the end of this decade. Increased complexity of functionalities and sharing of computing resources across electronic control units, vehicle domains, and the mobility and cloud infrastructures reduce the software development productivity. Many non-compatible SW platforms used at different OEMs (and often even within one OEM) create big redundant and non-value adding effort in development and even more in maintenance. This leads to delays and cost overruns for software projects. Additionally, the industry is facing a major software talent shortage.

1.2 Challenges in the European automotive Industry

The development of a robust European Software-Defined Vehicle (SDV) ecosystem faces several critical challenges (see Figure 1) that must be addressed to ensure global competitiveness and technological sovereignty. At the core the SDV software stack—particularly operating systems and middleware—remains fragmented across OEMs. The effort to integrate will stay high, turnaround times continue to be long, and standardization focused on an SDV ecosystem will not happen.

SDV Stack (OS/MW)	• Inconsistent OS/MW building blocks and stacks across OEMS • High effort for configuration, integration leading to long turnaround times • Missing SW Management organization focused on enabling an SDV ecosystem
SW Toolchain & Process	• Lack in toolchain automation and cohesiveness from spec over code to integration towards validation and verification • Significant non-value creating effort in quality related processes (ASPICE, Safety, Security etc.)
Regulatory impediments	• Regulatory lag in type approval • Fragmented cybersecurity regulation • Restrictive data protection laws • Burdensome AI regulation • Homologation and safety certification does currently not incremental certification
Lacking technology leadership	• Slow and complicated innovation funding • Lack of European leadership in efficient SDV standardization • Semiconductor dependency from other markets, missing European Silicon ecosystems
Other/Expertise	• Missing expertise in creation of scalable ecosystems and digital business models (create "fly-wheel effect") • Foreseeable shortage of skilled automotive software developers in Europe

Figure 1: Pain points of automotive industry in SDV development

Toolchain inefficiencies further increase the challenges, with limited automation and cohesion along the development pipeline across suppliers —from specification to validation. Quality assurance processes, including ASPICE, safety, and security compliance, demand significant additional resources.

Regulatory barriers also pose a major obstacle. Delays in type approval, fragmented cybersecurity regulations, restrictive data protection laws, and burdensome homologation procedures hinder innovation:

- Regulatory Lag in Type Approval: European type approval law must be able to handle software speed. This is because the SDV and its ecosystem are defined by continuous and fast updates of applications and functions – they are a decisive differentiating and quality feature for the SDV. A new approach to type approval is therefore needed that rebalances entrepreneurial freedom and security, considering approval-relevant updates of software and hardware over the entire life cycle, establishing uniform and harmonized procedures, e.g. through digital vehicle files.
- Fragmented Cybersecurity Regulation: The multitude of EU cyber legislation leads to a patchwork of regulations (e.g. NIS 2.0, UN R155, CRA, among others). Therefore, it is necessary to systematize and structure IT security law and reform computer criminal law to enable innovation.
- Restrictive Data Protection Laws: We observe highly restrictive, unbalanced and innovation inhibiting interpretations of the data protection supervisory authorities for the European General Data Protection Regulation (GDPR). Therefore, a comprehensive review and adaptation of the regulations is necessary, or its national implementation rules, incl. for the cross-sectoral, legally compliant exchange of vehicle-generated data.
- AI Regulation: The current legal framework, in particular the reporting obligations of the 'EU AI Act', makes rapid vehicle development more difficult due to high additional costs. Therefore, we require facilitations for AI-supported vehicle-specific development systems, such as protected experimental spaces as well as regulatory relief in the Code of Practice. A focus should be to rapidly leverage the ready-to-use legal provisions of the AI Act to launch regulatory sandboxes for controlled experimentation and testing; and real-world-testing.
- Homologation and safety certification does not currently support incremental SW updates: Homologation and safety certification should

support incremental certification originating from software updates.

There is an urgent need for regulatory frameworks that support incremental safety certification and agile development cycles.

Europe's technology leadership in automotive electronics and software is at risk due to cyclical and rather static innovation funding mechanisms, limited standardization influence, and continued dependency on non-European semiconductor supply chains.

Compounding this is a growing shortage of skilled automotive software developers and a lack of expertise in building scalable digital ecosystems and business models capable of generating network effects.

Addressing these pain points requires coordinated action across industry and government, with targeted investment in open-source collaboration, regulatory modernization, and workforce development to unlock the full potential of SDV innovation in Europe.

1.3 Rapidly changing competition

The European automotive industry is facing increased global competition in this rapid transition towards SDV as new non-EU manufacturers have an advantage on software productivity, having adopted a software-driven approach from the outset. Large tech companies and hyper-scalers with enormous software budgets and resources, exploiting indirect business models, are entering the market and already dominate certain domains. Moreover, significant state aid, especially for new companies in East Asia, allows them to enter the market rapidly.

With these software-capable players such as Tesla or BYD blazing a new trail in this regard and anchoring customer expectations, traditional well-established OEMs are forced to catch up and rapidly build sought-after features. Large non-EU semiconductor companies are offering integrated hardware-software platforms and have announced numerous automotive partnerships leading to vendor lock-in and dependencies. The above-mentioned hyper-scalers are expanding their power on consumer platforms into the vehicle. These transformations are putting the strategic autonomy and competitiveness of the European automotive industry at risk.

Over the past three years, the geopolitical landscape has fundamentally reshaped the automotive industry and is now directly reshaping SDV software delivery: U.S. Section-301 hikes (including a 100% tariff on China-built EVs) and the EU's definitive countervailing duties on China-built BEVs have raised costs and forced regionalized sourcing and assembly strategies, complicating common software baselines and OTA roadmaps [1], [2], [3], [4].

At the same time, the Nexperia dispute exposed how governance and export-licensing shocks in "mature-node" chips can reverberate through SDV programs triggering line-stop risks, re-sequenced OTA bundles, and delayed validation gates [5], [6].

1 Venable LLP. Biden Administration Imposes Tariffs on Electric Vehicles and Key EV Components from China (Jun 6, 2024). [https://group.atradius.com/dam/jcr:ba63c7c3-917b-40cb-a6dc-d74372de636e/Industry%20trends%20automotive%20November%202025.pdf]

2 EY. Additional tariffs upon completion of China Section-301 review (May 15, 2024)

3 European Commission (Access2Markets). Definitive countervailing duties on BEVs from China (Dec 12, 2024; applicable Oct 30, 2024). [https://fobberg.com/2025/10/13/chinas-graphite-export-controls-trigger-global-supply-shake-up/]

4 S&P Global Mobility. How EU tariffs will impact the BEV market (Nov 19, 2024). [graphitehub.com]

5 CNBC. Where the Nexperia auto chip crisis stands now (Nov 1, 2025). [https://www.spglobal.com/automotive-insights/en/blogs/2024/11/how-eu-tariffs-will-impact-the-battery-electric-vehicle-market]

6 AP via TechXplore. A crisis at chipmaker Nexperia sent automakers scrambling (Nov 8, 2025). [https://cms-lawnow.com/en/ealerts/2026/01/battery-electric-vehicles-from-china-a-timely-update-on-the-eu-s-anti-subsidy-duties-and-the-commission-s-new-guidance-on-price-undertakings]

Tightening export controls on advanced semi-conductors and lithography tools - together with the Netherlands' expanded licensing on ASML systems - are pushing OEMs/Tier-1s toward dual compute baselines and higher verification cost for perception/AD stacks [7], [8].

Controls on gallium/germanium and, later, graphite and high-energy battery technologies add volatility in inverters, BMS and pack availability, forcing heavier reliance on virtualization/HIL in SDV validation [9], [10], [11]; rare-earth and magnet licensing has intermittently threatened traction-motor supply, requiring software re-calibration of torque, thermal-management and safety cases [12], [13].

In North America, USMCA rules-of-origin and dispute interpretations cascade into SBOM/origin traceability for software-loaded components and more variant management [14], [15], while war-driven harness disruptions in Ukraine have forced redesign of network topologies and re-testing of timing/diagnostics in zonal architectures [16], [17].

Collectively, these dynamics demand that political and industrial leaders pair trade and industrial-sovereignty measures with SDV-specific investments—hardware-abstraction layers for rapid substitution, regionalized yet unified code-line management (feature-flag/product-line engineering), and compliance-by-design SBOM automation—to sustain competitiveness in an increasingly fragmented market [18], [19].

To address these challenges, automotive companies need to focus more on modular software with improved maintainability, portability, and faster time-to-market without sacrificing automotive quality and ensuring the evolution of modern vehicles. By focusing on software and hardware, manufacturers can increase value for the end-users and stay ahead of the competition.

1.4 Industry and EC take up the SDV challenges

So far, EU car companies have focused on developing proprietary technology platforms, impeding efficiencies when such investments replicate efforts on elements that are not differentiating and visible

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[7] U.S. GAO (GAO-25-107386). Export Controls: Advanced Semiconductor Rules (Dec 2, 2024). [https://www.pwc.com/us/en/services/tax/library/usmca-panel-rules-against-us-position-in-auto-origin-dispute.html

[8] Government of the Netherlands. Expanded export control measure for advanced semiconductor equipment (Sept 6, 2024). [https://www.automotivemanufacturingsolutions.com/press-and-body/chinas-rare-earth-magnet-export-ban-threatens-global-ev-and-automotive-manufacturing-as-us-european-and-asian-carmakers-scramble-to-secure-critical-materials/542047]

[9] USITC. Germanium and Gallium: U.S. Trade and Chinese Export Controls (Mar 2024). [https://kpmg.com/kpmg-us/content/dam/kpmg/pdf/2023/impact-auto-industry.pdf]

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[11] Herbert Smith Freehills Kramer. China imposes export controls on lithium-batteries and artificial graphite anode materials (Oct 10, 2025). [https://orfamerica.org/newresearch/chinas-critical-mineral-export-controls]

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[14] Congressional Research Service. USMCA: Automotive Rules of Origin (Dec 6, 2024). [https://www.cnbc.com/2024/09/06/netherlands-expands-export-curbs-on-advanced-chip-tools.html]

[15] USTR (USMCA Panel Report). United States – Automotive Rules of Origin (Dec 14, 2022). [https://www.government.nl/topics/export-controls-of-strategic-goods/news/2024/09/06/the-netherlands-expands-export-control-measure-advanced-semiconductor-manufacturing-equipment]

[16] Reuters/Yahoo Finance. Ukraine invasion hampers wire-harness supplies for carmakers (Mar 2, 2022). [https://www.nbcnews.com/news/world/us-announces-new-export-controls-china-chip-industry-rcna182579]

[17] KPMG. The impact of the Russia-Ukraine war on the auto industry (2023 brief). [https://www.congress.gov/crs_external_products/R/PDF/R48642/R48642.5.pdf]

[18] Automotive Manufacturing Solutions. Geopolitics and shifting investment plans reshape 2026 automotive strategy (Jan 20–21, 2026). [https://www.iiss.org/publications/strategic-comments/2024/10/the-eus-approach-to-tariffs-on-chinese-electric-vehicles/]

[19] S&P Global Mobility. Automotive Industry Outlook & Tariffs theme page (Jan 2026). [https://news.dealershipguy.com/p/nexperia-tug-of-war-wages-on-leaving-global-auto-production-on-edge-for-2026-2025-12-01]

to the customer. A rising number of partnerships and alliances across varying types of actors of the automotive and digital ecosystems shows a growing openness to join forces. They, however, do not cover systematically all the non-differentiating elements of the software stack and lack in many cases sufficient implementation. They would benefit from stronger cross-initiative coordination and governance.

In this context, the European automotive, embedded SW and semiconductor industry together with the European Commission have started complementary but distinct industry driven initiatives to reinforce EU strategic autonomy and leadership in the automotive value chain on the vehicle of the future. They address the need for an open automotive hardware platform and an open "Software-Defined Vehicle of the Future" (SDVoF) ecosystem driven by European actors. The SDVoF initiative focuses on an open and pre-competitive collaboration across European OEMs and suppliers on non-differentiating elements of the vehicle software stack. This initiative aims to reinforce the coordination between existing alliances by orchestrating distributed developments and ensuring close links with EU initiatives on an open automotive hardware platform. Stronger cross-initiative coordination and governance would benefit these partnerships and alliances.

2 European initiative on the “Software defined Vehicle of the Future (SDVoF)”

2.1 Two kinds of vehicle SW

It is essential to understand that there are several very different software types in a modern vehicle.

The following figure illustrates the change going on in automotive software:

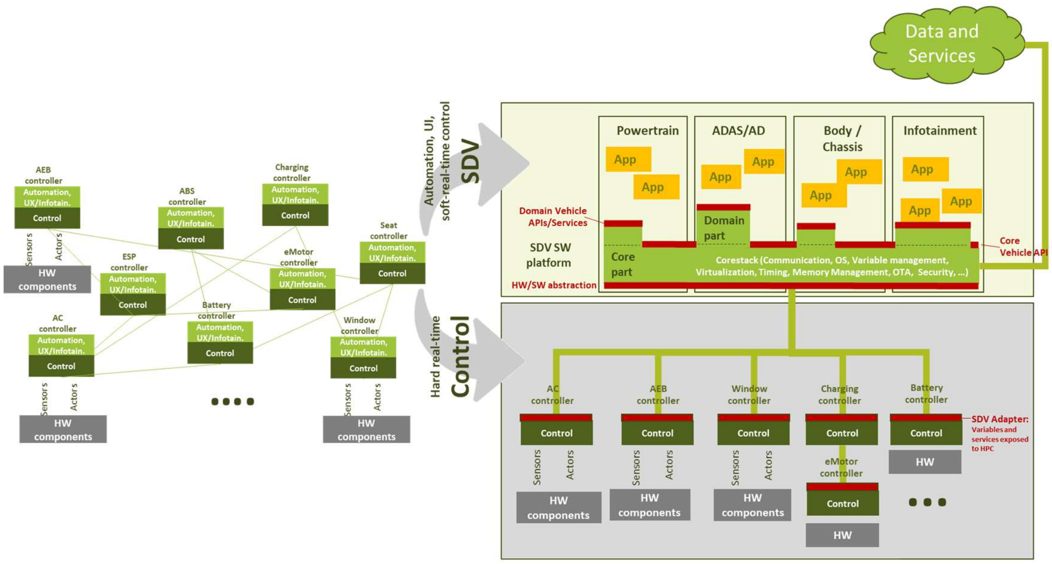

Figure 2: Automation and UI moves to central high-performance computers

In the past, software in vehicles replaced mechanical controllers in mechatronics components as combustion engines, brakes, transmissions, seat adjustment systems, window opener and so on. Over time automation functions were added to the different controllers, which needed signals acquired by other controllers. This led to a quite complex spiderweb of controllers as indicated at the left side of Figure 3 In Software Defined Vehicles, automation, infotainment and edge2cloud applications move to central high-performance computer(s) in the vehicles.

In SDV zonal controllers acquire and preprocess signals and, in many cases, do also hard real-time control functions. The zonal controllers provide the interface to the physical world in the vehicle and are close to sensors and actuators to minimize cable length. Controller software runs on zonal controllers or sometimes also on centralized computers combing the control of several mechatronics components. An example for the later kind is a new Motion controller combing all controllers for longitudinal and lateral movement of a vehicle as well as recuperation and braking. Zonal controllers may also be connected to legacy controllers via classical vehicle communication lines, which allow a smooth transition from classical controller networks to new SDV EE-architectures. This software is called **Control software** throughout this white paper.

The SDV high-performance computers run many different applications, many of which need AI and/or large language models. The necessary hardware support is provided by the SDV HW platforms. This software runs in most cases on POSIX operating systems and is typically using virtualization technology to separate different application domain software packages. We call this kind of software the **SDV** (application) **software** throughout this white paper.

The following figure shows an exemplary SDV EE-architecture following the thoughts above.

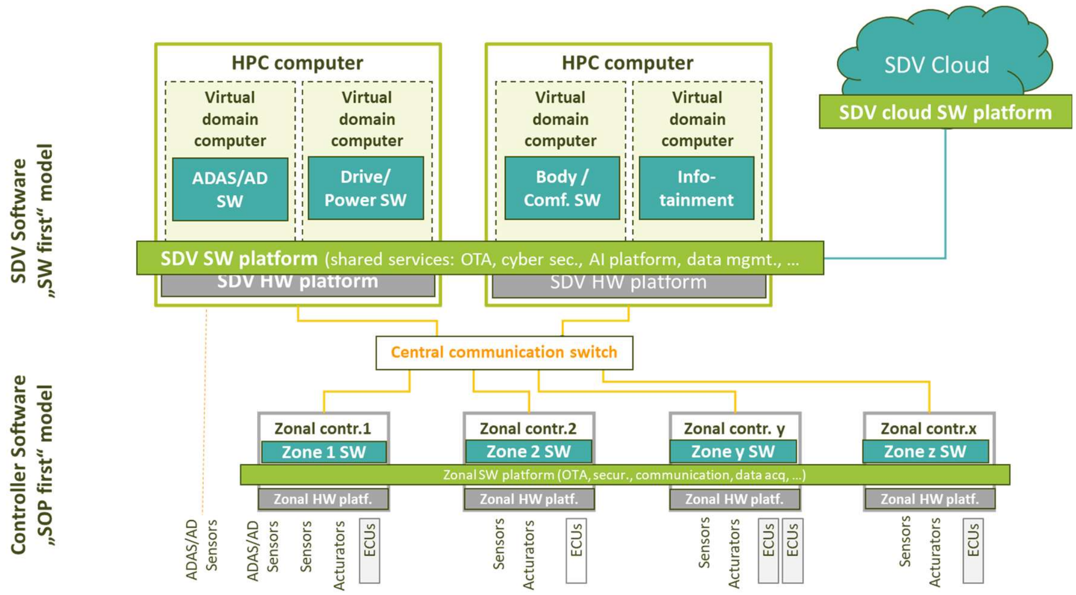

Figure 3: Example for a SDV EE-architecture

2.2 Software is not equal to Software

With respect to software skills, there are huge differences requiring knowledge in various frameworks and programming languages.

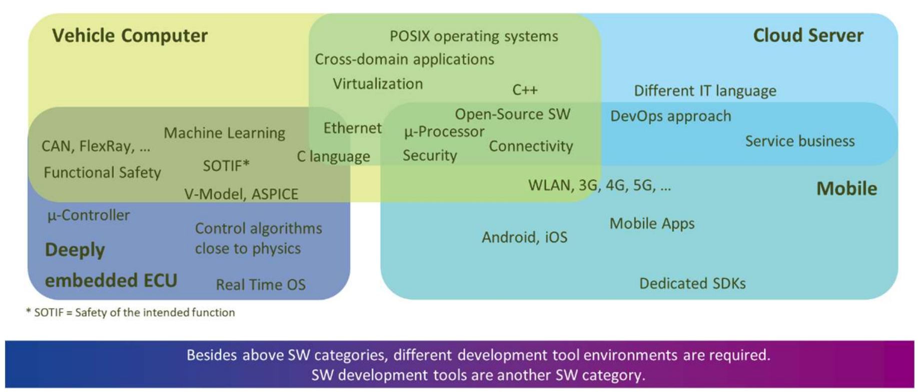

Figure 4: different software categories in a vehicle[20]

[20] FZI Open House 2025; Detlef Zerfowski; ETAS GmbH; 2025-02-27

2.3 SW software categories in SDVs

The automotive software can be structured into the following two main software types:

1. **Control Software:** This typically refers to low-level, hard real-time software responsible for the control and operation of safety-critical systems like engine control units (ECUs), transmission systems, inverters, etc. They tend to use specialized software frameworks and operating systems (like RTOS or bare-metal implementations) for high reliability and deterministic performance. The most common SW platform for hard-real-time controllers is Autosar-Classic. It has only a weak HW/SW abstraction and relies on API-Interfaces used by the controller applications. This software has typically a static configuration without dynamic memory allocation processes etc. to reduce safety risks as much as possible. This software runs often on zonal computers or classical ECUs.

2. **SDV Application Software (ADAS, Infotainment, etc.):** This includes higher-level functions like Advanced Driver Assistance Systems (ADAS), body and chassis automation, infotainment, and telematics. These are often less time-sensitive and interact more with user interfaces and network communication. ADAS/AD software must be also deterministic but has softer real-time requirements than vehicle control software This software typically runs on general-purpose POSIX operating systems (like Linux, QNX, or even Android) and relies on middleware and application frameworks to handle interactions with two abstraction layers: HW/SW abstraction between the hardware platforms and the SDV SW platforms and the Function-Abstraction between the SDV SW platforms and the SDV applications.

   SDV applications typically have software running **in the vehicle** and **software in the cloud.** Cloud and backend software are essential for managing data, updates, and services in real time. These systems enable over-the-air (OTA) updates, allowing vehicles to receive new features and security patches without visiting a service center. They also support advanced data analytics for predictive maintenance and personalized user experiences. Additionally, cloud platforms enable crowd-sourcing applications like Mobileye REM, which use data collected from vehicles to create detailed, continuously updated maps[21,22]. Overall, cloud and backend software ensure a connected, secure, and continuously optimized driving experience.

Both software categories are split into a **non-differentiating SW platforms** (Infrastructure Software) layer and a differentiating application/control-algorithm layer. The **SW platform layers** support the execution of both control software and application software. It includes the operating system, middleware, hypervisors, OTA infrastructure, and communication protocols. The role of the SW platforms (infrastructure software) is to provide a unified and consistent environment for both types of software, enabling things like secure communication, hardware abstraction, inter-process communication, and system resource management.

The SW platform layer offers its features to the application layer in APIs and services. It connects to the hardware via a hardware/software abstraction interface, where the hardware functionality is offered to the SW platform layer in a uniform way independent of the hardware type and manufacturer.

The lower part of the SW platform layer typically includes a **hypervisor.** In actual automotive systems, hypervisors are used to virtualize the hardware, enabling both real-time control software and non-critical software (like infotainment or ADAS) to run on the same platform, isolated from each other. This allows the use of both real-time systems and

[21] Mobileye REM™ | Road Experience Management
[22] The Road to the Future of Mobility is Being Mapped by REM™

general-purpose OS on the same hardware, with the hypervisor managing the allocation of resources.

Over-the-air updates are becoming increasingly important for both control and non-control systems. The infrastructure to handle these updates (e.g., secure boot, update mechanisms) is often common across both areas, though the content and scope of the updates might differ. This feature is therefore an important part of the SW platform layer.

There is some overlap between the SW platforms for control software and application software, but they normally differ in its focus and features.

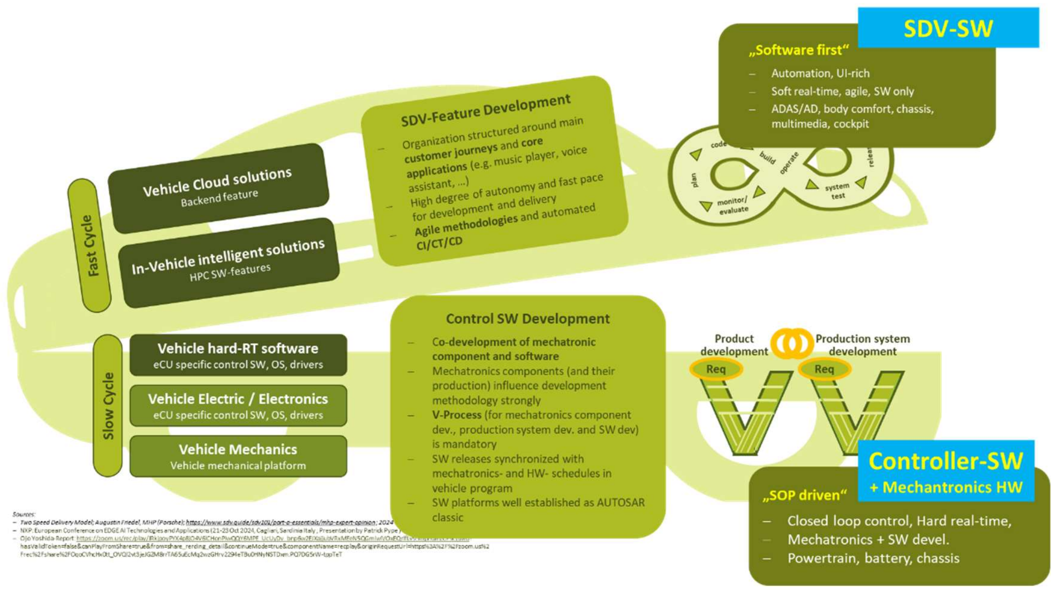

Figure 5: Two speeds of software development in vehicles[23]

A similar split into two main software types leading to very similar results is visualized in Figure 5 have the following characteristics:

– For **Vehicle control software**, infrastructure software typically needs to be **lightweight, reliable, and deterministic**. It might use real-time operating systems (RTOS) or other specialized software that ensures precise timing, guaranteed performance, and safety. For instance, safety-critical systems might require specific certification standards like ISO 26262. Control software is typically very safety relevant.

– For **SDV application software**, infrastructure software is more focused on providing higher-level services, like rich user interfaces, media management, connectivity, and flexibility for app development. The OS here could be a general-purpose OS (e.g., Linux, QNX), and the infrastructure could include middleware for handling complex interactions with infotainment, cloud services, or over-the-air (OTA) updates.

Consequently, the development of new SDV features demands a fundamentally different skill set—illustrated on the middle and right side of the figure above. These capabilities are well-established within large IT companies (hyperscalers), but many OEMs have begun building internal expertise, recognizing SDV software as a new core area of the automotive business. As a result, software development is

[23] *Two Speed Delivery Model; Augustin Friedel, MHP (Porsche); https://www.sdv.guide/sdv101/part-a-essentials/mhp-expert-opinion ; 2024*

shifting from traditional Tier-1 suppliers toward OEMs and hyperscaler-led teams. This transition is reshaping the traditional collaboration models between OEMs and suppliers, fundamentally altering roles and responsibilities in the automotive value chain.

To manage the complexities of SDV development, OEMs adopt a two-speed delivery model shown in Figure 5: Fast Cycle vs Slower Cycle. This approach allows manufacturers to address both the demand for rapid innovation and the need for robust platform-level development.

- **Fast Cycle:** The fast cycle focuses on feature development, leveraging DevOps and agile methodologies. This approach enables quick iterations and faster delivery of new features. Key elements are for example: CI/CT/CD pipelines for streamlined development and integration and Shift-North strategies to accelerate innovation and feature rollouts.
- **Slower Cycle:** The slower cycle involves platform-level development using systems engineering models like the V-model. A shift-left approach ensures early identification and resolution of issues during development, minimizing costly fixes later in the process. This dual-speed framework helps OEMs balance rapid feature delivery with robust platform development.

2.4 Towards in an SDVoF ecosystem – Objectives and goals of the initiative

To overcome the challenges described in section 0, the SDVoF initiative has jointly identified the following objectives:

Objective 1: Improving agility and automotive grade quality in (hardware and) software development

Automotive software (onboard, and increasingly also offboard) has always had particularly high quality, reliability and dependability requirements. Being safety-critical systems, vehicles need to fulfill stringent safety and security standards and legislation, with emphasis on development methods, processes, verification, and validation. The first objective of this initiative is to improve development agility while sustaining automotive grade quality.

Open source plays a significant role in the global software industry. The success of the Linux operating system, the software components in most of the cloud software systems, and many more applications gained agility and development speed through open-source approaches. Therefore, the SDVoF initiative also adopts an open-source approach wherever possible and useful. Moreover, open-source software (OSS) projects provide global open access (if not restricted by law), which has shown to attract top talent, thereby building an ecosystem with pools of experts needed in industry. Additionally, the “code-first” approach shall ensure that time-consuming standardization and industrialization work is only spent on successfully implemented, integrated, and tested software building blocks.

It is intended to avoid time-consuming and costly unnecessary developments in using available components and concepts as much as possible. Cooperation with all relevant initiatives such as COVESA, SOAFEE, AUTOSAR, ECLIPSE-SDV, etc., is essential.

Objective 2: Reduce time-to-market and developing costs by collaboration

Collaboration in non-differentiating areas together with automation - wherever possible and useful in the whole lifecycle of software from inception, development, maintenance to field monitoring across OEM and Tier boundaries shall deliver the necessary agility in the development process, significant reduction of development costs as well as a faster time-to-market.

Objective 3: Support new business models in the automotive industry enabled by the Open SDVoF platform

As Software defined vehicles will be updated and functionally extended throughout their operational lifetime (via over-the-air updates), new (largely service oriented) business models are introduced on the automotive industry. The SDVoF SW structure and building blocks shall support this new automotive business models.

Objective 4: Fostering open communities for collaborative creation of Open SDV source SW components

Collaboration with existing open-source initiatives and fostering the creation of new open-source communities shall create a vibrant open-source ecosystem for SDVoF SW stack components. Close alignment with the sister initiative “High-Performance Automotive RISC-V Reference Platform" shall allow fast take-up of new European SDV-HW platform implementations.

Objective 5: European strategic autonomy in SDV-HW and SDV-SW

The creation of an European SDV software ecosystem working on a commonly agreed SDV software structure and (open source) building blocks will help to ensure the European strategic autonomy in SDV software. Similarly, the sister initiative on “High-Performance Automotive RISC-V Reference Platform" will do the same on SDV hardware.

Objective 6: Joined effort of industry and public authorities for the design and implementation of an Open SDV platform

The establishment of a level playing field for the European SDV industry in the fierce global competition shall be achieved by public-private cooperation in funded projects constituting the SDVoF initiative. Common non-differentiating building-blocks, an agreed SDV software structure and consensual interfaces will enhance technical interoperability and help create an open ecosystem. This will reduce vendor lock-in allowing companies to compete in a fair way. By relying largely on open-source and by ensuring transparency and broad dissemination, the initiative will allow actors outside the funded projects to participate in the ecosystem.

Objective 7: Generate an Open Source automated AI assisted development, validation and homologation toolchain to speed up and significantly lower SDV SW development costs

The final objective emphasizes automation throughout the software development lifecycle. An integrated DevOps toolchain simplifies the adoption and use of new software layers, streamlining processes such as continuous integration, testing, deployment, and monitoring. By automating these steps, the SDVoF initiative accelerates development cycles, enhances quality, and ensures timely updates.

2.5 Guiding principles towards the objectives of the SDVoF initiative

The initiative addresses the following areas:

- The development of non-differentiating building blocks which help to develop SDV SW stacks faster and more efficiently.
- The creation of a reference structure for SDV SW stacks (based on open APIs).

The development of methods and tools for automotive software engineering, which cover the complete life cycle of software defined vehicles.
The guiding principles for the initiative agreed by the industry are explained in the following sections.

Collaborative development of open non-differentiating building blocks

All OEMs are currently working on OEM specific SDV software architectures in various partnerships. The initial focus of the "Software-Defined Vehicle of the Future" initiative is the creation of software building blocks, which will be integrated and used in company-specific SDV software stacks. A consensual definition of interfaces for these non-differentiating building blocks is highly important. The integration into the company (OEM or Tier) specific software stacks may require adding thin layers of company-specific software ("glue logic") to cope with the differences in the existing as well as future company-specific architectures.

As the focus of the building blocks is in the non-differentiating area, they will reside in mainly layer 2 depicted in in Figure 1 on page 20, which consists of essential functionalities as virtualization, car (meta) operating system, HW/SW abstraction, the on-board middleware, API framework and cloud middleware. Virtualization concepts are a key concept for safety relevant (and mixed-criticality) implementations of the vehicle SW stack. They are considered differentiating. Therefore, implement-tation might not be open source, but agreement on common interfaces is crucial.

Open-source and Code-first

The initiative adopts "code-first" principles to create fast tangible outcomes for the industry. Together with demonstrators and ecosystem building, open-source code development will become the foundation and a crucial success factor of the European SDV ecosystem and drive industry standards in an agile and widespread adoption, thus helping to reduce time-to-market. Only building blocks used successfully in industry SW stacks will be used as base for standardization of interfaces.

The "Code-first" approach has several goals:

- Iterative development to sequentially improve building blocks and integrate them as soon as possible into industrial SW stacks. Standardization effort is only started, when building blocks have proven their functionality, robustness, and quality in real-world usage.
- Test driven development is a very good development methodology of an agile "code-first" approach. It basically means, that the test procedures are designed and already implemented as part of the requirement specification. This also helps to significantly improve the quality of requirements and subsequently of the code. Additionally, it supports the automation of testing.

"Open-source" is used because:

- The use of open-source in the non-differentiating layer of the SDV SW stack creates an open ecosystem to achieve pre-competitive goals. It helps to avoid the risks of violating competition laws and thus helps to ensure compliance with antitrust regulations.
- The creation and use of open-source allows universities and research institutes to use and contribute SW components in their Research and educational programs. This is an essential contribution to solve the shortage of SW talents in the automotive industry.
- The automotive industry is already using many open-source components in industrial SW stacks of vehicles. They are mainly used in non-safety critical areas as infotainment, communication etc. These open-source components are in most cases not initiated, specified, and developed by automotive companies. As the SDVoF SW stack also includes many safety-critical SW components, the extensive experience of automotive OEMs, suppliers and academia is necessary to create open-source building blocks useable in automotive SW-stacks. This requires a transition from "consuming only" open-source to "contributing and consuming" open-source in the automotive SW industry.

Agility and speed through rapid demonstration in representative use-cases

To pave the ground for rapid adoption of new components, emerging building blocks will be demonstrated gradually in representative use-cases. This should help participating companies to integrate them as soon as possible in the SW stack of their future solutions, products, and vehicles in general.

HW/SW abstraction and virtualization

The SDVoF initiative aims to provide modular and scalable software architecture for OEMs and Tier1s to build their SDV systems. The initiative focuses on decoupling software-implemented functions from the underlying hardware, reducing dependencies and vendor lock-in. However, it is important to note that becoming hardware agnostic does not mean becoming hardware ignorant. Hardware requirements must be defined from the SDV application perspective, and emerging hardware features must be exploited in software for performance optimization, additional functionality, or safety/security. It is important to note that HW requirements need to be defined early and stay fixed, the requirements for the SDV SW applications are changing over the lifetime of the car.

The SDVoF initiative is therefore closely collaborating with the sister initiative "High-Performance Automotive RISC-V Reference Platform". For OEMs, the HW and SW abstraction layer simplifies the migration from existing OEM specific (often non-European) automotive high-performance computing platforms to new HW platforms based on the results of the sister Initiative "High-Performance Automotive RISC-V Reference Platform".

Working in a common structure of the SDV SW stack

The initiative has agreed on a three-layer structure for SDVoF HW/SW stacks as depicted in Figure 6. The initiative aims to develop collaboratively non-differentiating building blocks in the "Middleware and API framework" and "Car meta operating system & HW abstraction" layers with implementations in-vehicle as well as off-board in the cloud. Wherever useful and possible, open source shall help to gain agility as well as a selection of the best SW technologies and/or solutions. The building blocks will be used in existing or new SW stacks of OEMs or tiers, which will bring the new functionalities into vehicles on the road.

- **Layer 2 (SDV-middleware & hardware abstraction & OS):** This software Layer 2 is the major focus of the SDVoF initiative. It consists of (mainly open-source and mostly non-differentiating) software building blocks, which connect the hardware layer with the applications layer to allow separate hardware and software development cycles necessary for software-defined vehicles of the future. This layer also ensures the safe execution of the applications of layer 3. It shall consist of software building blocks, which can also be used in existing OEM specific SW stacks. As many applications have on-board and off-board (cloud) parts, a service-oriented interface layer shall also exist in the cloud.

  Layer two consists of two sub-layers: 2a) HW abstraction, virtualization, and operating system (OS) and 2b) SDV middleware and API-framework and service interface.

  Layer two may use different operating systems in different software-defined vehicle domains such as infotainment, ADAS, automated driving, chassis/powertrain control, body-comfort, etc., but the interfaces shall be the same. Also standardized communication between different SDV domain implementations is provided by the software in layer 2.

- **Layer 3 (SDV-Applications)**: This layer contains the differentiating parts with applications in automotive domains such as infotainment, automated driving, advanced driver assistance functions, chassis and powertrain control, cockpit user interfaces, e-charging, routing, (body and) comfort functions, etc. Many of the applications have parts onboard of the vehicle and other parts in the cloud.

- Tools and tool chains designed for the SDV of the future

The complexity of vehicle software stacks in SDVs is increasing rapidly, especially for safety-relevant features (e.g., automated driving, vehicle-to-grid) for SAE level 2 to 5. This makes it very likely that new unknown safety critical situations and scenarios will arise in the operational phase of the vehicle despite rigorous hazard and risk analysis (HARA) and V&V in already in early phases of the development. This can lead to safety hazards or security issues for passengers and other traffic participants, which will therefore require software corrections and updates in very short time periods.

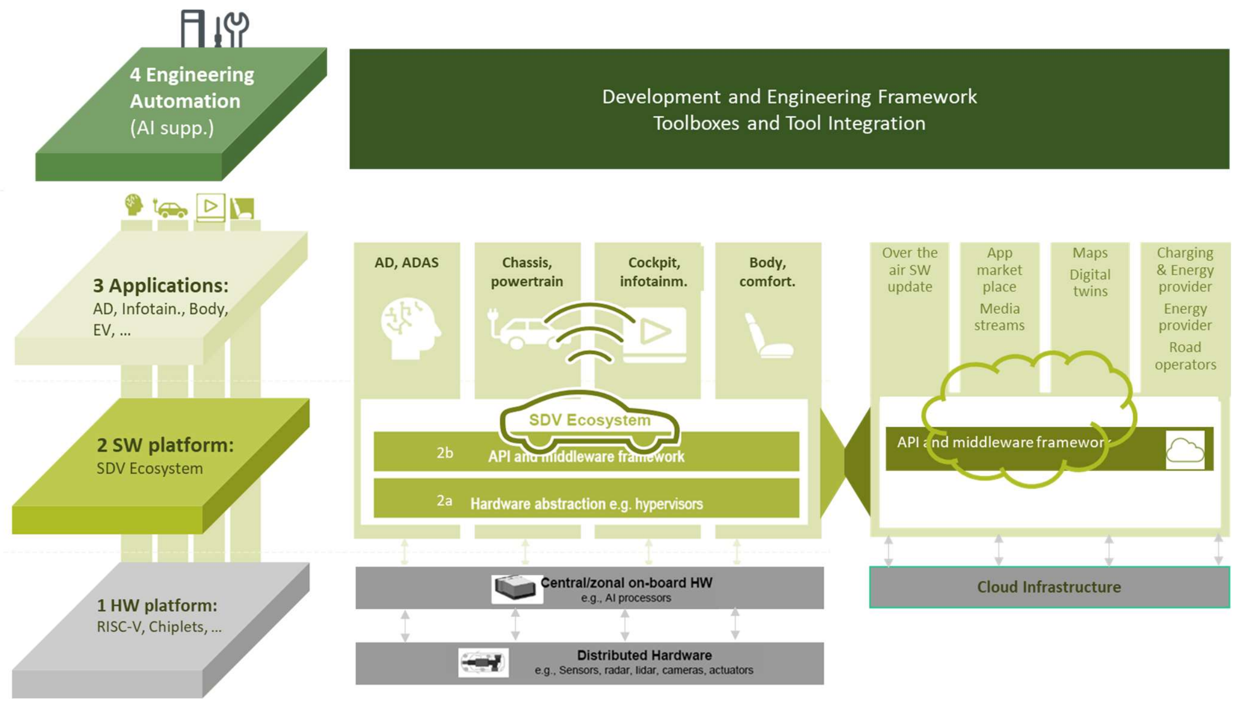

Figure 6 Basic structure of SDVoF HW/SW stack

The SDV SW stack must support continuous updates during the life cycle of the cars using update functionalities offered by the stack itself. These updates can be perfective as well as corrective updates. As corrective updates may have to solve safety critical issues, the integration and testing of the complete SW stacks must be completed in single digit weeks compared to double digit month nowadays. This motivated the second important part of the initiative: the development of new SW-DevOps Standard Development Kits (SW-SDKs). SW-SDKs include new methods, CI/CD toolchains, tool-building-blocks, and building blocks covering the complete life-cycle of SDV SW stacks, providing automated functionalities for the creation and delivery of SW stacks This layer includes new methods and corresponding building blocks for tools and toolchains covering the complete life-cycle of SDV SW stacks, which allow the creation of SW stacks deliveries. The building blocks of the DevOps toolchains shall use existing proven components (tools) wherever possible; open-source plays also here a major role. More details are described in the subsequent paragraph.

Furthermore, the trends towards more complex software functions and the concentration of software on central computing platforms lead to significantly larger complexity and increased time periods required to test new software updates. Current workflows and modes of collaboration between OEM and multiple tiers complicate integration, testing, and bug fixing in the software distribution process significantly. Today's time span between implementation of a software bugfix and delivery of the modified software over-the-air to vehicles might reach a couple of months, which is not acceptable anymore. New processes and related development tools are required to largely automate this process and are therefore also in the scope of this initiative. AI-based and model-based technologies are promising to improve and speed up the specification, implementation, and test steps. As a result, software updates will be created and deployed much faster and more frequent, which not only keeps vehicles safe and secure, but can also raise brand attractiveness through "software freshness", enabling new functionalities and experiences to users.

Support of the collaborative development of high-performance (open) SOCs designed for SDVoF

This SDVoF initiative will closely work together with the sister initiative "High-Performance Automotive RISC-V Reference Platform". This will ensure fast integration of the new high performance automotive SOC developed in the sister initiative with the SDVoF SW buildings blocks and reference SDVoF stack of this initiative.

Close collaboration with existing initiatives to avoid "reinventing the wheel"

Agility and development speed are crucial challenges. It is mandatory to reuse existing proven building blocks and design patterns wherever possible. Cooperation with accepted initiatives in the automotive industry working on various aspects of the SDV is essential to avoid duplication of effort and to reduce the time-to-market. Essential partners to the SDVoF initiative cover different important stakeholder groups.

Automated AI assisted development, validation and homologation toolchain(s) and processes

Automated, AI-assisted development, validation, and homologation are becoming essential for Software-Defined Vehicles (SDVs) as traditional engineering processes cannot keep pace with rapidly growing software complexity and continuous updates.

Modern vehicles contain hundreds of millions of lines of code, and manual or hardware-bound validation methods are too slow, costly, and incomplete for today's OTA-enabled, AI-powered architectures. Industry analyses show that cloud-native virtual validation and AI-driven test automation dramatically accelerate development cycles, expand test coverage to billions of scenarios, and strengthen compliance with regulations such as ISO 26262 and UNECE cybersecurity and software-update requirements.

In homologation, AI already reduces approval time by automating test-case generation and improving accuracy - critical as SDVs require continuous compliance over their lifecycle. As SDV architectures become centralized, data-driven, and AI-enabled, in SDV architectures, fully integrated automated toolchains are indispensable to ensure safety, reliability, and competitiveness in global markets with continuous updates and improvements of software via over-the-air updates.

2.6 Automotive middleware software initiatives

Eclipse SDV[24]: Eclipse Foundation is providing an open technology platform for the software defined vehicle of the future; accelerating innovation of automotive software stacks through a vibrant open-source community.

S-CORE is one of the most essential project in Eclipse-SDV, which works on the first SDV SW platform reference stack. It also created rules, procedures and tool chains for the CI/CT/CD SDV integration and testing process. Additionally, S-CORE is also using this process and the defined tools in the integration of already existing software building blocks and creating missing building blocks necessary for the S-CORE reference SDV SW platform stack. This used process combines fast and agile open-source principles with proven automotive safety development principles. The reference stack is prepared for automotive safety certification. The certification itself is not part of the S-CORE project, but can be provided

[24] Software Defined Vehicle | The Eclipse Foundation: https://developers.google.com/cars/https://sdv.eclipse.org/

later by automotive Tiers or OEMs at significant lower costs as in previous time.

AUTOSAR[25] (AUTomotive Open System ARchitecture): AUTOSAR is a global partnership of leading companies in the automotive and software industry to develop and establish the standardized software framework and open E/E system architecture for intelligent mobility.

COVESA[26]: COVESA is an open, collaborative and impactful technology alliance; accelerating the full potential of connected vehicles. The workgroups in COVESA focus on Data models as the Vehicle signal specification (VSS), common vehicle interfaces, electric charging as well as other topics.

SOAFEE[27]: SOAFEE is an industry-led collaboration between companies across the automotive and technology sectors working together to build open-source architecture for software-defined vehicles. Together to work on creating a shared platform for vehicles using cloud-native architectures that accommodate multiple hardware configurations.

Catena-X[28]: CATENA-X is an open and interoperable data ecosystem and an open-source community. Its goals are: Give transparency and provide an environment for the creation, operation, and collaborative use of data chains along the automotive value chain.

AAOS[29] **and AOSP**[30]: Android Automotive OS (AAOS) is a full-stack version of Android designed to run natively within vehicles, serving as the car's primary operating system rather than simply mirroring a smartphone like Android Auto. It powers everything from infotainment and navigation to climate control and vehicle-specific functions, offering seamless integration with apps such as Spotify, Google Maps, and Audible. AAOS supports voice assistance for hands-free interaction and allows manufacturers to customize the system using the Android Open-Source Project (AOSP), tailoring it to their specific hardware and user experience. Developers can build and test AAOS on emulators or real automotive hardware, making it a powerful platform for embedded innovation in the automotive industry.

[25] Home AUTOSAR: https://www.autosar.org
[26] COVESA: https://covesa.global/
[27] Soafee: https://www.soafee.io/
[28] Catena-X: https://catena-x.net/en/
[29] Android for Cars https://developers.google.com/cars/
[30] AOSP Overview https://source.android.com/docs/setup/about

2.7 Automotive industry associations

ANFIA [31]: It represent the interests of its associate members (automotive component manufacturers, car designers and engineering companies, motor vehicle companies) and ensure effective communication between the Italian motor vehicle industries on the one hand, and the Public Administration and Italian political bodies on others, regarding all technical, economic, fiscal, legal, statistical and quality-related issues referred to the automotive sector.

CLEPA [32]: CLEPA represents over 3,000 European companies supplying state-of-the-art com-ponents and innovative technology for safe, smart and sustainable mobility.

EUCAR[33]: EUCAR, the European Council for Automotive R&D of the major European passenger car and commercial vehicle manufacturers, is the R&I arm of the European Automobile Manufacturers' Association (ACEA[34]). EUCAR facilitates and coordinates pre-competitive research and development projects; its members participate in a wide range of collaborative European R&D programs.

PFA[35]: The Automotive Platform (PFA) brings together the automotive industry in France. It defines and implements, on behalf of all partners (manufacturers, equipment manufacturers, subcontractors, and mobility players), the sector's strategy in terms of innovation, competitiveness, employment and skills. It carries the voice and expression of the common positions of the sector.

VDA [36]: VDA is the association of the automotive industry (VDA) in Germany. It works on the right framework conditions so that its member companies, from start-ups to global corporations, can realize their visions as climate neutrality until 2050 and successfully bring their offerings to market.

INSIDE Industry Association [37] : INSIDE Industry Association is the European Technology Platform for research, design and innovation on Intelligent Digital Systems and their applications.

2.8 Defined governance of European driven SDV SW platform initiative (part of ECAVA)

The automotive industry and the European commission agreed on the need to establish a joint platform to align this initiative, the initiative for a European SDV hardware platform and a European initiative on autonomous driving. The EC published the terms of reference for the European Connected and Autonomous Vehicle Alliance[38] (ECAVA) in late August 2025.

ECAVA is a lean, outcome-oriented industry forum designed to foster strategic cooperation and technological progress among automotive stakeholders across Europe and globally. It serves as a discussion and advisory platform to guide innovation in connected and autonomous vehicles (CAVs), focusing on near-term EU-driven efforts in software-defined vehicles (SDVs), hardware architectures, AI models, and standardization. ECAVA also supports long-term goals for transitioning to software-enabled, AI-powered mobility, contributing to Strategic Research and Innovation Agendas (SRIA) for the 2028–2034 Multiannual Financial Framework (MFF) prepared and

[31] ANFIA: https://www.anfia.it/en/
[32] CLEPA – European Association of Automotive Suppliers: https://clepa.eu/
[33] EUCAR - European Council for Automotive R&D: https://www.eucar.be/
[34] ACEA - European Automobile Manufacturers' Association: https://www.acea.auto/
[35] PFA - Automotive Platform: https://pfa-auto.fr/
[36] Verband der Automobilindustrie e. V. | VDA: https://www.vda.de/de
[37] https://inside-association.eu/
[38] European Connected and Autonomous Vehicle Alliance (ECAVA) https://digital-strategy.ec.europa.eu/en/policies/vehicle-alliance

maintained by the three private members in the Chips-JU (AENAES, EPOSS, INSIDE-IA).

Structurally, ECAVA is governed by a Steering Committee composed of key industrial stakeholders, with the European Commission participating and providing a supporting secretariat. This secretariat manages operations, including the formation of thematic Working Groups and an Alliance Forum. These Working Groups focus on specific industrial priorities and may be proposed by Steering Committee members, the Commission, or Member States. Membership is open to organizations active in relevant fields, provided they sign the Alliance Declaration and meet the Terms of Reference.

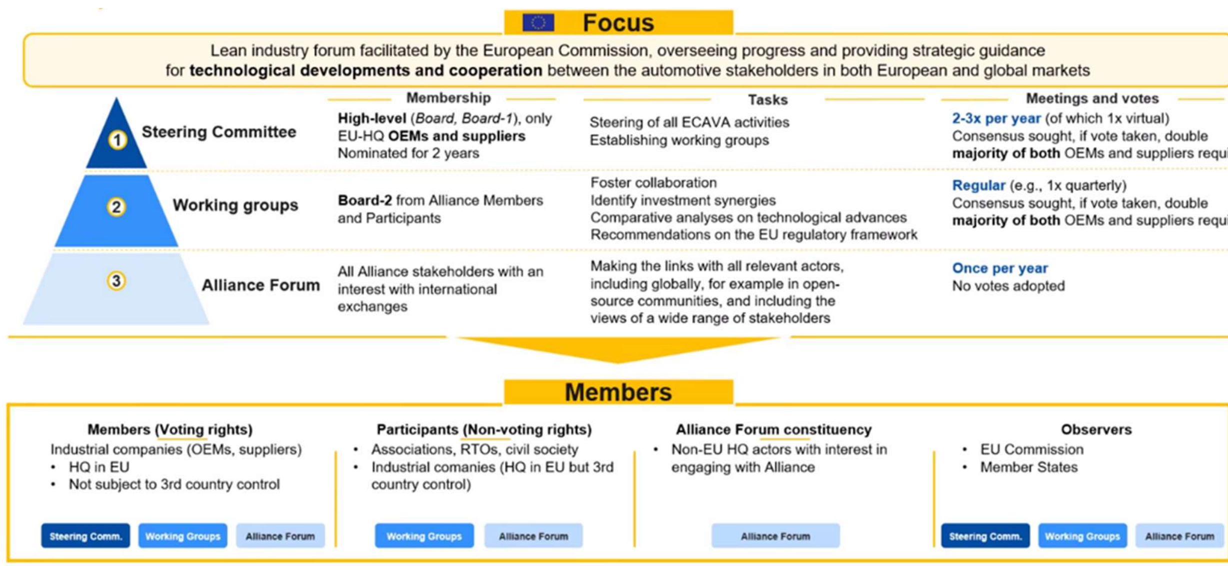

Figure 7: Setup and Governance of ECAVA

By replacing existing alignment groups like the SDV Sherpa Governance Group formed in the SDVoF imitative and aligning with open-source initiatives as ECLIPSE-SDV or COVESA as well as industrial initiatives such as CCAM, 2Zero, and the Chips Joint Undertaking, ECAVA aims to overcome collaboration barriers, ensure regulatory compliance, and build critical mass for shaping the next generation of vehicles.

The ECAVA working groups continue to develop the guiding principles for the vision and roadmaps of the SDVoF initiative created by the SDVoF sherpa governance group. ECAVA oversees and governs also the work of the CSA project FEDERATE and the funded projects initiated by the SDVoF initiative as HAL4SDV and SHIFT2SDV.

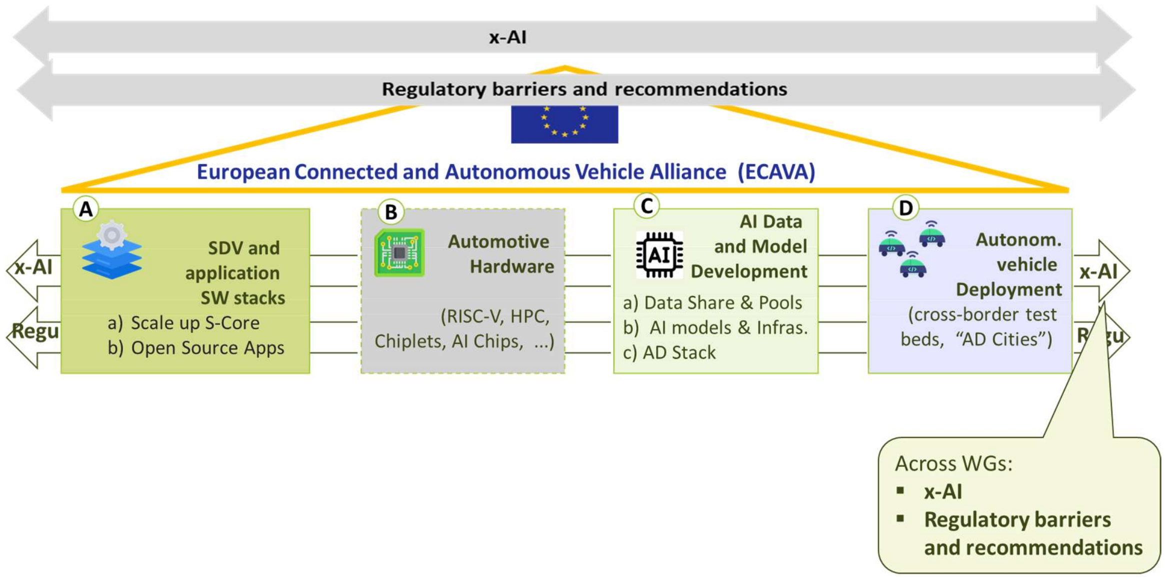

Figure 8: Proposed ECAVA working groups

It aligns also these activities with the relevant activities in open-source software projects as for example, the leading OSS project Eclipse-SDV S-CORE. Participants of ECAVA aim to establish a strategic collaboration to create a strong open SDV ecosystem driven by European actors with the shared vision to keep the European automotive industry competitive.

The ECAVA steering committee establishes working groups deemed necessary to support and align the agreed collaboration activities in ECAVA. Currently 5 working groups are envisioned as depicted in **Error! Reference source not found.**.

Bi-annual convergence conferences organized at the beginning by the CSA FEDERATE and later by ECAVA help to align the SDV SW platform projects in the open-source software initiative and the collaborative EC projects in Chip-JU, CCAM and 2Zero.

Participation in the ECAVA SDVoF ecosystem and ECAVA alliance forum

The ECAVA and its proposed SDVoF working group are driven by the European automotive industry and by the goal to reinforce the industry's strategic autonomy and global success. Considering the global nature of the industry, participants consider it essential to be able to use the outcomes of the initiative in all regions and to drive standards on the global market. European leadership on the one hand, and openness and collaboration with the broad ecosystem, including companies from other regions, on the other hand, is a key success factor

The different levels of the initiative allow for three degrees of participation:

1. **Active participation in the Strategic governance level of ECAVA**: the participation in the ECAVA steering committee and the ECAVA SDV working groups of representatives of EU headquartered OEMs, Tiers, and Associations, which is facilitated by DG CONNECT and supported by the Co-ordination and Support Action under the Chips JU FEDERATE, ensures that the direction and vision of the initiative and its projects are aligned with the objective of reinforcing the competitiveness of the European automotive industry.
2. **Active participation in open source SDV projects and/or EU-funded projects**: Contributing to and using Open-Source Ecosystem results: Since a large part of the outcomes of the initiative will be open-source, they will be open by nature to any actors in the open-source ecosystem, under the limitations of the OSS license and the rules of the relevant open-source foundations or entities. Actors outside the SDV projects in open-source initiatives as well as EU-funded

projects will be able to contribute to OSS projects and use their results.

3. **Staying informed by joining the Open ECAVA Alliance Forum:** All interested SDV stakeholders globally are invited to join the Forum free of charge. All Open SDVoF Forum members get regular updates about the European SDVoF initiative, invitations to networking events and information about relevant conferences.

3 Expected results of the SDVoF initiative (part of ECAVA)

Rapid progress is essential, as the transformation described in section 1 is already in full swing. The key elements of the European SDV of the future initiative laid out in section 2 are expected to unfold their benefits to the European automotive industry as well as to vehicle customers and operators very fast.

3.1 Large positive impact on the open SDV communities and SDV tool ecosystem

The SDVoF requires a large cohort of excellent engineers, designers, and scientists available at OEM's tiers, SW vendors, industrial research, and academia. The coordination and support action (CSA) FEDERATE started 2023 and subsequently ECAVA will foster the vibrant European SDV community needed, by organizing the annual SDV Ecosystem forum, developer conferences, training activities etc. The projects jointly funded by public authorities and industry in the SDVoF initiative will speed up the creation of the open SDV communities and SDV tool ecosystem.

3.2 Pool of open automotive grade building blocks for SDV SW stacks (bottom-up approach)

As explained in chapter 1, the SDVoF initiative focuses on the development of non-differentiating reusable software building blocks for SDV software stacks in the vehicle and in complementary parts on the cloud and agree on their interfaces. This will help speeding up the development of SDV software stacks, their integration, and deployment in commercial products.

These building blocks shall be developed in many OSS projects as well as public funded collaborative projects in a vibrant SDVoF ecosystem. The building blocks often developed as open-source in this community can then be industrialized, integrated, and tested in existing OEM/Tier-specific SDV software stacks, to be subsequently used in vehicle software updates. This bottom-up open-source-based approach generates short-term benefits and ensures that the most attractive building blocks will obtain a sustainable position in the ecosystem. The collaborative development of non-differentiating yet essential building blocks for the SDVoF in public-funded research, development, and innovation (RDI) or other open-source projects will result in a significant reduction of the development costs by sharing them across the industry and public authorities if we avoid added complexity due to collaborative development. Yet, this approach is also expected to result in highly dependable, robust, secure, and well-tested components, based on commonly agreed concepts and interfaces.

Candidate building blocks are expected in the “Middleware and API framework”, the “HW abstraction, virtualization, operating system”, as well as the “off-board / cloud API interface” layer, and in the supporting SDV engineering methods and tools. The open-source approach supports the “Survival of the fittest” principle in case of competing building block implementations.

In the first phase starting in 2024, the focus is on building blocks in the layer 2a and 2b (see Figure 6), addressed by two collaborative RDI projects in the Chips-JU program (call 2023 for layer 2a HW/SW abstraction, and 2024 for layer 2b middleware & API framework). In parallel, the next generation HW SDV computing layer will be developed in sister automotive RISC-V initiative in the Chips-JU program (more details, see chapter 1).

Building blocks shall be continuously maintained and extended to fully support new HW components and deliver new functionalities. The necessary infrastructure must be setup in the coming years. This shall allow OEMs and tiers to quickly migrate from the existing HW to the new HW developed under the open “High-Performance Automotive RISC-V Reference Platform" in the sister-initiative, facilitating the integration of emerging European high-performance HW.

3.3 Reference SW stack composed of SDVoF building blocks (top-down approach)

SDVoF reference structure

A commonly defined reference structure supplies the groundwork for all following activities. The reference structure is derived from the result of workshops in the Sherpa Governance Group depicted in **Error! Reference source not found.** and on-going work in the FEDERATE project team. A common glossary for the precise definition and mapping of terms goes with the reference concept. The FEDERATE project will continuously improve and update both the reference structure and a glossary to ensure design consistency considering also safety, security, and privacy.

Common layer definition and high-level interface description

Based on the multi software-layer approach, the (micro-)services and their high-level interfaces will be defined. This will ensure consistency and interoperability of the results. Design a reference structure and SW stack from the building blocks of the SDVoF initiative

In parallel to the usage of bottom-up building blocks in OEM specific SDV SW stacks, a reference SDVoF software stack shall be implemented as open-source in projects (see Figure 9) to ensure the consistency and fitness of the building blocks. Scientific knowledge and best practices from industry will be integrated in a joint effort to develop the building blocks and the reference SDV SW stack. Over time, common interfaces and building blocks will lead to further convergence between currently available unaligned OEM specific SDV architectures in the market.

The reference SDVoF SW stack can in a later step be industrialized and subsequently integrated into products of OEMs or tiers (top-down approach). In that case, an association or similar entity should take over the further coordination to establish a working business model and ensure the development, maintenance, and quality assurance of software building blocks for the SDV SW stack and the SDV engineering environment.

Both approaches “bottom-up” and “top-down” are explained in more detail in the following chapter.

Bottom-up and supplementing Top-down approach

The initiative follows two approaches: in the first phase of the initiative the *bottom-up* is used (implementing building blocks, which are then integrated into existing software stacks), and later a *top-down* approach is added (starting from a harmonized SW stack and implementing missing building blocks). The bottom-up phase ensures the inclusion of the existing (legacy) technologies in the SDVoF, introducing an inclusive ecosystem for the EU stakeholders. The top-down phase will support and guide this ecosystem to the full adoption and exploitation of industrialized HW/SW stacks for SDVoF. Functional clusters will combine building blocks required for different functionalities such as for example, secure cloud communication, plug & charge etc. in different views. These two approaches are depicted in Figure 9:

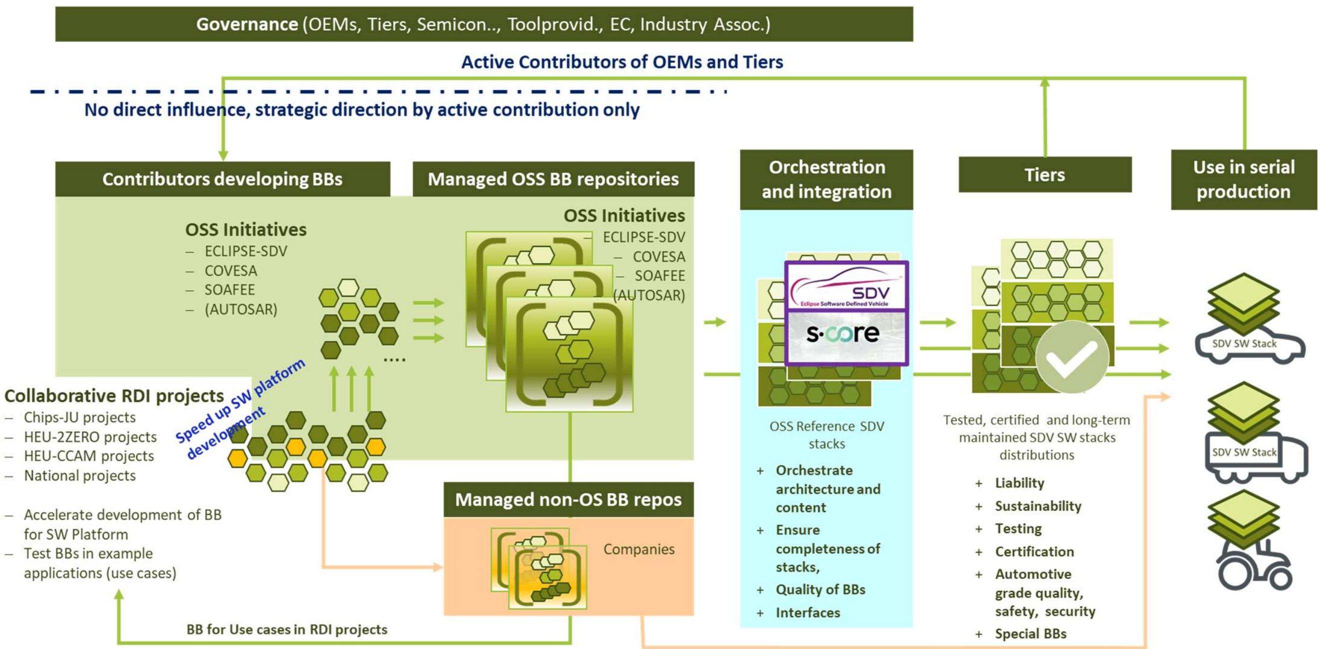

Figure 9 Integration of SW building blocks into industry specific as well as reference SW stacks

The focus on the creation and usage of collaboratively developed non-differentiating building blocks in the first phase of the initiative provides speed and efficiency in the use of the results by the OEMs in their SDV products. This bottom-up approach considers that OEMs and tiers are already using different architectures and are working in different existing collaborative initiatives (e.g. AUTOSAR, COVESA, ECLIPSE-SDV, ...).

Reference stacks and integration projects

The top-down approach is added by integration projects. One or several integration projects will combine building blocks from well-maintained repositories of OSS initiatives such as ECLIPSW-SDV or COVESA to reference stacks for different domains and use cases. ECLIPSE-SDV S-CORE is the first integration project working on a reference stack for the middleware of an AD/ADAS stack.

Integration projects are industry driven and maintain their integration timeline as well as processes for the acceptance of building blocks into a reference stack. This ensures a predictable quality level. Integration projects are performing integration tests to ensure a consistent quality of the reference stack as shown in Figure 9.

Therefore, the timeline of the integration projects acts as heartbeat of the SDVoF ecosystem.

The integration projects collaborate in an architecture group, which helps to align the architecture of different integration projects to a useful extent.

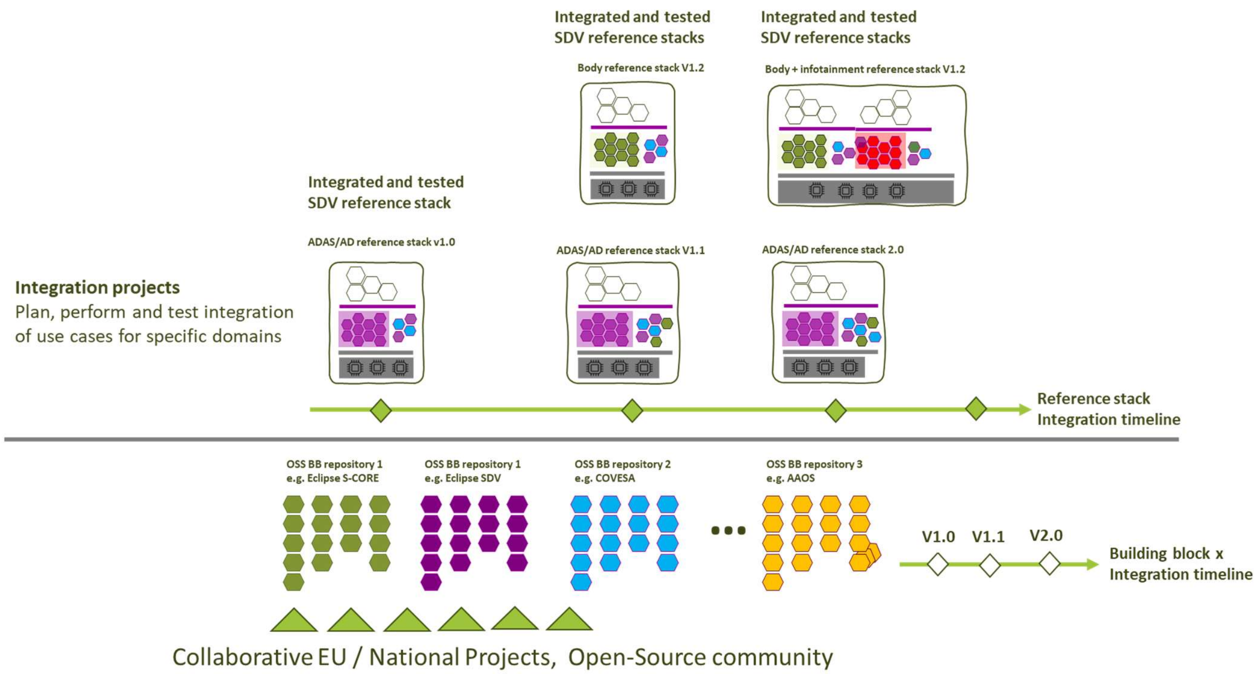

Figure 10: Integration projects using modular building blocks

An architecture group shall work on alignments between the integration projects and their reference stacks. The architecture group was started by the Chips-JU project HAL4SDV and will be continued in ECLICPE-SDV. It is supported by the work of the scientific board of the CSA FEDERATE and potentially later by a similar group in ECAVA. It shall ensure future proven architecture and a consistent structure on which the non-differentiating building blocks are based. This also supports the interface standardization of building blocks, whenever they are successfully used in software defined vehicles on the market.

As last step, automotive companies (tier 1) will industrialize the reference stacks and create a well-tested and maintained automotive quality grade open source-based middleware for SDV, which can be used in parts or as a complete stack by OEMs. This can again significantly reduce the development effort for SDVs and allow OEMs to faster deliver new SDV functionalities to the market (see also Figure 9).

3.4 Automotive grade SW engineering environments for the whole SW lifecycle for SDVoF

To supplement the fast, agile, and efficient development of SDV SW stacks, the SDVoF future has also a focus on a significantly improved automotive SW development and validation methodology combined with corresponding toolsets. This shall allow the fast creation of dependable, secure, and efficient SDV software. It shall also support the fast deployment of high quality over-the-air software updates to the market. This is especially important in the ADAS/AD (Advanced driver assistance systems / automated driving) application domain. This advanced support for HW/SW engineering also represents a crucial factor to cope with the lack of skills Europe is experiencing and with the lack of human resources, which can be mitigated through the high automation of HW/SW engineering.

Methods and tools for efficient and fast cross-company collaboration

OEMs will continue, and due to the growing SW complexity even intensify, a tight collaboration with tiers, SW and data vendors, and hyper-scalers. Therefore, a seamless integration of automated CI/CD-toolchains allowing tight connected workflows across partners is required. This will ensure that SW updates can be deployed and become available at vehicle level in single digit days (compared to sometimes double-digit weeks today) in a secure way.

Methods and tools for fast and efficient verification and validation

The development, testing and release (including re-homologation if needed) of SW deployments requires (nearly) fully automated continuous integration / continuous deployment (CI/CD) cloud-based toolchains to get the envisioned large productivity gains. Automotive-grade quality standards must still be ensured by rigorous quality checks. Therefore, adequate methodologies and tools will also be required for OSS components, covering all aspects of verification (including test-driven development, regression testing, and homologation support, handling corrective vs. perfective maintenance). This will be addressed by collaboratively implementing and integrating building blocks in CI/CD – Test pipelines. Whenever possible, already existing components on the market will be used. Industry-standards, partially open-source test tools and methods are therefore expected to become major contributors as enabler for industrial use.

4 Roadmap for the SDVoF SW stack

The Software Defined Vehicle of the Future initiative together with the sister "High-Performance Automotive RISC-V Reference Platform" initiative are committed to support the implementation of the building blocks (software and hardware) for the Software Defined Vehicle of the Future through a sequence of funded research, development, and innovation (RDI) projects (see Figure 11).

4.1 Roadmap for SW building blocks and middleware

Many of these projects are publicly funded projects in different EU or national RDI programs. The described governance structure (see page 23) gives direction and organizes the exchange of information and results towards realization of the vision of the European SW defined vehicle of the future initiative. This is complemented by the creation and nurturing of a vibrant SDV ecosystem supported by coordination & support action.

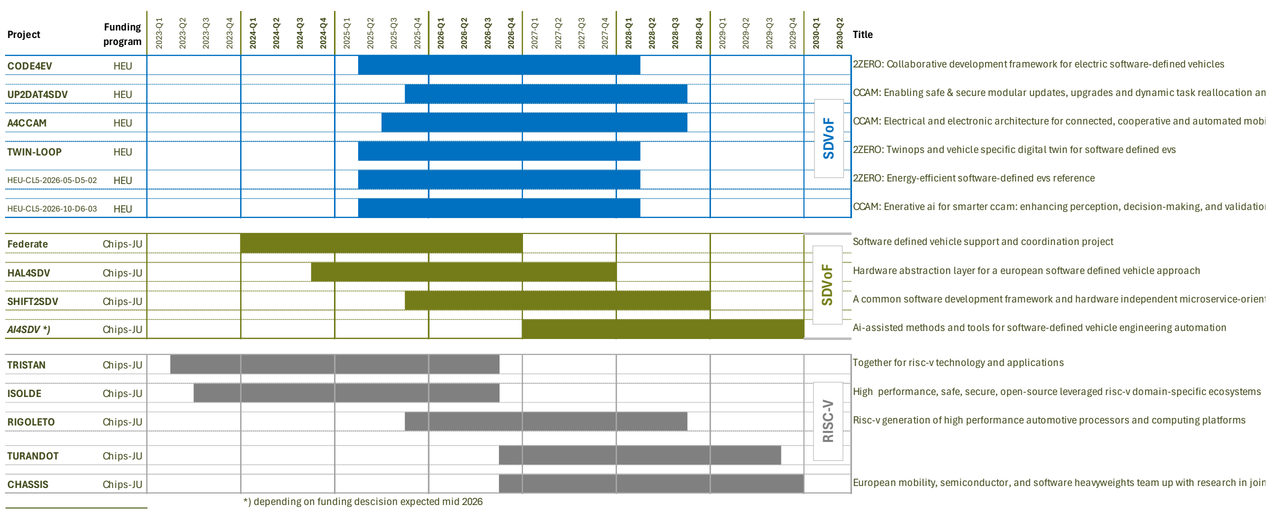

Figure 11: Roadmap of the SDVoF initiative

The roadmap in Figure 11 is organized according to the SDV SW stack structure model used in the initiative. The SDV ecosystem is working in several projects organized in phases mirroring the layers to realize the non-differentiating building blocks and reference implementation defined in the SDVoF initiative as well as building blocks for the SDV DevOps tool chains.

The building blocks developed in the initiative will be combined with company specific SW building blocks and hardware components to implement application use-cases as well as the proofs of concept described in Table 1. The proof of concept (PoC) use-cases (UC) in the projects shall demonstrate achieved objectives of the SDVoF initiative.

The roadmap shows the development of the different layers (explained on page 19) of the SDVoF SW stack. Many building blocks might even require a sequence of projects. These projects (linked-projects) are built on top of each other and use the results of previous. The building blocks will be used already in early phases in industrial stacks as described on page 27, while in later phases of the initiative the results of the projects in the different layers will be integrated into industrialized stacks, which can used by OEMs or tiers.

The planned work in the development of the different layers is explained in more detail on the following pages.

Work in layer 2a HW/SW abstraction

Concept, methods, and components for a highly performant, scalable, and cyber-secure hardware abstraction provides the foundation of SDV stacks. The de-coupling of HW and SW enables SW-definable functionalities (both real-time (RT) and non-RT) throughout the stack with full functional flexibility. This will allow reusability, code portability and fast time-to-market. It is complemented by developing appropriate tool chains for fast integration and standardization.

Project HAL4SDV (Hardware Abstraction Layer for Software Defined Vehicles) was selected to cover this layer in the HORIZON-KDT-2023 call and started in Q2-2024. The development work is done in close alignment with the project RIGOLETTO answering the call "High-Performance Automotive RISC-V Reference Platform" in the non-initiative call of HORIZON-Chips 2024-1-IA-T2, [39].

Planned in layer 2 b Middleware and API-framework (Chips-JU 2024 focus topic IA)

The upper part of Layer 2 of the SDV stack shown in Figure 6 consists of basic services and building blocks are required for exposing high-level system services and APIs to the layer 3 differentiating SDV-applications. The middleware and API framework builds on top of the interfaces of the hardware abstraction layer developed in the HAL4SDV project. Interoperable, and non-differentiating building blocks will simplify to build modular platforms, which enable fast and efficient development of in-vehicle and cloud-based applications. Integration into existing OEM/Tier specific SW stacks, and support of existing framework initiatives such as ECPLISE SDV, AUTOSAR Adaptive, COVESA, SOAFEE, digital.auto is essential.

The Chips-JU focuses on the development of the necessary building blocks in the middleware. A project proposal working on building blocks in this layer was selected in the HORIZON-Chips-2024 non-initiative call[40] to address these topics, started in Q2 of 2025 named SHIVE2SDV.

Additionally, calls in the CCAM private public partnership[41] are expected to contribute building blocks to the middleware and API-framework (e.g. cybersecurity, communication to cloud services, piloting the emerging SDV framework for automated vehicles in mobility infrastructure, use SDV building blocks for auxiliary functions, …) as well pilot the usage of the building blocks in vehicle applications in cooperative, connected and automated mobility use-cases.

Figure 12 pictures the active projects in **Digital Vehicle of the Future** initiative at the beginning of 2026. The **Digital Vehicle of the Future** initiative comprises the Software defined Vehicle of the Future initiative and the RISC-V based SDV Hardware platform initiative.

[39] HORIZON-Chips-2024 Work programme 2024 (Non-initiative part) 1-IA T2 Focus topic on "High Performance RISC-V Automotive Processors supporting SDV"

[40] 2024-1-IA-T3 Call (Service Oriented Framework and API for SDV)

[41] HEU-CL5-2024 (Horizon Europe Cluster 5 Workprogramme 2024) D6-01-01 "Centralised, reliable, cyber-secure & upgradable invehicle electronic control architectures for CCAM connected to the cloud-edge continuum"
To be confirmed: HEU-CCAM-2025/2027 (Horizon Europe Cluster 5 Workprogramme 2025 and/or 2027) "Integration of SDVoF building blocks in CCAM applications and test in real world traffic"

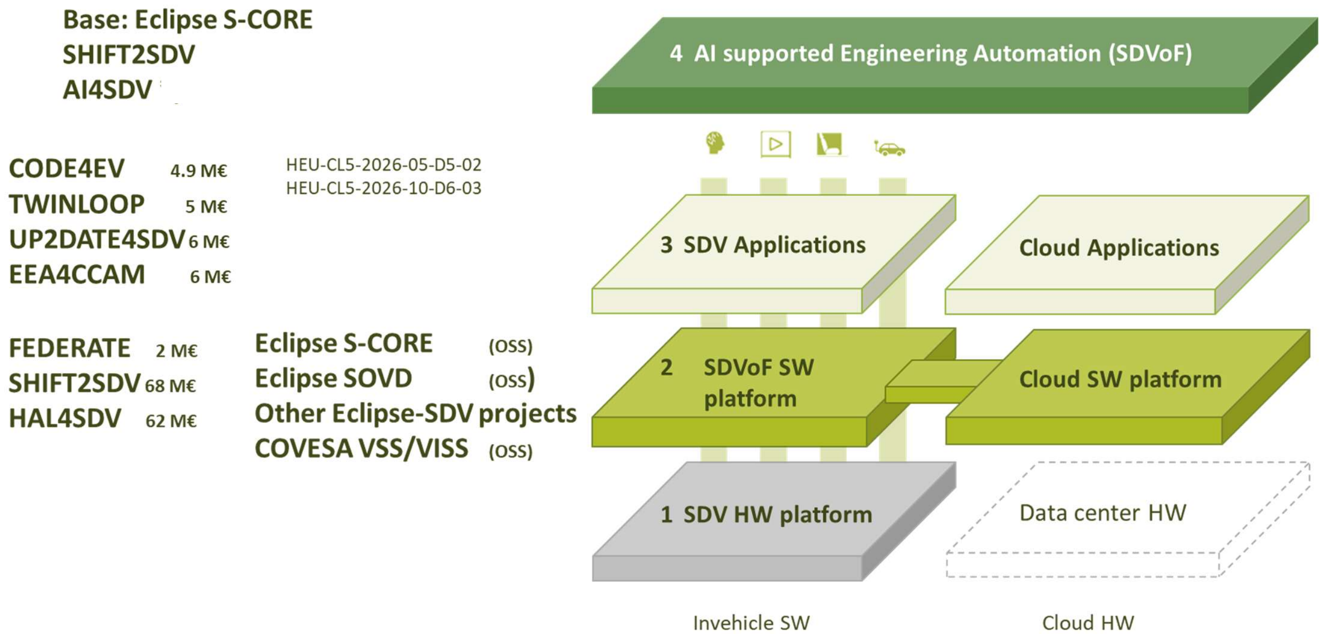

Figure 12: Projects in SDVoF active at Jan 2026

Calls in the 2Zero program[42] are piloting the usage of the emerging SDV framework in vehicles for CO_2-free mobility. CCAM and 2ZERO calls concentrate mainly on the usage of the middleware building blocks in vehicle applications.

Planned work in area "Supporting Tools and Toolchain"

Highly automated engineering methods, tools, and toolchains shall help to improve the efficiency, productivity, quality, and dependability of the engineering process for automotive ADAS, AD, infotainment, sensing, and control systems. The engineering process support should rely on existing (open source) solutions wherever possible, extended and/or complemented by newly developed methods, toolchains, and tools when required. Building blocks are encouraged to be open-source wherever adequate. The software development and maintenance tools shall improve productivity and support the SDV SW stack DevOps lifecycle. The use of AI and generative AI will give an added important boost in productivity.

Two projects from the 2Zero[43] program started in 2025 (Codee4EV and Twinloop) and contribute methods and tool-building blocks. The project selected from the HORIZON-Chips 2024-1-IA-T3[44] call is also contributing to this phase. A larger project is suggested by the SDV-SGG for the HORIZON-Chips-JU call 2025 working on (generative-)AI enhanced design and engineering tools envisaged to start in 2026.

[42] HORIZON-CL5-2024 (Horizon Europe Cluster 5 Workprogramme 2024) D5-01-05: "Advanced digital development tools to accelerate the development of software defined vehicles that enable zero-emission mobility (2ZERO)"
To be confirmed: HEU-2ZERO-2025 (Horizon Europe Cluster 5 Workprogramme 2025) "Piloting the emerg.SDV framew.for optim.energy usage in EVs embedded in the energy infrastructure"

[43] HORIZON-CL5-2024 (Horizon Europe Cluster 5 Workprogramme 2024) D5-01-05: "Advanced digital development tools to accelerate the development of software defined vehicles that enable zero-emission mobility (2ZERO)"

[44] HORIZON-Chips-2024 Work programme 2024 (Non-initiative part) 1-IA T3 Focus topic on "Service Oriented Framework for the Software Defined Vehicle of the future"

Planned work in phase Maturing structure and SW stack

In the second phase of the initiative, the focus will be on maturing the structure and the building blocks of the SDVoF SW stack as described on page 27. The results of the initiative will be continuously improved and extended. It is also envisioned, that a new or existing organization(s) will take over the results of the initiative and form and support industrialized automotive grade SDV SW-Stacks. A dedicated call is suggested by the SDV-SGG for HORIZON-Chips-JU call 2026 to support this phase. In this project also the results of the sister initiative will be combined with the SDVoF results.

Coordination and support actions for the Initiative

The HORIZON-KDT-JU Coordination and Support Action (CSA) FEDERATE started at the end of 2023 to support and foster the European SDVoF community and partnership between EC and industry, research, the Open-source communities, and public funding agencies. FEDERATE provisions orchestration of SDV Research, development, and innovation activities across Member States, and organizes and hosts technical discussion panels (concept, glossary, high-level use-cases and requirements) and strategic alignment (vision, roadmap, research calls and activities). These activities shall be continued either by a follow-up Coordination and Support Action or by an association or similar entity (as described on page 27) taking over these activities from FEDERATE.

Planned project in the sister initiative "High-Performance Automotive RISC-V Reference Platform"

Scalable automotive processors, spanning from cost-efficient, real-time control to high-performance super-scalar application processors and hardware accelerators shall be developed for the automotive market, based on the RISC-V family in a project called the HORIZON-Chips-2024 program. It shall support hardware abstraction and virtualization of the SDV concept and facilitate certification according to automotive safety and security standards. Instruction and data level parallelism (super-scalar and vector instructions), fast context switching, and accelerators support are needed to satisfy performance needs of complex AI/ML applications. A project proposal was selected in the call HORIZON-Chips-JU 2024 [45] as project RIGOLETTO. it is part of the roadmap for the sister initiative[46]. The RISC-V Scaler joint-venture founded in 2023 supports the sister-initiative on RISC-V HW. It aims to develop an ecosystem for RISC-V inspired by the ARM ecosystem handling licensing, toolchain support, updates etc. Its Initial application focus will be automotive.

These initiatives are also merged into ECAVA coordinated by the **ECAVA working group Automotive Hardware** as joined action between the European Semiconductor Alliance and ECAVA.

Support of the successful uptake of SDVoF results in European vehicles

As indicated above, the private public partnerships CCAM and 2ZERO have also indicated their support of the SDVoF initiative. Alignment meetings between SDVoF and the 2 partnerships are on-going. CCAM and 2ZERO will also support in their co-programmed calls the adoption of the SDV building blocks and tools for cooperative, connected and automated mobility (CCAM partnership) and for electrified vehicles in CO2 neutral mobility (2ZERO partnership), as well as the piloting of the operation in the relevant infrastructures.

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[45] HORIZON-Chips-2024 Work programme 2024 (Non-initiative part) 1-IA T2 Focus topic on "High Performance RISC-V Automotive Processors supporting SDV"

[46] Report "High Performance RISC-V Automotive Processors supporting the vehicle of the future" prepared by the European RISC-V working group, draft version Feb 9th, 2024.

4.2 Proof-of-concepts by implementation of real application use-cases

A set of high-level application use-cases (UC) is suggested to prove at early stages of the initiative, that the building blocks can be successfully used in automotive products. Some of the application use-cases will additionally serve as proof-of-concepts (PoC) for the successful implementation of the principles described in section 1.1. The application use-cases will also help to identify building blocks and allow their validation. This resembles a powerful tool to check if all goals of the initiative are achieved.

Table 1 lists use-cases as discussed in the SDVoF Sherpa Governance Group.

Table 1: Agreed use-cases

Application Use-cases (UC)	Description of UC
Plug & Charge (also bi-directional) and Open-Source UC	Plug and charge including in the medium term also bi-directional charging. Usage of secure and stable open-source with automotive grade in company specific SDV SW Stacks.
ADAS HW Platform replacement UC	HW-System abstraction, which allows replacement of HW platform (e.g. supporting shared sensors) with no or only little changes to application SW.
Chassis domain (vehicle motion control) UC	Vehicle motion control. The description will be refined throughout the initiative.
Cockpit user experience (hypervisor) UC	Common execution environment for user experience, this use-case shall also demonstrate user experience in a hypervisor architecture.
Shared Sensor ADAS/AD – Cockpit UC	Cross-domain, e.g. cameras for several apps supporting multiple features within the car (e.g. ADAS and cockpit) and being interoperable between different app stores beyond Google Play.
Collaborative SW Development UC	Collaborative (multi-firm) DevOps tool chain, demonstrating critical SW updates from code to car in a week instead of months.

Table 1 will be updated during the SDVoF projects duration. Several additional use-cases candidates will be collected but need further refinement. The current list is shown in Table 2.

Table 2: List of potential use-cases, to be further discussed

Potential additional application UC collected so far	Description of UC
Service Orchestration UC	Demonstrate secure orchestration of in-vehicle functionalities with cloud services from multiple domains (also OTA), e.g., building automation and infrastructure services.
Cyber-security Incidence Response UC	Demonstrate anomaly detection and tool support for fast identification and analysis of cybersecurity vulnerabilities and exploits, as well as fast patching, across different vehicle types and makes.

The use-cases will be demonstrated by at least two OEMs or at least two Tier1s in projects of the SDVoF initiative and prove the successful implementation of the goals of the initiative. Several use-cases will require cooperation between projects and thereby span across two or more projects, working on different building blocks of a SDV SW stack as well as the integration into vehicles SW stacks also integrating the results of the sister initiative on automotive RISC-V.

Change History

Version	Date	Change
1	Apr 10th, 2024	– Initial version 1.0
2	May 28th, 2026	– European Connected and Autonomous Vehicle Alliance (ECAVA) integrated – Update of the collaborative project roadmap – Update of Eclipse-SDV projects, S-CORE, Covesa projects – Version 2.0