Open Source Software in the Automotive Industry

Vision Paper

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Executive Summary

As the automotive industry undergoes a transition from a primarily hardware-focused approach to becoming more software-centric, it faces challenges and opportunities that demand both introspection and action. This paper investigates the current state and future potential of open source software (OSS) in this industry. It presents the following findings:

The Imperative for OSS Adoption: OSS's adoption in the automotive landscape is more than a trend; it is a necessity. The competitiveness of the automotive industry in any region hinges on this adoption, addressing both the ability to leverage OSS and the willingness to share advancements. It is essential not only for technological advancement but also for navigating the complexities of strategic lock-in and ensuring digital sovereignty for an important European industry.

Capacity-building and the Shift to Software: The transformation in the automotive industry, driven by electrification, autonomous driving, and other technological advancements, signals a clear transition from hardware to software. While these changes present opportunities, they also pose challenges too vast for single entities to address alone. The industry's historical hardware-centric focus sometimes acts as a barrier to embracing these shifts. Addressing these challenges requires an investment in capacity-building for OSS. Initiatives such as Open Source Program Offices (OSPO) are instrumental in fostering understanding, strategic utilisation of OSS, and in cultivating a future-ready culture. These structures make the sector appealing to the next generation of software talent.

Challenges of the Traditional Model: The conventional hierarchical supplier structure in the automotive industry often clashes with the collaborative ethos of OSS. Transitioning to an ecosystem-centric approach, grounded in OSS principles, is vital. Government intervention can act as a catalyst in facilitating this shift, providing both facilitation and financial support This intervention paves the way for a reimagined collaboration-competition dynamic.

Rethinking Collaboration and Competition: In contrast to sectors where software plays a foundational role, automotive firms often favour in-house software development, which limits their competitive advantage. Distinguishing between differentiating and generic technology is crucial, urging the industry to reassess its stance on collaboration and competition. Collaborative endeavours, particularly around software supply chain sustainability, emerge as the clear path forward.

Digital Sovereignty and Open Platforms: Experts interviewed for this paper unanimously voiced the need for building future software-defined vehicle (SDV) platforms on OSS and open standards. In a world grappling with increasing regionalisation, the concept of "digital sovereignty" — the ability to make decisions independently and align with regional mandates — becomes even more significant. While this aspiration is paramount, the OSS model not only aligns with this vision but also contributes to the overarching goal of enhancing the industry's global competitiveness.

Introduction

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The automotive industry has a long history marked by continuous evolution fueled by technological advancements and industrial disruptions. Today, four major disruptions – electric vehicles, autonomous driving, connectivity, and servicification – are leading the charge. As these forces converge, they propel the industry towards an emphasis on software. It is no exaggeration to suggest that the future of automotive companies hinges on how swiftly they can respond to the challenges and seize the opportunities presented by the evolving software landscape.

Open source Software (OSS), in this context, is not just a subtopic under the broader banner of software. We have chosen it as the perspective of this paper, as we see it as the innovation model that stands as a beacon for how the automotive industry, in particular, but all industries, can get better at harnessing software's potential, both in terms of innovation and value-creation for the bottom line. OSS is seen more broadly here as the most impactful model, established and tried, for collaborative innovation. As such, it is a response to the European automotive industry's challenge: to achieve more, faster, with less.

A representative from Mercedes-Benz Tech Innovation GmbH, a 100% subsidiary of the group, whom we interviewed, encapsulates the sentiment:

> ***"Open source software is indispensable. It is not just vital to the software industry, it is vital for the automotive industry; it is vital for every sector that uses software. The entire European industry needs to champion open source to maintain digital sovereignty, increase efficiency, and remain competitive with the rest of the world."***

Why emphasise OSS rather than the broader theme of the industry's digital transformation? Historically, the automotive sector has shied away from open collaborations, relying on traditional business models. But the landscape is shifting. OSS presents a great opportunity; it fosters collaboration while adhering to competition law and dovetails with traditional business models. More than that, it champions a shared ecosystem for the Software-Defined Vehicle (SDV)[1], levelling the playing field for all involved–whether established Original Equipment Manufacturers (OEMs), Tier 1, 2, or 3 suppliers, or emerging software companies aiming to innovate in the automotive space. Embracing OSS enables companies to keep

[1] A vehicle whose features and functions are primarily enabled through software, which is upgradeable and updateable through over-the-air connectivity throughout the vehicle's lifetime.

pace with global competition, avoiding the pitfalls of technical dominance from any single vendor or region.

The currency of today's fast-paced world is speed, particularly in terms of innovation cycles, and code-first, collaborative innovation is its enabler. OSS holds the promise of both speed and scalability, rendering it an indispensable asset for businesses seeking to stay ahead.

But should OSS be a mere component of a digital strategy, or should it be woven into the fabric of a company's overarching strategy? Our research highlights that the automotive industry is eager yet slow to embrace OSS. Viewed from a policy perspective, Europe is at a juncture where inaction equates to our industry lagging behind.

OSS emerged from our conversations with industry experts as more than just code. It is a discourse on the delicate balance between collaboration and competition. The 'softwarization' of the industry has redrawn this line, and companies are grappling to recalibrate.

This vision paper aims to explore the potential of OSS in the digital evolution, particularly in the transition to 'softwarization' of the automotive sector, with a forward-thinking approach. We conducted qualitative interviews with ten industry experts, including OEMs, Tier 1 suppliers, a Tier 2 supplier, and governmental bodies. These participants provide a varied geographical and organisational scale perspective. Through this diverse sampling, our intention was to gain a broad insight across multiple contexts. Having achieved this, we hope that this paper will help to:

- Illuminate the current and anticipated trends, opportunities, and challenges of OSS in the automotive sector.
- Establish a research roadmap for future explorations in the realm of OSS and open technologies.
- Enrich the burgeoning ecosystem around OSS in the automotive industry by fostering collaboration.
- Provide actionable recommendations for both industry stakeholders and policymakers to bolster growth in this domain.

At the heart of our recommendations lies the imperative of identifying and collaborating on both new and existing technology in the commodity layer, transcending the traditionally conservative and closed approach to doing business. We advocate for increased industry-wide collaboration, particularly on the non-differentiating aspects of SDV technology. Establishing standardised interfaces and shared building blocks can foster innovation and healthy competition, optimising utilisation of resources. However, looking to the future, it is prudent in this evolving landscape to explore how collaborations on

competitive technologies could also effectively advance the industry at a pace aligned with the opportunities technology provides.

For this paper, we have taken an expressly European perspective. This is reflected in the problem definitions, the interviewees, and ultimately the recommendations. Nonetheless, we hope that the insights presented offer valuable lessons for automotive and industrial companies seeking to retain their competitive edge. We argue that prioritising the adoption and sharing of OSS is crucial, both industrially and politically, for achieving this goal. Only through such prioritisation can we navigate the complex challenges of strategic lock-in and truly champion digital sovereignty.

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Research Design

The goal of this vision paper is to investigate the role and potential of OSS in the digital transformation, and in particular the softwarization, of the automotive industry taking a future looking perspective. A qualitative interview survey was conducted with ten experts from industry representing both Original Equipment Manufacturers (OEMs), Tier 1-suppliers, one Tier 2-supplier, and government entities. The different actors further represented a diverse spread in geographical representation, and size. The goal with this sampling was to attain a wide understanding across different contexts. Table 1 provides an overview of the interviewees by name. Throughout the report they will be referred to as representatives of their respective organisations to improve clarity and context in terms of statements provided.

Table 1: Overview of interviewees surveyed in the report.

Name	Title	Organisation	Category
Philipp Ahmann	Technical Business Development Manager	Bosch	Tier 1 supplier
Martin Schleicher	Head of Software Strategy	Continental	Tier 1 supplier
Christian Heissenberger	Chief Architect SW Innovations	ETAS (a Bosch subsidiary)	Tier 1 supplier
Max Lemke	Head of Unit, Internet of Things	European Commission	Public institution
Adam Konopa	Technology Director, Automotive and Mobility	Intellias	Tier 2 supplier
Wolfgang Gehring	FOSS Ambassador	Mercedes-Benz Tech Innovation GmbH	OEM
Nikita Peters	Head of Open Source & Software Asset Management	Porsche	OEM
Jonas Öberg	Manager, Chair of Open Source Program	Scania	OEM
Endo Masato	Group Manager of Value Chain Service & Technology	Toyota	OEM
Carl-Eric Mols	Open Source Strategist	Volvo Cars	OEM

All interviews were conducted with a semi-structured approach virtually by the two authors using a pre-defined questionnaire. All interviews lasted for about 1 hour, were recorded, and

automatically transcribed. Transcriptions were coded iteratively using thematic analysis, where topics and themes were developed based on initial codes and descriptive summaries. Notes from interviews, along with quotes were used to enrich the description of the overarching themes and narrative presentation.

Transcripts, summaries, and a draft version of the report were iteratively verified with interviewees to validate findings, and to confirm any quotes and statements related to interviewees. A follow-up focus group was conducted with four participants from OEMs and public institutions (although ten additional participants were invited), which confirmed the main findings of the report, and provided further input to the themes.

While interviewees reached saturation in terms of identified themes, along with the confirmatory focus group, findings may not generalise over the whole automotive industry. The qualitative nature of the investigation calls for the reader to consider the context and source of knowledge from where the findings were derived.

1. Use and reuse of OSS today and tomorrow

The adoption of OSS by the automotive industry, both in terms of the capacity to use and willingness to share, must become an industry and policy priority in Europe. This strategic focus is central to maintaining the competitive edge of the European automotive sector, while simultaneously addressing challenges of strategic lock-in and, by extension, digital sovereignty.

OSS is an established part of company strategies

OSS integration is an essential part of digital strategies for automotive companies, and is viewed as a key factor in driving competitiveness. As the sector becomes increasingly software-centric, companies acknowledge that collaboration on common infrastructure and platforms expedites innovation, boosts development efficiency, and enhances product quality and safety.

There is a common need to reuse and collaborate on common building blocks. No single actor can build everything themselves. This fact is becoming increasingly appreciated by executives as the automotive industry is rapidly becoming more software-driven. By collaborating on common infrastructure and platforms, companies have the potential to accelerate both internal and common innovation. Simultaneously, this collaborative approach improves development efficiency, shortens lead times, and enhances product quality.

The recognition of these potential benefits is reflected in the increasing attention OSS within companies. Many organisations view OSS as a tool for value creation in their overarching software strategies and have implemented specific policies to guide the effective utilisation of OSS[2].

At Porsche, OSS is firmly anchored in its core software strategy[3]. According to a Porsche representative, teams are directed to "*utilise open source wherever feasible. This applies whether it is vehicle development, digital, or enterprise IT. Before initiating any project, we always consider the possibility of using open source.*" The OSS program extends its focus to all teams and subsidiaries globally across the organisation. Porsche has also "*implemented role-specific guidelines, whether one is a project manager, developer, or architect, there are clear directions on how to approach open source.*"

In Mercedes-Benz, OSS was adopted into the group-level IT strategy in 2018[4], but it started as "*a grassroots movement towards open source. Many have advocated for its adoption, capturing attention early on. Recognising its potential, the company then incorporated it into the official IT strategy.*"

These strategy statements are not only internal, but some statements are made publicly aimed to communicate to the broader OSS ecosystem. At Mercedes-Benz, for example, the FOSS Manifesto was published in early 2021. In the context of the automotive industry, it is noteworthy that the signatories of the Mercedes-Benz FOSS Manifesto included the CIO. That the external communications aimed at the OSS ecosystem comes from the C-suite, if

[2] https://cdn.continental.com/fileadmin/__imported/sites/corporate/_international/english/hubpages/10_20press/01_press_releases/10_20ces/2023/202301_continental_foss_manifesto.pdf;

[3] https://newsroom.porsche.com/en/2023/company/porsche-foss-movements-open-source-software-strategy-33413.html

[4] https://opensource.mercedes-benz.com/static/mb_FOSS_manifesto-463ceb64a98efdba98ddbdfb0a951154.pdf

not the CEO, is standard practice in the software industry. The appreciation of the strategic importance among automotive executives still has some way to go.

Adoption of OSS is higher outside than inside the vehicle

The embrace of OSS finds greater resonance in applications outside vehicles than inside them. The limited adoption within vehicles is primarily due to the stringent functional safety standards that demand rigorous software development processes, a benchmark that many, but not all, OSS initiatives often fall short of.

Among the companies surveyed for this report, OSS is primarily used in infotainment systems. Notably, Linux-based operating systems Android Automotive and Automotive Grade Linux stand out as prime examples. Volvo Cars also uses OSS in the communication component enabling its 5G features and in the security gateway. Porsche reports that while OSS is mainly found in the infotainment system, suppliers are progressively adopting OSS in other Electronic Computing Units (ECUs[5]) as well. Toyota also notes an increasing adoption of OSS beyond the infotainment system.

The ETAS representative also states that the adoption of OSS in a car's software stack is generally limited. However, its use varies across different domains within the car, including, beyond infotainment, ADAS (advanced driver assistance system), deep embedded, and vehicle edge. ADAS encompasses technologies that assist drivers in safely operating a vehicle, including self-driving support. The deep embedded layer interfaces with the ECUs, such as those for window openers or the combustion engine. The vehicle edge provides the connectivity interface between the infotainment, ADAS, and deep embedded domains and the external environment and infrastructure of the car.

Infotainment is estimated to incorporate approximately 50 percent of OSS, while the other three domains have significantly less OSS integration. A main reason is the safety-critical context and the related functional safety standards, such as ISO26262, which mandate that software in a car undergoes rigorous development processes--requirements not universally used or applicable to many OSS projects. Smaller components within the vehicle can leverage OSS when isolated with controlled input and output, but certification according to established standards is still necessary.

Looking outside of the vehicles, the adoption is much greater and expected to increase. The Scania representative reports a substantial presence of OSS in development tools and cloud technology. The Continental representative emphasises the significance of tools and infrastructure for developing, testing, simulating, and shipping software, critical for rapid technological development in areas like connectivity and autonomous driving. The Porsche representative reinforces this view, and adds the importance and presence of OSS in general IT infrastructure used for both development and service provisioning. Fig. 1 further illustrates the broader importance of OSS across various environments beyond the actual vehicle through different OSS projects hosted by the Eclipse Foundation.

[5] An embedded system in automotive electronics that controls one or more of the electrical systems or subsystems in a car or other motor vehicle.

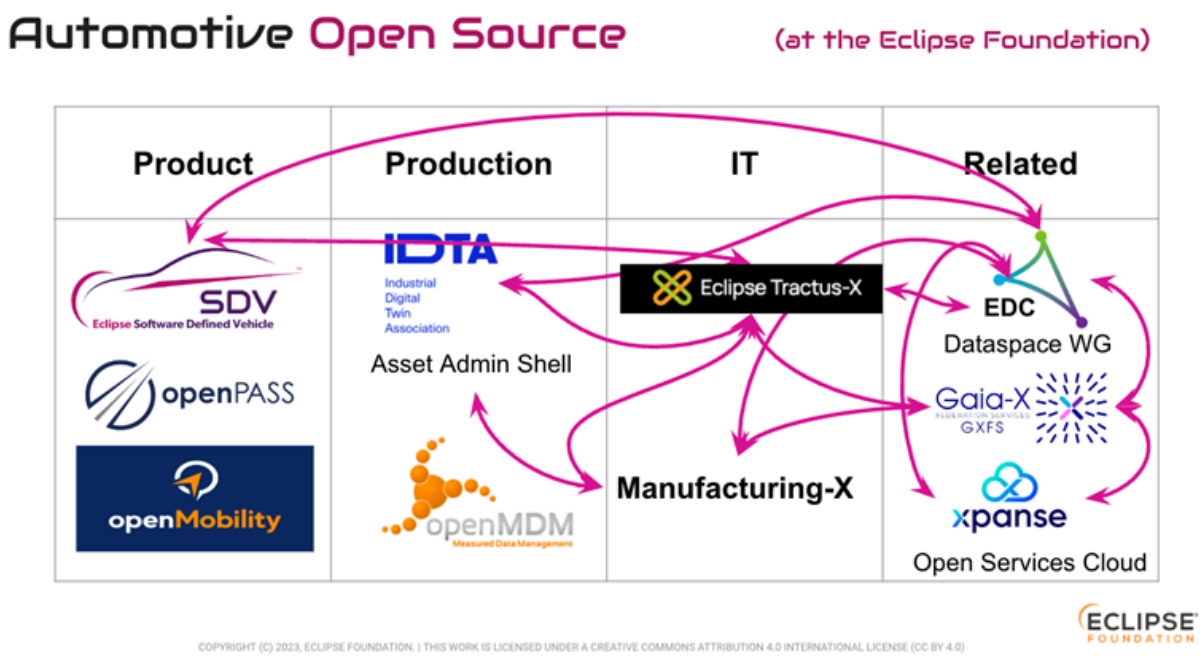


Fig 1. An overview of different Automotive-related OSS projects hosted by the Eclipse Foundation.

A recent example, highlighted by the representative from Mercedes-Benz Tech Innovation, concerns the Eclipse openDuT[6] – a planned open framework to automate the testing and validation process for automotive software and applications.

Centralisation of in-vehicle computing

The automotive industry is moving towards a centralised computing architecture, in contrast to the current norm of highly decentralised structures in vehicles. Presently, most cars come with 150-250 ECUs, and trucks around 90. Notable exceptions, like Tesla, employ just 2-3 main computing units, suggesting a potential direction for future computing architecture.

Today, automotive vehicles generally have a very decentralised architecture. A typical car has between 150-250 ECUs and a truck about 90. Notable exceptions, such as Tesla, manage with reportedly 2-3 main computing units, potentially indicating the future direction of SDVs in terms of computing architecture. The Scania representative confirms a trend towards consolidating ECUs into single onboard computers, running logical functions in virtualized and containerized environments. The Bosch representative further emphasises, from an overarching perspective that:

> ***"We are currently witnessing a trend towards centralization in E/E (electrical/electronic) architectures, which is being driven by the capabilities of modern SoCs (system-on-chips) and SiPs (system-in-packages). These chips offer significantly more computational performance than their predecessors from just a few years ago. As a result, modern architectures can combine multiple workloads and functions in a single system, allowing for***

[6] https://projects.eclipse.org/proposals/eclipse-opendut

> ***more functions to be bundled on one device than ever before. However, this centralization also creates new challenges and increases complexity. The workloads run on different operating systems and need to be isolated, and some may even be connected to the internet, which increases the risk of security breaches and intrusion. To address these challenges and reduce the risk, techniques such as virtualization and containerization are used to separate system elements. Additionally, open source software can help manage risks, create standard interfaces, and share the maintenance burden."***
> **- Bosch representative**

The Volvo Cars representative explains the migration towards a centralised architecture as an ongoing process, driven by OEMs wanting to gain control over sourced components and integrate functionality more tightly. This facilitates more efficient and qualitative testing and verification. Technology developments, such as ADAS and autonomous driving, are also pushing for higher performance computing and centralization. The ETAS representative further underscores that computing power must be sufficient to meet future software and service requirements, considering the rapid progression of technology and demand.

A distinction can be made between central ECUs dedicated to real-time safety-critical operations and those allocated for general purpose and less-critical operations. The former would potentially require a more hardened and lightweight Real-Time Operating System (RTOS) to manage time-critical applications. In contrast, the latter could host a General Purpose Operating System (GPOS) capable of managing more general purpose applications, where high-priority operations can be delayed in benefit for the overall performance of the system.

Working towards a common yet decoupled SDV platform

The automotive industry is moving towards establishing a unified yet decoupled SDV platform, expected to comprise exchangeable and interoperable building blocks, along with commonly defined interfaces and architectural design. This platform should seamlessly integrate with multiple ECUs, regardless of their quantity, and extend connectivity to cloud services. Currently, there isn't a singular, universally-adopted platform.

All surveyed companies agree that there is a need for a common SDV platform within vehicles that can act as the glue between the many ECUs, irrespective of their quantity, by utilising commonly defined interfaces and abstraction layers. It is also expected to connect seamlessly with cloud and connectivity-based services. Currently, however, there is no common platform available. Many OEMs are either working on developing their proprietary operating systems and related middleware or leveraging existing ones. For instance, Volvo Cars is currently leveraging QNX[7], a proprietary and functional-safety certified operating system by Blackberry, and building its own related technology stack on top. Similarly, others like Volkswagen are actively developing their own internal platforms.

[7] https://blackberry.qnx.com/en

The disjunct approach within the industry has also been noted by the European Commission in their workshop series convening the European automotive industry.[8] They describe how OEMs have different approaches to working towards an SDV and may not agree on a single SDV platform. More likely, however, is that they will agree to collaborate on building blocks, continuing what is already in existence, preferably with joint governance. This perspective is confirmed by, among others, the Bosch-representative:

> ***"First, it is important to determine which operating system (OS) is best suited for each task. This could be a commercial OS, a real-time operating system (RTOS), or a Linux-based system. Once the appropriate OS is selected, virtualization and/or containerization can be used to combine them. In fact, some experts suggest using different virtualization methods and even combining hypervisors in one system. This approach requires a more modular way of thinking, which can lead to the creation of separated services and building blocks. The differentiating factor between these blocks will be their specific function, while the use of OS, container frameworks, and virtualization becomes a commodity. However, it is possible that we may require functionality from other building blocks that does not yet exist. In this case, collaboration, and exchange between building blocks on all levels can take place to ensure that the system works as expected." - Bosch representative***

A future SDV platform is likely to consist of multiple and exchangeable building blocks, incorporating both OSS and proprietary elements supported by single or multiple vendors. Additionally, there will be several layers of middleware and infrastructure for containerisation and parallelisation of different services and operations. OEMs and suppliers will have the flexibility to combine and switch these building blocks based on their specific needs. Ideally, they can contribute and collaborate on the different building blocks. The abstraction layer to cloud and connectivity-based services, along with data transmission, is highlighted by several interviewees as critical aspects of a future SDV platform. This is essential for enabling connected features and seamless updates across models and brands. The Intellias-representative highlights how:

"Abstraction level enables OEMs and solution providers to build new components with variable configurations. It gives flexibility to switch between hardware and software from different vendors, at the same time, allowing seamless integration between diverse ecosystem of providers"

To enable a modular SDV platform with exchangeable building blocks, there is a need for standardised interfaces and abstractions, a development that is actively underway through various industry collaborations. The establishment of common interfaces will empower manufacturers, suppliers, and vendors to innovate on top of the platform while agreeing common layers for the technology stack. The Intellias-representative further adds:

[8] https://digital-strategy.ec.europa.eu/en/library/concept-paper-open-european-software-defined-vehicle-platfo

> ***"Standardisation is crucial to ensure interchangeability and accelerate development for automakers. The software complexity is skyrocketing now, and we need to make its development easier. Therefore, collaborative efforts to establish and adhere to standards become critical" - Intellias representative***

Development ongoing but slow-paced

Predictions about the establishment of a common SDV platform diverge within industry circles. Some experts, including OEM-representatives, forecast a timeline stretching between 5 to 20 years. This long trajectory is only anticipated to be shortened if a notable industry player successfully crafts, open-sources, and then institutes its platform as the benchmark across the industry.

This fragmented approach has been recognised by the European Commission, which suggests that while a unified SDV platform may be elusive, OEMs could potentially find common ground by pooling resources to develop essential building blocks under shared governance.

One OEM representative believes it will take up to 10 to 20 years before a common platform is in place, with the exception if a specific actor manages to create, open source, and establish its own platform as an industry standard. However, several interviewees point to ongoing initiatives aimed at creating a standardised Linux-based automotive stack predicted to emerge within a 5-year period.

The Volvo cars representative stated, *"Most OEMs believe they can create their own platforms, possibly incorporating some external components. While collaboration is likely, the chance of a single player offering a complete solution is slim. The shift will occur, but it should take between 4 to 8 years."* Regarding the driving force behind this shift, he stated that we are currently witnessing a *"competitive race with China in the automotive OSS-sector."*

One of the more mature alternatives mentioned is an upcoming Linux-based "In-Vehicle Operating System"[9] and related middleware from Red Hat, which is slated to be certified for safety-critical systems. The operating system is being developed in collaboration with General Motors (GM) and will serve as the foundation for their internally developed on-top platform, Ultifi, which is intended to provide "*frequent and more seamless delivery of software-defined features, apps and services to customers over-the-air,*" along with standardised interfaces for developers to integrate with.[10] Interviewees estimate that it will be in place in about 2-3 years.

These predictions should, however, be considered in the context that an SDV platform is expected by the interviewees to have a modular structure, with standardised interfaces, where both proprietary and open source building blocks will be available. Hence, the

[9] https://www.redhat.com/en/solutions/automotive

[10] https://www.redhat.com/en/about/press-releases/red-hat-and-general-motors-collaborate-trailblaze-future-software-defined-vehicles

question of when a complete SDV platform will be available depends on the perspective of each actor, as illustrated by the interviewees.

New technologies driving the transition

As electric vehicles and autonomous driving continue to rise in prominence, software complexity intensifies. While electrification simplifies certain aspects of engines, the convergence of electrification, autonomous driving, connectivity, and the transition towards service-oriented models amplifies technological challenges. These multifaceted issues necessitate broad OSS collaboration, as they surpass the capacity of individual companies to tackle alone. Consequently, OSS collaboration becomes not only an industry-wide imperative but also arguably a challenge for the EU as a whole.

The European Commission identifies electrification, autonomous driving, connectivity, and servicification as the primary technology drivers and challenges facing the automotive industry in the near future. This perspective is also echoed by Toyota, which believes these challenges will compel the adoption of OSS across the industry, as they are too complex for any single actor to tackle alone.

The Scania representative highlights that, looking 2-3 years ahead, OSS can be anticipated in the integration and communication between vehicles (vehicle-to-vehicle) and in support of the high-performance computers that will run on trucks. With autonomous vehicles projected to contain 10-100 times more code than traditional trucks, a substantial portion of this code is expected to be OSS.

Continental describes how the proliferation of electric vehicles and autonomous driving technologies will increase software complexity, albeit with the former mitigating some complexity inherent in combustion engines. Additionally, connectivity and integration with cloud technologies will become pivotal aspects of this transformation. Scania also notes that connectivity is critical, cautioning against over-reliance on a single technology, such as 5G, due to associated risks. To mitigate these risks, Scania is increasing research and investment in the area through partnerships and by developing its infrastructure for standardised routes.

The adoption of OSS is also anticipated to occur as an indirect consequence of technology advancements, as many of the tools and infrastructure utilised for developing and enabling technologies like ADAS and autonomous driving are based on OSS.

2. Growing the automotive industry's capacity for leveraging OSS strategically

It is paramount for the companies in the automotive industry to invest in capacity-building for OSS, given its strategic importance in the sector's future trajectory. The automotive industry is undergoing a significant shift from a hardware-focused to a software-centric model, driven by technological advancements such as electrification and autonomous driving. This evolution introduces complexities that single companies can't tackle alone, advocating for a collective approach via OSS. However, the sector's deep-rooted culture, historically focused on hardware, creates resistance to this transition. Furthermore, the challenge of attracting skilled personnel is exacerbated by the industry's legacy reputation. It is critical to bolster internal knowledge, particularly in OSS, to facilitate this transformation. Proactive engagement in OSS not only assists in navigating the transition but also makes the industry more appealing to top talent. Organisational structures, like Open Source Program Offices (OSPOs), are pivotal in promoting OSS adoption and fostering a forward-looking culture.

Transitioning from hardware to software-centric

The automotive industry is shifting from a hardware-centric to a software-focused model, driven by advancements such as autonomous driving and electrification. However, this transition is hindered by cultural legacies, and the pace of innovation in software is impeded by resistance to open collaboration through OSS.

The automotive industry is undergoing a profound transformation from traditional manufacturing to software-centric businesses. This shift is driven by technological advancements such as autonomous driving, electrification, connectivity, and servicification.

> ***"Automotive companies have traditionally focused on hardware, building cars. This is in contrast to digital-native car manufacturers, who directly began as software-defined vehicle entities. European companies, with their rich history, are transitioning more gradually to this SDV model."*** **- European Commission representative**
>
> ***"We're becoming a software company, less of a hardware company as we've been in the past. We're still building a foundry, but most of the new developments are on the software side. You control things with software, you don't change the hardware, you reconfigure using software." - Scania representative***

As suggested by the Scania representative, many companies in the automotive industry are traditionally viewed as hardware-centric entities. Transforming into software companies poses significant challenges, particularly due to cultural factors, with varying levels of advancement among different firms. Legacy considerations play a crucial role as companies gradually navigate this transition, unlike Tesla, for instance, which began as an SDV company without legacy constraints. OSS offers a platform for managing and facilitating this transformation, but it necessitates a paradigm shift towards open innovation, fostering a culture of collaboration and sharing.

Culture, safety regulation, legacy tech and vehicle lifespan slowing down the transition

The automotive industry faces considerable inertia due to its deeply entrenched cultural legacy. This transition will likely be more prolonged compared to sectors due to several factors. Vehicles are safety-critical products with extended life spans lasting over a decade, and the automotive domain itself is structurally intricate, with a historical backdrop spanning over a century. This long-standing conservative and competitive nature impedes the rapid adoption and collaboration on OSS, resulting in the sector lagging behind others in this regard.

According to the Volvo representative, this transformation will take time, for example, compared to the mobile industry. Reasons include that products are highly safety-critical and have long lifespans beyond ten to fifteen years. The automotive industry is large and complex in its hierarchical structure, and because the industry is rather conservative and

competitive with a history spanning 130 years. Such a cultural legacy makes the adoption and collaboration on OSS very slow and lags behind other industries such as telecommunications.

Although many automotive companies are adopting software-defined approaches, the traditional hardware-centric mindset, which primarily focuses on building cars, acts as a barrier to embracing newer paradigms. The challenges extend from internal communication problems across organisations to difficulties in conveying this shift to higher management.

This rationale is shared by many of the interviewees, highlighting a general need to mature in collaborating to move towards OSS, where some companies are more advanced than others. Previously, infotainment was the main area where OSS was used. However, with the change in vehicle architecture and the transition towards SDVs, OSS is becoming more prevalent and can no longer be avoided. This necessitates managers to decide on a policy, as highlighted by the Continental representative.

Knowledge and capacity needed to enable change

Enhancing internal skills and knowledge is crucial for accelerating the cultural and software evolution in the automotive industry. Both engineering teams and management require training and empowerment, particularly in actively engaging with OSS projects and their corresponding communities.

Growing internal capabilities and knowledge are highlighted as key levers for driving forward the culture and software transition. Engineering departments need training, but more importantly, they need to be empowered to actively develop and collaborate with OSS projects and their communities.

Interviewees emphasise the importance of not only educating and training developers but also focusing on management. Getting management on board is considered pivotal to enabling a cultural shift and transition towards SDVs. One interviewee observes that many managers come from a mechanical background and possess qualifications suitable for a traditional manufacturing industry, but may lack the expertise needed for the software-centric business towards which automotive actors now are transitioning.

Fear and uncertainty surrounding the disclosure of IP, sustainability challenges, and the general security awareness for OSS projects are areas of specific concern within the automotive industry. While understanding the risks in a more nuanced manner is crucial, it is also important to understand the business drivers underpinning a potential adoption of OSS as a strategic instrument. Key drivers mentioned by interviewees include ensuring technical fit for internal requirements and architecture, influencing the development of industry-common technology and standards, and contributing to the sustainability of the critical OSS projects.

OSS foundations can play a crucial role in educating and raising awareness about OSS within organisations, at both developer and management levels. They can also help in standardising development practices and processes for creating and maintaining OSS in a manner that is compliant with functional safety standards over the long term. Furthermore,

OSS foundations can provide a safe space for companies and competitors to collaborate on shared standards and building blocks, overcoming conservative culture and risk aversion that might otherwise inhibit collaboration.

The challenge of availability and attraction of skilled personnel

A robust engagement in OSS offers the additional benefit of addressing skills challenges in the automotive industry. Acquiring and retaining skilled engineers and managers is paramount for the evolution towards software-defined vehicles (SDVs). A company's OSS capacity and reputation play different roles in talent attraction. On the one hand, it attracts the staff who want to work with cutting-edge technology. On the other hand, it is a way to up-skill engineers already employed within the organisation.

Having skilled engineers and managers is a crucial enabler for the transition towards SDVs. However, the automotive industry faces challenges stemming from its technical and cultural legacy, as well as competition from the more attractive digital industry. To overcome these challenges, it is essential to cultivate a positive culture and attractive environment for skilled engineers and managers within the automotive industry.

OSS plays a fundamental role in creating such an environment and attracting talent from the broader digital industry. Engineers already within the automotive industry, therefore, need to be encouraged to actively engage in the OSS ecosystem and articulate their company's interests and culture on the topic. The representative form Mercedes-Benz Tech Innovation notes how he has:

> ***"...met people who listened to a keynote at an open source conference held by a Mercedes-Benz employee that inspired them to send an application. So, yes, I think it is very important for recruitment as well"*** **- Representative from Mercedes-Benz Tech Innovation**

On an aligning note, the Bosch representative highlights that:

> ***"...the use of open source software (OSS) has a significant impact on recruitment, as it is becoming increasingly important for companies to utilise OSS in order to remain competitive. While OSS is not the sole driving force behind recruitment, it is becoming a more attractive element for potential employees. Working on OSS projects is seen as a desirable skill for software engineers, and companies that use OSS are more likely to attract top talent. Therefore, the use of OSS is an important factor in recruitment, as it helps companies to remain competitive and attract skilled software engineers."*** **— Bosch representative**

The Volvo Cars representative describes the dual nature of OSS in relation to talent acquisition. On the one hand, developing and collaborating on OSS is generally sought for its benefits. On the other hand, there is the fact that much of today's modern technology is based on OSS, which engineers have an interest in engaging with.

OSPOs: Internal support and processes for OSS adoption and culture

Leveraging OSS strategically is essential for companies to handle the complexity and software-centric shifts in the automotive industry due to technological advancements. Companies building Open Source Program Offices (OSPOs) are central to this effort, as they establish the necessary capacity, attract the required talent, and nurture an open-source-centric culture within organisations.

Several of the organisations surveyed for this report had organisational support functions in place, commonly referred to as Open Source Program Offices (OSPOs) — although this label is not always used.[11]

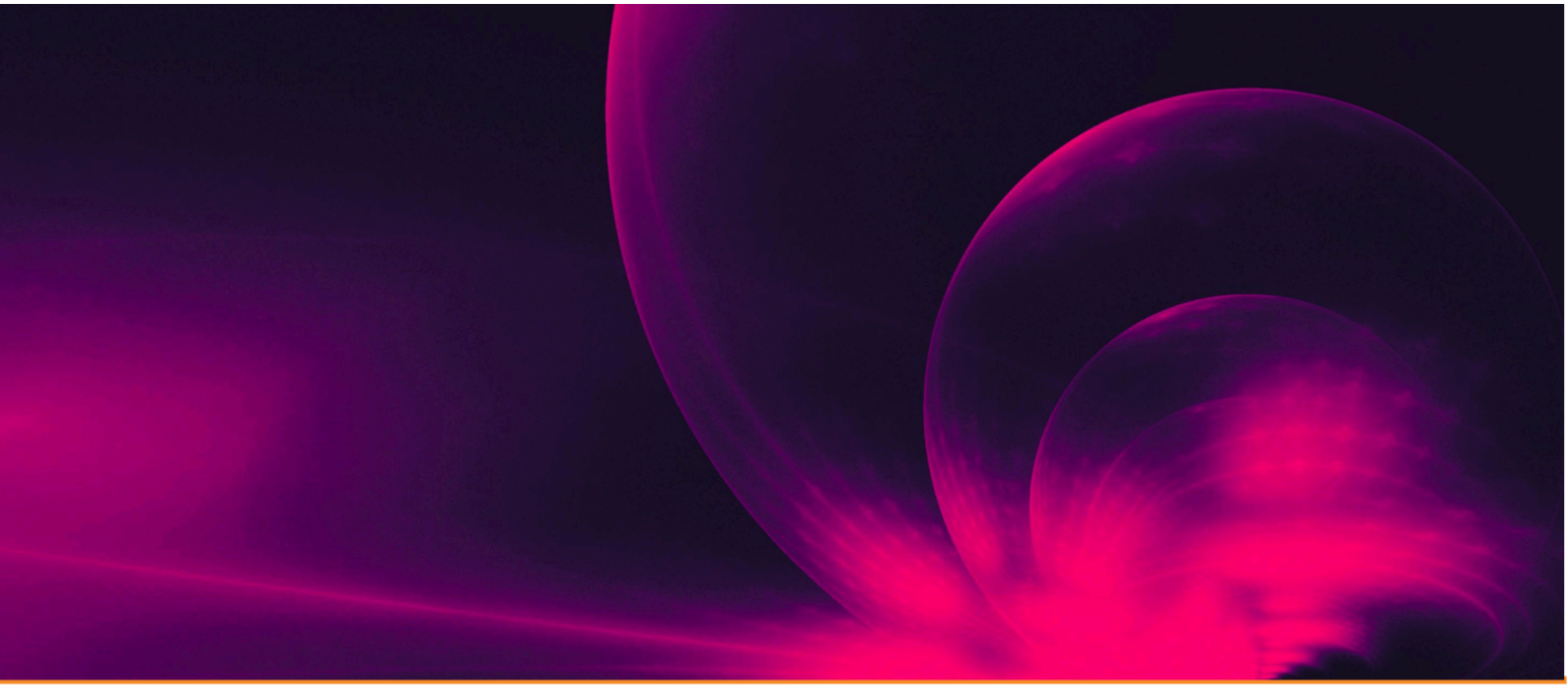
> ***"For many years, we have had an "Open Source Program Office" (OSPO) in place, which has helped us to manage our use of open source software. However, we are now looking to further leverage the benefits of our OSPO and find a new strategic direction for our use of open source. This means that we are exploring new ways to use and contribute to open source software to improve our products and services, and to benefit from the advantages it offers" - Bosch representative***

The OSPOs, as in the case of Bosch, were typically initiated with a compliance focus. Over time, they evolved to also encompass enabling areas such as OSS consumption and development, inner source collaboration, and active consideration of OSS sustainability and supply chain security.

Several interviewees also highlighted that when OSPOs' expand their focus beyond merely compliance to include cultural change and ecosystem outreach, they can increase internal capacity of the current staff to leverage OSS and increase the attractiveness for new OSS-skilled engineers to work in the automotive industry.

The Porsche-representative highlights the importance of "leading by example," which means *"that our whole tech ecosystem - from FOSS Compliance to enabling contributions - is based on open source technology and we are an active contributor in the community. In addition, we [the OSPO] are going to open source several solutions in the beginning of next year. This approach makes it much easier to push forward the overall open source initiative and strategy as all internal employees and product teams experience that we set a good example"*.

[11] Open Source Program Office (OSPO) is a designated function within an organisation that manages and coordinates the organisation's OSS activities and policies. The OSPO serves as a centre of competence, ensuring that OSS practices and contributions align with the business goals and legal requirements of the organisation. For a case study of an automotive industry OSPO: https://todogroup.org/resources/case-studies/porsche/



3. Nurturing an OSS ecosystem in the automotive industry

The automotive industry's traditional hierarchical supplier structure poses challenges to OSS uptake due to its incompatibility with the interdependence demanded by modern systems and actors. Transitioning to an ecosystem-oriented model necessitates fostering active collaborations, which OSS will both drive and benefit from. Government intervention, through facilitation and funding, emerges as a potent catalyst for this transformation. This sets the stage for a deeper discussion about the balance between collaboration and competition, examining the automotive industry through an OSS lens.

Hierarchical supplier structure incompatible with interdependent systems and actors

The prevailing hierarchical supply chain model in the automotive industry is increasingly becoming an impediment to the intricate and interconnected nature of modern vehicle systems. There's a growing need for a transition from isolated tiers to integrated ecosystems, where collaboration and shared responsibility are paramount.

The automotive industry is currently entrenched in a hierarchical supply chain structure, which limits both collaboration and innovation, or as articulated by Continental:

> ***"We need to move from this classical OEM - tier one supplier working with a contract with a tier two supplier, and so on, into ecosystems and partnerships." - Continental-representative***

As highlighted, there are often cross-dependencies between software and suppliers that OEMs need to realise. They are accustomed to exerting pressure on single suppliers, which will require a shift in mindset and culture towards embracing and encouraging open collaboration and shared responsibility. The Bosch representative confirms that while the classical structure of the supply pyramid with different tiers remains prevalent in day-to-day operations and customer projects,, partnerships with an ecosystem structure are now more commonly adopted for long-term perspective and strategic initiatives to leverage different competencies and resources available. The Intellias representative notes:

> ***"that is how ecosystem looks like, software engineering companies, hardware providers, and OEMs all combine their unique skills and partner for one goal – better product experience for users." - Intellias representative***

The Bosch representative further adds that Tier 1 suppliers used to be responsible for the hardware up to the application layer. However, now, different parts are sourced from multiple parties, and OEMs take on more responsibilities in the system design and integration. This transition creates an ecosystem structure moving away from the traditional tiered structure, enabling actors to collaborate directly rather than through intermediaries. According to Intellias representative, the automotive industry is already shaped as the diverse ecosystem that collaborates on standardisation and OSS. The number of players will grow in future, requiring even more effort from ecosystem members.

Moving to an ecosystem structure through active collaborations

The automotive industry is navigating towards an ecosystem-focused structure, as evidenced by a surge in collaborations aimed at developing common 'standards' and foundational building blocks. While the initial intent behind these collaborations is to design individual components, the overarching goal is a harmonised solution for SDVs.

Interviewees note the presence and evolution of several collaborations, indicating that the automotive industry is slowly moving towards an ecosystem structure. There is acknowledgement of the need to design common standards and building blocks. However, there is still some way to go in building a cohesive solution for SDVs as the collaborations are currently mainly focused on the design of individual components. As highlighted by the Continental-representative, the litmus test will be when the collaboratively developed software is mature enough to be directly shipped in vehicles.

Several key collaborations were highlighted by the interviewees, all complementing and overlapping each other in creating common platforms, building blocks, and standards for an SDV. The main collaborations referred to include:

- **Automotive Grade Linux:** A Linux-based infotainment operating system hosted by the Linux Foundation.
- **Automotive Open System Architecture (AUTOSAR):** A collaboration facilitating the development of and providing proprietary architectural standards for ECUs, both traditional (AUTOSAR Classic) and adaptive use cases such as autonomous driving (AUTOSAR Adaptive). Standards are also provided for specific interfaces and acceptance testing.
- **Autoware:** An independent foundation focusing on OSS projects for autonomous driving.
- **Catena-X:** An open data ecosystem for the automotive industry with common standards for sovereign data exchange between companies along the entire value chain.
- **Connected Vehicle Systems Alliance (COVESA):** Previously known as the GENIVI Alliance, this alliance develops signalling specification and a vehicle signalling catalogue.
- **Digita.auto:** A vendor and technology-agnostic collaboration focused on enabling SDV-related use cases using state-of-the-art technologies and methodologies.
- **Eclipse Software Defined Vehicles Working Group:** Hosts numerous OSS projects related to a future SDV platform, both in terms of building blocks and tools and infrastructure for its development.
- **Enabling Linux In Safe Applications (ELISA):** A project hosted in the Linux Foundation focusing on functional safety standards across domains, including the healthcare and medical domain.
- **Khronos Group:** A consortium of diverse companies collaboratively developing open standards for different areas, typically related to computing. Examples include SYCL™, OpenCL™, and Vulkan® SC, which are standards related to safety-critical environments such as the automotive industry.

- **Navigation Data Standard (NDS):** A collaboration for developing a standard format to collect, store, and communicate map data in and between vehicle systems, including ADAS or autonomous driving systems.
- **Scalable Open Architecture For the Embedded Edge (SOAFEE):** A new collaboration developing a cloud native stack for automotive. A reference implementation is about to be released, and the project is currently hosted by ARM and potentially moving to the Eclipse SDV Working Group.
- **Zephyr and ApexOS:** Two operating systems that are (or in the process of) being certified as functional safety-critical and potentially relevant for the automotive setting.

Due to the vast number of collaborations, it is challenging for actors to be involved everywhere, necessitating prioritisation. Several interviewees describe difficulty in maintaining an overview, although some are represented in the governing bodies of some collaborations. Yet, all agree on the need and importance for these collaborations as places where common standards and building blocks in the automotive industry can be hosted and managed with standardised governance and development processes. Continental believes that the emerging Automotive software stack will be driven by different foundations and communities, each taking responsibility for different parts.

Some of the interviewees further note that the different initiatives are more progressively interacting and collaborating with each other on various initiatives. For example, the ETAS representative describes how initiatives like AUTOSAR, SOAFEE, COVESA, and the Eclipse SDV Working Group are actively seeking out synergies and overlaps. These cross-synergies are expected to grow even more in the future in the joint effort towards creating common architectures and standardised interfaces for a future SDV platform. This approach allows for a diverse set of building blocks (open and proprietary) and enables actors to innovate on top of each layer of the technology stack.

Government facilitation and funding as a driver for change

Governments and public institutions, with their facilitative role and funding capacities, have the potential to significantly influence and accelerate the transformation of the automotive industry. Interviewees underscored the pivotal role of entities like the European Commission, which can provide a neutral environment, bolstered by their research resources, to facilitate discussions among key industry stakeholders, such as OEMs and Tier 1 suppliers. Such neutral platforms can ease industry politics and foster higher-level discourses, mitigating competitive tensions.

A means for bridging the different collaborations can be for governments and public institutions to help in enabling and facilitating discussions, as highlighted by several

interviewees. The European Commission, along with their dedicated R&I funding, provides such opportunities. They aim to provide a safe space for the OEMs and Tier 1 actors to

connect and discuss common grounds for open and pre-competitive collaboration. Having a neutral and trusted entity facilitating the discussion can ease tensions and politics which may otherwise be present in the specific collaborations, while also helping to elevate the level of discussion.

The Volvo Cars-representative underscores the standardising effect of government support behind key OSS projects, as well as the political rationale to do so:

> ***"The European Commission's primary lever is to bolster R&D in and around open source projects for the European automotive industry. Garnering collective industry support for a project and pursuing a unified solution can set industry standards. If the European Commission doesn't do it, global competitors, be it American or Chinese, government or private, will take the lead. Just look at the mobile industry — no one took the initiative, and Google filled the gap."***

Governments can further play a key role in pushing and requiring safety requirements for the automotive industry. Additionally, they can assist with the transition of automotive companies into software entities, as well as the shift from combustion to electric motors.

Public investment into an automotive OSS stack would indeed be a significant way to advance the entire automotive industry during this transition period. European-focused R&I investments by the European Commission was highlighted both as a potential means of enabling European OEMs to collaborate in a pre-competitive environment and take the lead, as well as enabling a global collaboration for a shared SDV ecosystem and creating an equal playing field for all actors.

The European Commission-representative describes how they have recently initiated an internal forum for European OEMs and Tier-1 suppliers to discuss potential collaborations on R&I and standardisation. Two calls for R&I funding were opened based on the initial conversations. The commitment of funds, on the order of tens of millions of euros, may seem small compared to industry spending, but it can help bring the actors together and initiate open collaborative approaches.

While most interviewees express positivity regarding the funding, there is also some scepticism voiced. One interviewee views funding research programs as having limited effectiveness, as they typically rank low in the TRL (technology readiness level) scale. Outputs from a three-year research project must be more mature for deployment in production environments. The interviewee suggests that research programs should adopt a more agile approach and continuously deliver outputs to become more relevant and impactful. The Bosch representative adds that the funding should focus on existing open projects, particularly on supporting, hardening and securing these projects at a community level so they can be utilised, even in safety critical environments. This is a challenge shared by everyone and of common interest.

If investments are to be allocated, the Scania representative highlights that such distribution should preferably be handled through trusted, neutral public entities such as national transport authorities. Collaboration with OSS foundations is an option but not a necessity.

Trust in the distributing entity and the sustainability of targeted projects are highlighted as the most important factors.

OEMs and Tier 1 suppliers pushing and pulling each other

Tier 1 suppliers play a pivotal role in driving OSS adoption and collaboration in the automotive industry. However, as OEMs seek greater control over their software stack and align with upcoming regulations, they too are progressively embracing OSS. This indicates a comprehensive maturation in the industry's digital transformation towards a unified SDV platform.

Tier 1 suppliers are frequently portrayed by multiple interviewees as progressive entities that drive OSS adoption and collaboration. They typically have a cost incentive to increase OSS adoption, aiming to reduce complexity and customise base functionality for various OEMs. Given that many OEMs rely heavily on suppliers, this trend can facilitate the evolution of OEMs in terms of OSS maturity, as inbound components increasingly incorporate OSS from the outset. However, for OEMs with a lower dependence on suppliers and significant investments in internal development, this evolution may face the risk of slowing down.

Some interviewees, however, note that OEMs have begun to adopt OSS more progressively in recent years, catching up to the Tier 1 and 2 suppliers. One reason mentioned is the perceived need to enhance internal capabilities and control of the software stack, as well as reduce reliance on specific suppliers. Some OEMs suggest that this shift will, in turn, drive further adoption among suppliers, as there will be increased demand for adopting Software Bill of Materials (SBOMs) to enhance cybersecurity and compliance, while also aligning with upcoming legislation such as the Cyber Resilience Act.

Considering both perspectives, it appears that the drive for OSS adoption and collaboration will emerge from both the manufacturing and supplier sides of the ecosystem. This indicates a general maturation of the automotive industry, which is a positive sign for advancing its digital transformation and moving towards a unified SDV platform.

Strategic partnerships as a means of complementing internal capabilities

Strategic alliances with tech giants are crucial for automotive entities due to the inherent limitations in their in-house technical capabilities and expertise. Notably, Google's Android Automotive platform serves as a recurring example of this trend. However, a significant concern among several stakeholders is the looming threat of over-dependence on singular platform providers.

Strategic partnerships with technology companies are considered critical as individual actors often lack the internal capabilities and necessary skills. Google is frequently highlighted as an example, particularly in relation to the Android Automotive platform. Porsche recently announced its collaboration with Google, stating that the "*goal is to provide a seamless digital experience in combination with our well-known Porsche communication*

*management (front-end) in future vehicle generations by integrating Google services such as navigation, speech and the respective app ecosystem" (*Porsche representative).

A risk highlighted by some interviewees is that OEMs may become overly dependent on single platform providers like Google for Android, potentially limiting their role to merely being the carmaker. This concern has led many to attempt constructing their own operating systems, but with limited success, according to several interviewees. Porsche emphasises that "in the future, ecosystems from different providers that are relevant for customers will be integrated directly into the vehicle via standardised interfaces and platforms.

4. Collaboration under competition

Compared to software-first firms, automotive companies predominantly develop software in-house over participating in OSS collaborations with industry peers. As a result, this approach limits both their own competitive edge and that of the established industry. Distinguishing between unique and commoditised technology remains challenging, underscoring the industry's need to reconsider the nature of collaboration and competition.

Identifying and collaborating on commodity technology

There is an industry-wide push for collaboration on non-differentiating aspects of SDV technology. Establishing standardised interfaces and common building blocks is seen as a way to foster innovation and resource efficiency. By utilising tested solutions, organisations can concentrate on developing their unique selling points.

There is a recognition among interviewees that developing all required components independently is not feasible, as it can result in a growing burden of legacy systems that must be internally maintained. From a business strategy perspective, it is typically preferable for an organisation to release technology as OSS before it becomes commodity, as alternative and competing solutions might otherwise be adopted.

Identifying which parts of internally developed technology truly differentiates an organisation from its competitors, and determining where it stands in terms of commoditization, is a recognized challenge, especially given that different parts and systems have varying lifecycles. The Bosch representative has emphasised the need to integrate new technology areas and services, including cloud connectivity. In the automotive industry, there may be a shortage of domain or internal experts available to handle these new technologies and services. Therefore, the automotive industry may be more willing to open up and collaborate when everyone is on a similar level of expertise with the same needs but limited domain experts. The Continental representative explains the distinction as follows:

> ***"In general, the rule of thumb is that what is differentiating is what provides user experienceable function, and that means not just the cockpit or the instrument cluster, but also driving in general." - Continental representative***

Along the same line, the interviewee further explains that from an architectural perspective, the operating system and middleware layers would be considered non-differentiating However, some actors still prefer to customise these parts as well to optimise, for example, the driving experience. Such optimization, however, stifles innovation and leads to resources being inefficiently spent, as Tier 1 suppliers have to tailor their components to each OEM's specific requirements.

Several interviewees accordingly stress the need for accelerated development and collaboration focused on non-differentiating aspects of SDV technology. This is vital for the industry to catch up with international competition. Establishing standardised interfaces and common building blocks is seen as a way to stimulate innovation and resource efficiency, with Tier 1 suppliers playing a key role in this regard. The representative from Mercedes-Benz Tech Innovation describes the rationale as follows:

> ***"It is all about focusing on what the specific company can do best rather than using tried and tested solutions, it is about unique selling points. The wheel does not need to be reinvented over and over again."* - Representative from Mercedes-Benz Tech Innovation.**

5. Safety and security of automotive OSS

The safety-critical context of the automotive industry imposes rigorous requirements on software and its underlying development processes. These requirements are not typically on par with OSS, which is why the automotive industry needs to consider how to merge OSS and functional safety certifications in a way that creates value rather than friction. Equally important is the need for securing the supply chain and sustaining the OSS building blocks on which the whole industry relies. Both aspects require a proactive and rigorous approach that can support the safety and security throughout the long life cycles cars commonly maintain.

Functional safety certification and OSS development

Functional safety standards require stringent development processes for automotive software, a criterion many OSS projects do not meet, according to several interviewees. As a result, beyond exceptions like infotainment systems employing Android Automotive or Automotive Grade Linux, the application of OSS components is largely restricted. However, anticipation is growing around imminent launches of functional safety-certified Linux-based operating systems and associated middleware.

Functional safety standards mandate that software included in a car must undergo rigorous development processes, which many OSS projects do not adhere to, according to some interviewees. Consequently, the availability and adoption of OSS-based components are generally limited, especially in safety-critical areas such as ADAS, deep embedded systems, and the vehicle edge. In the less critical areas, such as the infotainment system, OSS-based systems are already in place, including Android Automotive and Automotive Grade Linux.

Beyond proprietary options such as QNX from Blackberry, there are currently no widely available OSS-based platforms on the market[12]. However, multiple interviewees are referring to upcoming functional safety-certified Linux-based operating systems and related middleware to be released by companies like Red Hat within a two-to-three-year period. Creating a certified Linux-based operating system was considered key to increasing OSS usage in the automotive industry, and an area that would benefit from public funding and support, according to the Volvo Cars representative. According to the ETAS representative, a success factor for any OSS-based system is that professional support and long-term maintenance will be guaranteed.

The Scania representative raises the question whether existing OSS can be reused or if new ones must be created, as functional safety certification may require heavy investments from companies. The Volvo Cars representative believes the standards such as ISO/PAS 8926[13], a forthcoming extension of ISO 26262,[14] may enable pre-existing software to be certified, thereby opening up the possibility for some OSS components to also be certified.

The Continental representative adds that the revision of guidelines and processes for developing functional safety-critical systems, such as ISO 26262, is crucial to accommodate the collaborative development practices implied by the OSS development model. This includes addressing questions such as how the OSS is developed, who has the right to contribute, and how governance is managed. The ETAS representative further emphasises the importance of adopting stricter requirements in OSS development, including documenting and verifying architecture, requirements, and processes, and integrating the OSS development as part of established audit processes (e.g., ASPICE). There are several

[12] In November 2023 the Eclipse Foundation announced the Thread X project (https://threadx.io/): a vendor-neutral, open source, safety certified RTOS. At the time of writing, the code was not yet released.

[13] https://www.iso.org/standard/83346.html

[14] https://www.iso.org/standard/68383.html

endeavours in the industry and also within ISO to enable OSS code to also comply with functional safety requirements with appropriate measures.

Another concern raised by several interviewees pertains to how a certification should be performed, specifically whether a new full validation would be needed for each contribution This approach could effectively inhibit any release and collaboration on functional-safety critical OSS.

The processes, regulations, and requirements create friction that encourages suppliers to continue building proprietary systems, incorporating some internally hardened OSS components. According to the Intellias representative, it seems like it may take a long time before a completely open platform is available on the market. He expects the use of OSS to increase; however, vendors will still tailor proprietary alternatives due to the complexity of functional safety regulations, development processes, and the challenge in growing sustainable communities around OSS projects.

Ensuring the health and sustainability of the OSS supply chain

The assurance of safety and security through OSS necessitates a comprehensive understanding and proactive management. For the benefit of systems longevity, which often exceeds a decade in the automotive industry, it is imperative for OSS projects to be actively sustained. This demands prolonged commitment and investment from the automotive industry.

The responsibility falls on OEMs and suppliers to bolster their capabilities, as the perpetual presence or suitability of service providers isn't guaranteed. Resources, both in terms of funds and engineering time, need to be committed to OSS projects. Developers must be empowered to actively engage with OSS communities, rectifying vulnerabilities, and ensuring the software's continuous quality.

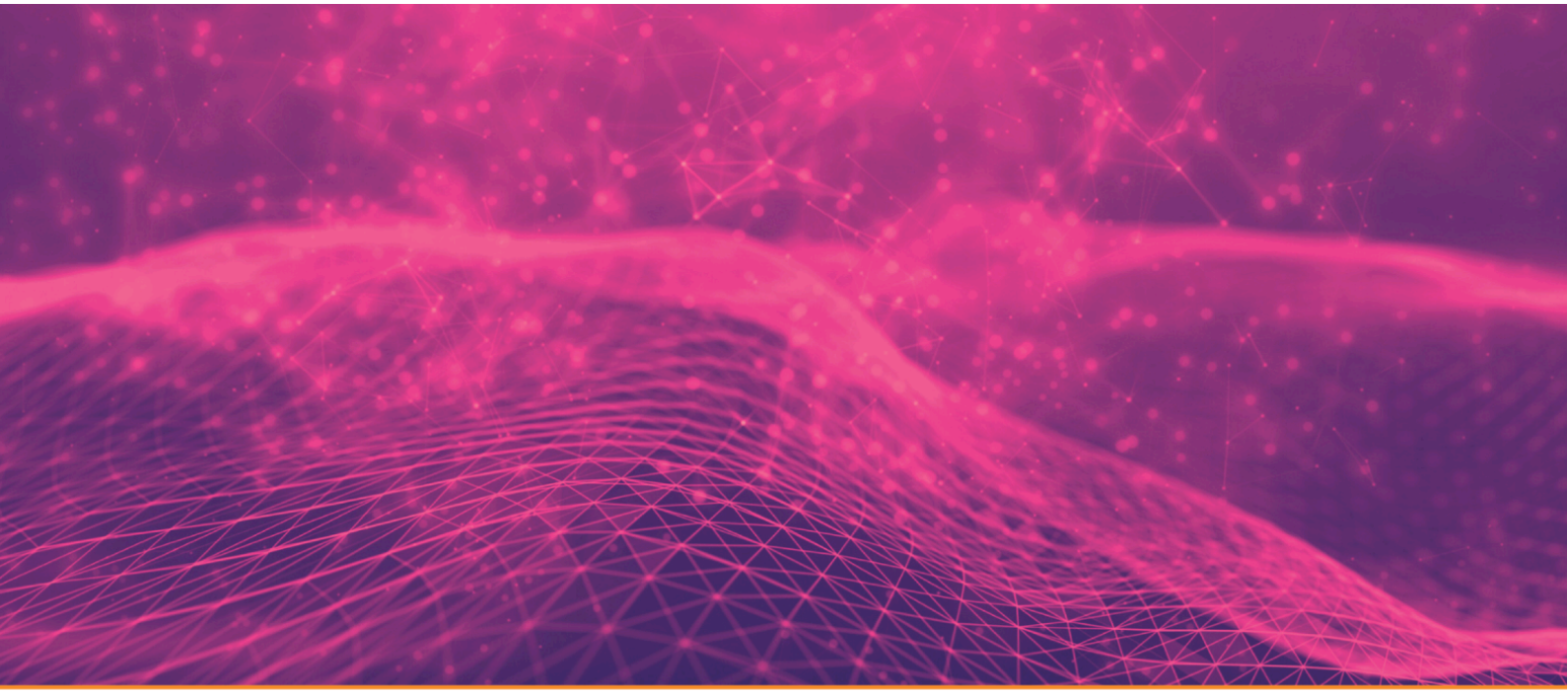
OSS can indeed provide a means of maintaining and improving the safety and security of systems, but there is a need for understanding how this can be achieved. OSS systems must be actively maintained and sustained long-term, requiring a significant commitment and investment from its users, namely, the industry. The long-term perspective is critical, as sustainability and quality need to be guaranteed for product lifespans of ten years or more. This creates a potential market for new service suppliers such as Red Hat.

However, OEMs and suppliers also need to enhance their own capabilities, as dedicated service providers may not always be available or suitable. Developers must be empowered to contribute and engage with OSS communities to address vulnerabilities when necessary and proactively maintain the quality of the OSS, and thereby reducing the risk of vulnerabilities being introduced in the first place. This also necessitates awareness through the use of SBOMs to understand which OSS is utilised both directly and indirectly through suppliers. The adoption and utilisation of SBOMs vary among interviewees, particularly in the case of suppliers such as Scania.

> ***"[The suppliers] still have a lot to learn in how to actually get the provenance of the software that they deliver and how to formulate that in a way that is consistent with our requirements, how to create a software bill of material, for instance, in a way that we can actually make use of it" - Scania representative***

OSS sustainability is indeed a challenge, not only for the automotive industry but globally. The automotive industry, with its complex supply chain, faces particular difficulties in managing software within this chain, as noted by the Toyota representative. Additionally, another OEM-representative raises concerns that the automotive industry is not currently involved in broader sustainability efforts such as OpenSSF This lack of participation could potentially result in automotive-specific OSS not receiving prioritised funding and maintenance efforts.

Actors in the automotive industry will need to learn and adapt as OSS adoption is expected to grow, particularly with the emergence of complex technologies in areas such as autonomous driving, connectivity, and servicification. Pooling resources through common efforts can enhance the sustainability of OSS projects and increase the potential for cost efficiencies. Formal collaborations, such as Eclipse, can play a crucial role in educating and raising awareness about OSS within organisations, at both the developer and management levels.



6. Maintaining digital sovereignty and improving competitiveness at the same time

All participants highlighted the urgency for future SDV platforms to be open, enabling entities to make informed technical design and sourcing decisions that align with regional laws, requirements, and values. As global regionalisation deepens, achieving "digital sovereignty" or technical independence is paramount, but it has a complex relationship with increasing the automotive industry's competitiveness.

"Open source software is indispensable. It is not just vital to the software industry, it is vital for the automotive industry; it is vital for every sector that uses software. The entire European industry needs to champion open source to maintain digital sovereignty, increase efficiency, and remain competitive with the rest of the world." - Representative from Mercedes-Benz Tech Innovation

Need for an open SDV platform in a more deglobalised world

All interviewees are in agreement regarding the necessity for a future SDV platform to be open, empowering stakeholders to make technical design and sourcing decisions in accordance with local laws, needs, and values. This technical independence, also referred to as digital sovereignty, is growing in importance due to the ongoing regionalization and geopolitical shifts on the global level.

One interviewee predicts that an emerging SDV platform will be driven by different foundations and communities, each taking responsibility for different parts Additionally, different clusters may emerge, centred around the US, Europe, and China, each with different flavours of the platform and its building blocks. Geopolitical factors are expected to strongly influence the formation of these three clusters, according to the interviewee.

Despite the prevailing direction, there is still an interest among OEMs and suppliers to continue selling their products across markets and maintain access to technology that is not locked to a vendor located on the “wrong” side of a border in a changed global environment, as expressed by one interviewee. Export controls can hinder sales across borders if, for example, certain chips are blocked.

Avoiding lock-in through internal capabilities and collaboration

To mitigate the risks associated with potential trade-wars and export controls, as well as capturing value derived from the software-driven transformation of cars, many interviewees highlight the importance of adopting a diverse sourcing strategy. This strategy may include replicating infrastructure and customising products to each continent, such as the US, EU, and China. However, the discussion of potential lock-ins extends beyond the political climate and is also raised from a general competition perspective.

One interviewee describes how the cost of a car will increasingly be composed of software. If a company aims to maintain control of its value chain, this includes software as well, ensuring independence from specific vendors. OSS provides a vital means of creating and collaborating on an open platform, where there should be a vested interest for the actors to participate and influence.

Another interviewee highlights that even with OSS, there remains a risk of a soft lock-in to vendors if the customer lacks clarity in formulating requirements. For instance, if specific customisations are not integrated into the upstream OSS version of the product, or if a service relies on routing and management through the vendor's infrastructure. The interviewee’s organisation encountered such a lock-in situation previously and had to incur costs to have the developed features integrated upstream. However, if many actors depend on a specific project, there is also an option to collaborate on a fork and alternative solution, as evidenced by recent examples in infrastructure tools within the cloud-native space.

The slow but steady emergence of SDV platforms may also be viewed as a response to the current lock-in to proprietary solutions, such as the QNX OS from BlackBerry, a situation shared by multiple interviewees. It is anticipated that such lock-in situations will be challenged with the efforts towards an open SDV platform, where OEMs are supporting vendors such as Red Hat to develop alternative solutions free of such lock-in.

Automotive companies must develop a comprehensive data strategy that goes beyond avoiding lock-in. Major software players' platforms are still evolving, but they are improving rapidly. Several interviewees, in particular, emphasised the critical importance of gaining control over the data collected and processed by vehicles and related services. One interviewee shared anecdotes illustrating how dominant vendors and platforms have created effective lock-in effects, drawing parallels with similar situations in the mobile industry.

Some interviewees highlight how the Chinese automotive industry benefits from government support, whereas the US is accelerated with support from technology leaders within the digital industry. Governments, regardless of regional location, are considered to play a pivotal role in supporting a more level playing field, both through direct funding and facilitation, as well as through regulation. One interviewee regards regulations as an effective means of commoditizing certain functions, making them essential for all players. OSS provides a suitable mechanism for collaborating on such required functionality.

Recommendations

The softwarization of the automotive industry entails multifaceted challenges for its companies, spanning from functional safety and digital sovereignty to the complexities of global supply chains. All companies need a balanced approach between proprietary systems and OSS, encompassing in-house development and deployment of software developed externally. However, our research underscores that the current balance falls short of fully realising the potential of OSS in the European automotive industry. This shortfall leads to decreased competitiveness which, for policymakers, poses challenges related to digital sovereignty and economic growth.

Our recommendations aim to champion innovation while leveraging the benefits of the OSS model to ensure security, regulatory compliance, and adaptability. Amid geopolitical shifts and the drive for competitiveness, we hope that this paper has underscored the imperative role of OSS for the automotive industry to navigate this terrain with strategic intent.

For Decision-Makers in the Automotive Industry

- **Embrace OSS**: Recognize the inherent value of OSS and actively support its integration into automotive platforms. Acknowledge its potential for innovation, customisation, and avoiding vendor lock-ins.
- **Create an OSS Strategy:** Identify how OSS can be leveraged as an instrument to achieve value and support your company's overall business goals, and formulate an explicit OSS strategy for your organisation to execute on. The goals listed below are a place to start.
- **Prioritise being a good OSS citizen**: Commit to being a responsible OSS community member by consistently contributing enhancements back to OSS projects. Adhere to established best practices for upstream contribution, to ensure your contributions are impactful and align with community standards.
- **Build OSPOs with Strong Mandates**: OSPOs should be mandated to help your company achieve the goals listed in your company's OSS strategy. Positioning and structure depends on the needs and context of your organisation. Engage in and study resources from OSPO networks, including the OSPO Alliance,[15] and the TODO group.[16]
- **Develop Internal OSS Capabilities**: Empower developers to contribute to OSS projects, rectify vulnerabilities, and ensure software quality. Establish training programs should be established to keep teams updated.
- **Invest in Functional Safety**: Work towards bridging and integrating the collaborative development OSS with the processes and guidelines of established functional safety

[15] https://ospo-alliance.org/

[16] https://todogroup.org/

standards (e.g., ISO26262), and audit processes (e.g., ASPICE). Additionally, seek and promote the creation of functional safety certified OSS, including operating systems and middleware.

- **Engage with OSS Communities**: Allocate resources (providing funds, engineering time, and code contributions) to actively engage with OSS communities. This ensures the continuous quality and sustainability of the software, as well as enhances your company's reputation within the OSS community.
- **Gain overview of OSS consumption**: Ensure a thorough understanding and documentation of all OSS components used directly and indirectly, collaborating within your industry and beyond. Software Bill of Materials (SBOMs) provide a critical component. Established standards include SPDX[17] and CycloneDX.[18]
- **Ensure licence compliance:** Survey and fulfil the conditions and obligations of OSS components consumed to avoid legal risks and respect community norms and expectations from using the software. OpenChain ISO/IEC 5230:2020 can help structure an internal compliance process.
- **Maintain security awareness:** Establish and maintain an awareness of current risk exposure by continuously scanning for vulnerabilities and proactively analysing the health of OSS projects, both in production and under consideration for intake. Identify metrics and tools for analysing health and sustainability of OSS projects, such as those provided by the CHAOSS project[19] and research.[20]
- **Avoid Soft Lock-ins**: Aim to adopt OSS from projects with open governance and development process, where necessary knowledge and infrastructure are openly available, to minimise the risk of potential (soft) lock-ins.
- **Collaborate on Open Platforms**: Participate in established and emerging collaborations with other industry players to define standardised interfaces and architecture, as well as to develop OSS building blocks. This enables the creation of a modular and flexible SDV platform.
- **Convert to Open Standards:** Aim to adopt and define open standards that can be freely implemented in OSS applications to facilitate innovation for the entire industry. Proprietary standards can resist the growth and pace of common technology development, thereby limiting the potential for OSS in the industry as a whole.
- **Attract talent**: Empower developers to actively use and engage with OSS projects, and promote opportunities to enhance the company's appeal to current and prospective employees.

[17] https://spdx.dev/

[18] https://cyclonedx.org/

[19] https://chaoss.community/

[20] https://dl.acm.org/doi/pdf/10.1145/3555051.3555067

For Policymakers at the EU and National Levels

- **Promote Open Standards**: Encourage the adoption of open standards in the automotive industry to mitigate proprietary lock-ins, foster competition, and facilitate the use of OSS. Ensure that any standards promoted are implementable in OSS.
- **Support OSS R&D**: Allocate public funding for research and development in OSS projects, particularly those with potential applications in the automotive sector. Develop programs in close collaboration with stakeholders from the industry.
- **Establish Functional Safety Norms**: Collaborate with industry consortia and stakeholders to develop clear guidelines and standards for functional safety certification that take into account and leverage the benefits of OSS characteristics.
- **Facilitate Collaboration**: Cultivate environments that promote collaboration among OEMs, suppliers, and OSS communities to drive innovation. Government bodies can act as neutral grounds and trusted facilitators for fostering co-opetition and facilitating open dialogues in an otherwise conservative industry.
- **Educate on OSS**: Implement educational initiatives about the benefits and best practices of OSS for businesses, particularly in sectors like automotive. These initiatives should involve a wide rangey of stakeholders, including companies, industry bodies, policymakers, research funders, researchers, higher teaching institutions, innovation support organisations, and small and medium-sized companies.
- **Consider OSS as a Geopolitical Concern**: Take proactive steps to understand the geopolitical landscape of software and its implications for the industry. Adopt and support open technologies, including OSS, open standards, and open hardware, both in industry and government, to enhance regional sovereignty and global competitiveness.
- **Engage with Global OSS Sustainability Efforts**: Governments should engage in and encourage industry participation in global OSS sustainability efforts to ensure the longevity and support of OSS. Support may include diverse options such as funding critical projects, promoting OSS in public procurement, raising awareness and knowledge of the risks related to the global supply chain, and encouraging organisations to sustain their own upstream dependencies.