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THE POWER OF OPERATING SYSTEMS & MIDDLEWARE

Decoding the success formula for Software Defined Vehicle Transformation

The first global comparison and evaluation of OEMs, Tier-1 suppliers, and Tech-entrants based on their future strategies.

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01

INTRODUCTION

Today´s complex automotive ecosystem is facing a fundamental change when it comes to the topics of software and technology: The transition from an electronic, hardware component driven car architecture, towards a new architecture where the valuable differentiator lies within the software. The need to react to this change is seen amongst all players on the market – from traditional manufacturers (OEMs), and new players (Tesla, NIO, Rivian, etc.), to Tier-1 companies, technology/software providers and hyperscalers (Google, Apple, Mircosoft, etc.).

There are some OEMs that are interested in standards and believe that the middleware and operating system are not the key differentiators for the SW defined vehicle. They believe in the power of the ecosystem in terms of scalability, time to market, and integration complexity. They are therefore eager to participate in standards, standardization initiatives, and open platform approaches.

Other players may be seeing flexibility in building their middleware and OS and focusing more on integrating their legacy system/softwarethan they are willing to integrate with the ecosystem standards. Thus, they are not involved.

Nevertheless, a lot of companies joined consortia like COVESA, Catena-X, Eclipse, etc. because they want to be part of a standard and win insights regarding ecosystem integration and interfaces. They also don't want to be left out in case one of them sets the baseline for future developments. One of the most promising initiatives is SOAFEE, powered by ARM, with an increasing number of diverse players working together for one solution.

What is important to acknowledge within the strategy of the electric/electronic (E/E) architecture discussion is the increasing role of a standardized vehicle middleware and vehicle operating system(OS). Having a way of setting apart hardware from applications is critical to the deployment of a flexible software strategy and to work toward a truly software-defined vehicle vision.

The days of OEMs solely defining specifications, and Tier-1 suppliers delivering on these dictated specifications are approaching an end. Neither OEMs nor traditional Tier-1 suppliers can thoroughlyoutline the technology requirements of new systems since neither of them can afford to build and sustain the whole platformin isolation. A fully integrated ecosystem is vital in paving the path towardthis standard platform.

This study focuses on the EU and the US and aims to draw light on the topic of standardized SW platforms (Middleware and Vehicle OS) and the need for collaboration between key players to achieve such a standardized platform.

Capgemini Invent Automotive Market Unit performed the study in collaboration with ASIMI (Automotive Software Interfaces and Middleware Initiative), which was established by high-ranking, experienced members from the automotive environment from the Technical University of Munich.

Furthermore, to guarantee additional valuable insights, a range of eminent industry experts (from universities, OEMs, Tier-1s, and technology companies) were interviewed to identify adaptation needs and share their points of view about vehicle OS and middleware. The study incorporates a questionnaire and a qualitative interview, tailored to new challenges and changes in the vehicles' software-driven environment. From the interviews and the questionnaire, new insights could be gained, and emerging developments in the software-driven vehicles field could be substantiated.

02

NEXT GENERATION SDV VEHICLE SOFTWARE ARCHITECTURE

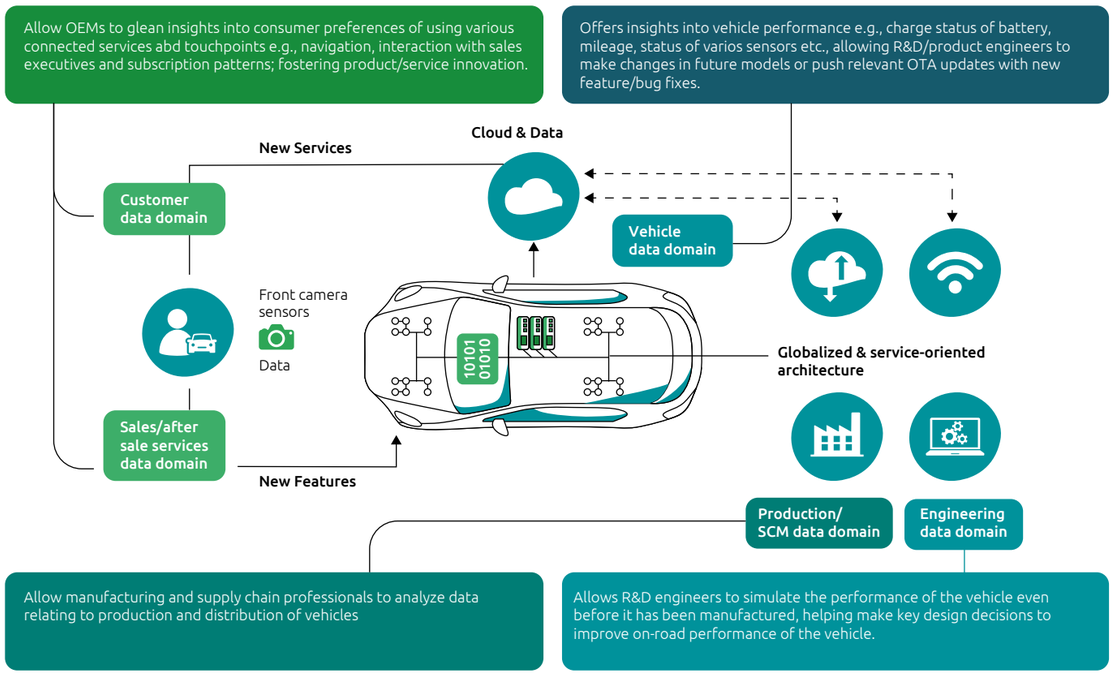
Considering the automotive ecosystem, one central shift can be observed: The hardware no longer functions as an innovation driver for vehicles. It has become evident that software and data are becoming more and more important. This leads to a changing role of hardware. It is no longer driving the function but becoming a part of the software and data platform.

This software-driven transformation will redefine the global automotive industry, creating the concept of the SDV "software-defined-vehicle" as the strategic driver for the automotive industry.

The powerful trends C.A.S.E. (connectivity – autonomous – shared – electrification) are reshaping customer experience and expectations. Furthermore, they are driving the OEMs to turn to software to address them.

Here, the "software-defined-vehicle" is a concept that describes a **vehicle whose differentiating features and values are primarily functionalities enabled by software**. This is a direct result of the current huge trans-formation wave of the automotive industry, from factories building products that are mainly hardware-based to software-centric products and mobility providers, with new perspectives of the vehicle as the "smart-phone on wheels" or the "data center on wheels".

Figure 1: Software and data enable transformation of OEMS' vehicles, systems, operations, and consumer-facing services



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2.1 Evolution of End-to-End Vehicle System Architecture

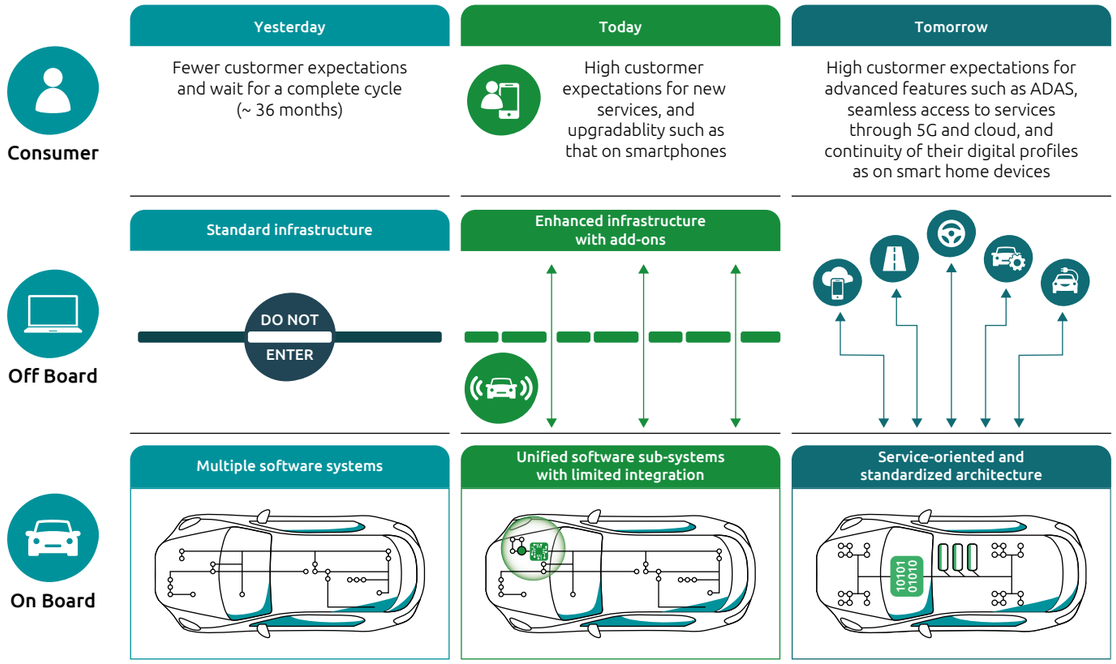
Cars have in the past been dominated by electronic control units (ECUs) that control very specific parts of the vehicle. These ECUs act independently and may amount to millions of lines of code. **93% of OEMs currently have a traditional vehicle architecture with independent controls for each vehicle function**. With the additional complexity of functions such as advanced driver assistance systems (ADAS), edge computing, and vehicle safety, we are moving fast towards an automotive world where the growing complexity of vehicle architecture is likely to massively increase vehicle development costs and time for hardware and associated software, while also increasing warranty and recall costs if not managed well.

A service-oriented architecture is therefore paramount to the success of a software-driven transformation of the vehicle. In the service-oriented approach, every module – for instance, electronic control units that help operate various components of the car (such as windscreen wipers, windows, air conditioning, etc.) – functions by means of a service that can be invoked via APIs (application programming interfaces).

It allows a more granular and simplified operation of various electronics units of the car by means of software. This approach can be further simplified if various ECUs within each domain (infotainment, body, engine) can collaborate with other domains via a central computing unit.

This transformation will accelerate the trend of a vehicle running on a single platform for the operation of the car, instead of the current situation, in which there are multiple and independently working pieces of software. The service-oriented architecture will reduce this complexity and ease the engineering process by introducing a "middleware" layer that can be developed according to industry standards. OEMs must pursue this standardization at a fast pace as it is critical to harnessing the full potential of software.

Figure 2: Evolution of end-to-end vehicle system architectureSource: Capgemini Research Institute Analysis



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2.2 The Rising Importance of Collaboration on Middleware

The set of strategic actions for OEMs includes a plan to keep the cost of ever-growing HW and SW development under control, and to establish a more agile, cross-functional development organization. Cross-functionality would benefit tier-1 suppliers too, as it would lead to an active partnering with OEMs to define their E/E architecture. Tier-2 suppliers will want to further specialize and scale within an attractive niche to thrive, even as many components become a commodity.

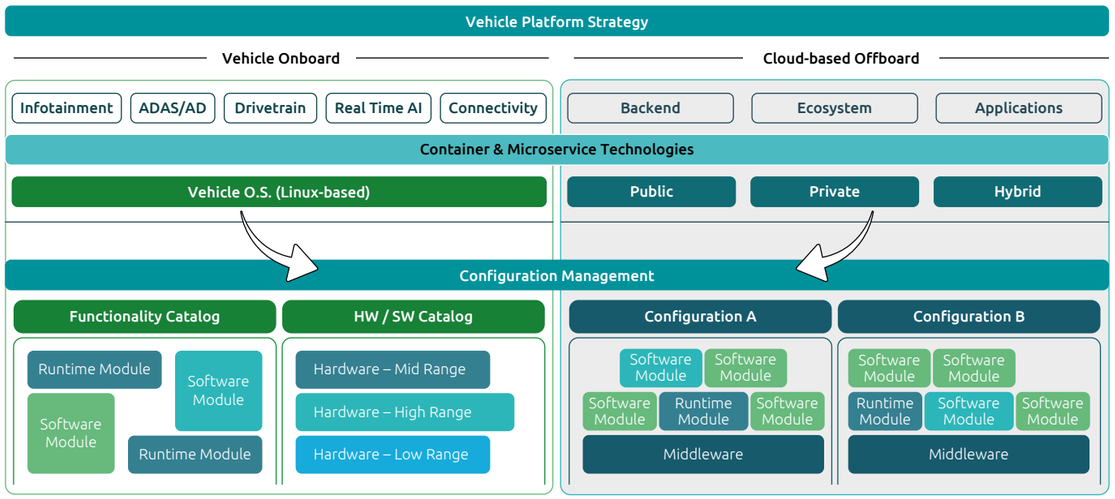
The use of open-source platforms and standardization of product offerings would likely result in reduced cost of application and firmware development. The latest technological advancements in commercial aspects of automotive software have pushed consumers as well as OEMs to, among other things, increase their focus on automotive infotainment systems and these manufacturers are contending based on the software or OS that is used in these systems. At present, vehicles support operating system platforms such as Windows CE, Android, Apple OS, QNX, and Linux-based OS. Furthermore, the adoption of ADAS features in vehicles and the rapid adoption of connected vehicles have made actors aware of the growing need for standardized SW platforms.

Figure 3 shows another aspect, which is that the vehicle architecture must be considered from chip to cloud, rather than each in isolation, or in separate "onboard" vs "offboard" silos. An end-to-end architecture is needed that fulfils the needs of superior performance at the vehicle level without compromising vehicle safety, data privacy, or cybersecurity.

As the architecture evolves, several computing requirements of the vehicle (such as infotainment, and non-safety-critical services) will be completely offloaded to the cloud to take advantage of virtually unlimited storage and computing resources.

That will happen either on-premises at the OEM's site or on private/public clouds operated by cloud service providers. On the other hand, more safety-critical elements, edge computing use cases, and autonomous/ADAS system software will continue to be served by the vehicle's onboard computers. **Seamless connectivity via 5G will provide new use cases such as augmented reality enabled displays.**

Figure 3: Platform Strategy Requires Smart Configuration Management to Meet Functionality and Scalability Requirements



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03

SHORT- AND LONG-TERM MIDDLEWARE STRATEGIES

Developing the core SW functionality is the first step in the development process. The important sub-sequent processes are customization for the specific vehicle platform, followed by validation, verification, and integration. After the start of production (SOP), there is the OTA and the maintenance of the SW, which would be virtually impossible if standard middleware and O.S were handling the abstraction between the different variants and the flow of additional software-enabled features added on a weekly or monthly basis to the car.

"The rising complexity of SW and electronics systems in the car required for AD (autonomous driving) and other functionalities of the future will make it impossible for a single player to develop and maintain the system end to end"- says Frank Weber, BMW Board Member. "It is a dead end for OEMs to each develop their operating system."

OEMs should increase their competencies along the full technology stack – i.e., across the elements of middleware, OS, HW abstraction layer, and cloud computing. This increased capacity will allow OEMs to specify the different technology stack elements to enable HW-SW separation and follow a best-of-breed sourcing approach. Create a cross-functional development organization by breaking up their domain silos in the development organization and moving decision- making power for SW and E/E architecture to central departments. OEMs can speed up time to market for new E/E architecture definition and sourcing decisions. Tier-1 suppliers must react to the OEM's increased capabilities and changed sourcing behaviors. To do so, Tier-1 suppliers can redefine their SW and E/E strategy through three strategic moves:

- Jointly define the E/E architecture by becoming a thought partner; Tier-1 suppliers can work with OEMs to co-create a vision for the future E/E architecture and together shape the requirements.
- **Investing in SW development and integration capabilities, Tier-1 suppliers can become significant players in this growth area by building the necessary SW-related capabilities**. They can also create a dedicated development, integration, and validation tool chain to enable continuous integration and development.
- Tier-1 suppliers can seek to establish new partnerships or join existing ecosystems aiming to create standards and open platforms. Like what AUTOSAR did 15 years ago.

In any comprehensive make-or-buy strategy, companies should use standard and open-source building blocks, since these can provide a huge advantage during software development. Companies will need to establish clear rules and processes for using open-source blocks, however, and pay careful attention to li-censing, liability, and maintenance issues. Often, OEMs and suppliers will need a formal legal agreement to incorporate open-source components into a product.

Like in any make-or-buy strategy, OEMs will keep production of differentiating features in-house while out-sourcing development of noncritical software to other providers or contractors.

Among other benefits, this approach will significantly reduce the demand for software talent.

Finally, automakers should develop strategic partnerships and identify ecosystem collaborators, since these connections allow companies to learn from each other while expediting development and keeping costs low. Co-development also reduces risks related to late market entry.

> "It is a [dead end] for OEMs to each develop their own operating system."
>
> **Frank Weber,**
> BMW Board Member

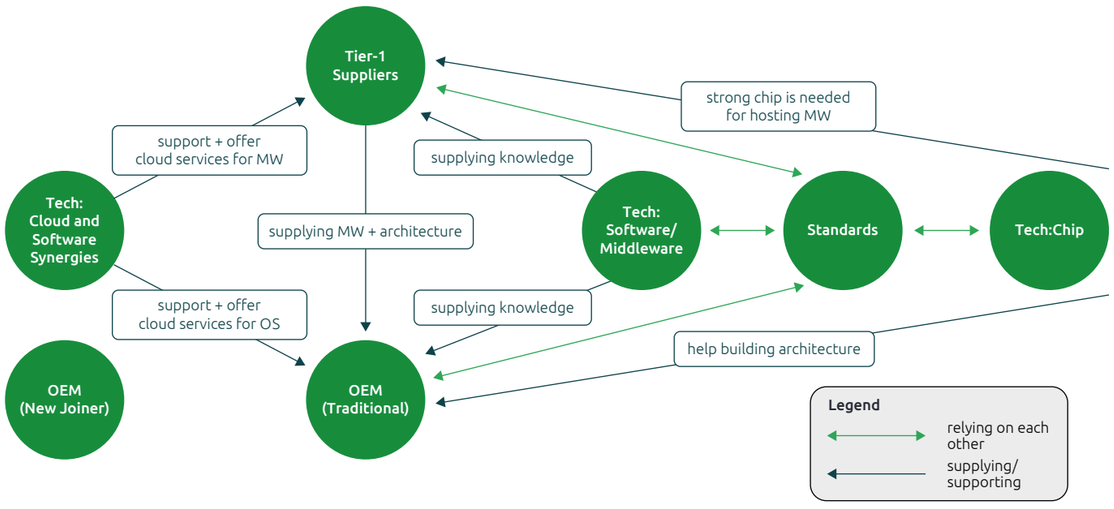
3.1 Near Future Market Overview (Current – 2025)

A market analysis has been conducted that took into consideration several different groups along the supply chain – including companies from all over the world. Since the automotive industry is changing, and software aspects are becoming more and more relevant, technology companies were taken into consideration as well. Furthermore, current standards will inevitably change, therefore they were also taken into a review. The Excel sheet in chapter 5 shows all considered groups and players.

Patterns from the market analysis are drawn to show the connections between the different key player groups:

- OEMs rely on the infrastructure (cloud services) and software know-how from companies like Amazon, Google, and Microsoft, to support them.
- OEMs outsourced their SW competencies to Tier-1 suppliers; therefore, these have a broad SW know-how. Their services are shifting towards offering middleware solutions and the creation of E/E architectures.
- Chip manufacturers lead the SW architecture on the ADAS/AD (Autonomous driving) domain.
- Tier-1 suppliers need reliable computer chips to implement a cross domain functioning middleware.
- Current standards are used for the implementation of middleware which is focused on an ECU level. The most common standard is AUTOSAR, whereas AUTOSAR adaptive covers domain level ex. Infotainment.
- new players (OEMs) are not involved in standards because their architecture is created on a green field and built-in isolation from the existing automotive market partnerships.

Figure 4: General collaborations between groups along the supply chain



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> “Automakers should develop strategic partnerships and identify ecosystem collaborators.”

Collaboration Strategies of Different Players

Some OEMs are developing their OS by themselves (BMW, Toyota, Tesla, Rivian,…), and some have formed alliances with Tier-1 suppliers (Mercedes Benz, VW,…) or other technology/software companies (Stellantis, Volvo) to benefit from their experiences. Furthermore, some OEMs are heavily investing in creating their own “Software”-Units for building OS. Mercedes has created a Unit with multiple Software developers on its site in Sindelfingen. Toyota has founded its own software start-up called Woven and VW already has its own software subcompany Cariad, that is focused on software development which focuses on middleware and OS development.

Apart from the OS itself, another challenge is the development of the middleware. As mentioned before, Tier-1 suppliers are the key players for developing a futureproof middleware, that can function as one centralized middleware solution. Most prominent collaborations and alliances are with companies from these areas: Computer chip manufacturers, software houses and cloud services. All three major German tier-1 suppliers (Bosch, Continental, ZF) collaborate with one or more computer chip manufacturers (Nvidia & Qualcomm). TTTech Auto on the other hand has a collaboration with Infineon on fail-operational electronic architecture for highly automated driving. TTTech Auto’s “Motionwise” middleware, a safety software platform for highly automated driving have been in series production for VW Group, SAIC, Hyundai, and others for several years.

Other Tier-1s are weighing similar partnership models with Tech companies specially for infotainment and automated driving domains.

These collaborations are important because the evolution towards centralized domains/middleware needs powerful computer chips to support demanding workloads. Another type of collaboration they have in common is working with a cloud provider. Bosch and ZF are working with Microsoft, to benefit from their Azur Cloud. In addition to the cloud benefits which Continental is gaining from Amazon (AWS), their collaboration also includes the creation of a framework which allows for the integration of Alexa into cars. This is a great benefit for OEMs since they don’t have to develop their own AI-Algorithm for voice control.

Looking at the strategies of these three Tier-1 suppliers, the one from Bosch is slightly different. Whereas Continental and ZF formed alliances with APEX and KPIT (both software companies) to accelerate their software development process, Bosch is developing middleware software using its subsidiary ETAS (100% owned by Bosch) without another software company. One reason for the deviating strategy from Bosch is that they have the most software developers of all Tier-1 suppliers.

Tier-1 suppliers are the key players for developing a futureproof middleware.

Some OEMs are heavily investing in creating their own “Software”-Units for building OS.

Different Standards and their Effects on the Industry

In the previous section, the ambitions of different market players for collaborations were presented. The goal is to bundle knowledge and develop a holistic baseline for building SDV. To achieve this, several market players acted and formed alliances besides their partnerships, allowing them to create standards that minimize the programming effort to make profitable SDVs.

Standards harmonize interfaces, thereby decreasing collaboration boundaries, increasing knowledge, and encouraging diverse cooperation. The participants' expertise and manpower help identify new potentials, features, and solutions. Standalone solutions don't have the resources to unlock a centralized middleware's potential. Therefore, market players teamed up with consortia or found development partnerships to create a standard as a fundamental base to realize the potential of a centralized middleware that benefits the customer.

Developing different standards lowers the benefits of the initially described standard. To understand the current situation, presenting some of their standards, including their objective, standardization strategy, and the participating market players:

- AUTOSAR[1] developed the most common standard for intelligent mobility solutions. Their standard focuses on modification flexibility, scalability, and the complexity caused by increasing the functional scope. AUTOSAR aims to accelerate the development and maintenance process and to re-use the software, thereby reducing the cost of software systems. By developing a platform, AUTOSAR focuses on a common base every user can adapt and use independently. As one of the most common standards for middleware, AUTOSAR is now developing itsstandard further to the new AUTOSAR Adaptive, which has a centralized middleware in scope. AUTOSAR is a worldwide developing partnership with several players from different groups along the supply chain. Figure 4 presents the market players considered in this study: "Table of all players included in the market research". The following organizations are part of the development partnership of AUTOSAR: BMW, VW, Mercedes, Volvo, Stellantis, Ford, Toyota, Great Wall Mo-tors, Bosch, Continental, ZF, Magna, Nvidia, Intel, Siemens, Aptiv, Vector, KPIT, and QNX.

> "Standalone solutions don't have the resources to unlock the potentials for a centralized middleware possesses."

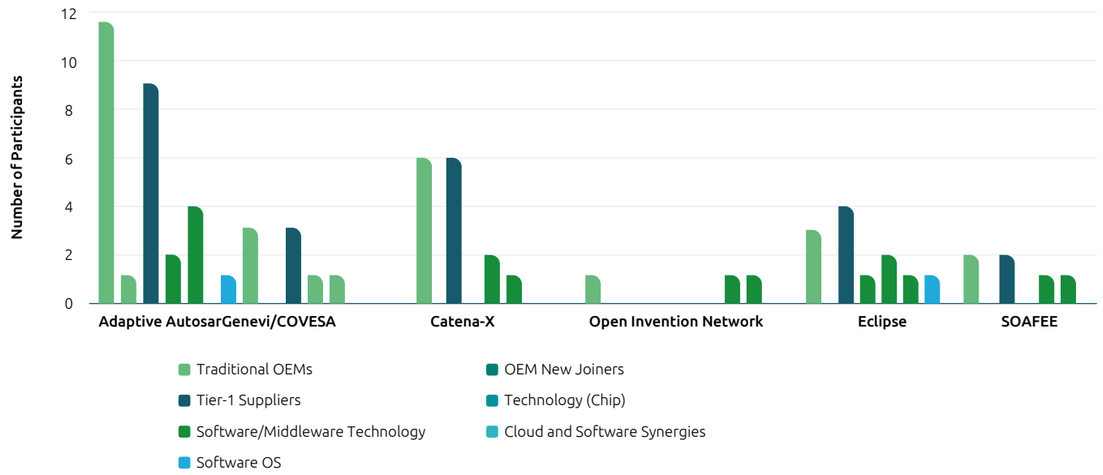
- Another standard is the connected vehicle systems alliance (COVESA)[2]. COVESA includes like-minded market players who want to realize the potential of connected vehicle systems. The standard focuses on innovative technologies like in-vehicle, on-edge, in-cloud services, interfaces, and dataexchange, to create a more diverse, sustainable, and integrated mobility ecosystem. Therefore, COVESA is developing open software standards to be used by all participants of the consortium. As a founding partner of the consortium, BMW is heavily interested in the results of COVESA. Further, consortium partners are Ford, Bosch, Nvidia, Aptiv, and other companies that are not within the scope of this study.
- As a third standard, Catena-X[3] can be mentioned. Although it is not an onboard standard, it is meant to be an alliance for safe and standardized data transfer. Catena-X embodies the belief that innovation can only be caused by collaboration. Its objective is to develop data transfer technologies to enable cross-sector communication and create a global network to connect suppliers with users.
- Catena-X follows the standardization strategy of an open software standard to enable further improvements. As it is a consortium, several companies use the results of developing the Catena-X standard. This consortium includes BMW, VW, Mercedes, Volvo, Stellantis, Ford, Bosch, ZF, Magna, Siemens, and Red Hat.
- A fourth standard, and the most promising one in our view is the Scalable Open Architecture for Embedded Edge (SOAFEE)[4] project. This is an industry-led collaboration defined by automakers, semi-conductor suppliers, cloud technology leaders, open source and independent software vendors. The initiative intends to deliver a cloud-native architecture enhanced for mixed-criticality automotive applications with corresponding open-source reference implementations to enable commercial and non-commercial offerings. SOAFEE builds on these specifications and standards with a reference framework to standardize key non-differentiating middle-layers,such as the hypervisor, operating system, container runtime, and hardware abstraction layers.
- Additionally, there are other standards like the Open Invention Network (OIN)[5] or the Eclipse Foundation[6]. Both follow different standardization strategies but have fewer supporters than the presented ones. Only Toyota, Red Hat and Google invest in OIN development while ZF, Red Hat and Microsoft support the Eclipse Foundation. OIN focuses on providing the standard as an open-source, while the Eclipse Foundation take an open platform approach.

> "One of the most promising standards is the Scalable Open Architecture for Embedded Edge (SOAFEE) project."

[1] *https://www.autosar.org/*
[2] *https://www.covesa.global/*
[3] *https://catena-x.net/en/*
[4] *https://soafee.io/*
[5] *https://openinventionnetwork.com/*
[6] *https://www.eclipse.org/org/foundation/*

After introducing different standards, the study will now focus on analyzing the participation of the different groups along the supply chain in standards.

Figure 5: **Adaptation of most popular standards by key players**



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- **Almost all OEMs are participating in AUTOSAR and Catena-X, making these two standards the most relevant**. A standard must be distributed to be relevant, which is why many big players like OEMs must be participants. The high acceptance of AUTOSAR adaptive (in-vehicle) and Catena-X (offboard) by OEMs also shows that OEMs are eager to establish standardized solutions. There is a possibility for standardized solutions to increase the number of potential suppliers, thereby reducing the dependency on specific suppliers. It can also highlight that OEMs understood the limits of their resources in comparison to the resources needed to develop SDV.
- **On the contrary, the new OEM players do not participate in standards. A reason could be that the new market players try to develop their own solutions to outperform the standards and create a unique selling proposition**. This is a risky strategic decision. If the performance of their own solution is good, then their market share will increase. But if it isn't, the gap between OEMs participating in alliances and the new players will increase.
- Established Tier-1 suppliers command the same positioning as OEMs. These suppliers are participating in AUTOSAR and Catena-X. This behavior may indicate the historical connection between the OEMs and Tier-1 suppliers.
- In the case of the technology companies providing chips, as well as software and middleware, there is no observable trend. Most of these companies are part of AUTOSAR. Further participationin other standards are exists but does not follow any specific trend. It seems like the chip supplier operates independently from general standards and doesn't participate much in other standards. Software technology companies are mostly not involved in the common standards such as AUTOSAR and Catena X. If participation in standards does exist, then usually in the smaller standards. This could emphasize the power and independence these tech giants like Amazon, Google and Microsoft have. They participate in selected and more specific standards.
- Lastly, almost all companies that provide software operating systems are not participating in standards, with few exceptions like QNX. This might be due to the flexibility and independence of their products regarding standards.

> "Standards harmonize interfaces, thereby reducing the boundaries to collaborate, increase knowledge, and encourage diverse cooperation."

Summary

Ecosystem development between OEMs and suppliers is expected to become not just prevalent but necessary. In addition, tech-native companies have already entered this space. Sustaining this eco-development is only possible when hardware (HW) and software (SW) sourcing becomes more separate. This separation would disturb the existing ecosystemby reducing entry barriers.

The days of OEMs solely defining specifications and Tier-1 suppliers delivering on these dictated specifications are approaching an end. Neither OEMs nor traditional Tier-1 suppliers can completely outline the technology requirements of new systems since neither can afford to build and sustain the whole platform in isolation. A fully integrated ecosystem is vital in paving the path toward this standard platform.

3.2 Future Market Outlook (After 2025)

Due to the complexity of SDV, holistic solutions are not expected of single players. Defining ecosystems based on clear standards is fundamental to allowing all players along the supply chain to participate so that others can use their solutions.

Using the knowledge of each player is a key approach to deal with the complexity in SDV.

Smartphone industry is an example. Besides Apple, no smartphone manufacturer is creating their own operating systems or applications. This is mainly due to their success in building a complete ecosystem that complements and integrates the various components of the digital experience of their targeted clients. The operating system embodies the standard that manufacturers and app developers can rely on to create a huge portfolio for the customer in a profitable way.

In the automobile industry, the company trying to create an individual solution and an ecosystem is Tesla (Apple in thiscontext), while many others are joining standards and partnerships to bundle resources.

The next years will show which further measures are necessary to provide absolute safety and which standard will prevail and set the baseline for future development. AUTOSAR set a promising baseline for middleware on an ECU level. Whether AUTOSAR Adaptive will be the future standard for a single middleware solution and whether it can cope with the required speed and flexibility, will be seen in the next years. For the moment, there is no standard established among all players.

Possible Development Scenarios for the Automotive Industry

The next few paragraphs will show possible scenarios that could impact the industry if not standardized.

The first possible outcome is that while multiple OEMs (traditional and new players) are currently developing their own OS, one will advance. If one OS advances, there will be two possibilities for the competitors. Either they implement the OS into their cars or invest even more resources to improve their own. For the OEM with the advanced OS, licensing would have great benefits through generating an additional, constant income stream, while preventing others from further developing competing OSs. This idea is based on the statement Tesla has given regarding the possibility of licensing their leading autonomous driving system to other OEMs in the future. Based on the market analysis, and by comparing the ambitions of the OEMs regarding OSs, possible candidates for creating an advanced OS are Tesla, and the Stellantis-Amazon Partnership. Tesla is currently leading the software implementation and features within the industry and their whole company is operating more like a software company rather than a tradition OEM. Stellantis has a collaboration with Amazon based on an open software-defined platform that seamlessly integrates with customers' digital lives.

> "The next years will show which standard will prevail and set the baseline for future development."

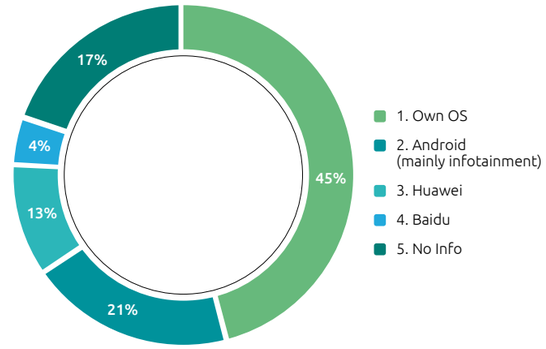
The graph shows that 46% of the OEM's are building their own O.S, while about 21% of the OEM's use the Android-based operating system by Google, which is currently mainly used for the infotainment but moving towards applying a safety certified version of Android in other domains like Body & Chassis.

To the licensing idea from Tesla, one further scenario for the future could be that certain applications like autonomous driving, infotainment, voice control, implementation of AR and many more will be delivered to the whole industry by different players, who are advanced in this field. An example is Nvidia for the ADAS/AD domain. This perspective further underlines the importance of standardized middleware to combine all these different software solutions.

Having talked about Android Automotive brings up the next possible scenario. Since all the big tech companies like Google, Amazon, and Microsoft are currently mainly acting in a supporting role by supplying their clouds and other software knowledge, the fear of them taking over the automotive industry and making the OEMs irrelevant hasn't become a reality yet. However, Google, behind Android Automotive, could try to leverage their position in the infotainment segment and expand to other areas by using their enormous resources and software experience.

This last scenario is probably the least likely. However, it has been seen in the past that entering new markets has become more common since a core skill to master for this undertaking is to be able to control the supply chain. That is an approach which Amazon especially has proven to be able to do. This becomes even more relevant due to the movement towards electric vehicles while the hardware complexity is decreasing at the same time.

Figure 6: **Usage of Operating Systems across OEM Key Players**



Source: Capgemini Research Institute Analysis. © Capgemini Invent 2022

04

EXPERTS PERSPECTIVES

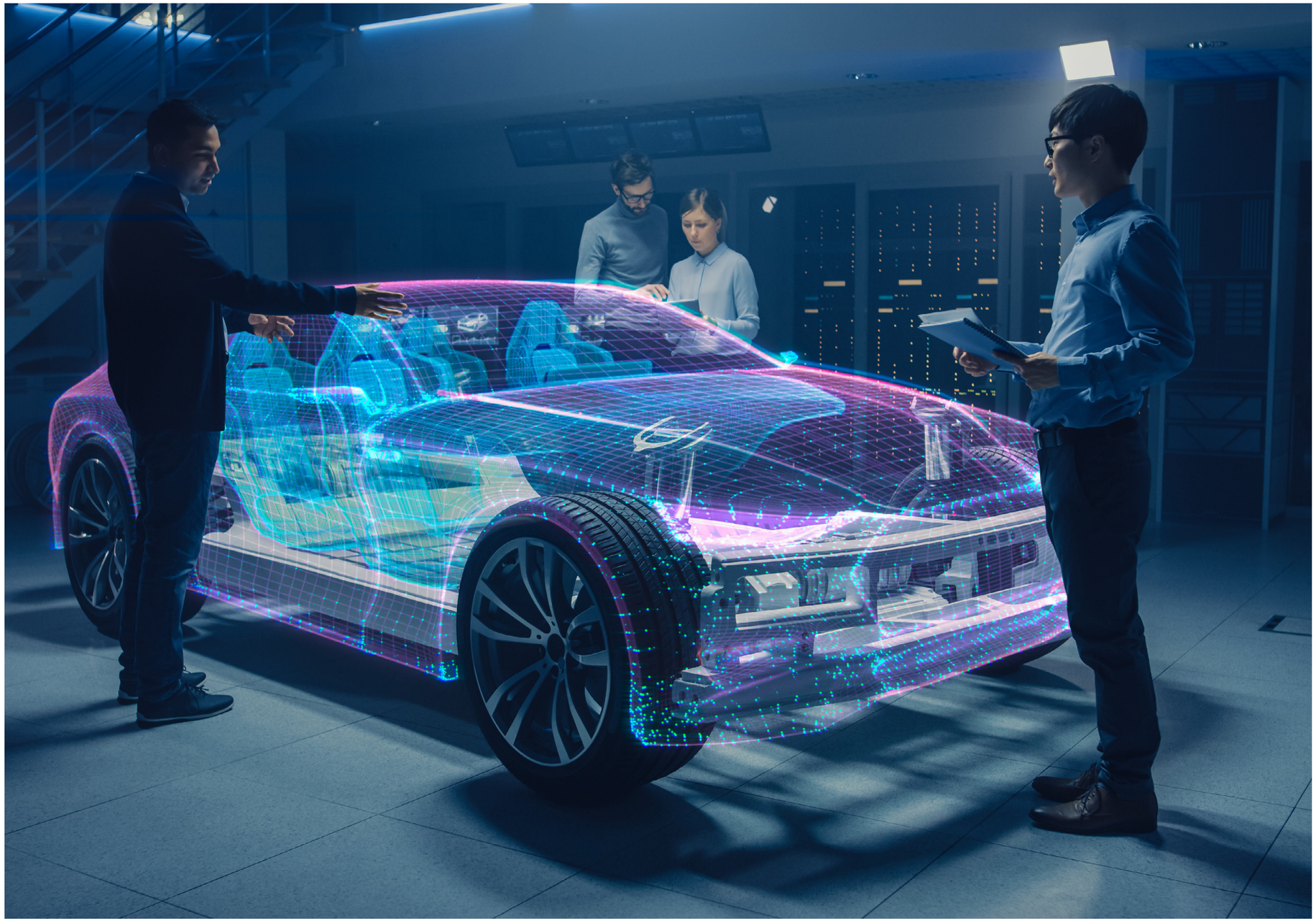
This study was done in cooperation with the Automotive Software Interface & Middleware Initiative (ASIMI), founded by:

- Elmar Frickenstein, former senior vice president of fully automated driving and electric and electronic for BMW group.
- Uwe Michael, former vice president of electric/electronics at Dr. Ing. h.c. F. Porsche AG and has led the electronics development at Porsche for more than eighteen years.
- Alois Knoll, the former Chief Digitalization Officer at Siemens ITS (Intelligent Traffic Systems), heading the Department of Informatics at the Technical University of Munich (TUM).

Through the questionnaire they developed, the opinions and beliefs of several high-ranking industry experts from traditional and new market player OEMs, Tier 1 suppliers, and technology firms were captured in 2021/22.

The survey consists of questions about the **challenges, benefits, technological trends, and implications ofthe topic of automotive middleware to explore and compare different expert perspectives**. In total, more than 55 subject matter and industry experts took part in this study. In the following subchapters, the key findings of the ASIMI survey are aggregated and visualized, and the ASIMI expert opinion are additionally highlighted in cursive letters.

> “The majority of OEMs regards Over-The-Air updates as the most impactful trend that will become a standard requirement.”



4.1 – Industry Transformation

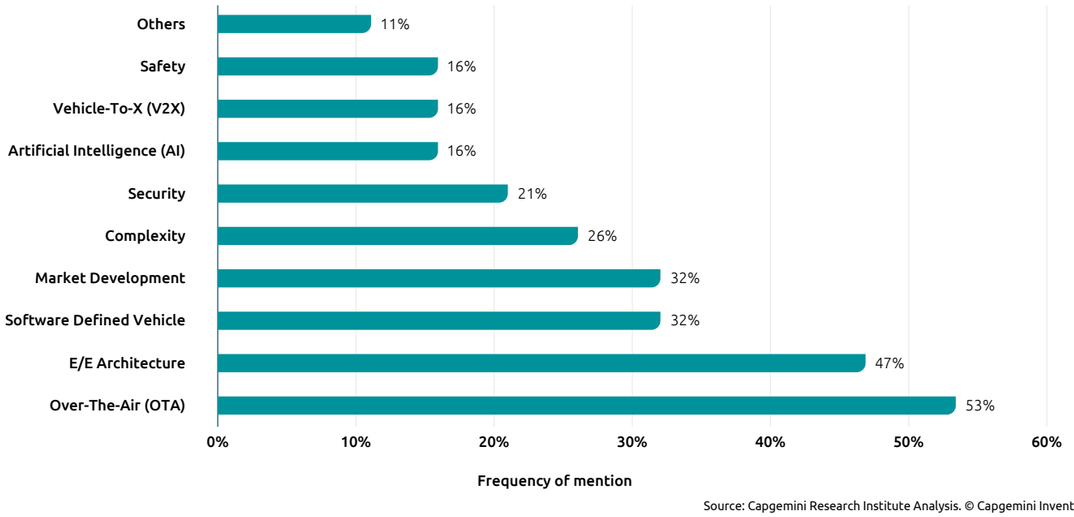
What do you see as the most important current trends shaping hardware and software vehicle architectures, (i.e., centralization, AI-support, energy awareness, over-the-air update, plug & play)?

Among the respondents, there is broad agreement that the automotive industry is undergoing multiple significant paradigm shifts. When asked about the trends shaping hardware and software vehicle architectures, most experts believe that a few specific trends are the driving forces behind this.

The majority (53%) regard Over-The-Air (OTA) updates as the most impactful trend that will become a standard requirement because it is the most visible and beneficial feature for end customers. It not only preserves but can also increase a vehicle's value over the life cycle through the ability to acquire new features from updates, AI applications, and new services. This connectivity is further accelerated by increasing 5G availability. However, it does require the further decoupling of vehicle hardware and software.

Around half of the respondents (47%) share the view that the electrical/electronic (E/E) architecture is changing rapidly and that the shift toward Service-Oriented Architecture (SOA) is a major topic. Related, dominant ideas are centralization, domain controllers and zonal architectures, that will create more functional flexibility. Some experts stress that High Performance Computers (HPCs) are likely to lead to a standardized functionality with a corresponding architecture that evolves incrementally to make components both 'plug and play' and future proof (e.g., Elektrobit, KPIT, Hella).

Figure 7: Trends Shaping HW and SW vehicle architecture



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How do these architecture trends impact your business?

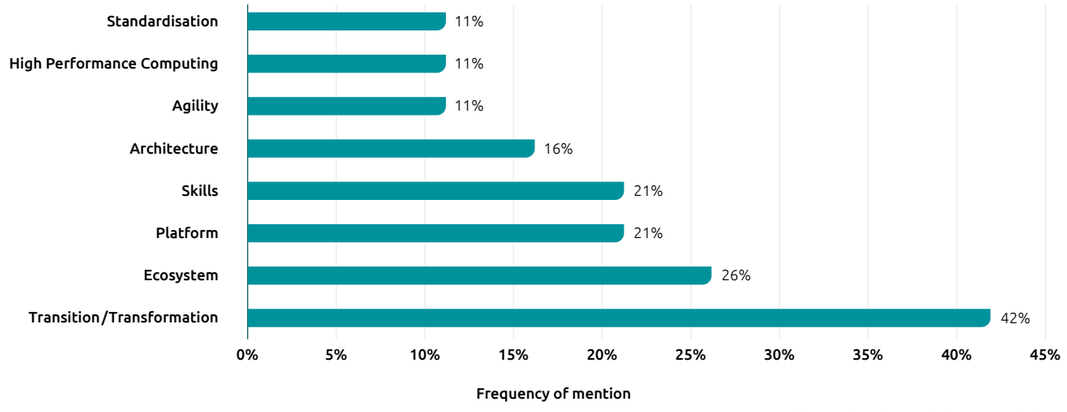
The before-mentioned architecture trends significantly impact on the business of all key players in the automotive industry. For example, OEMs face an increased need for software and system experts to overcome the challenge of transitioning from old to new architectures (Volkswagen). Furthermore, they rely more on cooperation models with Tier 1/2 and SW service providers.

One Tier 1 supplier, Continental, estimates that prices do not yet cover the additional R&D effort and that they will have to adapt their organizational structures to facilitate the necessary large projects around developming new software, such as middleware.

On the other hand, some technology providers see these architecture trends as an opportunity to extend and grow software product and service (DevOps) business (Elektrobit, QNX, Vektor,…). They also grow their influence as they can re-use principles from other markets (e.g., mobile phone, server market, etc.).

In conclusion, the ongoing paradigm shifts in vehicle architecture impact all automotive players in some way, and they need to be addressed. The figure below lists different dimensions of this impact on automotive businesses, and their counted frequency.

Figure 8: Impact on business



Source: Capgemini Research Institute Analysis. © Capgemini Invent 2022

In your opinion, what are the benefits you hope to gain from these architecture trends?

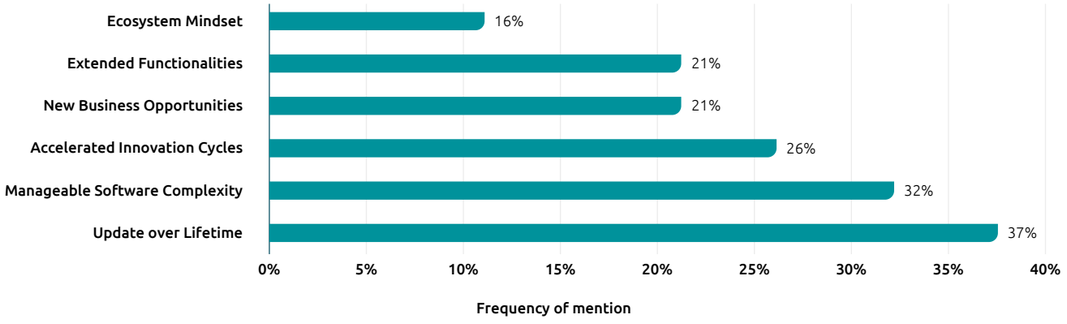
There is a shared understanding in the industry that the new architecture trends also have beneficial implications for the key players. Non-OEMs could get direct access to end consumers, which opens new business opportunities and changes the current role of suppliers. APTIV mentions the possibility of monetizing features directly from end consumers rather than OEMs as one scenario.

In addition, many experts **(37%) stress the possible gains from introducing updates over time through OTA technology. This would allow OEMs and other players to keep vehicle software up to date, introduce new features, and ensure safety, security, and compatibility with consumer systems over the lifetime of a car**.

Furthermore, software complexity management is expected to become easier with this new architecture, ultimately lowering development and maintenance costs through optimized software re-use of and other cost optimizations (Elektrobit). Consequently, standardization and harmonization of architectures in companies can accelerate innovation cycles (Arm).

Many of the expected gains mentioned can be grouped into six categories as in the below figure.

Figure 9: Expected beneficial gains



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What are the major challenges associated with these architecture trends?

While the automotive experts acknowledge potential benefits stemming from changing architecture trends, they see themselves confronted with a variety of complex challenges that need to be addressed. Although different industry key players have different perspectives, most face the same challenges.

The main challenges lie in four domains. The first is connectivity in general. The second and third are advancing towards autonomous driving and data sharing. The final challenge is electrification, in which, from the expert opinion, the German car industry has made the most advances thus far.

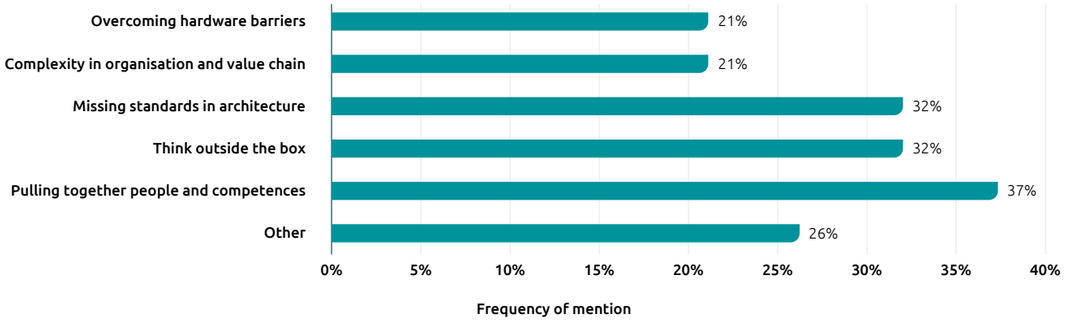
More than a third of respondents mention a **lack of competencies (e.g., software, systems engineering) and organizational barriers**. They state that to succeed, relevant competencies and people must be pulled together. **A lack of industry-wide standards for hardware (e.g., vehicle architecture) and software architecture with open APIs** is mentioned (mentioned by 32% of experts).

To enable mutually compatible solutions, companies must strive for more standardization. By using modern software engineering methods and fostering a solid development experience, scalable architecture can be developed, and enhanced developer productivity be enabled.

Other main challenges mentioned for OEMs in Germany are creating a scalable ecosystem and finding a way to add value to the end customer. “If you have achieved the operating system middleware, you end up with the question of how to create an ecosystem. Because you are at a point where you connect your operating system middleware with the cloud, send the data to the cloud, and create value for an end customer. (..), You will lose out if this ecosystem is only usable for one OEM. So, the question is – who will be able to build a scalable ecosystem?” In our experts´ view, this is unlikely to be done by Tier-1 suppliers focused on serving a specific niche.

30% of questioned experts advise key players to think about establishing an ecosystem, and deep vertical integration instead of working with many suppliers, investing in platforms, and collaboration between OEMs. Mindsets, processes and methods from the smartphone industry are necessary to overcome the before-mentioned challenges.

Figure 10: Challenges associated with architecture trends



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What are the major challenges associated with these architecture trends?

Keeping up with American and Chinese competitors was another challenge the interviewed experts saw as central. In their view, the players in the U.S and China are pursuing connectivity autonomy and sharing, whereas German producers don't, or at least not to the same extent. Additionally, the IT industry is trying to capture more and more segments of the car manufacturing industry. They have a lot of innovative potential, capital influx and an expertise in software that is difficult to acquire for OEMs. Even though they offer the possibility of working together, this can negatively affect OEMs on the long run. The danger remains that partnerships with OEMs end up working in terms of the technology industry, which makes decisions and degrades the auto industry to mere mechanical enablers while the higher profit margins remain with the software producers. To achieve this, tech companies often pursue a lock-in strategy. Tech companies develop software stacks that are only usable in combination with their other systems, forcing OEMs to buy all of them. The experts we interviewed think that the tech industry is goal oriented, starting with infotainment and acquiring different software applications step by step. "The OEMs risk becoming to cars what Nokia is to phones." The only way this can be avoided is to find partners who don't plan on targeting the same market segment.

4.2 Ecosystem

How would you establish technology partnerships to accelerate the path to those product realizations?

The survey participants broadly agree on the strategic importance of partnerships. The answers of the participants confirm the findings stated in chapter 3. As the future of the industry is increasingly relying on successful integration of software, profound knowledge how to drive large software projects and software re-use is essential for the ecosystems.

APEX AI proposes to work with "open, available, proven software architecture and APIs" as a foundation of cooperation.

AUDI emphasizes on partnerships by saying: "With CARIAD, Volkswagen Group's software company, Audi is moving full speed ahead with the introduction of automated driving technology and TTTech Auto is a key partner along the way."

> "The main thing one has to understand is that trying to control the entire system is sometimes detrimental and can hinder adoption."

With the challenges of cooperation, Realthingks[7] states, "If those problems are not solved, each project re-invents the wheel again and that will not be sustainable in terms of cost, talent and time" and KPIT adds "One company may not be able to do it". Aptiv further emphasizes that "The main thing that one has to understand is that trying to control the entire system is sometimes very detrimental and can hinder adoption." Prosperous collaborations, e.g., between European automotive ecosystems, will be the key to effectively counter more advanced players like Tesla. Continental further proposes financial support from the European Union to respect such commitment.

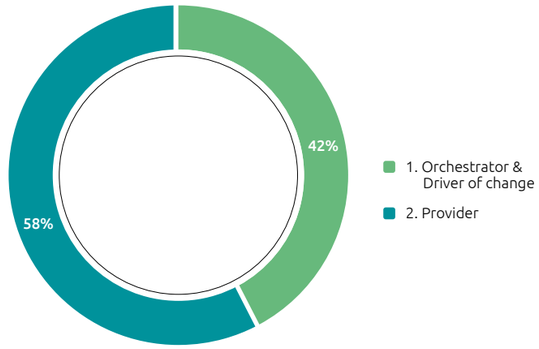
How do you see your own role during the upcoming changes?

Regarding the own role during the upcoming changes, two overarching functions emerge from the answers of the participants. Half of the participants (58%) assess themselves the role of a provider, whereas 42% envision their role as Orchestrator, that is an active driver of the change. Particularly, traditional OEMs like VW, Renault and Ford adopt the leading role in this question. In accordance, VW states "We are one of the drivers of the change in the market - we determine the new architecture with the help of relevant contributors."

Traditional suppliers like Hella describe their vision as "supporting the change collaboratively with old and new partners" and explain, "We have established and maintained leadership positions throughout our existence, and we expect to continue doing this."

A detailed overview can be found in the appendix.

Figure 11: Self-assessment concerning future role



Source: Capgemini Research Institute Analysis. © Capgemini Invent 2022

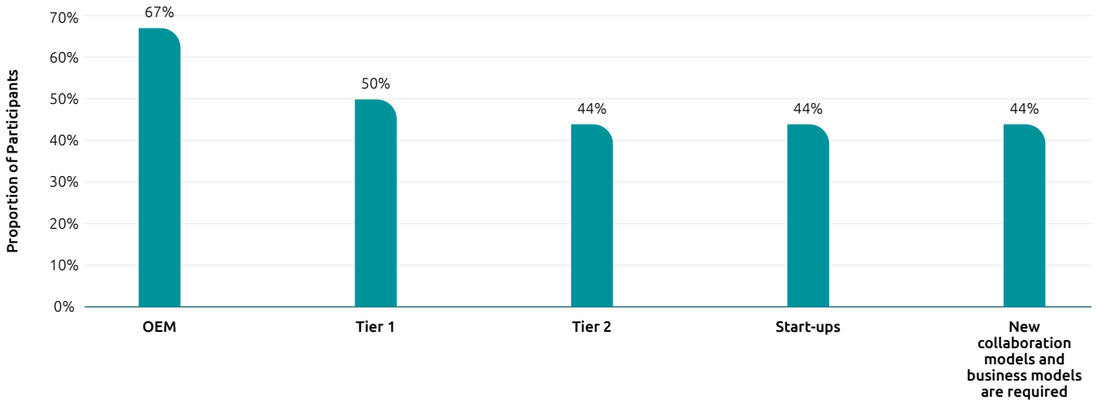
[7] *https://www.realthingks.com/*

Which value chain structure (OEM, T1, T2, startups…) do you consider relevant in support of the realization of the architecture trends?

Most survey participants also assign OEMs a key role and central responsibility in organizing an effective value chain structure to reach their goals. This is in accordance with the leading role OEMs assigned in the previous questions. Moreover, the traditional OEMS, such as VW, Ford, and Renault, also see themselves as the architects of a future structure of value chains.

Furthermore, the responses indicate that most experts believe that the current players will continue to play a role in the future architecture of value chains. Underlining this, Aptiv states, "All are important and should play a role in the overall solution. Excluding one party will have long-term effects on the quality of the system and the overall cost." In contrast, some voices call for a renewal of the traditional approach (44%). KPIT expects the present liability structure to hinder the development, as OEMs cannot adapt properly to new needs because of legal structures. APEX AI states that the former structure becomes less important, as cooperation increasingly becomes more transitive and hence skips traditional hierarchies.

Figure 12: **Responses concerning participation of traditional players in future value chains future value chains**



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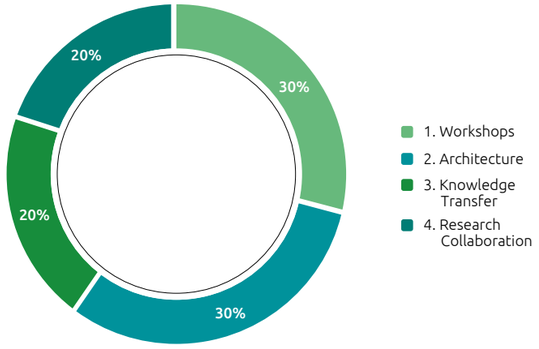
Could you see yourself or your company participating in the ASIMI initiative, and, if so, how?

In general, the interview participants display an overarching interest in the ASIMI initiative. A great majority (68%) supports ASIMI and would like to be actively involved. Moreover, they provide a broad variety of ideas on how to participate. Details of their proposed contribution can be found in the graph below. Realthingks explains, "Yes, we could be very helpful in terms of scope, architecture, and implementation to ensure that the software will be both valuable and reusable. "

Figure 13: **Expert's ideas on how to participate**



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The other part (32%) would like to know more about the scope and target of the ASIMI initiative. Interviewees who were unsure often expressed concerns about aligning with other initiatives, such as AUTOSAR or GENIVI. Furthermore, roles and responsibilities and the presence of OEMs need to be clarified.

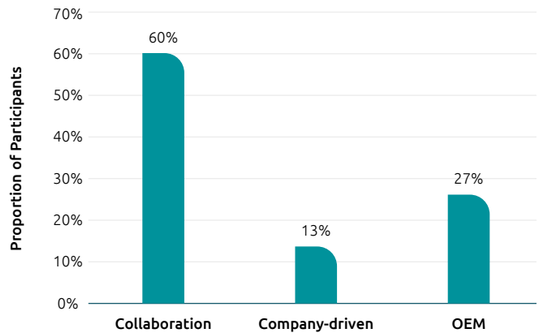
No participant declines participation in the initiative.

Who do you envision leading the industry for standardization, de facto standards, consortia, and reference architectures (OEMs, Universities, Tiers...)?

Three options dominate the answers among the participants. **Most experts (60%) envision a collaboration between companies and academia as the driving force**. VW explicitly states "It must be a common effort."Ford sees a collaboration or consortia of OEMs combined with BigTech as the leading force for standardization. About one-third of the interviewees (27%), refer to the role and responsibility of OEMs in the industry and expect them to lead.

Hella, for example, states: "OEMs are the gateway to the end-usersand play a unique role." and critically adds, "Whether they will actively lead the industry is another matter." A minority (13%) believe that single companies drive the lead. Generally, the participants agree that a strong force is needed to achieve any adoption of new standards.

Figure 14: **Who do you envision leading the industry for standardization?**



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> "OEMs are the gateway to the end user and play a unique role."

4.3 Software & Strategy

What do you see as important product realization milestones to be reached over the next few years and when can they be reached?

When asked about important product realization milestones to be reached over the next few years, most experts share a rather common understanding on the more generic milestones that will enable product realization.

First, they generally agree that in an initial step, **automotive key players must fully agree on business and collaboration models for middleware**. This model must pay off for OEMs, suppliers, and SW companies. Second, a significant number of OEMs must agree on using common APIs for middleware to enable a functioning software. Third, a common development model (continuous delivery) model for middleware should be established among OEMs that includes a common toolchain and file formats. Finally, the actual middleware should be implemented and delivered from a user experience perspective, i.e., from an application function API downwards (Elektrobit).

> “A common development model for middleware should be established among OEMs that includes a common toolchain and file formats.”

Accilium shares a similar view and estimates that within the next six months a project organization with representatives of the most important automotive OEMs, suppliers, public entities, data scientists, and experienced E/E architects will form. After another six months, a common understanding of objective, scope and solution space will likely be reached and within two to three years standardized middleware platform and interface standards will be developed according to Accilium.

Other industry experts expect first product realization milestones, such as SOA, zone architecture, and full HPC to be developed by 2025 (Aptiv, Stellantis, Continental, Ford, Volkswagen). KPIT on the other hand trusts that a fully central architecture will only be achieved by 2030 or beyond.

How relevant do you consider standardization, de facto standards, consortia, and reference architectures in support of the realization of the architecture trends?

To support the realization of the introduced architecture trends, standardization, de facto standards, consortia, and reference architectures are widely discussed in the automotive sector. Most participating experts in this study **(72%) firmly believe that software standards in the broader sense are crucial and potentially “one of the decisive factors in the race to stay competitive with new players, e.g., Tesla” (Accilium)**. This can further be underlined by the following reasons.

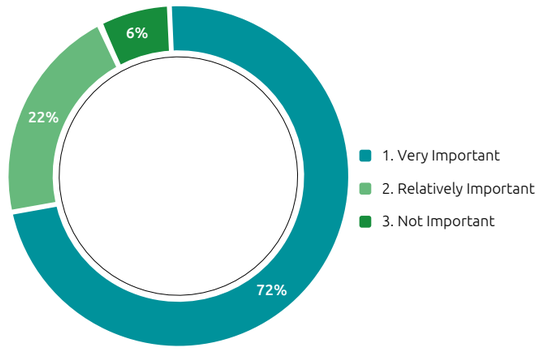
On the other hand, some experts (22%) are more critical towards standardization.

APTIV mentions that de facto standards and specifications like AUTOSAR already exist but adds that open source and reference designs will be beneficial. Stellantis considers most of the mentioned concepts as too slow and emphasizes that the selection of a few key partners is critical to win instead.

Also, Renault believes that standardization takes too long and that instead OEMs who have converging ideas should regroup to tackle the challenges of architecture trends.

The figure below shows the percentage of experts supporting standardization and their degree of support.

Figure 15: Perceived importance of standard software



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What is preventing us in the automotive industry from developing a common middleware?

After outlining how to address architecture changes in the automotive industry, this study wants to find out: What prevents key players from developing a common middleware in the end? Reasons are manifold but can be broken down into a few categories:

Competence: Relevant players have different competence levels, are in varying stages of development, and have separate approaches to accumulating competences in software development. Stellantis adds that it will become harder to find, attract and retain talent if companies are not becoming more attractive to the next generation.

The experts interviewed for this study saw several problems and hindrances to successfully transitioning to a software centered manufacturing approach. Almost all experts mentioned a major hindrance was the missing software expertise within the OEMs. Many management people don't understand a software strategy in general. While some might be familiar with it in the context of the manufacturing process, having a software strategy for the car itself is still an alien concept to many of them. In general, there is a lack of people who understand both software and car manufacturing. Some OEMs try to fix that by hiring as many software developers as possible, but that doesn't compensate for a lack of strategy.

Culture: A culture shift is needed for a variety of reasons. First, to become more attractive to next generation talent (Stellantis). Second, support from all stakeholders is essential for the success of initiatives because otherwise, they will be blocked by unwilling and change-resistant individuals (Continental). Third, unsatisfying cooperation in the past has led to mistrust and fear of theft of ideas, pushing most OEMs to develop their middleware instead of cooperating (Intron Tech).

> "A culture shift is needed to become more attractive to next generation talent."

Industry structure: Overall, the automotive industry is not a single body. "The historical setup of the industry, aligned with the size of certain OEMs and Tier1s and the prevalence of 'Not Invented Here' syndrome, do not suggest industry-wide alignment" (Hella). Different requirements between OEMs caused by diverse vehicle offerings cause slower jointdevelopment thanindividual development (Ford). In addition, companies face different internal pressures to achieve specific timing, and consortia and collaborations are often seen as too slow (Ford2). This encourages some players to feel less need to wait for a critical mass and do their own thing instead (Hella), leading to individual legacy systems.

Another set of problems is related to the attitudes of many key people within OEMs. According to one of our experts, they are often more focused on the immediate rather than the long-term future. There is also a general lack of flexibility in the industry. OEMs need to understand that when they purchase batteries instead of producing engines, the value they add to the process can decrease drastically. Many executives and engineers still see cars as autonomous products without a connection to infrastructure. They also often tend to underestimate the integration complexity of the applications they develop. Finally, there is a reluctance to make standards agreements and provide inputs to Open-source collaborations.

The last set of hurdles is more practical. Some companies struggle to focus on the future because they are tied down working on improving legacy systems already in place. "Demands on functionality, connectivity, and customers are built on old architectures, and vehicles that were based on standardized operating procedures have been developed at the same time," says one of the experts. However, if OEMs want to achieve their ambitious goals regarding modular software, there needs to be a degree of decoupling from the series of businesses.

What do you think OEMs should do to ensure a successful transformation?

We asked our interview partners what they see as solutions to the above mentioned challenges and problems. All of them thought it would be a good idea to create an independent and neutral European company that aims to create an operating system independent from the hardware and application deck. OEMs should find subsidiaries that specialize in technology and can attract the necessary IT talent. To increase scalability, OEMs should also build API and hardware layers independent from the actual hardware.

The experts generally favored **cooperation above working in silos**. According to one of the experts, OEMs should build everything together except for brand – distinguishing user functions.

Having ten different ecosystems that all become generally accepted would only create disadvantages for OEMssince they would create a huge expenditure in adaptation work. "We want to take care of the function, not the adaptation OS systems!" another expert says.

One way this could be achieved is through Open-source projects, but it can be tricky because someone has to "take the responsibility." Many OEMs don't understand that for Open Source to be a sustainable solution, they also need to contribute. "OEMs need to make a real commitment to Open Source." Another way to achieve collaboration is through the **establishment of partnerships**. OEMs should enrich their ecosystems with strong partners such as Microsoft for Cloud connection and ETAS for tools. **Platforms such as ASIMI can help bring partners together and serve as a neutral discussion platform for exchange**. Initiatives such as Eclipse and SOAFEE can also be interesting in this regard.

> "Many OEMs don't understand that in order for Open Source to be a sustainable solution, they also need to contribute themselves."

4.4 Business & Operating Model

How do you assess the current approaches of Tesla and Polestar?

In general, the **experts respect the current development and success of Tesla and Polestar and admit that there are several things to learn from their approach**. Realthingks especially highlights the simplicity Tesla used to solve complex problems: "[…] they also have a very simple form of OTA where they store the image on a separate hard disk and flash the vehicle at night. Tesla implements this pretty simple approach first and is successful. In the meantime, the rest of the world is trying to solve a part flashing problem which is much more complex.

On the other hand, many experts note that both Tesla and Polestar were able to focus on the architecture without constraints by a legacy of combustor engines. Accilium states: "They could focus on architecture from the beginning. It is standardized enough to apply scale effects yet modular enough to realize different types of vehicles with varying specs and functionalities. […] Therefore, they have an enormous advantage over the incumbent manufacturers." APEX AI further adds that "Tesla has implemented a highly vertically integrated hardware architecture from the beginning (2015), which other OEMs might reach in 2025." KPIT notes that Tesla has had anadvantage, but they also have fewervariants of software and hardware."

How do you see the role of open source, open eco systems, open platforms, and startups for the acceleration of innovation cycles?

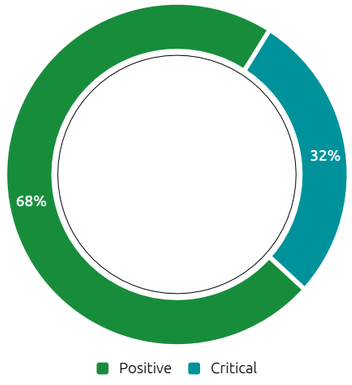
The experts predominantly have a positive attitude towards open collaboration and acknowledge the method as important to face the challenges and complexity of software development. Aptiv states, "I do see open source as key to wider adoption. What is important is not only to provide things as open-source but also make sure the technology has some traction already and that we do not reinvent the wheel."

Critical voices call for more effort toward safety-critical systems (Ford) and commitment toward quality and delivery (Continental). Moreover, APEX AI criticizes real-time execution and functional safety certification as reasons why open-source technology was not integrated into vehicles so far.

Furthermore, several participants mentioned the limited comparability between new players like Tesla and Polestar and traditional OEMs. Tesla has a much smaller product offering; the operating model can thus not be copied to an OEM that offers a full vehicle range (Ford). Elektrobit also warns "We need to understand the business principles from Tesla and Polestar and how they can be applied to the German automotive industry. Copying their actions and technologies will not be successful."

> "We need to understand the business principles from Tesla and Polestar and how they can be applied to the German automotive industry. Copying their actions and technologies will not be successful."

Figure 13: Expert's ideas on how to participate



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4.5 Expert interview insights Summary

As part of the study, several qualitative interviews were conducted with experts from the automotive industry.

The interviews contained several questions related to the transformation of the industry towards a more software-oriented approach and their personal experiences working in the field. This section gives an overview ofthe challenges, problems, and solutions discussed in chapters 4.1 to 4.4.

Figure 17: Expert interviews summaryfuture value chains

Challenges	• Connectivity • Autonomous driving • Electrification • Data sharing • Decoupling SDV from series business	• Over the air / AI • Creating a scalable ecosystem • Adding value for the end customer • America, Chinese, IT industry competitions
Deficits	• Lack of flexibility • Reluctance to contribute to Open-source projects • Missing expertise • Lack of competencies • Vehicles that were based on SOP developed with other architecture	• Lack of software strategy and competence • OEMs underestimating adaptation complexity • Missing culture shift • Missing standards
Recommendations	• Create subsidiaries that specialize in technology or independent European OS company • Give a clear commitment to Open-Source Bulit everything except for brand-designing user functions together	• Establish partnerships with strong partners • Commitment to standards • Have independent API and hardware layers

Source: Capgemini Research Institute Analysis. © Capgemini Invent 2022

05

MARKET OVERVIEW

For our study, we performed a market analysis in the form of desk research. For this purpose, we have set up 24 criteria for comparability on the X-axis, which cover the areas of Consortium /Ecosystem, Software Strategy, Operating System, Standardization Strategy, and Technology Capability since these categories are the most important criteria in realizing a successful middleware platform.

With this, we comparethe main alliances and relevant players (grouped by type) on aspects of key strategies, partnerships, and alliances. We included an evaluation based on a set of criteria grouped into three main categories: Standardization, Scalability, and Maturity of Technology.

On the Y-axis, we have compared 60 competitors within the automotive industry. With the outcome of the Excel table as a basis, further analysis is carried out.

The following pages zoom in on the complete overview in a readable way.

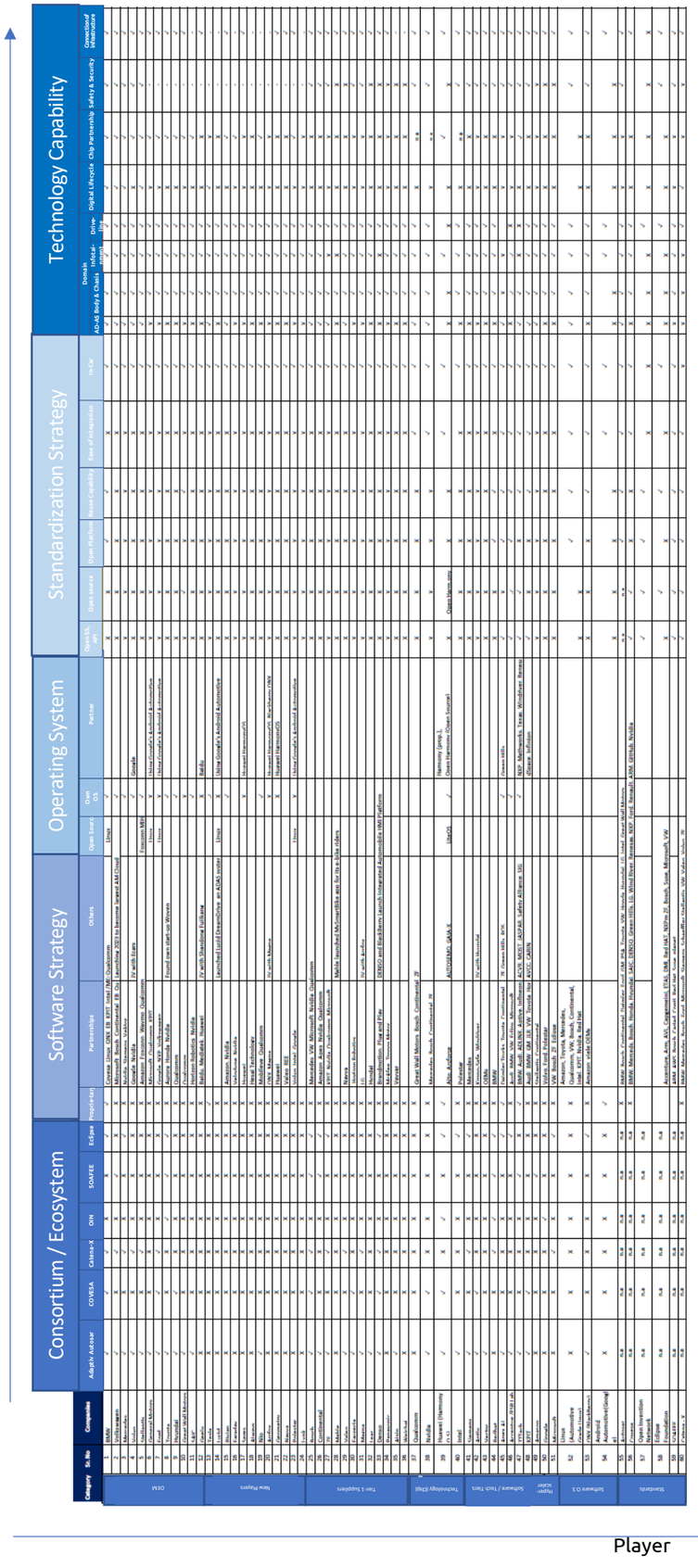


Figure 18: Market Analysis

MARKET OVERVIEW
Consortium/Ecosystem

Category	Sr. No	Companies	Consortium/Ecosystem					
			Adaptiv Autosar	CONVESA	Catena-X	OIN	SOAFEE	Eclipse
OEM	1	BMW	✓	✓	✓	X	X	✓
	2	Volkswagen	✓	X	✓	X	✓	X
	3	Mercedes	✓	X	✓	X	X	✓
	4	Volvo	✓	X	✓	X	X	X
	5	Stellantis	✓	X	✓	X	X	X
	6	General Motors	✓	X	X	X	X	X
	7	Ford	✓	✓	✓	X	X	X
	8	Toyota	✓	X	X	✓	✓	✓
	9	Hyundai	✓	✓	X	X	X	X
	10	Great Wall Motors	✓	X	X	X	X	X
	11	SAIC	✓	X	X	X	X	X
	12	Geely	X	X	X	X	X	X
New Players	13	Tesla	X	X	X	X	X	X
	14	Lucid	X	X	X	X	X	X
	15	Rivian	X	X	X	X	X	X
	16	Faraday	X	X	X	X	X	X
	17	Seres	X	X	X	X	X	X
	18	Aiways	X	X	X	X	X	X
	19	Nio	✓	X	X	X	X	X
	20	Arcfox	X	X	X	X	X	X
	21	Geometry	X	X	X	X	X	X
	22	Navya	X	X	X	X	X	X
	23	Polestar	X	X	X	X	X	X
	24	Lynk	X	X	X	X	X	X
Tier-1 Suppliers	25	Bosch	✓	✓	✓	X	✓	✓
	26	Continental	✓	X	X	X	✓	✓
	27	ZF	✓	X	✓	X	X	✓
	28	Mahle	X	X	X	X	X	X
	29	Valeo	✓	X	✓	X	X	X
	30	Faurecia	✓	✓	X	X	X	X
	31	Magna	✓	X	✓	X	X	X
	32	Lear	✓	X	X	X	X	X
	33	Denso	✓	✓	✓	X	X	✓
	34	Panasonic	X	X	X	X	X	X
	35	Aisin	✓	X	X	X	X	X
	36	Weichai	X	X	X	X	X	X
Technology (Chip)	37	Qualcomm	X	X	X	X	X	X
	38	Nvidia	✓	✓	X	X	X	X
	39	Huawei (Harmony O.S)	✓	✓	X	✓	X	✓
	40	Intel	✓	X	X	X	X	✓
Software / Tech Tiers	41	Siemens	✓	X	✓	X	X	✓
	42	Aptiv	✓	✓	X	X	X	X
	43	Vector	✓	X	X	X	X	X
	44	Redhat	X	X	✓	✓	✓	✓
	45	Apex.AI	✓	X	X	X	X	✓
	46	Accentue /ESR Lab	✓	X	X	X	X	✓
	47	TTTech Auto	✓	X	X	X	✓	X
	48	KPIT	✓	✓	X	X	X	X
Hyper-scaler	49	Amazon	X	X	X	X	✓	X
	50	Google	X	X	X	✓	X	X
	51	Microsoft	X	X	✓	X	X	✓
Software O.S	52	Linux (Automotive Grade Linux)	X	X	X	X	X	X
	53	QNX (BlackBerry)	✓	X	X	X	X	✓
	54	Android Automotive(Google)	X	X	X	X	X	X
Standards	55	Autosar	n.a	n.a	n.a	n.a	n.a	n.a
	56	Covesa	n.a	n.a	n.a	n.a	n.a	n.a
	57	Open Invention Network	n.a	n.a	n.a	n.a	n.a	n.a
	58	Eclipse Foundation	n.a	n.a	n.a	n.a	n.a	n.a
	59	SOAFEE	n.a	n.a	n.a	n.a	n.a	n.a
	60	Catena - X	n.a	n.a	n.a	n.a	n.a	n.a

MARKET OVERVIEW

Software Strategy

Category	Sr. No	Companies	Software Strategy		
			Proprietary	Partnerships	Others (ex. Membership)
OEM	1	BMW	✓	Covesa, Linux, QNX, EB, KPIT, Intel /ME; Qualcomm	
	2	Volkswagen	X	Microsoft, Bosch, Continental, EB, Qualcomm, Eclips	Launching 2023 to become largest AM Cloud
	3	Mercedes	X	Nvidia, Siemens, Vektor	
	4	Volvo	X	Google, Nvidia	JV with Ecarx
	5	Stellantis	X	Amazon, Foxconn, Waymo, Qualcomm	
	6	General Motors	X	Microsoft, Qualcomm, KPIT	
	7	Ford	X	Google, NXP, Volkswagen	
	8	Toyota	X	Aurora, Honda, Nvidia	Found own start-up Woven
	9	Hyundai	X	Qualcomm	
	10	Great Wall Motors	X	Qualcomm	
	11	SAIC	X	Horizon Robotics, Nvidia	
	12	Geely	X	Baidu, Mediatek, Huawei	JV with Shandong Fujikang
New Players	13	Tesla	✓		
	14	Lucid	X		Launched Lucid DreamDrive, an ADAS system in July 2020
	15	Rivian	X	Amazon, Nvidia	
	16	Faraday	X	Velodyne, Nvidia	
	17	Seres	X	Huawei	
	18	Aiways	X	Hesai Technology	
	19	Nio	X	Mobileye, Qualcomm	
	20	Arcfox	X	QNX, Magna	JV with Magna
	21	Geometry	X	Huawei	
	22	Navya	X	Valeo, REE	
	23	Polestar	X	Volvo, Intel, Google	
	24	Lynk	X		
Tier-1 Suppliers	25	Bosch	X	Mercedes, VW, Microsoft, Nvidia, Qualcomm	
	26	Continental	X	Amazon, Apex, Nvidia, Qualcomm	
	27	ZF	X	KPIT, Nvidia, Qualcomm, Microsoft	
	28	Mahle	X		Mahle launched MySmartBike app for its e-bike riders
	29	Valeo	X	Navya	
	30	Faurecia	X	Horizon Robotics	
	31	Magna	X	LG	JV with Arcfox
	32	Lear	X	Hyndai	
	33	Denso	X	Brandmotion, Plug and Play	DENSO and BlackBerry Launch Integrated Automobile HMI Platform
	34	Panasonic	X	McAfee, Tropos Motor	
	35	Aisin	X	Vayyar	
	36	Weichai	X		
Technology (Chip)	37	Qualcomm	X	Great Wall Motors, Bosch, Continental, ZF	
	38	Nvidia	X	Mercedes, Bosch, Continental, ZF	
	39	Huawei (Harmony O.S)	✓	Aito, Arcforce	AUTOSEMO, GAIA-X
	40	Intel	X	Polestar	
Software / Tech Tiers	41	Siemens	X	Mercedes	
	42	Aptiv	X	Krono-Safe, Windriver	JV with Hyundai
	43	Vector	X	OEMs	
	44	Redhat	X	BMW	
	45	Apex.AI	✓	Daimler Trucks, Toyota, Continental	ZF,Green Hills, ROS
	46	Accentue /ESR Lab	X	Audi, BMW, VW, Eclips, Microsoft	
	47	TTTech Auto	✓	BMW, VW, ADLINK, Aptive, Infineon, Samsung, Hundai, SAIC	ACVR, MOST, JASPAR, Safety Alliance, SIG
	48	KPIT	X	Audi, BMW, GM, JLR, VW, Toyota, Honda, ZF, Microsoft	AVCC, CARIN
Hyper-scaler	49	Amazon	X	Stellantis, Continental	
	50	Google	X	Volvo, Ford, Polestar	
	51	Microsoft	X	VW, Bosch, ZF, Eclipse	
Software O.S	52	Linux (Automotive Grade Linux)	X	Amazon, Toyota, Mercedes, Qualcomm, VW, Bosch, Continental, intel, KPIT, Nvidia, Red Hat	
	53	QNX (BlackBerry)	X	Amazon, viele OEMs	
	54	Android Automotive(Google)	✓		
Standards	55	Autosar	X	BMW, Bosch, Continental, Daimler, Ford, GM, PSA, Toyota, VW, Honda, Hyundai, LG, Intel, Great Wall Motors	
	56	Covesa	X	BMW, Merceds, Bosch, Honda, Hyundai, SAIC, DENSO, Green Hills, LG, Wind River, Renesas, NXP, Ford, Renault, ARM, GitHub, Nvidia	
	57	Open Invention Network			
	58	Eclipse Foundation		Accenture, Arm, AVL, Capgemeini, ETAS, DMI, Red HAT, NXPm ZF, Bosch, Suse, Microsoft, VW	
	59	SOAFEE		ARM, AWS, Bosch, Cariad, Conti, Red Hat, Suse, planet	
	60	Catena - X	X	BMW, Mercedes, Bosch, Ford, Microsoft, Siemens, Schaeffler,Stellantis, VW, Valeo, Volvo, ZF	

MARKET OVERVIEW

Operating System

Category	Sr. No	Companies	Open Source	Technology Partner
OEM	1	BMW	Linux	
	2	Volkswagen		
	3	Mercedes		
	4	Volvo		Google
	5	Stellantis	Foxconn MIH	
	6	General Motors	Linux	Using Google's Android Automotive
	7	Ford	Linux	Using Google's Android Automotive
	8	Toyota		
	9	Hyundai		
	10	Great Wall Motors		
	11	SAIC		
	12	Geely		Baidu
New Players	13	Tesla		
	14	Lucid	Linux	Using Google's Android Automotive
	15	Rivian		
	16	Faraday		
	17	Seres		Huawei HarmonyOS
	18	Aiways		
	19	Nio		
	20	Arcfox		Huawei HarmonyOS, Blackberry QNX
	21	Geometry		Huawei HarmonyOS
	22	Navya		
	23	Polestar	Linux	Using Google's Android Automotive
	24	Lynk		
Tier-1 Suppliers	25	Bosch		
	26	Continental		
	27	ZF		
	28	Mahle		
	29	Valeo		
	30	Faurecia		
	31	Magna		
	32	Lear		
	33	Denso		
	34	Panasonic		
	35	Aisin		
	36	Weichai		
Technology (Chip)	37	Qualcomm		
	38	Nvidia		
	39	Huawei (Harmony O.S)	LiteOS	Harmony (prop.), Ooen Harmony (Open Source)
	40	Intel		
Software / Tech Tiers	41	Siemens		
	42	Aptiv		
	43	Vector		
	44	Redhat		
	45	Apex.AI		Green Hills
	46	Accentue /ESR Lab		
	47	TTTech Auto		NXP, Mathworks, Texas, Windriver, Renesas
	48	KPIT		dSpace, Infinion
Hyper-scaler	49	Amazon		
	50	Google		
	51	Microsoft		
Software O.S	52	Linux (Automotive Grade Linux)		
	53	QNX (BlackBerry)		
	54	Android Automotive(Google)		
Standards	55	Autosar		
	56	Covesa		
	57	Open Invention Network		
	58	Eclipse Foundation		
	59	SOAFEE		
	60	Catena - X		

MARKET OVERVIEW
Standardization Strategy

Category	Sr. No	Companies	Standardization Strategy					
			open SS, API	open source	Open Platform	Reuse Capability	Ease of Integration	In-Car
OEM	1	BMW	X	X	✓	✓	X	✓
	2	Volkswagen	X	X	X	X	X	✓
	3	Mercedes	X	X	X	X	X	✓
	4	Volvo	X	X	X	X	X	✓
	5	Stellantis	X	X	X	X	X	✓
	6	General Motors	X	X	X	X	X	✓
	7	Ford	X	X	X	X	X	✓
	8	Toyota	X	X	X	X	X	✓
	9	Hyundai	X	X	X	X	X	✓
	10	Great Wall Motors	X	✓	X	✓	X	✓
	11	SAIC	X	X	X	X	X	✓
	12	Geely	X	X	X	X	X	✓
New Players	13	Tesla	X	X	X	X	X	✓
	14	Lucid	X	X	X	X	X	✓
	15	Rivian	X	X	X	X	X	✓
	16	Faraday	X	X	X	X	X	✓
	17	Seres	X	X	X	X	X	✓
	18	Aiways	X	X	X	X	X	✓
	19	Nio	X	X	X	X	X	✓
	20	Arcfox	X	X	X	X	X	✓
	21	Geometry	X	X	X	X	X	✓
	22	Navya	X	X	X	X	X	✓
	23	Polestar	X	X	X	X	X	✓
	24	Lynk	X	X	X	X	X	✓
Tier-1 Suppliers	25	Bosch	X	X	X	X	X	✓
	26	Continental	X	X	X	X	X	✓
	27	ZF	X	X	X	X	X	✓
	28	Mahle	X	X	X	X	X	✓
	29	Valeo	X	X	X	X	X	✓
	30	Faurecia	X	X	X	X	X	✓
	31	Magna	X	X	X	X	X	✓
	32	Lear	X	X	X	X	X	✓
	33	Denso	X	X	X	X	X	✓
	34	Panasonic	X	X	X	X	X	X
	35	Aisin	X	X	X	X	X	X
	36	Weichai	X	X	X	X	X	X
Technology (Chip)	37	Qualcomm	X	X	X	X	✓	X
	38	Nvidia	X	X	X	X	✓	X
	39	Huawei (Harmony O.S)	X	Open Harmony	X	X	✓	X
	40	Intel	X	X	X	X	X	X
Software / Tech Tiers	41	Siemens	X	X	X	X	X	X
	42	Aptiv	X	X	X	X	X	X
	43	Vector	X	X	X	X	X	X
	44	Redhat	X	X	✓	✓	X	X
	45	Apex.AI	✓	X	✓	✓	✓	X
	46	Accentue /ESR Lab	✓	✓	✓	✓	✓	X
	47	TTTech Auto	✓	✓	X	✓	✓	X
	48	KPIT	✓	X	X	✓	✓	X
Hyper-scaler	49	Amazon	X	X	X	X	X	X
	50	Google	X	X	X	X	X	X
	51	Microsoft	X	X	X	X	X	X
Software O.S	52	Linux (Automotive Grade Linux)	X	X	✓	✓	✓	X
	53	QNX (BlackBerry)	X	X	X	✓	✓	X
	54	Android Automotive(Google)	X	X	X	X	✓	X
Standards	55	Autosar	n.a	n.a	✓	✓	✓	X
	56	Covesa	✓	✓	X	X	✓	X
	57	Open Invention Network	✓	✓	✓	✓	X	X
	58	Eclipse Foundation	X	✓	X	✓	X	X
	59	SOAFEE	✓	✓	✓	✓	✓	X
	60	Catena - X	✓	✓	✓	✓	✓	X

MARKET OVERVIEW
Technology Capability

Category	Sr. No	Companies	Technology Capability							
			Domain				Digital Lifecycle	Chip Partnership	Safety & Security	Connection of infrastructure
			ADAS	Body & Chasis	Infotainment	Driveline				
OEM	1	BMW	✓	✓	✓	✓	✓	✓	✓	✓
	2	Volkswagen	✓	✓	✓	✓	✓	✓	✓	✓
	3	Mercedes	✓	✓	✓	✓	✓	✓	✓	✓
	4	Volvo	✓	✓	✓	✓	X	✓	✓	✓
	5	Stellantis	✓	✓	✓	✓	✓	✓	✓	✓
	6	General Motors	X	✓	✓	✓	X	✓	-	✓
	7	Ford	X	✓	✓	✓	X	✓	-	✓
	8	Toyota	X	✓	✓	✓	X	✓	-	✓
	9	Hyundai	X	✓	✓	✓	X	✓	-	✓
	10	Great Wall Motors	X	✓	✓	✓	X	✓	-	✓
	11	SAIC	X	✓	✓	✓	X	✓	-	-
	12	Geely	X	✓	✓	✓	X	X	-	✓
New Players	13	Tesla	✓	✓	✓	✓	✓	X	-	-
	14	Lucid	X	✓	✓	✓	X	X	-	-
	15	Rivian	✓	✓	✓	✓	X	✓	-	✓
	16	Faraday	X	✓	✓	✓	X	✓	-	-
	17	Seres	X	✓	✓	✓	X	X	-	✓
	18	Aiways	X	✓	✓	✓	X	X	-	-
	19	Nio	X	✓	✓	✓	X	✓	-	-
	20	Arcfox	X	✓	✓	✓	X	X	-	-
	21	Geometry	X	✓	✓	✓	X	X	-	✓
	22	Navya	X	✓	✓	✓	X	X	-	✓
	23	Polestar	X	✓	✓	✓	X	✓	-	✓
	24	Lynk	X	✓	✓	✓	X	X	-	-
Tier-1 Suppliers	25	Bosch	✓	✓	✓	✓	X	X	✓	✓
	26	Continental	✓	✓	✓	✓	X	X	✓	✓
	27	ZF	✓	✓	X	✓	X	X	✓	✓
	28	Mahle	X	✓	X	✓	X	X	X	✓
	29	Valeo	✓	✓	✓	✓	X	X	X	✓
	30	Faurecia	X	✓	✓	✓	X	X	✓	✓
	31	Magna	X	✓	✓	✓	X	X	✓	✓
	32	Lear	X	✓	✓	✓	X	X	X	✓
	33	Denso	X	✓	X	✓	X	X	X	✓
	34	Panasonic	X	✓	✓	✓	X	X	X	✓
	35	Aisin	X	✓	✓	✓	X	X	X	-
	36	Weichai	X	✓	✓	✓	X	X	X	-
Technology (Chip)	37	Qualcomm	✓	✓	✓	✓	X	n.a	✓	✓
	38	Nvidia	✓	✓	✓	✓	X	n.a	✓	✓
	39	Huawei (Harmony O.S)	X	X	✓	X	X	✓	X	✓
	40	Intel	X	✓	✓	✓	X	n.a	✓	✓
Software / Tech Tiers	41	Siemens	X	✓	✓	✓	X	X	✓	✓
	42	Aptiv	X	✓	✓	✓	X	X	✓	✓
	43	Vector	X	✓	✓	✓	X	X	✓	✓
	44	Redhat	X	✓	✓	✓	X	X	✓	✓
	45	Apex.AI	✓	X	X		X	X	✓	✓
	46	Accentue /ESR Lab	X	✓	✓	X	X	X	✓	✓
	47	TTTech Auto	✓	✓	X	X	X	✓	✓	✓
	48	KPIT	✓	✓	✓	✓	X	X	✓	✓
Hyper-scaler	49	Amazon	✓	✓	✓	✓	X	X	X	✓
	50	Google	X	✓	✓	✓	X	X	X	✓
	51	Microsoft	X	✓	✓	✓	X	X	X	✓
Software O.S	52	Linux (Automotive Grade Linux)	✓	✓	✓	✓	X	X	✓	✓
	53	QNX (BlackBerry)	X	✓	✓	✓	X	X	✓	✓
	54	Android Automotive(Google)	X	X	✓	✓	X	X	X	✓
Standards	55	Autosar	✓	✓	✓	✓	X	X	✓	✓
	56	Covesa	X	✓	✓	✓	X	X		✓
	57	Open Invention Network	X	X	X	✓	X	X	X	X
	58	Eclipse Foundation	X	X	X	✓	X	X	✓	✓
	59	SOAFEE	X	✓	✓	✓	X	X	✓	✓
	60	Catena - X	X	X	X	✓	✓	X	X	✓

06

CONCLUSION

From a retro perspective, all OEMs, Tier 1s and Tier 2s are developing their individual and specific solutions for 2025. For the OEMs, this may be the best solution. Unfortunately, this approach is not universally applicable to all players. In the supply industry, integrating the many different solutions takes significantly more effort. Confronted with the challenge that each player tries to establish new solutions individually; the growing complexity is not under control after 2025. The silo working concludes in not realizing upscale opportunities nor offering scalability to the rest of the automotive production (approx. 120 million vehicles per year).

A further challenge can be found in the IT sector. Instead of collaboration, a cannibalization strategy can be observed within the automotive industry from hypervisors like Apple, Google, Badiu, and others. The cause of this is that the IT industry is on its way to developing itsown technical and scalable solutions for the automotive industry and offering licensed or other business models (e.g., datadelivery). Consequently, a takeover of the value creation from the automotive industry is prefigured.

The answer to both mentioned challenges can be found in **building interdependent ecosystems in the future to break through those silos and prevent cannibalization**. This scaling of a common platform with a collective ecosystem can be realized through a **collaborative path of Joint Ventures, partnerships, and subsidiaries**.

Another challenge lies in the growing complexity within the automotive industry and software solutions. After 2025 there is no control over how individual-developed software solutions along the whole supply chain can be integrated with one and relate to another. Due to this complexity of SDV, single players cannot or should not develop holistic solutions.

This underlines the necessity of **an imperative for architecture alignments between OEMs, Tier-1s, and Tier-2s. Defining ecosystems based on clear standards is fundamental to allowing all players along the supply chain to participate so that** others **can use their solutions**. As Tesla is already creating a whole ecosystem, AUTOSAR sets a promising baseline for middleware on an ECU level.

If and who will offer the future standards for a single middleware solution, will be seen within the following years, as no overarching standard is established now.

With the study, another challenge could be outlined: The automotive players´ competence, organizational structure as well as culture is not ready for the future yet. This also includes the relevant Business/Operating Models. Relevant players have different competence levels, are in varying stages of the development and have different approaches to building competencies in software development. Furthermore, a culture shift is needed to become more attractive to next-generation talent, to overcome the mistrust from unsatisfying cooperation in the past and to enable the success of initiatives instead of blocking it by change-resistant individuals.

If one looks at the business/operating models of the automotive players, one challenge lies within different internal pressures to achieve specific timing. Consortia and collaborations are often seen as too slow to succeed. Furthermore, different requirements between OEMs caused by diverse vehicle offerings are one reason for slower common development compared to individual development. This encourages some players to feel less need to wait for a critical mass and do their own thing instead, leading to individual legacy systems. These observations are contrasted by the success of new players, like Tesla or Polestar with a standardized architecture that reduces complexity.

It is standardized enough to apply scale effects, yet modular enough to realize different types of vehicles with varying specs and functionalities. Here, the great opportunity of centralized architectures becomes apparent once again. Further approaches to solutions in the areas of competencies, organization and culture are revealed by **new possibilities for the industrialization and automation of the SW lifecycle based on AI.**

A central study finding is that first initiative standards like Eclipse, SOAFEE, etc. provide a good basis for a common OS/ middleware development with many partners. However, they are not sufficient as there can´t be complete stake development and HW independence realized. For instance, AutoSar has an approach via a common specification today, but for a massive speed increase, the development of a common SW stake needs to be pushed.

An Opensource strategy is THE way forward. But such a model must pay off for OEMs, suppliers, and SW companies. Furthermore, **the success lies in a significant number of OEMs agreeing on using common APIs for middleware** to enable a functioning software. What also weighs heavy is the **need** to **establish of a common development model (continuous delivery) for middleware amongst OEMs** that include a common toolchain and file formats. It is also essential that **the middleware should be implemented and delivered from a user experience perspective,** i.e., from an application function API downwards.

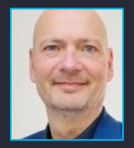
Competition needs collaboration:

A key take away is the necessity of creation of an ecosystem that governs the non-differentiating software components for the end customer (meaning the middleware and O.S), thus enabling OEMs – and other automotive players along the value chain – to pool collective services, improve quality, and win time to market.

The virtues of Middleware & O.S standardization for the OEMs is driving down the cost of development of Applications which in turn would benefit their ROI through leveraging consumers demand and adaption (cost driven) exactly as we witnessed in the smart phone transformation back in 2010 shifting from hardware-driven to software-driven, which is exactly the shift we drive today in the automotive market.

07
PERSONAS

Contributors of the study



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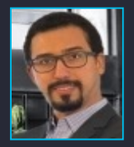

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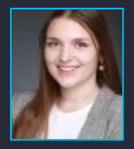

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About Capgemini Invent

As the digital innovation, design and transformation brand of the Capgemini Group, Capgemini Invent enables CxOs to envision and shape the future of their businesses. Located in nearly 40 studios and more than 60 offices around the world, it comprises a 10,000+ strong team of strategists, data scientists, product and experience designers, brand experts and technologists who develop new digital services, products, experiences and business models for sustainable growth.

Capgemini Invent is an integral part of Capgemini, a global leader in partnering with companies to transform and manage their business by harnessing the power of technology. The Group is guided everyday by its purpose of unleashing human energy through technology for an inclusive and sustainable future. It is a responsible and diverse organization of over 340,000 team members in more than 50 countries. With its strong 55-year heritage and deep industry expertise, Capgemini is trusted by its clients to address the entire breadth of their business needs, from strategy and design to operations, fueled by the fast evolving and innovative world of cloud, data, AI, connectivity, software, digital engineering, and platforms. The Group reported in 2021 global revenues of €18 billion.

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