The software-driven revolution redefining the automotive industry

EY Parthenon

Building a better working world

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Foreword

Through this paper, EY-Parthenon's Future Mobility team aims to analyze the disruption caused by the increasing importance of software in the automotive. We begin by looking at the existing challenges with the current approach to vehicle development and the limitations it places on software to grow. We also analyzed the key upcoming technology trends to combat the existing challenges and how they are giving rise to a new approach for developing SDVs. Lastly, we look at how the new development approach is redefining the existing automotive value chain and what this means for existing and emerging players in the future.

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Executive Summary

Demand for advanced automotive technologies like ADAS, electrification & connectivity are highlighting the importance of software in automotive and are characterized by independent development of software & hardware.

You can reach EY supplementary document "Connected Mobility Highlights & Key Trends" by clicking.

Software-Defined Vehicles are reshaping the automotive industry by enabling increased flexibility, customization, and remote upgradeability. This is leading to new business models, such as subscription-based vehicle ownership, over-the-air software updates and enabling OEMS to offer new services to customers. However, despite all the inherit advantages, software defined vehicles are marred by challenges such as changes in vehicle E/E architecture,lack of independent software development for distributed E/E architectures, lack of seamless connectivity options and cybersecurity concerns. OEMs have addressed these concerns by focusing on developing dedicated software platforms independent of hardware, consolidating the E/E architecture, and leveraging high-speed 5G connectivity to enhance the V2X connectivity. Overall, software-defined vehicles are disrupting the automotive industry by changing the way cars are designed, manufactured, and used. Traditional OEM-Supplier dynamics are changing; Tier 2s and pure play software players are expanding their market position and are utilizing this opportunity to start engaging with the OEMs directly, by-passing traditional Tier1s. Through this paper, EY-P explores this changing automotive landscape and proposes a 3-pronged approach (Prioritizing software opportunities, building software capabilities, evaluating partnerships / acquisitions) to enable a smoother transition to the software domain.

3 Introduction

Automotive consumers have increasingly come to expect a standard of convenience from their vehicles that they get from their smart phones, tablets, and appliances. Demand for advanced technology features, such as connectivity, driver assistance/autonomous-driving and safety, parallelly with market trends, such as vehicle electrification and increased efficiency norms, are placing an ever-increasing emphasis on the role that software plays in a vehicle.

Traditional vehicle development approaches of developing hardware and software in unison can no longer keep up with the exponentially rising complexity of software needed to meet evolving consumer and market demands.

Enter Software-Defined Vehicles (SDVs). SDVs are characterized by the radically different approach of automotive development, where software is separated from the hardware it runs on. Like smart phones and computers of today, SDVs aim to utilize standardized software platforms, running on next generation consolidated and centralized computing hardware, with a focus on high-speed connectivity to the cloud, other vehicles and smart infrastructure.

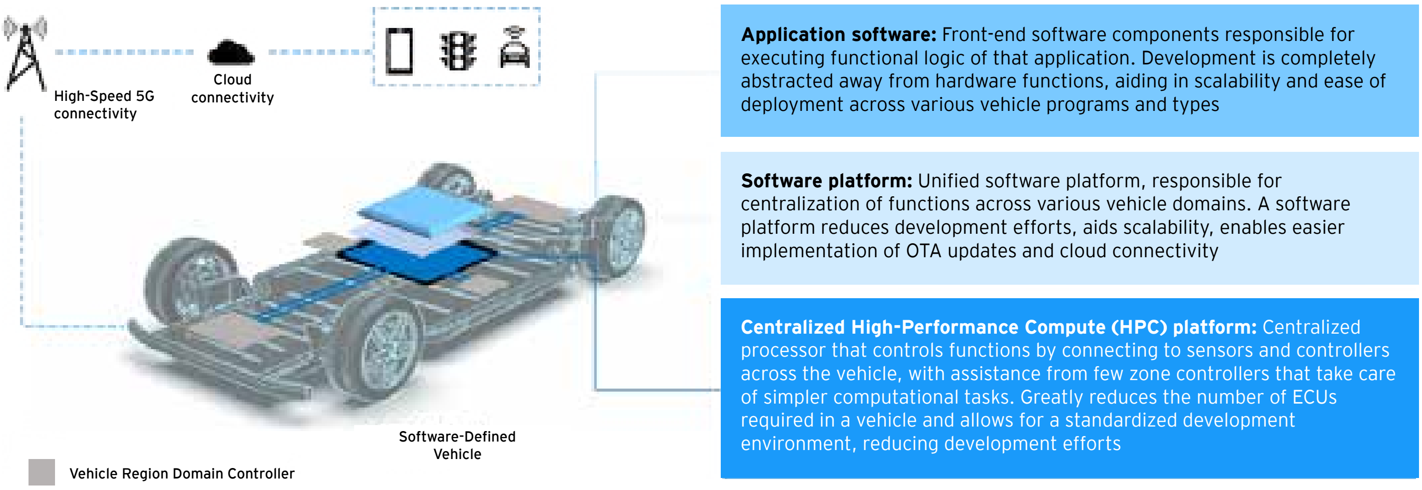

Figure 1 High level architecture for a Software Defined Vehicle

A key enabler for SDVs is Over the Air (OTA) updates. Besides security patches and incremental software performance improvements, OTA updates carry the potential to massively cut down costs and realize value from software for OEMs with the ability to roll out entirely upgraded features to customers without massive rollbacks or developing new vehicle programs. Players from markets like the US, EU and China are currently trendsetters and are leading the way in software development for various safety, convenience and performance related aspects of a vehicle. The US, with an extensive talent pool of software developers from Silicon Valley, has radically changed the way software for automotive is developed. New age automotive companies / Start-ups in this region have pioneered our understanding of SDVs today. They have adopted a "Software First" approach where the vehicle and all the hardware in it is centered around a centralized software platform.

The transition from current vehicle architecture to a software driven one is not a straightforward approach. OEMs are racing to achieve a fully software driven vehicle. However, this entails a ground-up transformation of vehicle architecture, development methodologies, and business models. There are several pathways that can be taken by leveraging different technologies and development approaches to cater to specific market needs. The transition is therefore disrupting the traditional automotive value chain, with entry of newer players, such as pure play software giants, redefined relations between traditional players and repositioning of suppliers across the value chain.

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Current challenges

One of the major challenges facing the automotive industry today is keeping up with the upcoming trends of Connectivity, Autonomy, Shared and Electrification (CASE) for automobiles. Advancements in these areas require significant boosts in on-board processing, integration of components across the vehicle, and the need for broader connectivity. However, given how vehicles are developed today, moving toward a software-defined future presents significant challenges. Currently, most OEMs are observing relatively lower than expected returns on their investments toward developing the next generation of automotive software platforms. Certain factors, highlighted below, are responsible for this trend:

Vehicle E/E architecture

The current distributed Electrical and Electronic (E/E) vehicle architecture means that for each specific feature, there might be several Electronic Control Units (ECUs). These ECUs contain a monolithic software stack as seen below (figure 2) and communicate with each other over the Communication Area Network (CAN) bus.

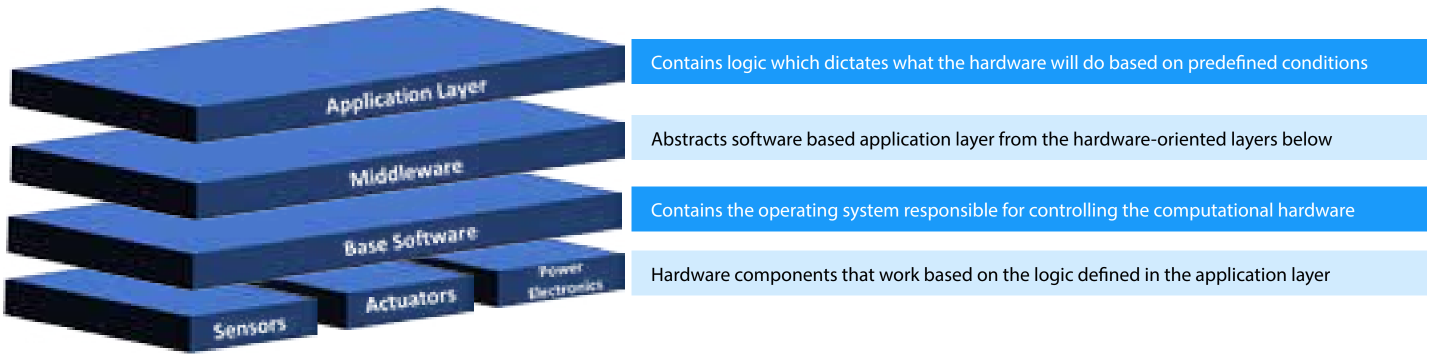

Figure 2 Monolithic Embedded Software Stack of a single ECU

This establishes the need for hundreds of ECUs in vehicles today, communicating through a relatively low speed communication protocol. Having a distributed approach creates one of the biggest challenges for the development of the next generation of automotive software.

- **Low compatibility with a centralized software platform:** Due to their distributed nature, architectures like this have very low compatibility with centralized software platforms, like those found in modern consumer electronics, such as mobile phones and computers.
- **High development effort:** The development effort for a distributed architecture is inherently high, as each ECU might have its own development environment and operating systems.
- **Lack of scalability:** With a distributed approach and the lack of a centralized software platform, it becomes difficult to scale the software products across multiple vehicle programs and variants.

Hardware-based development

With distributed E/E architectures, the software included in the vehicle is largely tied to the hardware components it runs on. Currently, a lot of these hardware components are sourced from Tier 1s, forcing OEMs to source black-box embedded systems integrated with the hardware components. This shifts the responsibility of developing, integrating, and updating software components toward the suppliers, leaving OEMs with little or no autonomy in implementing a centrally defined software strategy.

The consequence of such a supply chain and sourcing model is that the software is deeply linked to the hardware, posing several challenges, such as:

- **Lack of OTA updates:** Since the hardware and software are closely linked, deploying OTA updates to the software through the serviceable life of the vehicle becomes a challenge, as it would mean updating the hardware as well.
- **Lack of reusability:** Reusing software components across multiple vehicle programs or variants becomes challenging as this would require similar hardware to be deployed across multiple vehicle variants and programs
- **Low integration:** True integration among software components is very hard to achieve, thereby limiting processing power and latency, two key enablers for cross-functional features such as cloud connectivity and ADAS

Implementing connectivity

Due to the distributed E/E architecture and the deeply linked hardware and software, achieving true connectivity becomes challenging. Since the embedded systems are not truly integrated, the effort and cost required for connecting multiple ECUs to cloud based applications significantly increases. As a result, most vehicles today cannot fully leverage the benefits of high speed 5G connectivity, as the existing E/E architectures are simply not compatible due to their distributed nature. A major implication of this is that moving non-critical processing tasks to the cloud does not make any economic sense, as the development effort required far outweighs any productivity gains by implementing such a setup. This limits the capabilities of features, such as ADAS and Full Self Driving, preventing vehicles from achieving higher levels of autonomy.

Cybersecurity Concerns

Cybersecurity plays a crucial role in considering consolidated software platforms and increased vehicle connectivity. With a more distributed E/E architecture there are more potential points of entry for malicious actors to exploit. This can make it harder to keep the system updated with the latest security patches and to detect and respond to security breaches. Furthermore, a distributed architecture can also increase the complexity of the software running on the various ECUs, which can make it harder to test, validate and certify the system. Today, vehicles typically have somewhere around 100 million lines of code, whereas by 2030 it is believed that an average car will contain roughly 300 million lines of code. Identifying vulnerabilities across multiple ECUs for a large codebase becomes highly tedious as the interactions between the various ECUs and the software they run can be complex. This can make it difficult to identify and patch vulnerabilities in a timely manner.

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Shifting technology landscape

To overcome these challenges, OEMs have significantly increased allocation of budgets towards R&D for automotive software. Realizing the importance of automotive software and the role it will play to remain competitive in a market where automotive software acts as a key differentiator, OEMs are redefining software strategies, setting up dedicated software organizations and swiftly building capabilities.

Currently, the market conditions are highly fluid given the tectonic shift towards software focused development, however there are some trends that have indisputably come across as key technology enablers for this transition to be successful. These are:

Consolidation of E/E architecture

The growing needs of addressing higher vehicle complexity, scalability, higher vehicle security and connectivity will drive the expansion of ECUs.

"To manage complexity, OEMs are transitioning towards domain and vehicle centralized E/E architectures increasing reusability, scalability and reducing cost of development"

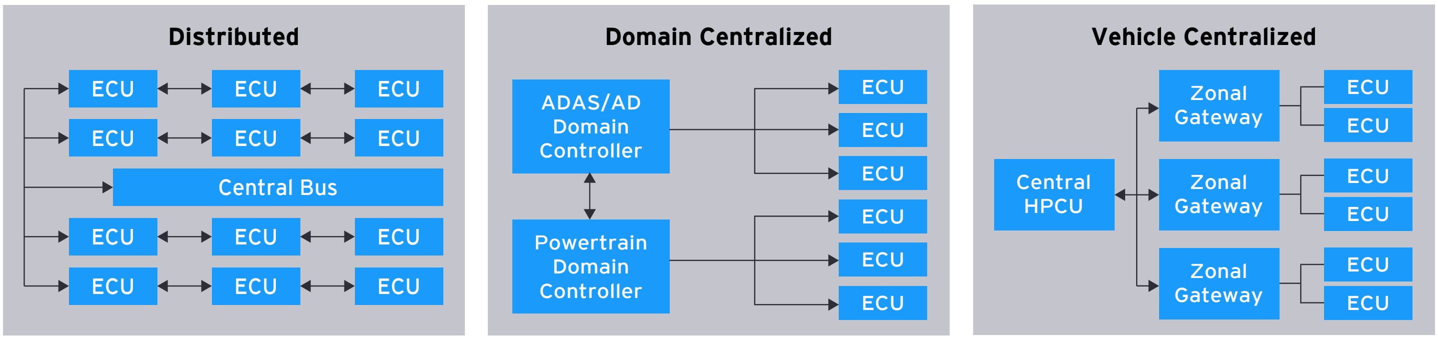


Figure 3 Evolving Vehicle E/E Architecture

The E/E architecture has evolved from ***distributed*** (with function specific ECUs) to ***domain-centralized*** (function specific ECUs bound to a domain specific ECU) today and is likely to move to a ***vehicle-centralized*** (consolidation of ECUs) ***architecture.***

The vehicle-centralized E/E architecture is characterized by a centralized high processing computing unit (HPCU) managing domain specific and function specific ECUs connected via high-speed automotive ethernet. This architecture is better suited to cater to cross-functional features such as advanced driver systems, vehicle connectivity, agile development methodologies and Over the Air (OTA) updates. These features require close integration of components, as they are required to function across all domains of the vehicle.

Software platforms

The evolving E/E architecture will pave out the way for development of standardized software platforms, compared to the previous approach wherein software was integrated into the hardware and sourced as black-box systems from multiple suppliers.

Using the traditional approach, achieving truly cross-functional capabilities, such as Full Self Driving (FSD), becomes a challenge. Each software feature is typically siloed and developed as an individual monolithic embedded system. Every individual software feature utilizes its own software stack, running different operating systems (Figure 4).

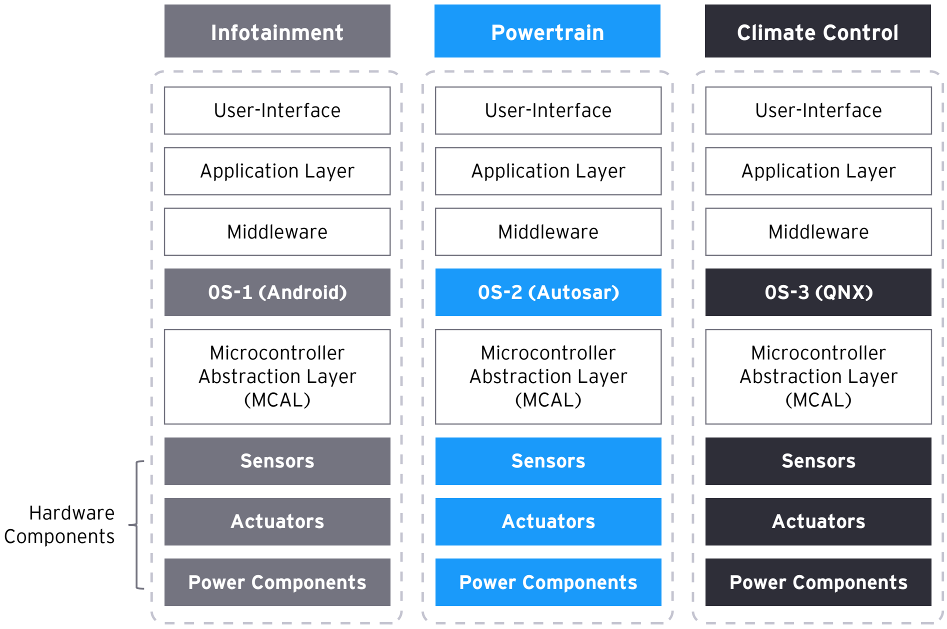


Figure 4 Traditional Monolithic Embedded Software Stacks

However, SDVs can leverage software platforms characterized by a horizontal integration of lower software layers, across multiple domains and functions (Figure 5). With horizontally integrated abstraction layers between the various software layers, development of high-level application is made independent of the hardware it is running on. Combined with the consolidated and centralized E/E architecture, a vehicle centralized software platform enables the emergence of a new software market.

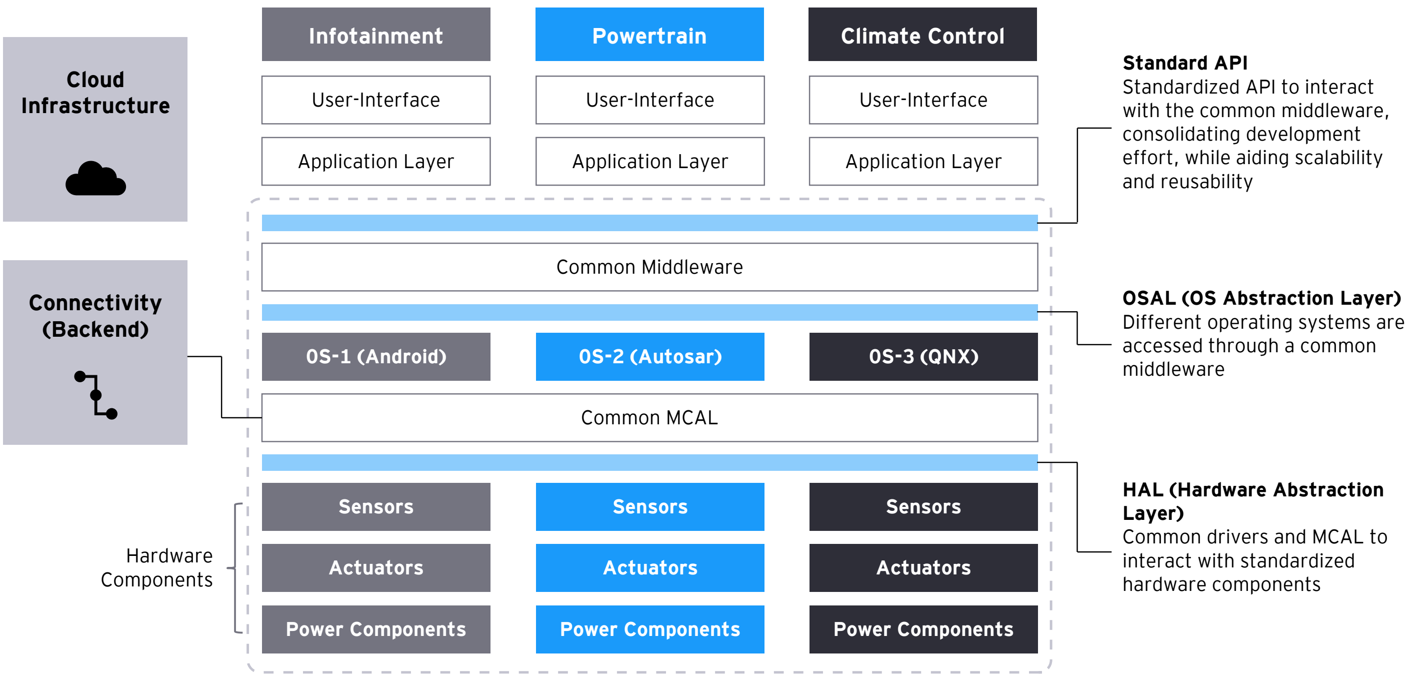


Figure 5: Standardized Software Platform Approach

Like app stores for popular mobile platforms, software platforms enable the automotive industry to observe reduced barriers to entry into the automotive software market for pure play software companies.

Coupled with a compatible centralized vehicle E/E architecture, some of the key advantages of a software platform are:

- **Support for a microservice architecture:** Breakdown of major functions (ADAS, In-Vehicle Infotainment, etc.) in to smaller and more independent software components called microservices. This would enable quicker release cycles of new features. For example, updating a function like ADAS would no longer require the developer to re-deploy the entire ADAS application on a vehicle. Incremental update to smaller services that make up ADAS (object detection, decision making, etc.) can be made, rolled back or decommissioned.
- **Agile development:** Since the SDLC (Software Development Lifecycle) is significantly shorter than the hardware lifecycle of a vehicle, agile development of software enables continuous development and improvement of software features leading to better customer experiences, security and has the potential to unlock new sources of revenue.
- **Scalability and reusability:** Developers would no longer need to concern themselves with ensuring compatibility with multiple hardware units their software needs to run on since higher-level software would be abstracted away from the hardware. This means the same application can be deployed across vehicle variants and programs, allowing the services to be scalable and reusable.

Several leading OEMs across the globe have already begun the transition to a software platform approach. However, it needs to be noted that a successful transition to a software platform approach must be underpinned by a compatible centralized vehicle E/E architecture.

V2X connectivity

With the next generation of consolidated vehicle architectures and software platforms, OEMs can leverage cloud computing and V2X connectivity with greater ease. 5G is one of the key enablers for bringing true connectivity capabilities in automobiles with advantages of low latency and increased reliability, allowing real time vehicle connection with surrounding smart infrastructure (V2I) and other vehicles (V2V), faster software updates, etc.

With the lower latency and higher data bandwidth, 5G in automotive would enable off boarding of non-safety-critical applications and processes from the vehicle to the cloud. Real-time connectivity to the cloud is one of the key defining features of an SDV. Some of the major benefits of integrating real-time connectivity with the cloud include:

- **Improvements in ADAS/AD:** Automakers and system developers can leverage data and insights collected from fleets of vehicle on road to train and enhance their ADAS and AD products and services by creating and running simulated environments on the cloud.
- **Rapid deployment and OTA updates:** Automakers and suppliers leverage automated data processing, training, and deployment pipelines to test, validate and deploy new or updated software products and services to vehicles on a recurring basis.
- **MLOps:** MLOps (Machine Learning Operations) refers to the practices and tools used to manage the production lifecycle of machine learning models. In the automotive context, this could include the development and training of machine learning models for tasks such as autonomous driving, predictive maintenance, and customer personalization. MLOps involves the collaboration of data scientists and IT professionals in order to efficiently build, deploy, monitor, and maintain these machine learning models in a production environment (figure 6). Connectivity is the key enabler for MLOps to successfully manage and continuously improve features, such as ADAS and FSD, at scale.
- **Data-driven organizations:** Data collected from fleets of vehicle on road can be leveraged by multiple enterprise domains such as R&D, manufacturing, after-sales, and maintenance to enhance product offerings, unlock new streams of revenue and enable data-driven innovation across the automotive value chain. Applications for this could include predictive maintenance, score-based insurance, large scale fleet optimization and management.

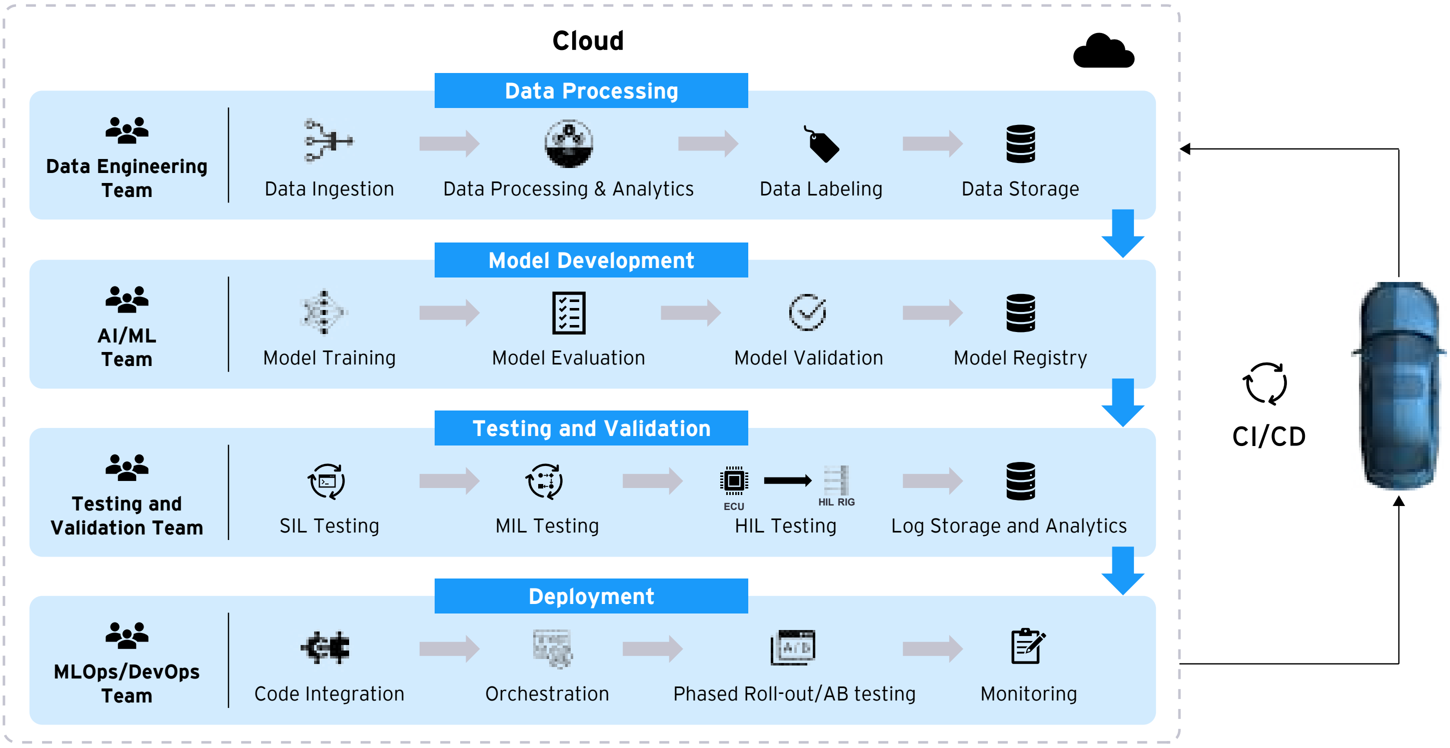
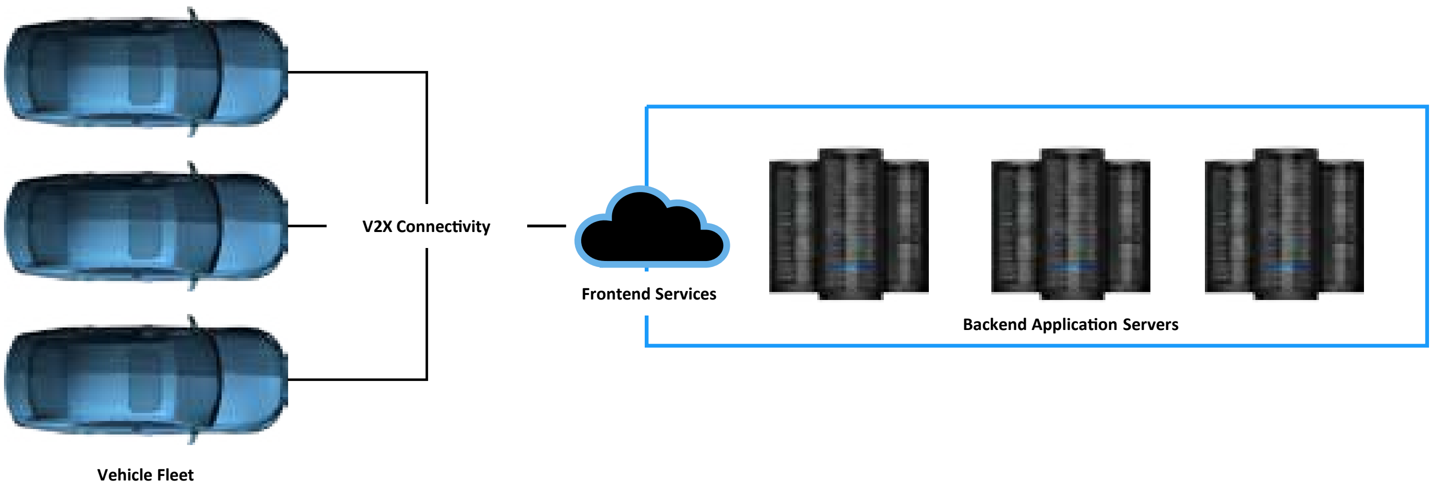


Figure 6 Automated Cloud Based Pipelines for Rapid Deployment of Software Products and Services

However, to successfully leverage all the benefits that cloud and vehicle connectivity offer, automakers must first successfully implement a compatible software platform and vehicle hardware.

Automotive cybersecurity

Currently, the regulations governing automotive cybersecurity are narrow in scope. Suppliers provide standard security solutions to OEMs with minor modifications based on the provided requirements. However, consolidation of the vehicle E/E architecture along with a centralized software platform can aid efforts to mitigate emerging cybersecurity risks across the various connectivity pathways (figure 7)



Vehicle-level threats	Transmission threats	Front-end threats	Backend threats
Spoofing attacks: Spoofing attacks to access critical vehicle functions like braking and acceleration **Physical access:** Accessing the vehicle computer through the on board diagnostics port to install malware or spyware	**Man in the middle attack:** Positioning transceivers between senders and receivers to acquire sensitive data such as login credentials, or to impersonate one of the parties to mount an attack	**Denial of service:** Disable service to vehicle that require critical data for functions such as ADAS or full self driving capabilities	**Unauthorized access:** Access backend data and applications by maliciously acquiring identity credentials or exploiting vulnerabilities

Figure 7 Emerging cyber threats in the era of SDVs

Advances in vehicle architecture and software platforms aid automotive cybersecurity in the following ways:

- **Reduced entry points for attack:** Centralized architectures consolidate the number of entry points for malicious attacks, making it easier to secure, monitor and manage the security of the entire system. This makes it easier to detect and respond to security breaches in a timely manner.
- **Regular updates:** Once detected, centralized software platforms make it easier and quicker to roll out security patches. With a consolidated architecture, it is also easier to implement security measures such as firewalls, intrusion detection systems, and encryption, as these measures can be centrally managed.
- **Building redundancy and fail-safes:** Implementing redundant systems and fail-safes to minimize the impact of any potential security breaches or failures becomes easier, as the effort to do so will be consolidated to a centralised system, rather than being spread across multiple ECUs

6

Development approach

With the above trends enabling the transition to SDVs, automakers are realigning organizational strategies to meet the demands of an industry increasingly pivoting toward software. To do so, leading OEMs and suppliers around the globe are taking inspiration from leading software and technology companies.

Traditionally, the development approach began with a requirement gathering phase, then sourcing hardware and software components from external suppliers, before moving on the testing, integration and validation. The sourcing of software was typically tied to the hardware of a specific vehicle domain (figure 8). For instance, the powertrain software was sourced together with the powertrain ECUs as an integrated unit. As software complexity rises, this methodology fundamentally lacks the ability to be scalable, agile or cost-effective owing to its sequential and time-consuming nature of development.

The software-defined approach fundamentally differs from the traditional approach by focusing on software development independent from hardware. By completely decoupling the development of software from hardware, vehicle software development can be accelerated, scaled and continuously deployed across a vehicle's serviceable life, all while incurring lower overall development costs.

However, to fully embrace this approach, automakers are rapidly transitioning to a new sourcing model where software is sourced independently from the hardware (figure 9). This model of sourcing is characterized by moving toward an organizational structure that reflects a cross-functional orientation of software teams, rather than domain specific ones. Internally, software budgets would be aligned toward development efforts for a unified platform rather than individual vehicle domain programs.

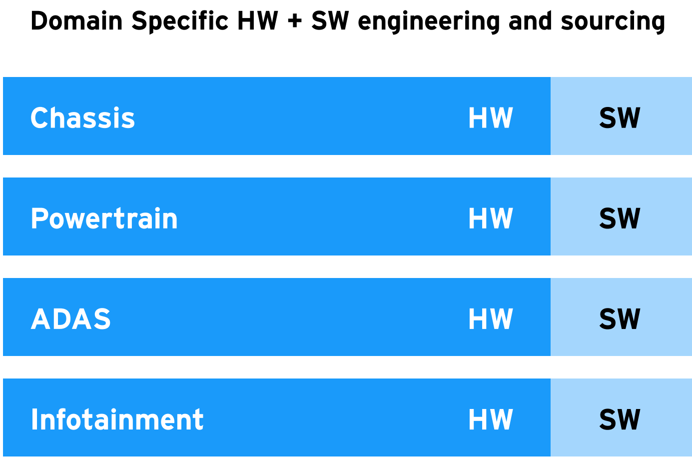


Figure 8 Conventional model for hardware and software sourcing

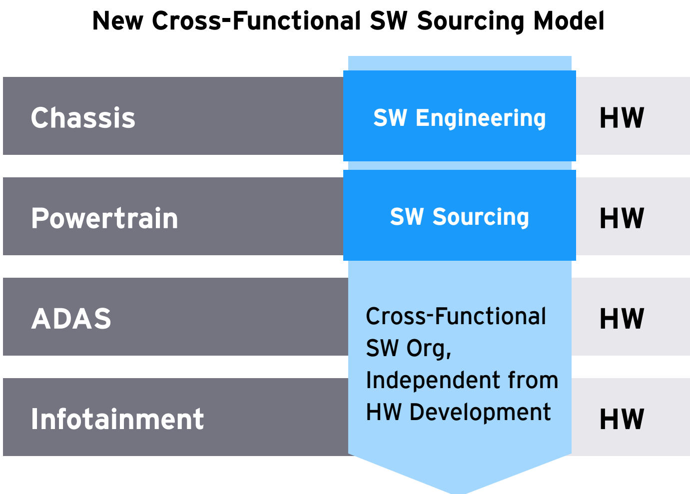


Figure 9 Vertically Integrated Cross-Functional Software Organization

This change in development approach is giving rise to a trend wherein leading automakers are setting up dedicated software organizations and, as a result, their demands and interactions with suppliers and pure play software companies are disrupting the traditional value chain.

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Shifting value chain

Traditionally, the relationship of OEM with suppliers has been straight forward and hierarchical with OEMs sourcing and interacting with Tier 1s directly, where Tier1s would acquire raw material/subcomponents from Tier 2s and 3s. Tier 1s would play the role of integrators (figure 10).

Figure 10 Traditional OEM Supplier Relationship & Hierarchy

Some of the reasons this model is incompatible with a software driven approach are listed below:

- **Lower autonomy:** Sourcing integrated HW and SW systems from Tier 1s reduces the autonomy automakers have over the software deployed in their vehicles. This includes the data generated and collected, and the update cycles for releasing new features and overall differentiation achieved through software.
- **Owning IP:** As software continues to play an increasingly pivotal role and serve as a key differentiating factor for vehicle sales, OEMs would like to own and retain IP and autonomy over end-to-end development of their software products.
- **Lack of integration:** Sourcing solutions from multiple suppliers to implement a distributed vehicle E/E architecture leads to lower integration among components and increased development efforts for a software platform

As a result of this, Tier 2s and pure play software players have had the chance to expand their market position and have utilized this opportunity to start engaging with the OEMs directly, by-passing traditional Tier1s. OEMs get the benefits of reduced complexities, opportunity to develop the technology jointly and later retain the IP while working with Tier 2s and new entrants in this space.

However, Tier 1s still can still maintain relevance in this shifting landscape. To do so, they would need to reposition themselves in the value chain and leverage their system integration and development expertise by transitioning to Tier 0.5s.

Under the shifting value chain, Tier 0.5 suppliers closely collaborate with automakers form a very early stage of development. Where typical Tier 1s measure revenues by one-time sales of integrated units, tier 0.5 provides development support and collaboration by acting as innovation partners. This includes collaboration from early-stage R&D efforts all the way through continuous development of software products.

Additionally, automakers will also rely on Tier 2s, Tier 2+, and pure-play software companies for collaboration on different areas such as sourcing of centralized high compute SOCs, implementing AI/ML frameworks as well as undergoing IT transformation to have standardized DevOps practices. This leads to a model underpinned by more collaboration across the value chain (figure 11).

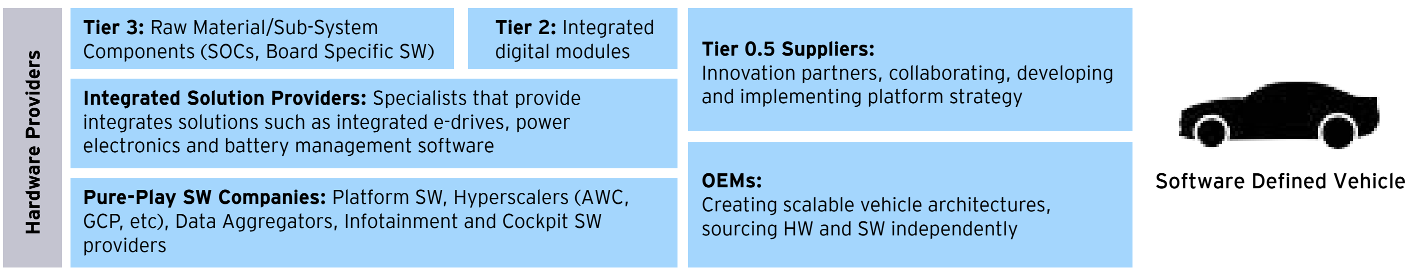

Figure 11 Redefined OEM Supplier Relationships

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The path forward: EY-P's Outlook

Development of capabilities in automotive software will require sizeable investments and development efforts. EY-P's New Age Mobility team has identified some key areas of focus for your business for it to be successful in this shifting technology landscape. These are:

Software-product strategy: prioritizing the right opportunities

OEMs are dedicating an ever-increasing amount of money to software R&D to remain competitive. The software R&D budgets are being dedicated toward the development of new features and a centralized platform strategy. However, generally, it will not be prudent for automakers to develop and control the entire stack in-house. To aid in the development efforts, they will continue to rely on suppliers, software players and solution providers in line with the redefined value-chain for SDVs.

Differentiating Value

Software differentiators

Non-safety critical software products that require relatively low development efforts, have easy to acquire capabilities, but serve as key differentiators for automakers

Example: Connected Mobile Applications, In-Vehicle Infotainment Software, Digital Cockpits

High-tech

Software products that require mature capabilities in the field of automotive embedded software and are highly sought-after by automakers

Example: ADAS offerings, Cloud Connectivity, Full Self-Driving

Commoditized products

Non-safety critical component level/low level software products that control basic hardware features of the vehicle

Example: Actuator control software (wipers, windows, mirrors, Automatic lights

Standardized products

Safety critical software product that require mature capabilities due to testing and compliance requirements with safety and automotive standards

Example: ABS, Emission Control Software, Power electronics control software

Development effort/Capabilities required

Figure 12 Strategic Framework for Choosing the Best Software Product Strategy

Therefore, to maximize returns on software development efforts it is important to establish a fundamentally solid product strategy. The chosen product strategy will vary on factors such as existing capability maturity, the value of the product/services offered and so on. Therefore, choosing where to play (figure 12) becomes essential for establishing a software-product strategy.

Building capabilities

Building on the foundations of a product strategy, focus on capabilities required to execute the development of software. The core competencies and capabilities will vary depending on where in the value chain you decide to operate your business. For Tier 1s, system architecture and integrations capabilities would be a priority, whereas pure play software companies can leverage agility by focusing on DevOps skills.

Partnerships/Acquisitions and academic tie-ups

Given the dynamic market conditions, it is essential to ramp up capabilities quickly. To stay relevant in a software-driven industry, it will be essential for supplier, pure play software companies and solution providers to strategically partner through JVs, and Mergers & Acquisitions. This enables cost sharing of the large investments required to develop software capabilities and transition to a software organization.

This is a phenomenon that has been observed across the industry with leading Tier-1 suppliers wholly acquiring or partnering with embedded software companies in this space.

For more advanced software offerings like ADAS and full-self driving, trends of OEMs and suppliers partnering with academic institution has been upcoming as well. To fully maximize these collaborative efforts, it is essential to set clear and strategic targets that align with the interests of both institutions. With a clear vision and established goals, such collaborations have the potential to yield high degrees of innovation by leveraging young talent and institutional funding.

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Conclusion

The transition to SDVs is disrupting the automotive industry across the value chain. How the roles of different players will shape out in the future is still highly fluid, with new entrants, traditional suppliers and automakers racing to grab a dominant position in this space. However, observing the current market trends (figure 13), one certainty that universally exists for all players is that software will play an ever-larger role in the automobiles of tomorrow and to stay competitive in the market going forward, automotive software would have to be a part of product offerings across the value chain.

Trends

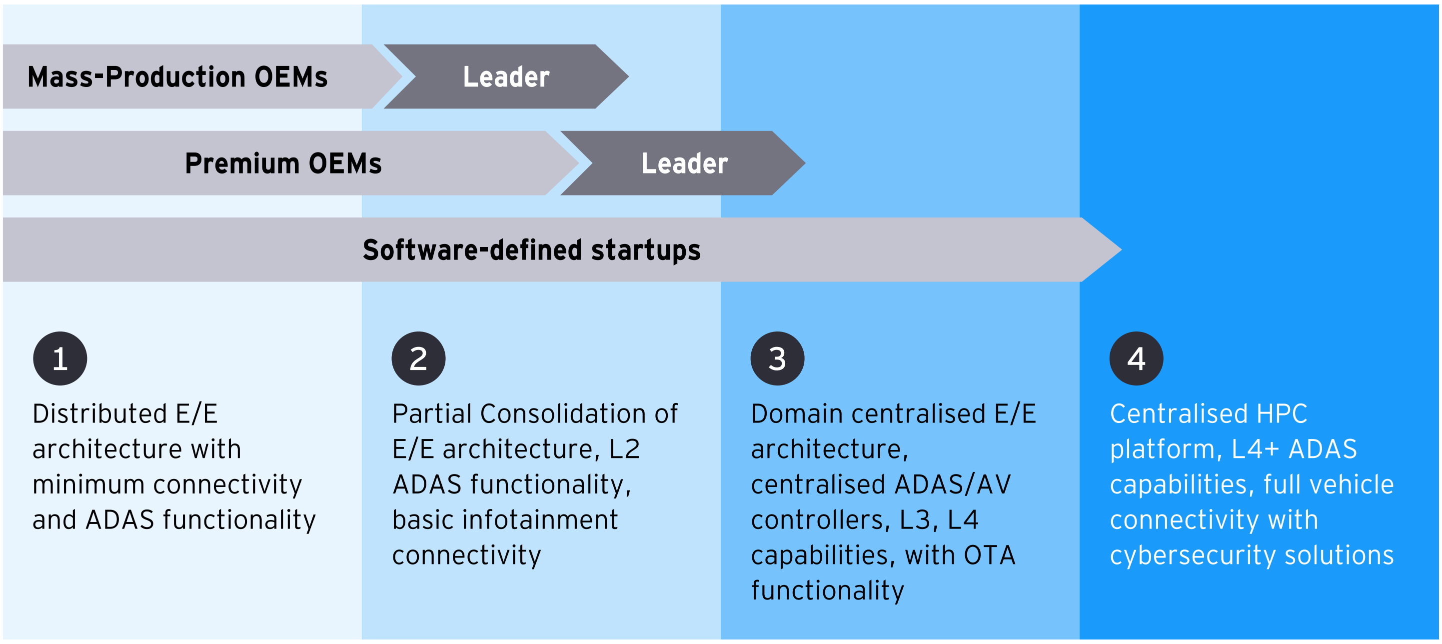

Figure 13 SDV Trends Observed by Automotive OEMs

Key takeaway for OEMs:

Key takeaways	Description
Vehicle E/E architecture	▶ Overhaul of E/E architecture to be more **consolidated, scalable and modular** for applications across vehicle programs and variants, in **close collaboration with Tier-1 suppliers**
Software strategy	▶ **Development of centralized software platforms** leveraging high-speed connectivity and **over the air updates to continuously improve and develop the in-vehicle software across the vehicle's lifecycle** ▶ Investments in R&D and **carving out a dedicated software organization** with focus on the SDLC ▶ **Decoupling hardware and software** to ensure faster software development times independent from hardware upgrades, scalability and tighter integration of software components
Cloud strategy	▶ Implementation of centralized cloud strategy to offload heavy processing tasks on the cloud ▶ Development of cybersecurity solutions to ensure vehicle safety across the vehicle, cloud and during transmission of data

OEMs across the globe are already racing toward achieving a centralized software platform and consolidated E/E architectures by inve4sting heavily in the R&D for software. Some notable examples are:

OEM	2021 investments in software R&D	Key achievements aligned to the software defined agenda
American multinational OEM	$1 - $1.5 billion	▶ Introduced over-the-air updates for new electric vehicle program ▶ Developed in-house software product engineering teams to enable full-stack development of software components
German multinational OEM	$3 - $3.5 billion	▶ Created a dedicated software organization ▶ Employing over 4,500 engineers and developers that were consolidated from various organizations to serve as an independent division, set up to service the software needs of all subsidiaries belonging to the OEM
Global Japanese OEM	$3.5 - $4 billion	▶ Developing and rolling out a dedicated centralized software platform for future vehicle programs ▶ Development effort for this software platform is consolidated and developed through a dedicated R&D subsidiary of the parent company

Key takeaways for suppliers and pure play software companies:

Key takeaways	Description
Consolidated organization	Mirroring the end customer, consolidating capabilities for in-vehicle software and computing to offer cross-functional products and services in the domain of SDVs to OEMs through a single dedicated entity with a scalable global organizational platform
Revised business models	Transitioning from manufacturing and selling coupled hardware and software products to closely collaborating with OEMs and providing specialized software engineering management services
Specialization	For pure play software companies and traditional Tier-1's, specialization in a particular domain with automotive software can lead to OEMs sourcing non-differentiating products such as the middleware from specialized suppliers
Acquisition of capabilities	To rapidly develop and scale software capabilities, evaluate partnerships, tie-ups and acquisitions

To conclude, Software-Defined Vehicles (SDVs) are symbolic of the paradigm shift that the automotive industry is witnessing and is marked by various megatrends like the consolidation of E/E architecture, evolving software development approach, V2X connectivity, cloud computing etc. Software is the epicenter around which these megatrends are shaping up.

EY-P's future mobility team can help you navigate the complex strategic decisions required to help your business be successful in the era of Software-Defined Vehicles. *You can reach EY supplementary document "Tesla Case study" by clicking.*

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Glossary

Term	Definition
OEM: Original Equipment Manufacturer	Companies that manufacture and sell vehicles or their associated components
ADAS: Advanced Driver Assistance Systems	Set of safety features in vehicles that use software to assist the driver and prevent crashes
SDV: Software-Defined Vehicles	Next generation of vehicles characterized by key features enabled through a centralized software platform and consolidated electronics architecture
FSD: Full Self Driving	Capability of a vehicle to safely navigate and operate without human input or supervision
OTA Updates: Over the Air Updates	Methods to deploy software, configuration, or security updates through wireless communication protocols
C.A.S.E.: Connected, Autonomous, Shared, Electric	Collective term to describe the major upcoming trends of connected, autonomous, shared and electric vehicles within the automotive industry
ECU: Electronics Control Unit	Control system, usually responsible for executing a single function within a vehicle
E/E Architecture: Electrical and Electronics Architecture	Hardware topology dictating the network layout of electrical systems and electronic controls
CAN Protocol: Communication Area Network Protocol	Standard communication protocol used by microcontrollers to transmit and receive messages within a network without the presence of a centralized host computer
HPC: High Performance Computing Unit	Collective term for integrated high-performance computing, storage, and network resources for processing complex workloads
SDLC: Software Development Lifecycle	Term used to describe the end-to-end processes required to create software products from concept to production in the most efficient manner
HMI: Human Machine Interface	Collection of functional elements that enable driver and passengers to interact and control various aspects of the vehicle in the most seamless way as possible
V2X Connectivity: Vehicle to Everything Connectivity	Umbrella term used to describe the connectivity abilities of next generation of connected vehicles. V2X can include vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), etc
SOC: System on a Chip	An integrated circuit that integrates all components of a computer or electronic system into a single chip
API: Application Programming Interface	Set of protocols, routines, and tools for building software and applications
HIL: Hardware in the loop	Method of testing in which a hardware component is integrated with a simulated environment to test the component's response to inputs and expected outputs
MIL: Model in the loop	Method of testing in which a simulation model of a component or system is integrated with the real-time environment to test the model's response to inputs and expected outputs
SIL: Software in the loop	Method of testing in which a software component is integrated with a simulated environment to test the component's response to inputs and expected outputs

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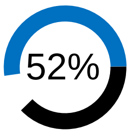
Highlights

5G adoption to unlock advanced connected car capabilities

5G network infrastructure is expected to expand rapidly with more than 50% penetration in key markets like North America, China, Japan by 2025.



Share of 5G enabled connected cars expected to be sold annually by 2030.

- All major auto OEMs are expected to launch 5G enabled cars by 2023 with Electric vehicles being the front-runners.
- 5G will pave the way for V2X communications, pivotal for advanced connected services
- V2X communications will be deployed initially to enhance safety, traffic efficiency and subsequently in more complex applications such as autonomous driving.

35.1m units

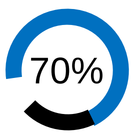
Global car parc with V2X Capabilities by 2026 from ~0.7 million in 2020

OTA updates and vehicle OS pivotal for OEM's software readiness

Vehicle centralized architecture* is essential for OEM's transition towards end-to-end over-the-air (OTA) software updates capabilities.

Premium PV and EV makers are leading the race for zonal architecture.

At least five automakers are expected to introduce OTA updates as a new revenue stream by 2023.



Of the vehicles are expected to use Android Automotive operating system (AAOS) by 2028

- Mass market OEMs prefer open-source OS reduce costs and development time.
- Premium automakers prefer to have their own OS with their user interfaces (UI/UX) as an USP.
- OEMs transitioning into mobility-as-a-service (MaaS) companies are expected to build own vehicle OS platforms for scalability of autonomous driving software.

** Vehicle centralized architecture or Zonal architecture: A centralized vehicle architecture which reduces software complexity, improves ADAS readiness and easier for OTA updates*

Highlights

Integration of new age technologies to provide immersive in-vehicle experience

Augmented reality (AR) and virtual reality (VR) technologies to enhance in-vehicle experiences : AR-head-up displays (HUDs), navigation systems, VR-video games etc.

Display screens are expected to shift from touch controls to haptic feedback and voice commands with advent of AI-based digital assistants.

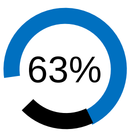
In-Vehicle Infotainment (IVI) systems to shift from vehicle-centric approach to consumer-centric approach with smartphone and third-party apps integrations.

36 million

Vehicles with Android infotainment services expected by 2030 with android apps featuring as a standard

Tier 1 suppliers and technology partners to focus on integrating real-time application such as autonomous driving, navigation, traffic information for OEMs.
Expansion of in-built applications into digital payments, in-vehicle ecommerce, music, radio etc bringing more digital connectivity to customers in-vehicle.

Connected capabilities will help to achieve higher level of vehicle autonomy



Of vehicles expected to have Level 2 or higher autonomy in 2025. Most OEMs have announced trail /launch of Level 3 autonomous vehicles by 2025.

Level 0 and Level 1 ADAS features are expected to become standard in vehicles as part of basic safety.

US$ 50 billion

ADAS market by 2025 with growing penetration of Level 2 / 2+ features and on-demand offerings such as hands-free driving.

- Integration of ADAS safety features with cloud connectivity through C-V2X communications to enable semi / fully autonomous active safety features.
- Firmware OTA updates to upgrade ADAS systems to higher autonomy is expected to increase penetration of Level 2/3.

In car navigation systems are expected to be enhanced with cloud, AR and AI technologies which are pivotal to support semi/full autonomous driving.

Highlights

IoT sensors to expand connected services in Well-being and Vehicle management

40%

Of connected vehicles expected to have in-built well-being features by 2025 with OEMs embedding more sensors and internet of things (IoT) into vehicles.

In-cabin technologies are expected to shift the focus of OEMs from passive safety features to driver & occupant monitoring features .

100%

Penetration of driver monitoring systems (DMS) in key markets by 2027 assisting in active safety and fleet monitoring services.

- DMS is expected to converge with occupant monitoring and cabin awareness systems to adapt to the requirements of Avs and shared mobility
- Aftermarket connected services to shift from predictive maintenance to proactive maintenance with penetration of OTA updates and remote diagnostics.
- Remote operations to expand into tele-operated driving, fleet management etc to support growing shared mobility.

OEMs unlocking new revenue streams with data monetization and cybersecurity

Data aggregators are playing key role as marketplace providers in the dynamic data monetization ecosystem between OEMs, third-party service providers, technology partners etc.

Current data monetization sources are independent aftermarket and usage-based insurance (UBI) providers while new avenues are expected to open up from e-health operators, analytics firms, third-party agencies.

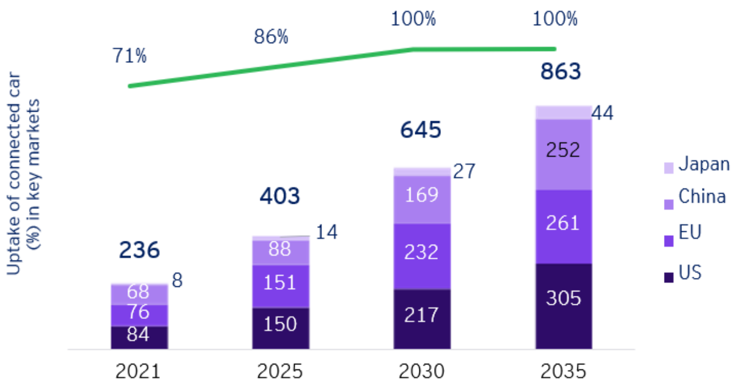
US$ 120 billion

OEMs are poised to capture larger share of the rapidly growing UBI market with telematics data monetization.

- With connected cars generating 380 TB to 5,100 TB of data in a year, OEMs are adopting hybrid strategy* for cloud storage and management.
- OEMs are also building in-house capabilities to gather, organize and secure transfer of data.
- New regulations on cyber-security are being rapidly adopted, with OEMs expected to provide cybersecurity as on-demand service in future.

Growth of connected car market is driven by key trends such as 5G adoption, V2X technologies, ADAS, next gen HMI, OTA capabilities etc

Connected car parc projections (millions) in key markets

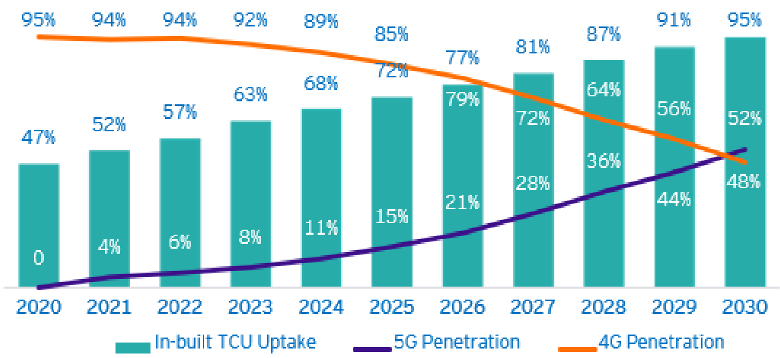


- Connected Car Parc is expected to cross 400 million vehicles in the Key markets with an uptake of 86% in annual sales by 2025.
- The US and EU regions will drive the connected car sales till 2025 while China is expected to show higher growth rate in connected car parc post 2025.
- Connected vehicles uptake is expected to reach ~100% by 2030 in the Key markets.

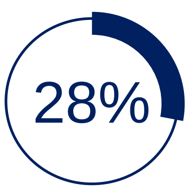
~ US$ 225 billion

Global connected car services Market size by 2027 with a CAGR of 17.1% till 2027

Uptake of Telematics connected cars* (%) in key markets, 2020–2030



- Connected cars use In-built Telematics units (TCU) or tethered devices to connect to the internet. In-built TCU's are expected to reach 95% penetration.
- 4G TCU in-built cars had 94% share in 2021. 5G enabled cars entered the market in 2021 and operating on 4G networks based on infrastructure availability.
- NA, EU and China are expected to lead in 5G infrastructure and adoption rate.

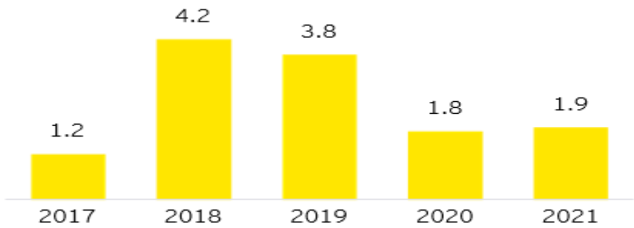


Share of in-built 5G Telematics unit cars among connected cars annually by 2027

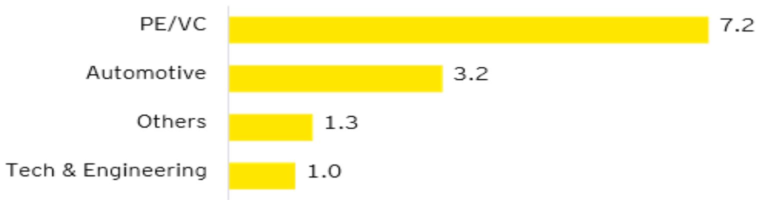
Automakers continue to step up investments in connected car with safety, security and diagnostic services garnering significant interest.

Yearly investment trend (US$ billion)

Investments in Connected space show early signs of recovery post the pandemic, with US$1.9 billion in investments

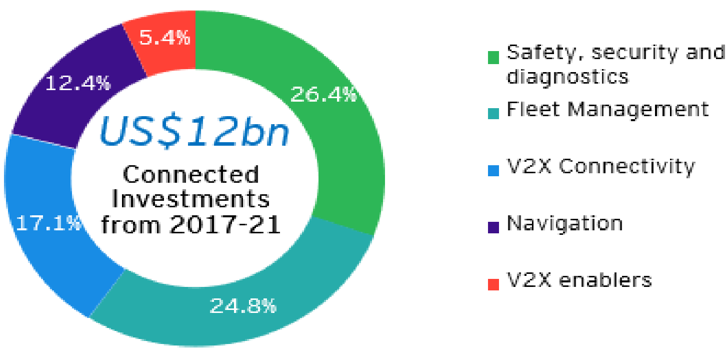


Cumulative investments by key players (US$ billion, 2017-21)



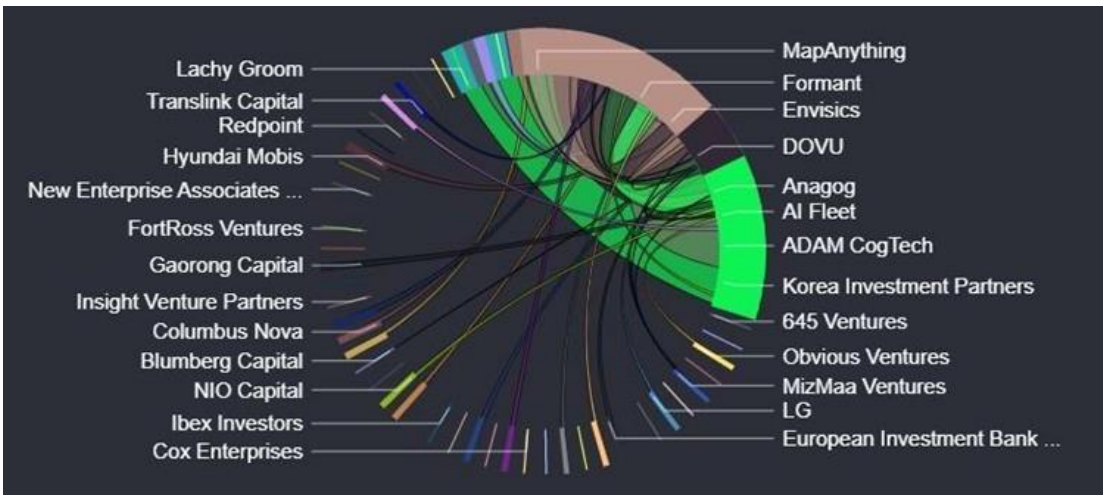
investment by sub-sector (% share) (2017-21)

Safety and diagnostics, including vehicle telematics constitute the majority of investments in this space

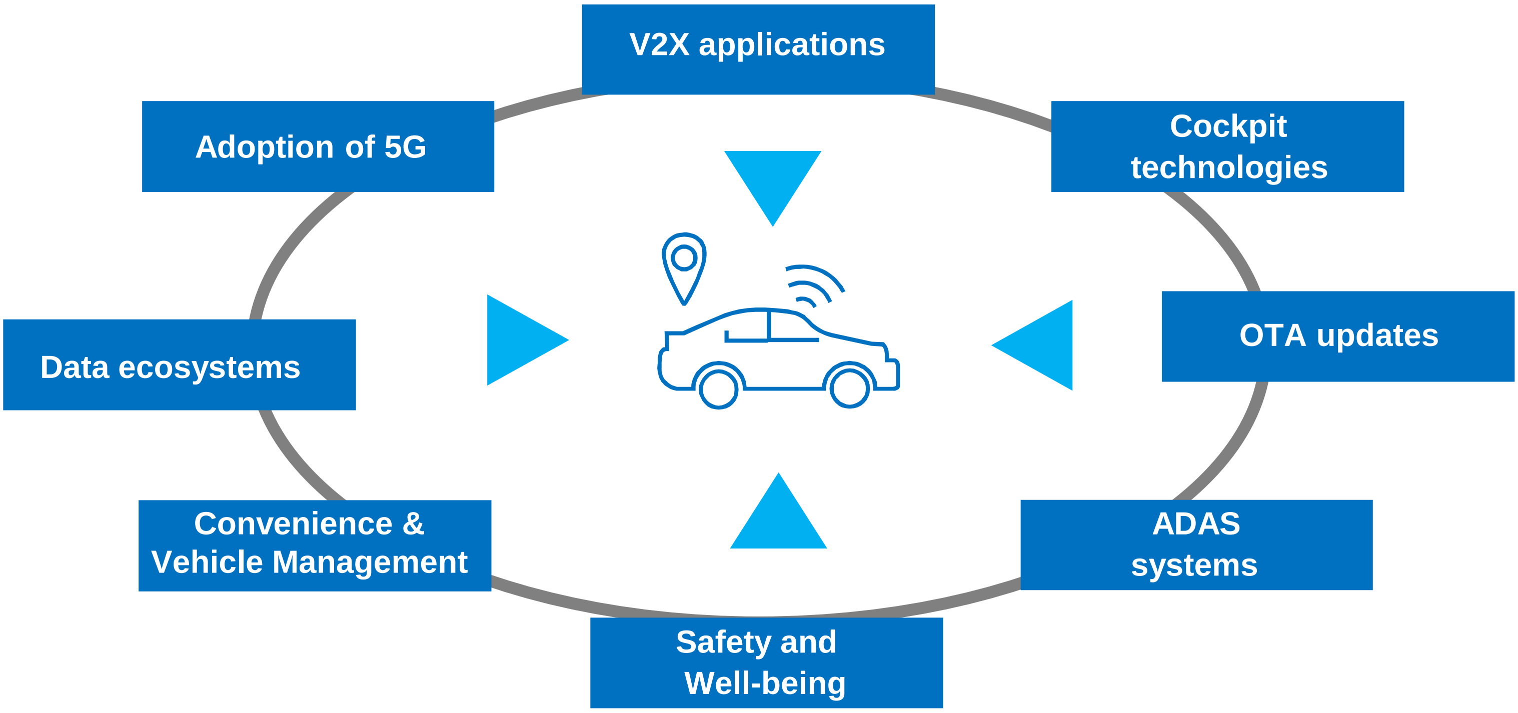


US$13.88b

investments by technology players (2017-21)



Growth of connected car market is driven by key trends such as 5G adoption, V2X technologies, ADAS, next gen HMI, OTA capabilities etc.



- Adaption of 5G: 5G communication will pave the way for data-rich services and V2X Applications.
- Data Ecosystems: Data Monetization, Cybersecurity, Data regulations etc.
- Convenience & Vehicle Management: Remote operations, EV specific operations, aftermarket services, fleet management services
- Safety and Well-being: Customized in-vehicle experience, driver monitoring systems, biometrics, voice-enabled services.
- ADAS Systems: Deploying driving assistance systems supporting level 1 and above autonomous vehicles.
- OTA Updates: Software updates over-the-air (OTA), Firm-ware updates (FOTA).
- Cockpit Technologies: Digital Cockpits integrated with New HMI trends, Augmented / Virtual reality to provide immersive experience
- V2X Applications: V2X technology will have wide applications in enhancing safety, traffic related services.

Case Study - Tesla

What differentiates Tesla from its competitors as the leader of software-defined vehicles?

	Description
Vehicle-Centralized Architecture	• Tesla's vehicle-centralized architecture provides advantage for cybersecurity, OTA updates and achieving higher levels of autonomous driving. • Adoption of centralized architecture by legacy automakers are in developmental stage which puts Tesla ahead of its competitors being a truly software-defined vehicle.
Advanced Firmware OTA Updates	• With most of the legacy automakers OTA capabilities limited to software updates for infotainment and navigation, Tesla is pioneer in the industry offering FOTA updates. • Tesla is one of the few EV makers which have FOTA capabilities such as upgrade its ADAS software FSD Beta, battery management systems etc.
ADAS Software: Full-self Driving (FSD) Beta	• FSD is the only ADAS software in commercial PVs which offers automatic navigation with auto pilot on limited access roads. • Offered to limited users with safety score* > 99, Tesla uses FSD program to train its AI based ADAS software and simultaneously expand its software-as-a-services (SaaS) revenue stream.
Tesla Arcade: In-Car Gaming Console	• While most of the connected-features in Tesla are comparable with legacy and EV automakers, Tesla is working on integrating Stem, a video game marketplace into its in-car infotainment system. • Building an in-car video game platform, Tesla Arcade through which it plans to offer games on-demand in future.

Tesla is far ahead in commercializing its advanced connected services with high software content per vehicle and unique offerings.

Tesla leads the industry in software content per vehicle

US$15,000
FSD Lifetime subscription*

Software content in Tesla is highest in the industry due to high cost of FSD Beta subscription.

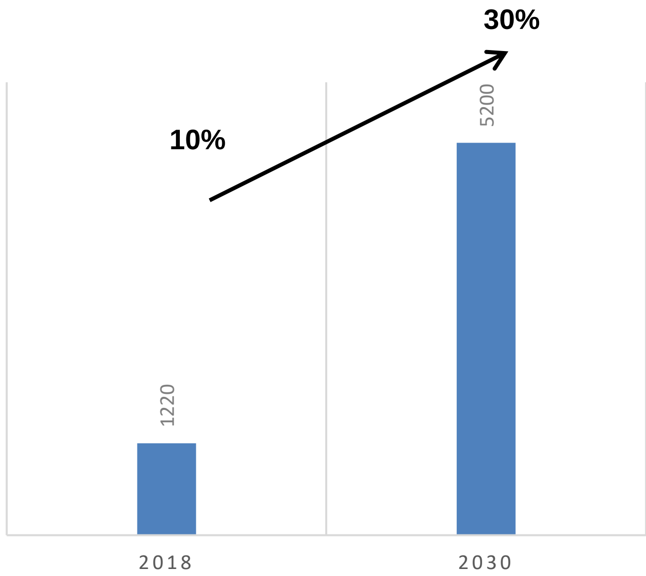
US$99
per year (US$9.99 / month)

Offers its connected services in "connectivity package".

~1.6 billion
Deferred revenues (FY'21)

Leader in Software revenues and its FSD revenues alone are expected to contribute 6% of sales and 25% of gross profit by 2025.

Average Software content per vehicle (D-segment) in USD, as a % of Overall content



How different are Tesla connected services from its competitors?

Plans to expand the FSD user base to 1 million+ by the end of 2022 and lowered the safety score requirement to 95+ to expand the program.

Re-launched enhanced autopilot package at US$6,000* to increase customer reach, which is comparable to auto pilot systems in its competitors such as GM Super cruise, BMW Auto pilot etc.

Offers **performance upgrade** called acceleration boost, unlocked OTA at US$2,000 which improves 0-60mph time by more than 0.5 seconds depending on model.

Offers predictive maintenance with self-diagnosis and pre-order of parts and included service appointment booking through its app.

Tesla uses driving data to offer usage-based insurance and is expected to **contribute 30%-40% of overall business in future.**