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Software-Defined Vehicles
A Forthcoming Industrial Evolution

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SMART TRAVEL
INTERACTION
KM/h


AR
MONITORING
ENTERTAINMENT

Contents

Introduction

Over the past few years, standardized hardware of smartphones and computers gradually reached physical limits, pushing industrial transformation from hardware upgrades to software development. The automotive industry is different from the smartphone and computer industries in terms of hardware standardization and technology. Thus, the automotive industry is not ready to replicate the exact development pattern of the smartphone or computer. However, with increasingly standardized hardware and narrowed technical gap, the automotive industry is now likely to go through a similar development process.

Hardware design and performance reached a peak due to the limitation of production process or physical properties of materials, and subjective factors such as consumers' stronger sensitivity and demand for an innovative experience, are driving the automotive industry to seek software technology-based transformation and development, attaching more software value to hardware technology.

The "software-defined vehicles" concept became increasingly prevalent in the automotive industry. Tesla is the quintessential leader of this trend, whose consumer-oriented OTA software services, autopilot packages, differentiated software marketing, as well as the agile undercarriage hardware & software development architecture and central computing platform are the focus of industry research and discussion. Looking at the innovation case of Tesla, the two most remarkable impacts of software-defined vehicles are: first, network functions decoupled from proprietary hardware appliances, enabling parallel physical and digital development of vehicles while software deciding differentiation; second, software becomes commercialized—the new business model represented by Tesla, such as monthly software updates for performance and function improvement, and software subscription like SaaS, maximizes the life cycle and value cycle of vehicles .

Some forward-looking OEMs have begun strategic transformation by enhancing their software capability, while some remain cautious about the software-oriented transformation due to various considerations, such as capital investment and difficulties with internal transformation. This report analyzes the origin of "software-defined vehicles", the driving forces, industry changes, transformation, and new opportunities for the industry, and provides several feasible response models and transformation strategies based on the location and capabilities of the stakeholders on the industry chain, aiming to help OEMs, parts manufacturers, and emerging software companies to comprehend the nature and development process of software-defined vehicles, make rational responses and on-demand layout, and focus on the high profit links of the industry chain transformation in advance.

1. Understanding "Software-Defined Vehicles"

In 2018 "Software-defined vehicles" became a industry hot topic; in 2019, Volkswagen CEO Herbert Diess said that Volkswagen would become a software-driven car company[1], marking the beginning of software-oriented industrial transformation. Since then, many interpretations of software-defined vehicles appeared on the market, including discussions on OTA (Over-The-Air) system construction and self-developed operating systems, as well as detailed analysis of electrical/ electronic architecture and basic software platforms.

Based on these interpretations, Deloitte seeks to have a more comprehensive and in-depth understanding: "software-defined vehicles" apparently refers to the state that the quantity and value of software (including electronic hardware[2]) in a vehicle which exceeds that of the mechanical hardware; furthermore, it reflects the gradual transformation of automobiles from highly electromechanical terminals to intelligent, expandable mobile electronic terminals that can be continuously upgraded. To become such intelligent terminals, vehicles are pre-embedded with advanced hardware before standard operating procedures (SOP)—the functions and value of the hardware will be gradually activated and enhanced via the OTA systems throughout the life cycle.

Consequently, the core capabilities of OEMs will shift from mechanical hardware to electronic hardware and software; the industry value chain will also change from one-off hardware sales to continuous software and service premiums.

First, software and automotive electronics account for increasingly more vehicle R&D costs. The value of in-vehicle software and electronic hardware is expected to exceed that of hardware to become the core value of a vehicle. Software cost currently accounts for less than 10% of vehicle BOM (Bill of Material) costs, which is expected to increase to 50% by 2030—the software includes application development software, AI algorithms, operating systems, as well as the software-hardware integrated controllers, chips and other electronic hardware.

Second, software and the corresponding improvement in performance and functions will determine the differentiation of future vehicles. Software maintenance and upgrading will be the most economical, convenient, and efficient way for future OEMs to provide differentiated experience and improve customer satisfaction. Software iteration will be achieved on the basis of hardware redundancy.

Last, enterprises on the industry chain, including OEMs and parts manufacturers, will strengthen their software capability and embark on "software-defined vehicles"-centered internal reform in product development, organizational structure, personnel structure, and operation system. In addition, emerging software companies will capitalize on the software-hardware synergy to satisfy the needs of various upstream and downstream enterprises and become the new Tier-1 companies on the automotive industry chain.

[1] Source: Volkswagen official website, Christian Senger becomes Brand Board of Management Member for new Digital Car & Services function, https://www.volkswagen-newsroom.com/en/press-releases/christian-senger-becomes-brand-board-of-management-member-for-new-digital-car-and-services-function-4664, February 25, 2019.

[2] Electronic hardware includes AI chips, microprocessors, domain controllers, etc.

2. Driving Forces of Software-Defined Vehicles

2.1 Industry development requirements

Software & algorithm—indispensable for the development of connected, autonomous, shared, and electrified automotive technologies

With continuous development of connected, autonomous, shared, and electrified automotive technologies, automobiles are transforming at an accelerated pace from mechanical equipment to highly digitalized intelligent information-based terminals. Many important functions such as monitoring and controlling the battery pack temperature, running the applications on the center console, human-vehicle interactions, and autonomous vehicle detecting and classifying the objects around can only be achieved by using software and algorithms. Taking autonomous vehicles as an example: an autonomous vehicle is a highly software-hardware integrated terminal and the software can be considered as its "brain" —the "brain" analyzes and utilizes the information collected by various sensors to help the vehicle make the best driving decisions. Higher levels (L3 and above) of autonomous driving will be more complicated to require more complex machine learning algorithms and deep neural network models.

Unlike the Internet industry, the automotive industry features embedded software development, which means that for each new function, a corresponding ECU (Electronic Control Unit) will be added and new codes will be developed. Both intelligent connected technology and autonomous driving require a large number of hardware devices and involve a huge amount of corresponding software development and data processing. Therefore, in-vehicle software codes increase exponentially. According to preliminary statistics, for luxury vehicles, the lines of code have exceeded 100 million due to the high loading rate of Advanced Driver Assistance System (ADAS) and L2 autonomous driving. In the next few years, the lines of software code are expected to increase from 100 million to 300 million.[3]

2.2 Consumer expectations

Consumers expect similar behaviors and experience from vehicles as with smartphones.

China has seen the world's highest smartphone penetration rate of nearly 60%. With ever increasing hardware performance, competition of smartphones now lies in the software ecosystem, innovative application of cutting-edge technologies and in-depth exploration of user value.

In recent years, smartphone manufacturers have accelerated development of in-vehicle infotainment products, and automobile manufacturers have increased their R&D investment in intelligence, connectivity, and man-machine interaction technologies, indicating that consumers' experience and habits on smartphones have expanded to vehicles, which means that the competition focuses with smartphones will also be replicated to vehicles.

The frequent iteration of smartphones allow consumers to experience major improvements in performance and functions through system upgrades, needless of buying the latest phones. The OTA is a double-edged model for the rapidly iterated consumer electronics. One apparent disadvantage is that consumers are replacing their phones less frequently, although mobile phone manufacturers continue to update their products once a year.[4] However, for durable consumer goods that generally have a replacement cycle of at least five years, the OTA model enables continuous performance optimization and function upgrades throughout the entire life cycle of a vehicle.

[3] Source: http://news.eeworld.com.cn/qcdz/ic501994.html, July 3, 2020.

[4] Source: https://kuaibao.qq.com/s/20190717A0DKYQ00?refer=spider, June 26, 2019.

2.3 Value chain transfer

Accelerated commercialization of hardware enables higher additional value for software

Like the smartphone and other hardware manufacturing industries, the automotive industry is undergoing the process of "hardware commercialization". As the industry signals major technological transformation and complex automotive electronics emerge, some traditional mechanical parts are rapidly commercialized and become white labelled products, meaning that hardware is becoming less differentiated and less profitable. As a result, the global parts giants with internal combustion engines as their major business segment experienced a stock price decline by about 30% over the past three years. However, software and services became more important on the industrial chain over the same period. Autonomous driving full-stack software companies, high-precision map manufacturers, as well as AI chip and other semiconductor enterprises have created a boom in the capital market. According to preliminary statistics, the autonomous driving enterprises worldwide raised $23.4 billion in 374 investment and financing activities.[5] Apple[6] established a strong software ecosystem and sustainable revenue model by virtue of the App Store, the Apple operating system, digital products and services. The automotive industry is gradually shifting from one-off hardware sales to "continuous hardware upgrade, subscription service" and other profitable models. In recent years, the rise of pre-embedded hardware + FOTA (Firmware Over-The-Air) model has propelled the OEMs to reconsider the value of OTA. With pre-embedded performance and advanced hardware, the vehicle owners can activate the hidden performance and apply new functions through the OTA system when the algorithms and software mature. The OTA model was valued in the last round of Internet Of Vehicle (IoV) evolution, however, it was limited to update of In-Vehicle Infotainment (IVI) applications and operation interface (i.e., SOTA, Software Over-The-Air), and remote updates did not bring consumers practical value-added experience. As FOTA technology matures, and hardware becomes commercialized and standardized, the hardware experience differentiation will quickly disappear. OEMs gradually realize that they must exploit software, the new functions software brings, and the new business models to provide consumers with differentiated experience and value.

In Tesla 'case, software services are becoming an increasingly important revenue and profit contributor. In addition to the traditional IoV services (data traffic + in-vehicle content/ services), Tesla's software revenue also comes from OTA upgrades and optional software packages. Tesla began to roll out paid OTA upgrades in 2019—a typical case is that Model 3 owners can pay $3,000 for the Acceleration Boost to improve the 0-100km/h time from 4.6s to 4.1s[7]. The more-favored optional autopilot package is expected to become the main source of income for Tesla' s software business. Tesla plans to change the one-time charging model of software and offer its Full-Self Driving (FSD) upgrade via a premium subscription service. Owners of Tesla with pre-installed FSD hardware will pay only $100/month for the service. Once the subscription service model is implemented, all cars with activated FSD are expected to continuously contribute to Tesla's cash flow.

[5] Source: https://kknews.cc/zh-tw/car/e5kk8vz.html

[6] "Apple" is the trademark of Apple Inc. registered in the United States and other countries.

[7] Source: https://kknews.cc/zh-tw/car/qx4lrvy.html, July 20, 2020.

[8] Source: https://auto.sina.com/bg/industry/sinacn/2020-09-21/doc-ihaaeezs2487027.shtml, September 21, 2020.

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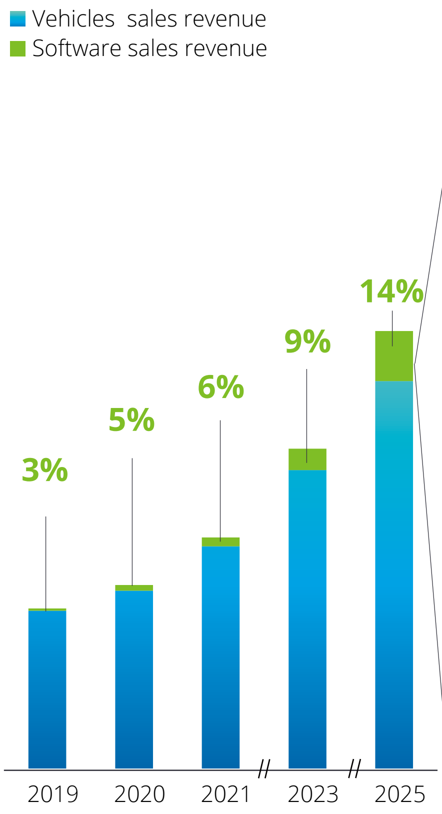
Figure 1: Software may become an important contributor to Tesla's revenue



Software revenue composition	Product picture	Specific functions /services	Charging model
Autopilot optional package (FSD)		·Enhanced autopilot: Auto-park, Navigate on Autopilot, Smart Hailing, etc.	·One-time charge of $8,000 for pre-installation; ·The subscription services ($100/month) may be available by the end of the year.
OTA upgrade optional package		·OTA upgrades to constantly introduce new features and improve performance ·Online upgrades for power-train, in-vehicle infotainment, autopilot, electronic, and chassis systems.	·Charge each time for the specific update services
Advanced IoV Service		·Advanced IoV connectivity services, including real-time traffic, karaoke, streaming, and other functions.	·Subscription service at $9.99/month

Source: Tesla's Financial Report, Guosen Securities

3. Gap between the Present and the Future

3.1 The automotive hardware and software architecture does not suit software-defined vehicles.

The electrical and electronic architecture has demonstrated constraints in computing power, drawbacks in communication efficiency, and uncontrolled costs of wiring harness.

The electrification and mechatronics of vehicles have been greatly improved since the ECU was first introduced into the automotive industry. The ECU's functions have expanded from only controlling engine operation to controlling the chassis, electronic components, as well as in-vehicle infotainment and networking devices, and now each vehicle function is controlled by one or more ECUs. In recent years, the number of electronic controllers rose significantly with the increasing fuel-saving, safety, comfort, and entertainment demands. Currently, more than 100 ECUs function on a L2 luxury car.

In the early development stage of mechatronics, the Electronic & Electrical Architecture (EEA) of vehicles adopts a distributed model where the sensors, ECUs and actuators are in one-to-one correspondence, which ensures anti-interference ability and independence of the system. However, as automotive intelligent and connected technologies continue to advance, the traditional distributed EEA with MCU at the core will no longer satisfy the development demands of intelligent vehicles. The pain points include:

First, the distributed EEA cannot keep up with the increasingly higher computing power.

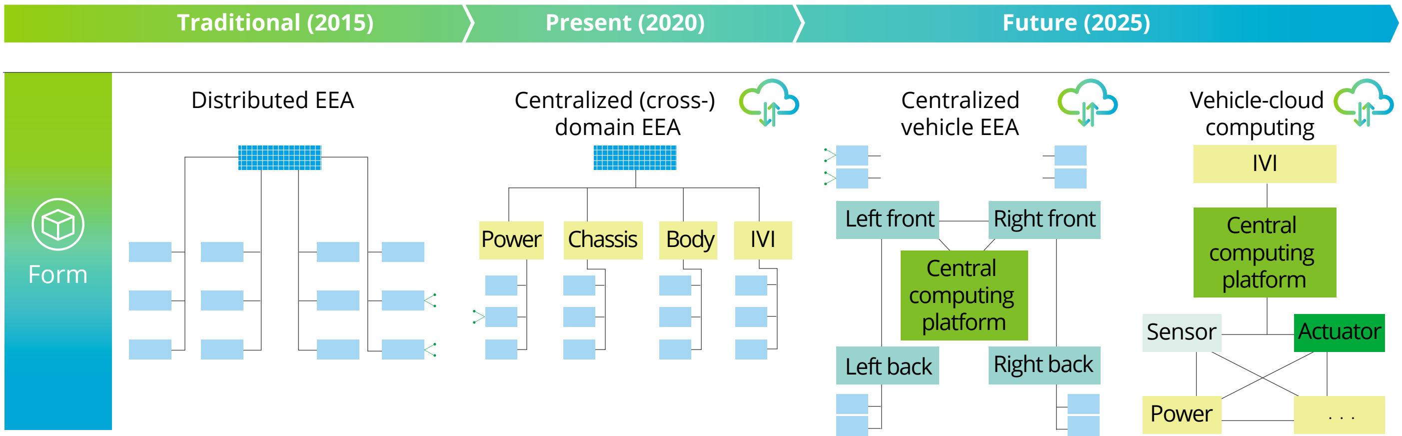
ECU is based on a microcontroller unit (MCU) and an embedded system—the MCU is a microcomputer, and the embedded system is used mainly for controlling but not computing. Therefore, a single ECU can only handle computing and control tasks involving a small amount of data, such as engine control, battery management, and motor control. In the future, the biggest challenge for vehicle development will be the surging higher demand for data processing and computing speed, either from intelligent connectivity or autonomous driving technologies. In particular, the development of autonomous driving technology will spark off complex logical operation and unstructured data processing scenarios. The computing of L2 autonomous driving software has already reached 10 TOPS (Tera Operations Per Second), and the computing power is expected to exceed 100 TOPS for L4, which cannot be handled by the current computing resources of microcomputers. Another flaw of the distributed architecture is being unable to share computing power among controllers—the computing power cannot be shared among control modules due to the one-to-one matching model of sensors and ECUs; therefore, it is difficult to optimize the distribution of computing power when processing similar functional logic, resulting in a large amount of wasted computing resources.

Second, another driving force for EEA architecture upgrading is the demand for higher communication efficiency and greater bandwidth capacity. The current EEA is a signal-based architecture, where signal is transmitted between ECUs through the CAN (Controller Area Network) bus. The CAN bus is simple, stable, low-cost, anti-interference, and safe, and a single-node failure will not spread to the entire network. However, with more sensors in the vehicle and higher demand of the smart cockpit for network bandwidth and latency, the demand for data transmission will surge and data communication will need to be completed at a higher rate. For example, in an autonomous driving vehicle, different sensors (laser radar, radar, camera, etc.) needs to complete real-time information processing and fusion, which requires higher communication bandwidth and transmission rate. The CAN bus operates at Mbps, while the new communication technology, the Ethernet, allows sensor data transmission at Gbps.

Last, difficulty in cost control: as ECUs and sensors increase in the vehicle, wiring becomes more costly and difficult. For autonomous driving at L3 and above, more hardware sensors will be deployed in the vehicle. In addition to an increasing number of ECUs, the wiring harness layout and installation will need to be redesigned. The complex wiring harness layout will lead to higher mechanical structure cost, thus increasing the overall BOM costs of the vehicle and affecting the automated production efficiency.

Therefore, no matter the stronger computing power, higher signal transmission efficiency or for vehicle weight reduction and cost control, the automotive electrical and electronic hardware architecture needs to be changed from the traditional distributed model to the "centralized, compact and scalable".

Figure 2: Automotive EEA Upgrade Roadmap



	Traditional (2015)	Present (2020)	Future (2025)	
Characteristics	•Distributed, independently functioning ECU •CAN and LIN bus-based communication, BCM integrated gateway	•Several major domains are formed based on the functions of the automotive electronic components, such as power, chassis, cockpit, autopilot, and body domain. •Communication network: CAN+ Ethernet	•The central computing platform is the top decision maker; the zone controllers are formed based on the physical locations on the vehicle, and act as a gateway to distribute data and electric power.	•Cloud computing + automotive central computer + sensor + actuator architecture
Pros & Cons	•Dedicated sensors, ECUs and algorithms, non-synergic computing power leading to redundancy. •Distributed architecture requires a lot of internal communication, resulting in a significant increase in wiring harness cost.	•Centralize the scattered ECUs to the domain controllers for easier OTA upgrades •Higher computing power •Available for more flexible, higher-rate communication networks •Higher requirements for security mechanism	•Simplified harness design to reduce costs •SOA software architecture that supports iteration and expansion of software function	•Seamless integration of in-vehicle and cloud architecture: vehicle-end computing for in-vehicle real-time processing, with supplementary cloud computing to provide non-real-time data interaction and processing (e.g., IVI) for an intelligent vehicle.

Functional ECUs · Domain controller unit · Zone controller unit · Central gateway · Sensors & actuators

Source: Bosch EEA Roadmap; www.shujubang.com

The earliest parts manufacturers that proposed the EEA concept developed a roadmap for OEMs to upgrade their electrical and electronic architecture (Figure 3). Bosch divides the vehicle EEA into six stages: modularity, integration, domain centralization, zone centralization, central computing, and vehicle-cloud computing.[9] Integration will make each ECU perform multiple functions, thus reducing the number of single-function controllers. However, the modular closed-type architecture can only meet the needs of autonomous driving below L2; it will not satisfy the computing power, function and safety requirements of higher-level autonomous driving.

"Domain centralization" can be divided into two stages: initially, five main domains can be clarified based on which functional domain the hardware modules are located, including the power domain, chassis domain, body domain, infotainment domain, and ADAS domain. Each domain will be matched with a domain controller unit (DCU) with strong computing power and wider control range, and usually equipped with multi-core processors.

Thus, the number of ECUs will be greatly reduced, and the functions will be simplified. However, some functions that require low computing power but high real-time and safety performance will still be controlled by ECUs. In-vehicle networks such as CAN bus will be used for intra-domain communication, while Ethernet technology will be introduced for communication between domains.

Later, "cross-domain fusion" will further integrate domain controllers at the same function safety and information safety levels. For example, the power, chassis, and body domains will be integrated to be the "vehicle control domain" to control the entire vehicle and perform better real-time and safety functions; the "intelligent cockpit domain" will replace the original infotainment domain to perform the man-machine interaction and T-box integration functions; the "intelligent driving domain" will be responsible for perception, planning, and decision-making for high-level autonomous driving. "Zone (a different concept from domain) centralization" will be a special stage, and also the earliest prototype of vehicle central computing.

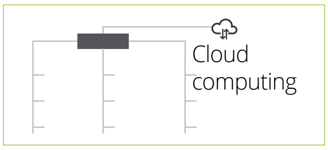
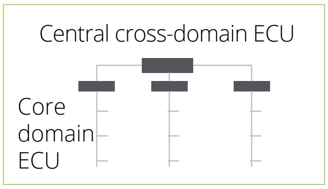
At this stage, the EEA layout will be actually guided by the wiring harness (the physical areas of the vehicle). The OEMs, with consideration of modularity, will optimize function classification and integration, and apply the software to the core zone controllers.[10] Finally, the vehicle computing resources will be concentrated in a few central computing units to uniformly control the sensors and actuators.

If further simplified, the hardware architecture of the automotive EEA will mainly evolve through three stages: integration, domain centralization (DCU and MCU), and vehicle centralization (as shown in the figure). At present, OEMs have stepped onto different transformation paths based on their technology and R&D (software talent) capabilities, as well as their relationships with parts manufacturers and cost balance.

[9] Source: https://www.sohu.com/a/426372694_733088, October 21, 2020.

[10] Source: https://www.eefocus.com/automobile-electronics/432370, March 25, 2019.

Figure 3: EEA Upgrade Paths of Mainstream Automakers

Upgrade approach	Characteristics	Architecture	Example
One-step	•Skip the domain centralization (multi-domain fusion) stage to directly to the in-vehicle central computing platform (the top decision-maker) to mobilize the resources at all levels for direct application/services.	Vehicle centralized EEA 	Tesla •In-vehicle computer + zone controller •Self-developed OS •Vehicle OTA upgrade available 2019* BMW •In-vehicle central calculator •Self-developed OS 2021 Mercedes-Benz •Based on the in-vehicle computing platform •Vehicle OTA upgrade available 2024
Radical	•DCU architecture: perform the functions of vehicle control, intelligent driving and infotainment through the classic five-domain or three large domain controllers.	Domain centralized EEA 	Volkswagen •New centralized EEA consisting of three in-car application servers (ICAS) •Self-developed OS
Step-by-step	•Steady progress by the Bosch EEA roadmap •Weak online upgrade capability of software; communication architecture still adopting the traditional CAN bus	Distributed EEA 	•Domestic automotive brands and some joint ventures

Source: Soochow Securities, Deloitte Research

According to the planning of automobile enterprises, we have summarized and classified the EEA upgrade paths into three types: first, the "one-step" approach: it skips the domain centralization stage and move directly to in-vehicle central computing. Taking Tesla as an example, the Model 3 adopts the zone controller + Central Control Module (CCM) model—the CCM integrates the ADAS and IVI modules, and the remaining domain functions (directed by the left and right vehicle body control modules) are deployed by the physical locations, which significantly reduces the wiring harness cost of the vehicle. The zone controller can achieve centralized computing as well as material cost balance of the vehicle. Second, the "radical approach": OEMs are not satisfied with the progressive upgrade approach of Tier-1 enterprises—the controllers are deployed in accordance with the OEMs' optimal scheme, such as Volkswagen. Third, the "step-by-step approach": the enterprises are relatively conservative and follow the upgrade path of Tier-1 enterprises.

Following the rules of the IT industry, the development of software will also drive automotive EEA upgrade. At present, both the distributed EEA and the automotive software development model (ECUs use an embedded system, i.e., highly coupled hardware and software, which are mostly delivered to OEMs by suppliers under the "black-box" model) are hampering the OTA functions, the expansion of application ecology, and OEMs domination in developing more advanced software in the future, specifically:

First, the low degree of modularization and platformation of automotive software has impeded centralized dispatching and collaboration of software resources. OEMs' ECUs are usually provided by different suppliers. In fact, many underlying software controllers are repetitive, and the code is mainly ensuring the normal operation of the controllers, such as transmitting and receiving the CAN bus signals, scheduling tasks, and reading and writing Flash data.

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However, the underlying code cannot be copied or migrated due to the suppliers' different software programming languages and interface standards, as well as the high degree of dependence of the software on the hardware. Therefore, ECU software development is highly repetitive and the resources are not efficiently utilized.

Second, software and hardware are highly nested, and OEMs cannot conduct extensive and in-depth updates or customized development. The distributed software architecture is a signal-oriented architecture, where information transfer between controllers is achieved via signals, but the entire system is closed and static, and is absolutely defined at the compilation stage. Therefore, when the OEMs want to modify or increase the function definition of a controller, the instruction of which will invoke the function of another controller, they have to upgrade all the necessary controllers, thus greatly prolonging the development cycle and increasing the development costs.

Therefore, automotive software development will follow the development rules of the IT industry and introduce the middleware and virtualization technologies to achieve software modularization, and hardware abstraction and standardization, thereby further breaking the coupling relationship between hardware and software to improve EEA flexibility and expansibility. Middleware is a technology that packages software at different levels of hardware dependency to achieve software modularization, and defines a series of standard application programming interfaces (APIs) to achieve software stratification. It decouples the upper-level application software and the underlying software, improving the reusability and expandability of software and reducing the complexity and risks of product development. For example, application developers can focus only on the specific application functions, needless of considering the differences of the underlying controller software. A more profound impact triggered by the decoupled automotive hardware and software is the gradual transformation from the current signal-based software architecture to a service-oriented architecture (SOA). The nature of SOA is that the software of controllers, regardless of the hardware platform and operating system they reside on, is shared, by providing abstract services, by other software components.

3.2 The traditional waterfall software development model has major limitations.

Based on the above changes in technology architecture, in the context of software-defined vehicles, automobile R&D will shift from the traditional waterfall development to agile development model. During the development process of software-defined vehicles, vehicles will gradually evolve into an intelligent mobile terminal and demonstrate more features of a consumer electronic product, raising new requirements on the control of development costs and development cycle; meanwhile, product iteration will just begin after the vehicle is delivered to the consumer. The traditional automobile R&D follows the waterfall development model to have a linear R&D eco-chain, where product R&D ends with SOP.

Under the traditional waterfall development model, the development of automotive software is divided into different parts of work based on different functional modules. The development team of each part focuses on developing one function, and each development stage follows the overall progress plan, which runs in a flow-line model like a waterfall. The relatively separate development parts are likely to cause a "silo effect"—there is only internal improvement with each part but no overall system/platform optimization; moreover, the development time of each part is varied, which requires a top-down work structure and a comprehensive development sequence plan to advance the development in an orderly manner. This work structure, which separates the business structure from the organizational structure, requires good internal coordination for overall work synergy. In addition, the development progress of each part being dependent on each other can easily lead to a queue effect—the overall development progress will be affected if one part is delayed. These problems emerge in practical work: every development stage with a long development cycle corresponds to an independent test stage, which will be verified level-to-level, thus the development and test cannot be conducted simultaneously; each stage depending largely on the results of the previous stage gives rise to a rigid overall process, leading to high costs and long development cycle. All these factors are contradictory to the software-defined vehicles that require the OEMs to shorten the time-to-market, develop products based on consumer needs, enable constant iteration, and respond quickly to market demands. Therefore, the traditional waterfall development model will increasingly demonstrate its limitations.

The agile development model that is mostly used in pure software development environments (e.g., software companies), better fits the requirements of software-defined vehicles with its unique features. Under the agile development model, the development teams are classified based on product features, and are completely responsible for their respective feature, including all functions of the feature, and all teams have certain freedom and decision-making power. When different product features involve common functions, the teams will establish cross-feature collaboration communities to conduct cooperative development and achieve overall optimization. In addition, the business and organizational structures under the agile development model are streamlined, which is conducive to achieving close coordination and cooperation and minimizing management costs; moreover, due to work flexibility, the development team can interact with customers and quickly satisfy the users' needs by providing minimum viable products (MVP) and making continuous innovation and iteration. All these characteristics are consistent with the requirements of software-defined vehicles.

However, it is important to note that, unlike pure software development environments, the automotive industry is unique and complex in its own way. Software-defined vehicles will ultimately be about combining software and automotive hardware, which means the application of agile development model in the automotive industry will face the complex challenges of hardware development and multi-suppliers environment. Tesla, a pioneer in agile development for software-defined vehicles, has provided valuable experience for the industry. In addition to the separated hardware and software development cycles, Tesla pre-designs the hardware and software, fully considers the future function expansion needs at SOP, pre-installs the standardized hardware required for future function expansion, and subsequently activates new functions of the hardware through software upgrades or function development. For example, Autopilot pre-installs hardware and the built-in functions will be sparked off through OTA updates, moreover, it supports full lifecycle software updates.[11]

[11] Tesla's 8.1 software update brings Autopilot 2.0 cars up to speed, March 30, 2017, TechCrunch, https://techcrunch.com/2017/03/29/teslas-8-1-software-update-brings-autopilot-2-0-cars-up-to-speed/

3.3 Organizational structure and talent supply are major shortcomings of software-oriented automotive transformation.

OEMs' organizational structure will be fundamentally reshaped: from a function-oriented structure to a platform development structure.

Some OEMs have begun organizational structure adjustment since the announcement of software-oriented transformation. For example, Volkswagen established the new software department, Car.Software, last June (which became independent this July). The department planned to recruit nearly 5,000 software engineers, and announced an overall investment of EUR7 billion in software architecture over the next 3-5 years.[12] Toyota, another mainstream automaker substantially advancing the software-oriented transformation, announced in this July that it would establish a new holding company—the Woven Planet Holdings, and two operating subsidiaries early next year, which will focus on developing autonomous driving, new vehicle operating system, high-definition map and other state-of-the-art software.[13] OEMs are actively bringing in interdisciplinary talent specializing in software, algorithms, IoV, autonomous driving, AI engineering, electronic engineering, etc., aiming to accelerate the adjustment of the current personnel structure and increase the number of software engineers to preserve competitiveness during software-oriented transformation and product innovation.

In China, SAIC is one of the few OEMs that made a strategic shift toward software. Earlier this year, SAIC established the software center, the Z-ONE, which will focus on intelligent driving system engineering, software architecture, basic software platform and data factory. This new software subsidiary is expected to scale up to 500 employees by the end of the year, 1,000 by next year, and 2,200 by 2023.[14] A few other domestic OEMs are increasing their positions for software talent, although no independent software subsidiaries have been set up. For example, more than 90% of the open positions at the R&D center of GAC Group are software engineers.[15]

Establishing an independent subsidiary for software development allows greater autonomy, independence and vitality. Automotive enterprises that have only set up a software team within the group need to further adjust their internal organizational structure and optimize the vehicle software development process. For example, a top-down platform software development organization shall be established to enable cross-department cooperation, and implement the common strategy or work towards the common goal. Automotive engineering development is divided by functional modules, such as powertrain, chassis & body, and infotainment, and each module is developed independently. However, as the automotive EEA is developing towards "domain center" and "centralization", the number of ECUs is decreasing, and the domain controllers or central computing platform is deployed in a layered or service-oriented architecture, the future automotive electronic software development is expected to be divided in a layered way.

Currently, automotive software talent are in short supply. Automotive electronic software is a branch of embedded software, which is a relatively closed industry, so the talent source is limited. Most of the embedded software development talent have flowed to tech companies, and they have little knowledge of hardware, automotive engineering and automotive software. These factors have caused the shortage of automotive software engineers. In addition, enterprises need to modify their recruitment and talent management models to cope with the areas where technologies such as autonomous driving that are still evolving and the business model is unclear, such as changing from position-centered to talent-centered model; in the meantime, they should be flexible in job duty setting, performance management, and incentive mechanism.

[12] Volkswagen with new software unit, June 18, 2019, VW Website https://www.volkswagen-newsroom.com/en/press-releases/volkswagen-with-new-software-unit-5092

[13] Toyota Research Institute - Advanced Development to Form Woven Capital, an $800 Million Global Investment Fund, September 10, 2020, Toyota Press Release, https://global.toyota/en/newsroom/corporate/33751885.html

[14] Source: https://auto.gasgoo.com/news/202007/22I70198617C601.shtml, July 22, 2020.

[15] Source: https://auto.gasgoo.com/news/202007/22I70198617C601.shtml, July 22, 2020.

3.4 Obstacles from the supply chain system

Connection between vehicle and parts enterprises changes from the tower-shaped vertical relationship to an annular flat relationship.

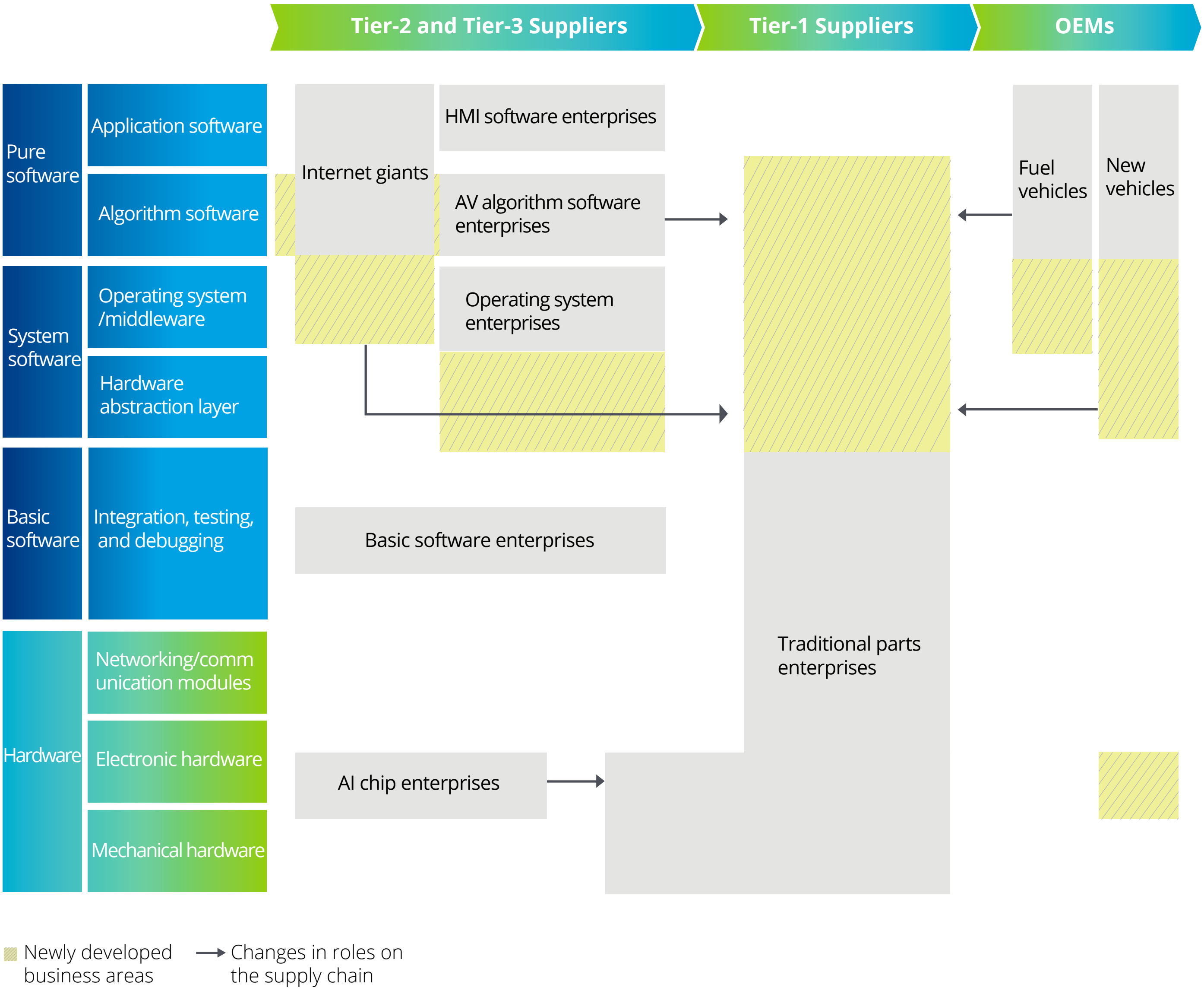
OEMs can quickly develop and deploy product functions with the help of Tier-1 suppliers. For example, for R&D investment in primary autonomous driving (i.e., L2 and lower level systems), most manufacturers have adopted the solution provided by the Tier-1 suppliers due to the high costs for all the development tasks and the lack of technological advantages. The international parts giants, with years of engineering experience, productization capability, and cost control experience, can provide mature products that meet the vehicle standards—no matter for the autopilot perception and decision-making parts (e.g., millimeter-wave radar, monocular and binocular cameras, and other sensors/ systems) or for the control parts (drive-by-wire systems). Therefore, for driver assistant systems, OEMs generally tend to directly purchase the software (chips, algorithms)-hardware (sensors) integrated products and solutions from the Tier-1 enterprises. At present, a large number of new vehicles are equipped with Mobileye's vision chips for the Advanced Driver Assistance System (ADAS), and most OEMs obtains the vision module capability for their L2 autonomous driving solutions from the suppliers. However, the supplier model has gradually shown its drawbacks: For example, the international parts enterprises are incapable of localizing their ADAS solutions and slow in responding to customer needs. Moreover, the parts manufacturers do not provide flexible solutions —Mobileye adopted the tie-in sale of algorithms and chips, which did not support OEMs' customized algorithms, thus holding up the OEMs' customized and differentiated product development and resulting in insufficient product innovation.

Therefore, reshaping of the current relationship between vehicle and parts enterprises is largely actuated by OEMs' desire to achieve autonomy and control over autonomous driving technology. In particular, automotive software is becoming increasingly important at the ADAS stage, and automakers are no longer satisfied with the black-box supply model, instead, they want to define requirements, functions and standards from the top down and purchase software, hardware and systems separately, and hope to break down the Tier-1 core technological barriers and directly cooperate with the core underlying parts enterprises. Driven by this emerging trend, in recent years, domestic and foreign OEMs have established partnership with autopilot full-stack enterprises, AI chip manufacturers, as well as laser radar and other sensor enterprises, in the form of equity participation or strategic cooperation.

A few other automobile manufacturers with greater dedication and R&D strength have chosen to build their software infrastructure from the ground up—they adopt independent development and vertical integration for core parts and system upgrades, to achieve technological superiority and differentiation, which requires enormous investment. Under the independent development model, OEMs are no longer bound by the supplies' technological and hardware performance barriers as well as development cycles, as a result, the most advanced processors will operate on the vehicles, and hardware iteration will coincide with software iteration.

The traditional supply chain relationship will change fundamentally, whether the automobile manufacturers choose to cooperate with the core software and electronic hardware enterprises, or to develop and vertically integrate their own products. The collaboration between OEMs and sub-suppliers will be further enhanced, breaking the tower-shaped (from Tier-2 to Tier-1 and then to OEM) supply model and eventually forming a flat supply network.

Figure 4: Changes in Supply Chain Relationship under the "Software-Defined Vehicles" Trend



Source: TF Securities, Deloitte Research, public information

4. What Are the New Opportunities

4.1 Industrial value chain under the "software-defined vehicles" trend

Taking the intelligent connected vehicles as an example, what changes have taken place to the value of the industrial chain in the wake of the software-oriented industrial transformation. From top to bottom, the industrial chain can be divided into the pure software layer, basic software layer, tool software, and electronic hardware stack. From the value chain perspective, the application and algorithm software as well as the software-intensive electronic hardware at both ends of the value chain have relatively high industrial added value, which is now the focus of OEMs, parts enterprises, and technology companies. The middle basic software underpins the software-oriented transformation of vehicles. As OEMs seek to enhance their autonomy and software capability, the basic software will be more important on in the industrial chain.

The pure software layer includes application and algorithm software. The application software contains the man-machine interaction and interface design of the infotainment system (replaced later by the smart cockpit that integrates the instrument panel, head-up display and other display devices), ADAS software (e.g. adaptive cruise control, collision warning), and body control software. Some application software is supported by various algorithms such as the vision and image processing algorithms of ADAS software, and the AI or deep learning-based core algorithms of autonomous driving software for environment perception, decision planning, and control execution.

The basic software layer mainly includes the operating system and framework software. Operating systems are divided into hard real-time and soft real-time systems, which undertake the function of controlling and distributing in-vehicle hardware resources. There are only a few operating system vendors in the industry, thus seeing a high degree of industrial concentration. The framework software is a middleware concept, which abstracts the hardware resources including the operating system, sensors, actuators and computing platform to provide a unified basic software interface for the upper-level application and algorithm software development, thus avoiding repetitive development due to differences in operating systems or hardware. AUTOSAR[16] is the most common middleware solution. It is an open and standardized automotive software architecture jointly developed by global major automobile manufacturers, parts suppliers, and hardware, software as well as electronics industries.

The tool suite specifically covers testing, design and R&D, such as ECU software testing and verification, simulation testing of autonomous driving system. The electronic hardware stack includes communication modules, data storage modules, GPS inertial navigation, sensors, chips, and controllers.

[16] Source: Autostar official website, https://www.autosar.org/

4.2 Prominent position of software platforms

Through clarifying the industrial chain, we believe that three types of software and the related tool chain suppliers will play a key role in the software-oriented transformation of the automotive industry.

First, operating system software. In the trend of "software-defined vehicles", the operating system will become increasingly important, and will be automobile manufacturers' focus point for business layout in the intelligent connected vehicle field as well as the new technology companies' strategic priority.

Operating systems can be classified into the Unix family, the Windows family, the Linux family (including Android), and the RTOS family (including QNX\Vxworks) according to the type of kernel. Different operating systems, with varied advantages, are used in different in-vehicle environments. For example, the IVI system often uses the Android system as it emphasizes consumer experience and diversified application ecosystem, and the instrument panel mainly adopts the QNX due to its requirement for high security, although both belong to the smart cockpit domain. With higher real-time and functional safety requirements, autonomous driving systems mainly adopt the RTOS, with currently three mainstream systems: RT-Linux, QNX, and VxWorks.

At the distributed ECU stage, OEMs only focus on in-vehicle information systems, developing customized IVI operating systems based on the above underlying operating systems. For example, the two Linux-based open source projects, AGL and Genivi, are widely adopted by OEMs—the two platforms allow OEMs to directly use the software codes (70%) that have been developed by the consumer electronics/communications industry, so they only need to develop the remaining 30% software for in-vehicle scenarios and differentiated experiences. This model lowers the software development threshold and difficultly for OEMs. Some automobile enterprises with strong R&D capability have joined hands with technology companies to customize their own operating systems (such as AliOS) based on open-source operating systems. In the meantime, technology companies have created some frameworks/middleware for developers based on specific requirements, such as DuerOS.

However, with the progress of software-defined vehicles, operating systems will become more complex and important. The automotive EEA has different requirements for operating systems at different development stages. For example, in the stage of "domain centralization", the operating systems are required to emphasize: openness, compatibility and ecology; as well as security, real-time capability and stability. In the stage of cross-domain integration and central computing platform, domain controllers with varied requirements for real-time capability, security and performance will be integrated, or merged into a central computing unit, which needs a single operating system with competent real-time computing capability and reliable performance.

As the operating systems "sink" to the bottom of the industrial chain, OEMs have begun to independently develop their operating systems based on open source systems—they will no long rely on the suppliers, and share core data, instead, they will control their own software stack, and fix problems or add new functions via OTA. In 2019, Volkswagen announced its huge investment in the R&D of the VW.OS operating system, aiming to create a unified OS platform that will be compatible with multiple underlying operating systems to enable intelligent interaction between different domain controllers and different displays. Before that, Tesla developed its real-time operating system (RTOS) based on Linux, which supports IVI system and ADAS[17].

[17] Source: http://finance.sina.com.cn/stock/hyyj/2020-08-11/doc-iivhuipn7999112.shtml

Second, middleware: the in-between software of application and operating system. The so-called distributed middleware is to offer a distributed computing and communication framework to shield the kernel differences of various underlying operating systems and provide standard interfaces and protocols for the upper-layer application developers.

Adaptive Autosar and ROS are typical operating system middleware. Currently, The Autosar R&D tool chain and basic software are dominated by a few overseas parts enterprises, including Elektrobit (acquired by the Continental Group[18]), Vector and Bosch. Recently, domestic enterprises have begun to develop their own tool chain, for example, Huawei's intelligent driving domain controller MDC is compatible with the Autosar standard architecture, and also provides a complete R&D tool suite.

Middleware is becoming increasingly important in the intelligent vehicle era. It is expected that intelligent vehicles will be using various operating systems for a long time. As EEA evolves rapidly and operating systems become incrementally complex, the middleware connecting the underlying hardware layer and the application layer has a great development space.

Third, virtual machine hypervisor. The application of virtualization technology is largely triggered by the demand of EEA for separation of hardware and software in the domain centralization stage, such as the one-core multi-screen multi-system trend of smart cockpit domain. One major trend of the smart cockpit domain is that the central panel will gradually integrate with the instrument panel, head-up display and other display devices, with microcontrollers of various hardware integrated into a single chip. The key demand behind multi-screen integration is cost reduction, as it is the cheapest way to run multiple operating systems of different security level on a System-On-a-Chip (SOC). Moreover, each screen corresponds to a different operating system, which means that the smart cockpit domain needs to support multiple operating systems such as the QNX, Android, and Linux. Therefore, a virtualization platform is needed on top of the physical hardware to support the operation of the operating systems.

Thereby, the virtual machine manager concept of avionics devices was introduced to the automotive electronics industry, and the AUTOSAR Hypervior[19] was created based on Autosar standard, which is like a software layer running between the operating system kernel and the physical hardware layer, providing a virtual hardware platform for the operating system to make it more irrelative to the hardware and applicable to various platforms. The current mass-produced products that are installed with a virtual machine hypervisor and have reached vehicle standards include the BlackBerry QNX Hypervisor, Wind River VxWorks, Green Hills INTEGRITY Muitivisor, Mentor Graphics Embedded Hypervisor, and OpenSynergy (acquired by Panasonic last year).

[18] Source: Elektrobit official website. https://www.elektrobit.com/about/

[19] Source: http://news.eeworld.com.cn/qcdz/article_2018030921931.html, March 9, 2018

4.3 From Tier-2 to Tier-0.5

Future vehicles will be a highly mechatronic intelligent device. Being software-oriented does not mean that hardware is negligible. On the contrary, hardware serves as an important carrier for software to perform its functions. Particularly, the software-intensive electronic hardware and semiconductor hardware will rake in greater added value and more profits on the industry chain.

The development trends in recent years have showed that algorithm and chip enterprises, originally Tier-2 enterprises, have strengthened their software-hardware co-development capability, and fully integrated hardware resource, system software and functional software, which enables them to satisfy diversified upstream and downstream demands of the industry chain; thus, they gradually change from Tier-2 sub-suppliers to Tier-1 or even Tier-0.5 suppliers of OEMs, holding a key position during the development of intelligent connected vehicles.

Taking AI chip industry as an example, domestic and foreign chip enterprises including NVIDIA, Mobileye, and Horizon Robotics have made significant adjustment to their product positioning, core competence and sales strategy over the past two years. Chip enterprises have long been evaluated by the computing power (utilization of computing power), power consumption ratio (TOPS/W), costs and mass production capacity for their competitivenss[20]. Seeing from their recent moves, chip enterprises are demonstrating to the upstream customers their full-stack capabilities such as software-hardware integration, ecological environment, and open tool chain. For instance, there is a subtle change in NVIDIA' s product strategy, with focus on promoting its open, expandable and customizable product features. Last year NVIDIA introduced the DRIVE AGX Orin, a software-defined platform for autonomous vehicles and robots; it is a set of open-source pre-trained AI models and training codes; Once the autonomous driving vehicle developers adopt this ecosystem, they can freely expand and customize models via the NVIDIA AI tools, thus improving the stability and capabilities of their autonomous driving system[21].

Domestic chip enterprises have made similar adjustments. Horizon Robotics' latest Journey™ 3 highlights high performance, low power consumption, expandability, safety and reliability, as well as its in-depth understanding of algorithms and solutions for various application scenarios of autonomous driving; besides, Horizon Robotics promotes its flexible and open product features, making available to customers its algorithm samples, AI chip tool chain, and the tool suite required for application development to help the manufacturers roll out products and applications at a faster pace[22].

In terms of sales strategy, some chip enterprises have maintained a close relationship with Tier-1 suppliers, while some directly cooperate with OEMs. For example, for the partnership between Geely and Mobileye, Mobileye, instead of only supplying semi-finished components to Tier-1 suppliers, will for the first time provide a complete solution stack including hardware, software, drive strategy and control; Mobileye also plans to provide subsequent software update services[23]. Skipping the Tier-1 suppliers, the core hardware vendors will gain higher profits and a greater say in the industry.

[20] Source: https://auto.gasgoo.com/a/70220737.html, October 14, 2020

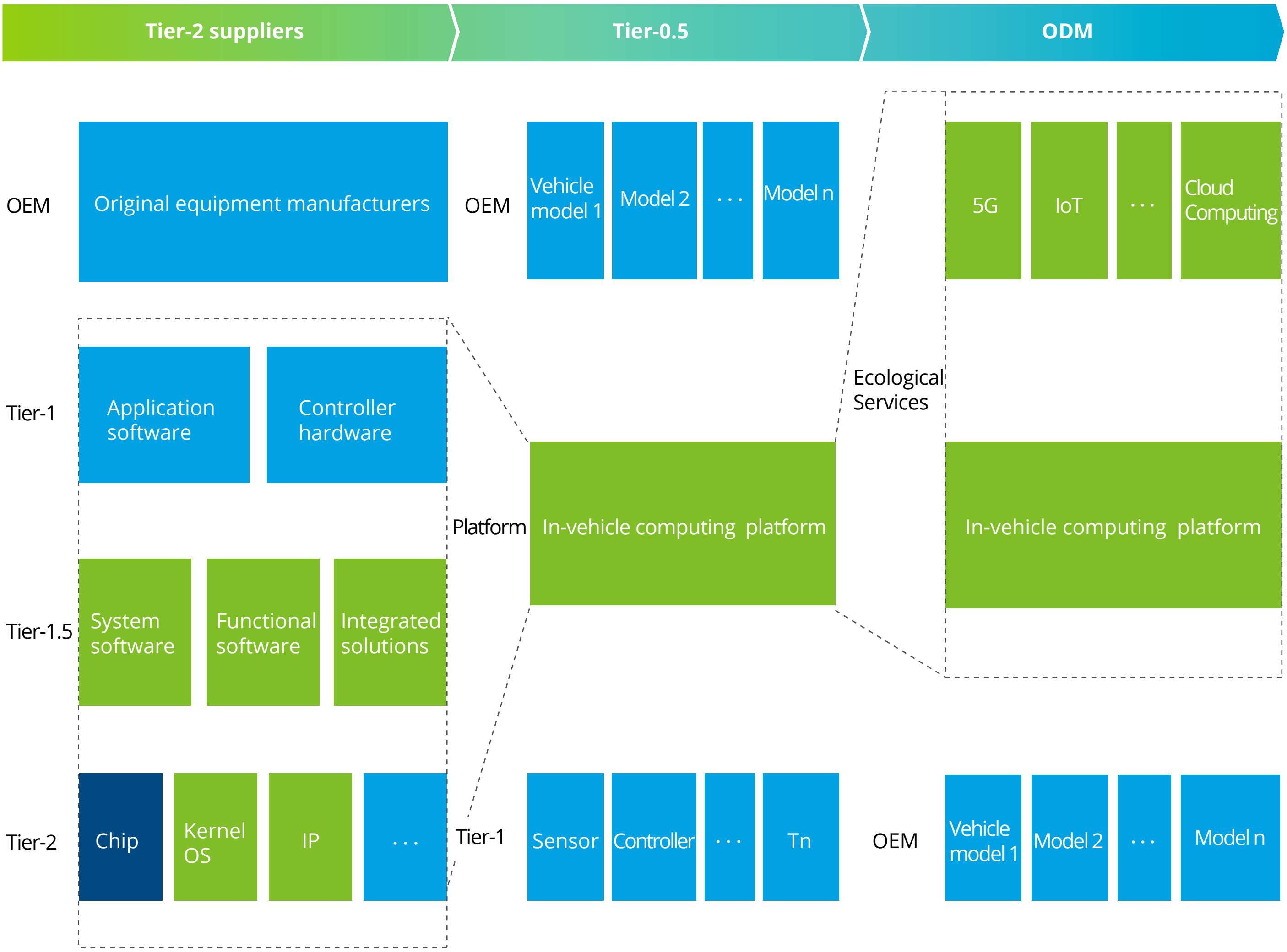
[21] Source: NVIDIA Introduces DRIVE AGX Orin — Advanced, Software-Defined Platform for Autonomous Machines, December 19, 2019, NVIDIA Website, https://nvidianews. nvidia.com/news/nvidia-introduces-drive-agx-orin-advanced-software-defined-platform-for-autonomous-machines

[22] Source: Horizon Robotics' official website. https://horizon.ai/journey3.html

[23] Source: https://new.qq.com/omn/20201009/20201009A074XB00.html, October. 9, 2020

*"Software-Defined Vehicles – A Forthcoming Industrial Evolution" is independently published by Deloitte and is not authorized, sponsored or officially endorsed by NVIDIA, Mobileye, Horizon Robotics, or any other companies.

Figure 5: Changes of the Role of AI Chip Enterprises on the Intelligent Vehicle Industrial Chain Chain



Source: Deloitte Research

5. How Should Different Enterprises Respond

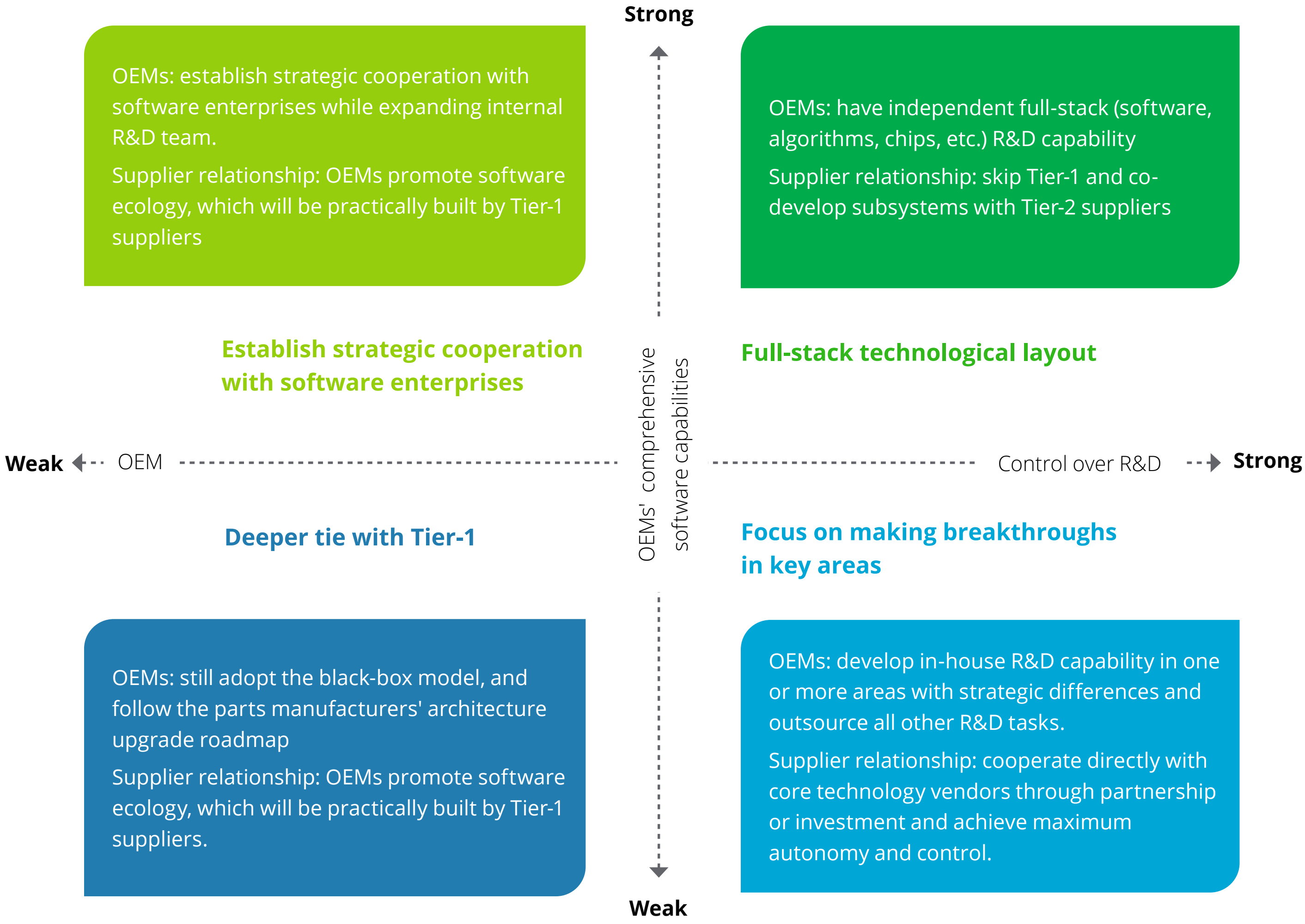
5.1 OEMs transform based on rational assessment and their capabilities

The global automotive industry began software-oriented transformation last year. Different from the past transformations, the cost and risk-sharing "alliance model" has been further broken, which is gradually replaced by the vertical integration model. In addition, the transformation is unprecedentedly deepened, extending even to product R&D process, organizational structure and supply chain network of OEMs.

Volkswagen, a typical traditional OEM, has invested heavily in building a software R&D team (a separate R&D team from the group) and developing its own operating system and other underlying software infrastructure, becoming a leader among OEMs in terms of transformation breadth and intensity. Tesla, a representative of new vehicle manufacturers, has demonstrated a high degree of independent development and vertical integration for application software, operating systems, AI chips and in-vehicle central computing platform.

We believe that OEMs need to decide a proper transformation path based on their business scale, R&D strength, cash flow status, and historical burdens. Brands with products for mass production and luxury brands will choose different transformation paths, so will fuel vehicle and electric vehicle manufacturers. Deloitte has identified four software-oriented transformation paths for OEMs according to the transformation measures some enterprises have taken and the future development trends. As shown in the figure below, the four paths are separated in four quadrants based on OEMs' software strength. Specifically, the right upper quadrant represents the most ambitious and thorough transformation path, which is characterized by the construction of full-stack technological capabilities from software architecture, software R&D, to software engineering, as well as the active promotion of vertical integration; the right lower quadrant represents a relatively ambitious but not exhaustive path: it mainly makes breakthroughs in one or two core technologies, focuses on the areas where marginal income is higher than marginal costs, and strives to improve user experience; the upper left quadrant represents a moderate transformation path: OEMs build their own software teams while actively cooperating with technology and Internet companies—they still need Tier-1 suppliers or newly-rising software enterprises to provide basic software as well as software-hardware architecture solutions before they develop adequate software R&D capability; the lower left quadrant represents the conservative path: OEMs continue the typical outsourcing model to engage Tier-1 suppliers for software development.

Figure 6: Four Paths for OEMs' Software-oriented Transformation



Source: Deloitte Research

5.2 With "oppression from both ends", parts enterprises should seek self-transformation

With the development of connected, autonomous, shared, and electrified automotive technologies, international parts giants have forayed into the software field, focusing on: 1) building more comprehensive and flexible software-hardware integration capabilities, and gradually shifting from outsourcing to self-development of core software; 2) adjusting personnel structure to better adapt to software development rhythms and cycle; 3) exploring new business models.

The strengths of parts manufacturers are their integration capability and mass production experience. However, driven by the "software-defined vehicles" trend, the core competence of parts manufacturers will be "openness", "compatibility" and "ecology". Taking the smart cockpit for example, Tier-1 suppliers have mature solutions for domain controllers' embedded software development and hardware integration. However, Tier-1 enterprises, driven by the industrial trends or new requirements of OEMs, must open up their domain controller development to allow OEMs to customize applications and functions, support heterogeneous multi-core operating systems as well as reusable and portable basic software, and accommodate more powerful computing hardware. Therefore, Tier-1 enterprises need to build more comprehensive and compatible hardware and software integration capabilities, open up their supply chain eco-network, and work closely with core subsystem enterprises to shorten the adaptation cycle.

In addition, like OEMs, parts enterprises are faced with the pressure of organizational structure adjustment. In July this year, the global parts giant Bosch announced that it had merged its automotive electronics and software businesses departments and established a new cross-domain computing solutions division; thus, the entire Car Multimedia division and parts of the Powertrain Solutions, Chassis Systems Control, and Automotive Electronics divisions that develop software-intensive, cross-domain electronic systems would be brought together in the new division.[24] Its competitor, Continental, planned to adjust its global organizational structure in 2019, and began the adjustment earlier this year[25]; Under the new structure, "Automotive Technologies" as well as the Powertrain and Rubber Technologies are separated, and "Automotive Technologies" was further divided into two business areas, the Autonomous Mobility and Safety (AMS), and the Vehicle Networking and Information (VNI); besides, the Holistic Engineering and Technologies was established to assume responsibility for central development activities (basic R&D and future-oriented technological development) in the automotive sector and support the two business areas AMS and VNI.

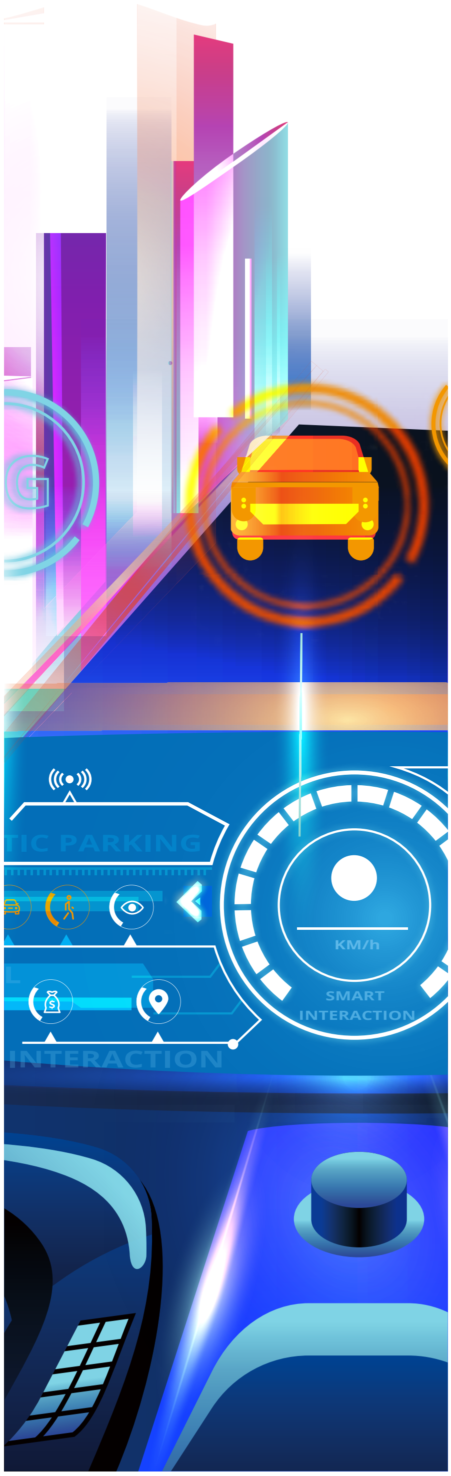
[24] Bosch pools its software and electronics expertise in one division with 17,000 associates, July 21, 2020, Bosch Website, https://www.bosch-presse.de/pressportal/de/en/bosch-pools-its-software-and-electronics-expertise-in-one-division-with-17000-associates-216256.html

[25] Source: Official website of Continental, https://www.continental-corporation.cn/zh-cn/新闻中心/大陆集团新闻稿/大陆集团宣布新管理层架构-166896?_ga=2.193074351.389119842.1603956091-778085108.1603956091, March 15, 2019.

[26] Source: https://www.sohu.com/a/424505398_115873, October 14, 2020.

Finally, software will significantly affect the revenue structure of parts manufacturers. The one-off hardware sales model that is based on material cost accounting will be no longer applicable. The marginal costs of software development will disappear, and charging of software may be conducted in varied modes throughout the product life cycle. First, before mass production, automotive software revenue mainly comes from the one-off project development charge—the fees charged to Tier-1 enterprises or OEMs during the R&D process for delivery of special software design and customized development, and the software loyalties—loyalties charged for the use of the software/systems/development tools independently developed by the software company. After mass production, software is charged in the form of "royalty fees", "technical service fees", and FOTA-based software upgrade fees. The royalty fees are the single-vehicle royalties charged based on the number of functional module IPs used by the customer and the shipments. In the future, automotive software enterprises may change to sustainable charging modes (like that of water and electricity), such as the SaaS model.

For traditional parts enterprises, the profit model pain point caused by the increase of the software quantity/value ratio is that they cannot accurately calculate the single-vehicle software costs, so they are unable to maintain their gross margin at a stable level based on the calculation of upstream raw materials costs as that with hardware sales. In addition, as a system integrator, it is difficult for parts manufacturers to obtain the highest added value during the industrial chain transformation. Tier-1 enterprises need to satisfy the upstream OEMs' customization requirements, and buy proprietary development tools or systems from downstream third-party software enterprises and pay the engineering costs (Mobileye's earlier business model). Software charges cannot be standardized due to software's customization property, thus, Tier-1 suppliers will gradually lose pricing power. Currently, Tier-1 enterprises are still exploring a flexible charging mode that will fit the era of "software-defined vehicles". For example, Bosch has expressed that its software and hardware may be sold separately or sold together in the future.[26]



5.3 Facing both opportunities and challenges, automotive software companies shall create value based on flexible positioning

As mentioned hereinbefore, along with the restructuring of EEA, software enterprises will become increasingly important on the software value chain, including the application software, basic software, and safety testing and verification software. However, automotive software development will inevitably encounter objective challenges. First, as automobile electronics and intelligent networking continue to advance, and the global market has an increasingly higher requirement for automobile safety, the international safety standard (ISO 26262) for automobile electronic and electrical functions has been set up. The high safety level of "ASIL-D" (applicable to ADAS/autopilot systems) under this standard has imposed strict access requirements on software enterprises' safety technologies and development techniques. Moreover, vehicle manufacturers strictly select suppliers, requiring not only safe functions and stable, reliable systems, but also technical support throughout the life cycle of vehicles. Second, the automotive software industry lacks a clear pricing model. If charging by value (i.e., pricing based on consumers' willingness-to-pay for the products or services) as that of the consumer electronics industry, it will contradict OEMs' strategies. Currently, OEMs view ADAS/autopilot technology as their core assets and capability, and are willing to pay a high premium. However, applications such as IVI and map are more viewed as commercial software products, so these software development companies have a weak bargaining power. Third, software development requires huge initial capital investment, but whether the subsequent scale effect will generate great economic benefit is unpredictable. Last, the lack of a software architecture standard in the industry will be another big challenge facing the automotive software suppliers.[27]

Anyway, software enterprises will have more opportunities than challenges. Taking into consideration their strength and positioning as well as the upstream demands, emerging automotive software companies/ Internet companies may focus on the following aspects to create value:

Full-stack software capabilities: under the trend of software-hardware decoupling, OEMs with strong R&D capability will seek semi-autonomous R&D. Therefore, emerging software companies may enhance their advantages in full-stack software layout and that in open, compatible tool chain, to accommodate OEMs' demands of independent development as well as cost and risk control.

Go-to-market efficiency: for OEMs that have begun to select software suppliers through bidding, software companies need to emphasize the productization and commercialization efficiency of their solutions.

Cooperation with core hardware enterprises to enter the automotive supply network: some large software and algorithm companies started to transform towards hardware-software integration last year, and have acquired underlying hardware enterprises or begun to develop their own hardware, expecting to become the new Tier-1 suppliers in the autonomous driving/ intelligent connected era, however, for small and medium-sized software enterprises, the most competitive and efficient market-entry strategy is to deeply cooperate with upstream core electronic hardware vendors. Mobileye worked closely with Tier-1 enterprises in the beginning to enter the OEMs' supply network; smart cockpit software enterprises may access the supply chain through close cooperation with processor vendors.

[27] Deloitte Insights, "Software is transforming the automotive world", June 18, 2020, https://www2.deloitte.com/content/dam/insights/us/articles/22951_software-is-transforming-the-automotive-world/DI_Software-is-transforming-the-automotive-world.pdf

Conclusion

For enterprises in the automotive industrial chain, "software-defined vehicles" is no longer an experimental path. Technology, market, consumers, and many other factors are substantially pushing the software-oriented transformation of the automotive industry. Automobiles, a complex hardware-based engineering product, will be increasingly marked by software.

The "software-defined vehicles" transformation will spread to every aspect of the automotive industry, covering OEMs' vehicle software and hardware architecture design, product development process, development organization framework, personnel development, as well as the supply chain system and business models of the entire industry. It may even lead to restructuring in some areas. During the transformation process towards software-defined vehicles, there will be difficulties and challenges for traditional automobile manufacturers as well as opportunities for the new automotive industry players, such as chip suppliers, software suppliers and Internet companies. The "software-defined vehicles" transformation will be an inexorable trend driving the development of the automotive industry over the next 5-10 years. All enterprises in the industrial chain should make thorough evaluation and forward planning, and find a suitable path to retain the initiative during the new industrial transformation.

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