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Software-defined vehicle Research Report 2021: Architecture Trends and Industry Panorama

The overall architecture of software-defined vehicles can be divided into four layers: (1) The hardware platform and heterogeneous distributed hardware architecture; (2) The system software

including virtual layer, machines, system kernels, POSIX. Autosar, etc.; The application (3) middleware and development framework, functional including SOA, software, etc.; (4) The application including software layer, HMI. smart cockpit ADAS/AD algorithms, algorithms, connectivity cloud platforms, etc.





The business model of smart car software is in the form of "IP + solutions + services". Tier 1 software suppliers charge in following modes:

(1) One-time R&D expenses and software packages, such as ADAS/AD algorithm packages;

(2) Software licensing fees per car, royalties (by a certain proportion of car shipments and unit price);

(3) One-time R&D expenses and license packages per car.

Take the software IP licensing fees as an example. Regardless of the highly complex AD software, we estimate that the software IP licensing fees for a single car is at least RMB2,000-3,000. As the functions of smart cars become more complex, the software IP licensing fees per car will continue to rise.

| Software IP | Estimated Single Vehicle Software License Fees (RMB) | Remarks | |
|---|---|---|--|
| Operating system kernel optimization | 100-150 | Software licensing fees for the two operating systems for vehicle control and infotainment, one responsible for vehicle control system (high reliability, high safety) and the other for infotainment system (abundant applications) are charged. By average unit price of vehicles, the cost of operating system optimization stands at RMB100-150/vehicle. | |
| Basic software, middleware | 200-300 | CP Autosar and AP Autosar, SOA software platform, as well as cockpit middleware, autonomous driving middleware, vehicle control middleware, etc. | |
| Hypervisor | 100-150 | In the case of intelligent cockpit, currently the main solution is the QNX Hypervisor + QNX cluster + Kanzi integrated solution. In spite of efficient technical support, it is hard to cut down the cost per unit from registration and membership to service and license in a short time, but it is worthwhile on the whole. Non-open source hypervisors may need payments for registration, membership, service and license fees and other development costs, and effective technical support. For example, the registration fee for BlackBerry QNX is about USD210,000. | |
| Human-computer interaction | 50-100 | UI/UX design software license fees, voice interaction fees (front-end sound source localization, noise reduction and recognition, voice cloud-based ASR and natural semantic understanding), gesture control authorization fees, etc. | |
| ADAS/ <mark>AD</mark> a <mark>lgor</mark> ithm framework | 200-300 | The core common functional modules (autonomous driving general framework connectivity, cloud control, etc.), algorithm programming frameworks (TensorFlow Caffe PaddlePaddle etc.). | |
| In-vehicle vision Al algorithm software | 50-80 | Driver monitoring system (DMS), face recognition, electronic rearview mirror, etc. | |
| Surround view and parking software | 200-300 | 360-degree surround view stitching, front-view algorithms (e.g., Mobileye EyeQ) built in chip, parking software, etc.; visual parking can be additionally sold to users in the form of software package. | |
| HD map software | 1000 | In current stage, the initial license fees for HD maps are RMB500700; the service update fees are RMB100/year; the ASP of electronic navigation maps during the entire vehicle life cycle will increase to more than RMB1,000/vehicle from RMB300 /vehicle in the past. | |
| Cloud services, OTA and security software | 200-300 | SOTA, FOTA, information security software, cloud services | |
| Connected software | 50-100 | 4G/5G traffic flow C-V2X software stack and license fee TCLI and gateway software | |

Estimated Software IP Licensing Fees per Car by Automotive Software



At the same time, OEMs are also vigorously expanding their internal software R&D teams to reduce the cost of software outsourcing. In the next step, OEMs' software R&D will still focus on software that can directly create value for consumers, such as cockpit HMI, autonomous driving, etc. Of course, OEMs can also cooperate with independent software vendors in R&D through the decoupling of software and hardware, like BMW and ArcherMind Technology team up, and ThunderSoft and Human Horizons collaborate. However, for general software (such as surround view splicing, voice, DMS) and common platform-based software (such as OS kernels, virtual machines, HD maps, cloud platforms, etc.), OEMs still give priority to outsourcing.

In general, as software becomes more and more complex, the life cycle value (ASP) of software for a single car may be as high as tens of thousands of yuan, which makes software a main part of the vehicle BOM cost.

With the continuous evolution of software-defined vehicles, the business model of the entire automotive industry has changed accordingly, from new car manufacturing and marketing model which lasts for a long time to a larger-scale software × ownership model. Automakers will charge customers for software license and OTA updates to complete the closed-loop business model.

For example, Tesla has boosted the price of its FSD (Full Self-Driving) Beta launched at the end of 2020 by US\$2,000 to US\$10,000, and it will further raise the price of the package for L3/L4 autonomous driving to US\$14,000. Tesla is trying to offer customers a way to subscribe and pay a monthly fee instead of US\$10,000 up-front for their premium driver assistance features in order to expand the potential subscriber base.

On July 16, 2021, Tesla started offering a monthly subscription for its FSD package for US\$199 per month in the United States. Tesla owners can cancel their monthly FSD subscription at any time. Customers who previously bought Tesla's Enhanced Autopilot package (EAP) can subscribe to FSD for a lower price of US\$99 a month but may require the HW3.0 upgrade. In other words, only Teslas that have the FSD computer hardware 3.0 (HW3) or above plus either Basic or Enhanced Autopilot configurations are eligible to subscribe to FSD; other owners can purchase a hardware upgrade for US\$1,500 to make their vehicles FSD-ready.

Once Tesla fulfills the transformation of its business model, all existing Tesla owners may become subscribers of the FSD package. Assuming 10 million Tesla owners subscribe to the FSD package with a monthly price of US\$100, a subscription fee of US\$12 billion will be incurred each year and Tesla's software gross margin will be as high as 70-80%. The software revenue from existing car owners is expected to be very stable and lucrative, posing a solid moat for Tesla.



A Trilogy of Software-defined Vehicle Transformation of OEMs

In the short term, the system kernel and middle layer are the key R&D directions. In the long run, SOA will bring about changes in business models. To complete the software-defined vehicle transformation, OEMs must at least achieve:

1. Vehicle EEA upgrade. The hardware architecture develops from distributed ECU to centralized domains, and further upgrades to centralized + regional controllers. As for the communication architecture, the automotive network backbone is upgraded from LIN/CAN bus to Ethernet;

2. Linux, QNX and other RTOS only provide kernels. On this basis, OEMs realize hardware abstraction, form a middle layer operating system that supports application development, define developer interaction logic, and build application layers, namely the so-called self-developed operating systems of OEMs, similar to Tesla.OS, VW.OS, Daimler MB.OS, BMW-OS and Toyota Arene. At the same time, more and more OEMs have followed suit, such as SAIC Z-One SOA, Lixiang Li-OS and Volvo Cars.OS. The ultimate goal of OEMs is to open up vehicle programming to all enterprises by simplifying the development of vehicle software and increasing the frequency of updates, so as to master the ecological resources of developers;

3. With further making use of the huge number of users to build a developer ecosystem, the profit engine of automakers has transferred from "hardware manufacturing" to "software development". For example, Tesla continues to boost the price of FSD software while continuously reducing the price of vehicle hardware in order to promote the rapid development of the automobile company dominated by software revenue.

In the short term, most OEMs are still in the stage of upgrading their hardware architecture. At present, only Tesla and Volkswagen have completed the development, construction and large-scale applications of customized OS kernels. The decoupling of automotive hardware and software is also in the early stages of development. Now, OEMs have focused on basic software (system kernels, AP Autosar, middle layers, etc.).

From a long-term perspective, SOA (Service-Oriented Architecture) will reconstruct the automotive ecology. The automotive industry is likely to replicate the software model of "basic hardware, middle-level operating systems and upper-level applications" for PCs and smartphones. Meanwhile, smart car middleware giants will emerge. Upper-level APP developers need not pay attention to the underlying hardware architecture, but should focus on application development instead.

By building operating systems and SOA platforms by themselves or with suppliers, automakers have introduced a large number of algorithm suppliers, ecological partners, etc. to form a developer ecosystem. In the future, automakers can provide users with software services covering the full life cycle. Under this background, OEMs have laid out SOA software architecture development. In the next 2-3 years, SOA mass production will reach its peak, and consumers will enjoy richer smart driving experience.



SOA Software Mass Production Deployment of Some Automakers

| Provider | Logo | SOA Software Platform Progress | SOP Plan | The automotive SOA | |
|------------------------|---------------------|--|-------------------------------------|---|--|
| SAIC Z-ONE Software | 2零束 | In April 2021, the SAIC Z-ONE SOA software development platform made a debut. It will enable the iteration speed of "T+0+1+7", which means that new application scenarios can be quickly launched at "T+0"; new light APPs can be launched quickly at "T+1"; new APPs can be launched quickly at "T+7". And based on standard service interfaces, development participants will be no longer limited to OEMs but include third-party application providers and even individual developers, with the ultimate aim of building a development platform similar to smartphone iOS/Android. | Planned SOP and application in 2022 | software platform is similar to Apple iOS and Goog Android in the smart phor field. It is not only generalized softwar architecture, but also a | |
| Xpeng Motors | | Xpeng Motors has developed central computing for EE2.0 dual-brain domain architecture, with the backbone network already realizing Ethernet + CANFD data; Xpeng Motors adopts hybrid service oriented architecture (SOA) to finally create a three-layer interactive vehicle software architecture form which is composed of body function layer, application layer, and interaction layer. The body function layer provides a small number of service interfaces to enable most of the local vehicle functions, which will eventually be replaced by service interfaces. The interaction layer defines service interface standards and manages all body function services in a safe and orderly manner. The application layer carries out a small number of local vehicle functions, and finally enables all local functions by calling the service interfaces, realizing remote terminal applications and cloud applications. | Planned SOP and application in 2022 | ecological platform fo developers. In the smar phone field, Apple iOS and Google Android basically monopolize develope resources, each of them holds more than 20 millior developer resources worldwide. Likewise, the automotive SOA software | |
| Weltmeister | WELTMEISTER 威马汽车 | Weltmeister applies the SOA platform in Weltmeister W6, and has launched the custom programming function, with more than 100 custom scenarios. Mobile terminals are synchronized with vehicle terminals. To meet the individual needs of users in mobility scenarios, the car first creates an easy-to-understand custom scenario programming function (Weltmeister Shortcut) in a complex SOA, using Weltmeister Zhixing App. | SOP in 2021 | platform may gradually head toward an oligopolistic market. | |
| Hozon (NETA Auto) | 日日こ日日 | Hozon Neta S plans to develop a whole system based on SOA. The product may be launched on market in the second half of 2022 and be first mounted on internally codenamed EP40, a flagship model which boasts a range of 1,000 km and adopts the "next-generation AI controller", "next-generation intelligent driving controller", "Ethernet-based SOA", etc. | Planned SOP in 2022H2 | | |



At the same time, the powerful ecosystem of Apple and Android developers has become one of the fatal technologies in the context of the Sino-US trade war. Especially after the US government placed Huawei on its Entity List, Google stopped offering Google Mobile Services to Huawei, which affected the operation of Huawei's mobile phones. In this case, Huawei had to launch HMS services and HarmonyOS. The underlying automotive software platform will also threaten the safety of the industrial strategy, and it has become a national strategy. It is urgent to build a standardized platform for automotive basic software.

Under the guidance of the Ministry of Industry and Information Technology of China, Neusoft Reach and China Association of Automobile Manufacturers have jointly planned and initiated China Automotive Basic Software Ecological Committee (AUTOSEMO). With more than 20 member units, AUTOSEMO will share experience and innovation, build open standardized software architectures, interface specifications and application frameworks, develop China's automotive basic software industry ecosystem with independent intellectual property rights, as well as promote China's automotive industry to accelerate the intelligent transformation.

On July 22, 2020, AUTOSEMO was established in Shanghai, with founding members including FAW, SAIC, GAC, NIO, Geely, Great Wall, Changan, Beiqi Foton, Dongfeng, FAW Jiefang, Xpeng, Neusoft Reach, Jingwei Hirain, NASN, VMAX, Horizon Robotics, Zhito, Wanxiang Qianchao, REFIRE and China Automotive Innovation. The first rotating chairman was assumed by Neusoft Reach.

The mission of AUTOSEMO is to forge basic software architecture standards and interface specifications dominated by local enterprises with independent intellectual property rights, share knowledge and achievements, as well as establish an industrial ecology, in response to the development needs of intelligent connected vehicles and autonomous driving technology in the future. Harboring the concept of independence, development, and innovation, it has created an automotive software ecosystem communication platform for the industry. It released the first China Automotive Basic Software Development White Paper 1.0 in November 2020, and the first Automotive SOA Software Architecture Technical Specifications 1.0 in June 2021 to accelerate the development of China's automobile industry towards intelligence.



For smart cars with new EEA, AP AUTOSAR and middleware OS will be the focus of many Tier1 suppliers

Automakers are committed to defining more unified middleware communications and services to reduce development costs and system complexity. Operating software (OS) and middleware are the underlying software components that promote the separation of software and hardware. Even if automakers choose to develop their own operating systems, they will also rely on standard middleware products provided by suppliers. In particular, the architecture of the basic software platform is extremely important, because it can greatly improve the development efficiency of software for the application layer.

Automotive electronic software standards mainly include AUTOSAR, OSEK/VDX, etc. Among them, AUTOSAR has been developing for more than ten years, and has formed a complex technical system and extensive development ecology, as the mainstream of vehicle control operating systems.

AUTOSAR includes Classic and Adaptive platforms, designed for safety control and autonomous driving respectively. The Classic AUTOSAR platform, based on the OSEK/VDX standard, defines the technical specifications of vehicle control operating systems. With an operating system based on the POSIX standard, the Adaptive AUTOSAR platform can provide standardized platform interfaces and application services for operating systems that support the POSIX standard and diverse applications.

At present, the world-renowned AUTOSAR solution vendors include ETAS (Bosch), EB (Continental), Mentor Graphics (Siemens), Wind River (TPG Capital), and Vector, KPIT (a US-based company began in India as a joint venture) and so on.

In China, overseas suppliers, including EB, ETAS, VECTOR, etc., dominate the development tool chain and basic software under the Classic AUTOSAR standard, followed by domestic suppliers like Neusoft Reach, Huawei, Jingwei Hirain, etc. In terms of Adaptive AUTOSAR, suppliers are still in their infancy. Continental EB cooperates with Volkswagen to apply AP AUTOSAR and SOA platforms to ID series battery-electric vehicles of the Volkswagen MEB platform.

Previously, China's automotive basic software architecture standards and industrial ecology were relatively backward. Following the trend of automotive intelligent transformation and upgrading, domestic vendors have focused on AP AUTOSAR and launched corresponding middleware and tool chain products to seize market opportunities.



| | [| Middleware Products of Some Suppliers | |
|-----------------|---|--|--|
| Vendor | Middleware | Description | |
| HUAWEI | Huawei's self- developed Yueying Operating System compatible with AutoSAR standard- compliant software middleware | Vehicle control OS (operating system): YueyingOS, Huawei's self-developed microkernel operating system, uses Huawei HarmonyOS microkernel which is compatible with Linux, that is, autonomous driving service developed on Linux system can be directly migrated to the MDC software platform for operation; Adaptive software components: Huawei's self-developed software middleware is compatible with AUTOSAR. It is used to loosely couple software and hardware. Wherein, the AI operator library contains a range of artificial intelligence models compatible with common middleware (e.g., Tensorflow and Caffe) for deep neural network learning. | |
| UNTOUCH 未动科技 | Hi <mark>gh-saf</mark> ety, high- performance autonomous driving middleware | The middleware products of Untouch Tech support a variety of POSIX standard- compliant operating systems, and processor platforms that are transplanted to different architectures. After rigorous safety testing and performance optimization, the middleware products are up to ASIL-D. The independently developed, controllable automotive middleware products are implemented with Adaptive AutoSar based on Rust language. By the end of 2020, Untouch Tech has secured designated projects for 30+ models of 10 OEMs. It is expected that the company will deliver 1.5 million units in the next five years. | |
| TITech | MotionWise Autonomous driving software platform | MotionWise safety software platform is a solution integrated with MotionWise services and third-party software stacks. Motion Wise runs in a multi-host environment where one Safety Host often runs Classic AUTOSAR, and one or more Performance Hosts run POSIX Operating System. The Safety Host supported by MotionWise is up to ASIL D. Globally, TTTech MotionWise products have been seen in more than 25 SOP models. | |



In November 2020, Neusoft Reach fully upgraded NeuSAR, an AUTOSAR-based system platform developed by itself for nextgeneration automotive communication and computing architectures, to the version 3.0, featuring ASIL-D functional safety, information security function expansion, high-performance SOA protocol stacks, virtual verification solutions, full support for SOA, application dynamic deployment, vehicle-cloud collaboration solutions and the like.

Neusoft Reach's basic software product NeuSAR builds a horizontal software platform that can realize effective decoupling of software and hardware. It converts the core functions and algorithms of Neusoft Reach's products into SOA services and provides them to application developers through standardized interfaces so as to support flexible application development modes.

In addition, the vehicle-cloud integrated system built by Neusoft Reach connects the in-vehicle SOA services with the cloud through the vehiclecloud collaboration middleware, and combines the cloud service platform with big data and CP/SP aggregation capabilities to enable the intelligent application scenarios of vehicle-cloud collaboration vertically.

NeuSAR, developed by Neusoft Reach independently, is compatible with the latest version of the AUTOSAR standard. It not only supports traditional ECU development, but also provides a wealth of basic software, middleware and development tools for software development based on domain controllers and new EEA. NeuSAR is widely used in domain control systems such as autonomous driving, intelligent cockpits, chassis power, and body control under the next-generation architecture.

Neusoft Reach's Software Architecture for SDV

Based on NeuSAR, build a technology ecosystem and achieve commercial use



Undertake the core values of customers, commercialize basic software in SDV mode Build "One Horizontal, One Vertical" ecological products and solutions, with basic software as the starting point and continuous efforts to cultivate





Strategies of OEMs, traditional Tier1 suppliers, and software vendors to cope with the trend of SOA and layered decoupling

Under the SOA software framework, OEMs, Tier1 suppliers, and other authorized developers will step in the application software development ecology.

There are three modes for OEMs to transform toward software:

1. While expanding the internal R&D teams, OEMs establish strategic alliances with software companies. OEMs promote the construction of software ecology, while the Tier1 software suppliers are responsible for execution; for example, GAC R&D Center, Neusoft Reach, ThunderSoft, etc. have erected a joint innovation center;

2. OEMs set up software subsidiaries to lay out full stack technology, gradually conduct independent R&D of software, algorithms, chips and other full technology stacks, bypass the traditional Tier1 suppliers to a certain extent, and co-develop subsystems with the former Tier2 software suppliers; CARIAD (Car.Software), a subsidiary of Volkswagen, SAIC Z-One, and Changan Auto Software Technology Co., Ltd. are the examples herein;

3. OEMs erect software R&D divisions to directly cooperate with core technology vendors by all ways like investment so as to be as independent as possible.

They mainly boast in-house R&D capabilities in one or more fields with strategic differences, and outsource some common software. For example, start-ups NIO, Xpeng, etc., which are smaller and more flexible and need not be comprehensive, focus on the development of core application software for smart cockpits and autonomous driving and have formed their own big R&D teams.

In the past automotive supply chain, powerful Tier1 suppliers generally provided software and hardware integrated "black boxes", so it is extremely difficult to decouple software from hardware. However, Tesla has broken through the business model of Tier1 suppliers. In the future, automotive electronics and auto parts will be tagged "white labels" like traditional machinery and body parts in the past. The hardware differentiation is getting smaller and the profits are becoming more and more transparent. It is possible that hardware will be sold to automakers at cost, while software will become the soul of vehicles and the new profit engine for OEMs. The differentiation and profitability of vehicles will shift to technology and related software stacks.



Under the trend of SOA and hierarchical decoupling, Tier1 suppliers or software suppliers have the following coping strategies:

1. For traditional Tier1 suppliers, it is a general trend that some system function development rights are taken back by OEMs. Therefore, they need transform and seek new ways urgently to avoid becoming hardware foundries. Traditional Tier1 giants are well aware of the fact that full-stack capabilities of software and hardware are the key to seizing the future overwhelming market share. More and more Tier1 suppliers, represented by Bosch, Huawei, Desay SV, etc., are committed to creating full-stack technical capabilities covering "hardware + underlying software + middleware + application software algorithms + system integration", so that they can not only provide customers with hardware and software separately, but also offer software and hardware integration solutions.

2. While further strengthening the autonomy and independent software development capabilities, **OEMs have begun to seek direct cooperation with software suppliers**. For example, OEMs will first seek to take back cockpit HMI system functions to themselves, but directly purchase UI/UX design tools, voice recognition modules, sound effect modules, face recognition modules and other application software from software suppliers, thus bypassing traditional Tier1 suppliers to accomplish independent development. For software suppliers, the more software IP portfolios they can provide, the higher the value per car they can secure. At the same time, software suppliers are also seeking to dabble in hardware design and manufacturing (such as domain controllers, TBOX, etc.) controlled by traditional Tier1 suppliers in order to provide diversified solutions. software with the overwhelming market share.

In general, software-defined vehicles are currently in varying forms. According to the objective development law of the software industry, the software-defined vehicle industry will show several characteristics in the long run as below:

1. The entry barriers of automotive software will continue to elevate, with higher and higher concentration. The development barriers of automotive software will threaten small and medium-sized vendors who may feel difficult to survive. Whoever can achieve rapid iteration and scale effects may thrive and grab a relatively high market share; for example, Kanzi, the UI design software of ThunderSoft, has occupied 80% of the domestic market share.

2. Automotive software will feature capital intensiveness, and needs more and more capital. External financing will be conducted in the hundreds of millions of dollars. In the end, there will be several large software suppliers in each segment of automotive software with the overwhelming market share.



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| | In-vehicle Infotainment (IVI) | ADAYO 华阳集团 ////LENNE |



Table of Content (1)

1 Overview of Software Defined Vehicle

1.1 Software Architecture Trends in EEA Evolution

1.1.1 Three Dimensions of Automotive EEA Upgrade: Software Architecture, Hardware Architecture, and Communication Architecture

1.1.2 Evolution of Vehicle Electronic/Electrical Architecture (EEA)

1.1.3 EEA Evolution: Centralized Computing + Zone Controller (Zonal Architecture)

1.1.4 EEA Evolution: Vehicle Central Computer (VCC)

1.1.5 Challenges in Software Development under the Traditional Distributed ECU Architecture 1.4.1 Vehicle Software Cost and Value Stream Estimation

1.1.6 Summary of Software Development Models under Different E/E Architectures

1.2 Intelligent Vehicle Software Architecture

1.2.1 Intelligent Vehicle Software Architecture Includes Hypervisor, System Kernel,

Middleware, Functional Software, and Application

1.2.2 Cores of Intelligent Vehicle Software (1): Overall Architecture

- 1.2.3 Cores of Intelligent Vehicle Software (2): Power and Chassis Controllers
- 1.2.4 Cores of Intelligent Vehicle Software (3): Body Controller
- 1.2.5 Cores of Intelligent Vehicle Software (4): Central Computing Unit
- 1.2.6 The core category of smart car software (5): Software and Hardware Design Goals
- 1.2.7 Synergy of Vehicle Software Architecture and Heterogeneous SoC
- 1.2.8 Evolution of Future Vehicle Software Architecture
- 1.2.9 Software Defined Vehicle R&D Process and System Transformation Trends
- 1.2.10 Software Defined Vehicle ASPICE Development Process

1.3 Intelligent Vehicle Software Business Models and Prospects

- 1.3.1 Transformation of Vehicle Sales Models: A Surge in Vehicle Software System Cost
- 1.3.2 Forecast of Global Intelligent Vehicle Software Industry Scale

1.3.3 Main Vehicle Software Business Models Includes One-time Pre-Installation Payment or **On-demand Subscription Payment**

1.3.4 Three Software Charging Methods of Tier1 Suppliers

1.3.5 Intelligent Vehicle Software Charging Models: IP License Fees for Single Vehicle Software

1.3.6 Estimated IP License Fees for Single Vehicle Software in Different Vehicle Software 1.3.7 OEMs Charge Customers Software License and OTA Update Service Fees to Build a **Closed Business Model Loop**

1.3.8 Transformation of Vehicle System Integration Modes: Roles of Various Hardware and Software Players

1.3.9 Platform + Ecosystem Model will Hold the Trend for Intelligent Vehicle Software

- 1.4 Cost Structure of Intelligent Vehicle Software
- 1.4.2 Software Costs of OEMs at All Levels

1.4.3 Cost Structure of Software and Electronic Hardware for Vehicle End Customers

1.5 Industry Chain Software Defines Vehicle Strategy

- 1.5.1 Overall Trend of Software Defined Vehicle
- 1.5.2 How the Industry Chain Responds to the Wave of Software Defined Vehicles
- 1.5.3 How Automakers Respond to the Wave of Software Defined Vehicles
- 1.5.4 Summary of Vehicle Software Companies Established by Major OEMs, 2019-2020
- 1.5.5 Three Path Models for OEMs to Transform to Software

1.5.6 OEMs Focus on Developing Middle-layer OS and Define Communications and Services to Simplify Systems from an Open Source Perspective

1.5.7 How Tier1 Suppliers Respond to the Wave of Software Defined Vehicles

1.5.8 Software Defined Vehicle Strategies of the 4 Types of Players such as OEMs and Tier1 Suppliers

2 Basic Software (System Kernel, Middleware and SOA)

- 2.1 Vehicle Operating System
- 2.1.1 Classification: Real-time and Non-real-time Operating Systems
- 2.1.2 Application of Vehicle Operating System (1)
- 2.1.3 Application of Vehicle Operating System (2)
- 2.1.4 System Kernels are the Core of Vehicle Software Architecture
- 2.1.5 System Kernels are Divided into Three Types: Micro Kernel, Macro Kernel, and Hybrid Kernel



Table of Content (2)

2.1.6 BlackBerry QNX2.4 T2.1.7 Linux & AGL2.4.12.1.8 Android Automotive & Android AutoArchi2.1.9 Huawei's HarmonyOS Hybrid Kernel Operating System2.4.22.1.10 Baidu Apollo's Open Source Autonomous Driving Software Development Platform2.4.32.1.11 AICC INC's ICVOS Autonomous Driving Operating System2.4.42.1.12 Domestic Cockpit Operating System Co-developed by China Automotive Innovation2.4.5Cooperation (CAIC) and PATEO IOV2.1.13 Volkswagen VW.OS2.1.15 Status Quo and Development Pattern of Operating Systems Inside and Outside2.5 SChina (System Kernel)2.5.12.1.16 Global Automotive Operating System Market Size2.5.2

2.2 Hypervisor

2.2.1 Hypervisor is the Foundation for Building an Intelligent Computing Platform Operating System

2.2.2 Automotive Hypervisor Providers

2.3 AUTOSAR

2.3.1 Comparison of AUTOSAR Classic Platform (CP) and AUTOSAR Adaptive Platform (AP)

2.3.2 AUTOSAR Encapsulates Basic Software into Packages Which are Called by Upper

Layer Applications Through Standardized Interfaces

2.3.3 AUTOSAR AP Architecture Follows SOA Concept

2.3.4 AUTOSAR AP and Ethernet Communication (SOME/IP) Protocol

2.3.5 Technological Revolution Route of AUTOSAR AP

2.3.6 Major AUTOSAR Tool Providers

2.3.7 Status Quo and Development Pattern of AUTOSAR Inside and Outside China (Software Platform, Basic Software)

2.3.8 Establishment of China Automotive Basic Software Ecosystem Committee (AUTOSEMO)

2.4 The Value of Domain Control Middleware will be Highlighted

2.4.1 The Value of Domain Control Middleware will be Highlighted as Communication

Architecture is Transformed from "Signal-oriented" to "Service-oriented"

2.4.2 Tier1.5s and New Development Models Will Come out on Computing Basic Platforms

2.4.3 Middleware is the Key to Future Software Value Growth

2.4.4 Domain Control Software Platform Providers Will Play More Important Role

2.4.5 Tier1s Work to Deploy Domain Control Basic Software

2.4.6 Status Quo and Development Pattern of Domain Control Basic Software Inside and Outside China

2.5 Service Oriented Architecture (SOA)

2.5.1 SOA Basic Software Architecture

2.5.2 Three Features of SOA

2.5.3 Transformation of SOA Communication Mode: from CAN Communication to Ethernet Communication

- 2.5.4 SOA Design under Central Computing EEA
- 2.5.5 Challenges in SOA Development and Application Model, and Strategies
- 2.5.6 Deployment of SOA Vehicle Software on Domain Controllers
- 2.5.7 SOA Software Deployment Cases of OEMs
- 2.5.8 Summary of SOA Software Platform Mass Production Progress of OEMs and Tier1s
- 2.5.9 Summary of SOA Software Platform Progress of OEMs and Tier1s (4)

2.6 Basic Software Business of Neusoft Reach

- 2.6.1 Position
- 2.6.2 Next Generation Operating System: NeuSAR
- 2.6.3 Helped to Found China Automotive Basic Software Ecosystem Committee (AUTOSEMO)
- 2.6.4 SDV (Software Defined Vehicle) Oriented Software Architecture
- 2.6.5 SDV (Software Defined Vehicle) Oriented Solutions
- 2.6.6 Basic Software Product NeuSAR 3.0 (1)
- 2.6.7 Basic Software Product NeuSAR 3.0: SOA Oriented Software Framework
- 2.6.8 AUTOSAR aCore Architecture
- 2.6.9 AUTOSAR cCore Architecture



Table of Content (3)

2.7 Basic Software Business of Huawei

2.7.1 Intelligent Vehicle "Computing + Communication (CC)" Architecture

2.7.2 Based on the CC Architecture, Launched Three Domain Control Platforms: MDC, CDC ad VDC

2.7.3 Intelligent Vehicle Solutions

- 2.7.4 Released Three Operating Systems: AOS / HOS / VOS
- 2.7.5 HarmonyOS Architecture Upgrade

2.7.6 100% Self-development Based on AUTOSAR, Achieving High Degrees of Matching, Integration and Freedom

- 2.7.7 Self-developed AUTOSAR CP and AUTOSAR AP Architectures
- 2.7.8 Intelligent Connected Vehicle Architecture

2.7.9 Autonomous Driving Operating System (AOS) and Intelligent Vehicle Control Operating System (VOS)

2.7.10 Vehicle Basic Software and SOA Service Framework

2.8 Basic Software Business of iSOFT

- 2.8.1 Profile
- 2.8.2 AUTOSAR Basic Software Platform Products and Technical Services
- 2.8.3 Major Customers and Dynamics in Cooperation

2.9 Basic Software Business of Jingwei Hirain Technologies

- 2.9.1 Profile
- 2.9.2 AUTOSAR Solutions
- 2.9.3 AUTOSAR AP Software Component Architecture

2.9.4 Schematic Diagram of Adaptive AUTOSAR Tool Chain Solution

2.9.5 AUTOSAR AP RoadMap

- 2.9.6 AUTOSAR AP Mass Production Project Cases
- 2.9.7 AUTOSAR AP Pre-research and Application Practices (AUTOSAR-based SOA Software Platform Practices)

2.10 SAIC Z-ONE Software 2.10.1 Launch of SOA Developer Platform 2.10.2 Timetable for Launch of SOA Software Developer Platform2.10.3 SOA Platform Architecture2.10.4 SOA Platform Developer Ecosystem

2.11 Zlingsmart2.11.1 Profile2.11.2 RAITE Hypervisor2.11.3 RAITE OS2.11.4 Intelligent Cockpit Solutions2.11.5 Main Dynamics

2.12 Elektrobit (EB)
2.12.1 Profile
2.12.2 Solutions Based on Adaptive AUTOSAR
2.12.3 Solutions Based on Adaptive AUTOSAR: HPC Software Architecture
2.12.4 Solutions Based on Adaptive AUTOSAR: Adaptive AUTOSAR Product Lines
2.12.5 AUTOSAR Software Tool Products: EB Tresos
2.12.6 AUTOSAR Software Tool Products: EB Tresos Studio
2.12.7 EB Tresos Solution for NVIDIA DRIVE? PX
2.12.8 ArcherMind Technology Became a Value-added Distributor of Elektrobit in China
2.12.9 Major Customers and Partners

3 Autonomous Driving Software Architecture Overall Software and Hardware Architecture of Autonomous Driving

3.1 Autonomous Vehicle Control Operating System

- 3.1.1 Autonomous Driving OS Platform Architecture
- 3.1.2 Classification of Autonomous Vehicle Control OS
- 3.1.3 Layering and Trends of Autonomous Driving OS
- 3.1.4 Comparison of QNX, Linux and VxWorks Vehicle OS
- 3.1.5 Deep Learning Software Related to Autonomous Driving Functional Software Modules



Table of Content (4)

| 3.2 Autonomous Driving Functional Software and Open Source Platform | 3.5.2 Business Model of HD Map |
|---|---|
| 3.2.1 Specifications for Design of Intelligent Driving Functional Software Platform | 3.5.3 HD Map Industry Chain Distribution |
| 3.2.2 Functional Software Modularizes Common Needs to Help Rapid Application Deployment | 3.5.4 Global and Chinese HD Map Players |
| 3.2.3 Summary of the World's Four Major Autonomous Driving Software Open Source | 3.5.5 Market Prospects of HD Map/Navigation Electronic Map |
| Platforms | |
| | 3.6 Autonomous Driving Simulation |
| 3.3 Autonomous Driving Middleware | 3.6.1 Overview of Autonomous Driving Simulation |
| 3.3.1 Introduction to Middle Base/Middleware | 3.6.2 Status Quo of Autonomous Driving Simulation Market |
| 3.3.2 Summary of Autonomous Driving Middleware Product Progress of Global and Chinese | 3.6.3 Global Mainstream Autonomous Driving Simulation Software Companies |
| Her1s 2.2.2 Obie de Autor anore Drivie e Middlesser Market Oir e | 3.6.4 Huawei Autonomous Driving Cloud Service: Octopus |
| 3.3.3 China's Autonomous Driving Middleware Market Size | 3.6.5 Market Prospects of Autonomous Driving Simulation Test Software |
| 3.4 Autonomous Driving Algorithm Application Software | 3.7 Neusoft Reach |
| 3.4.1 Overview of ADAS/AD Algorithm Software (1) | 3.7.1 Full-stack Autonomous Driving Software Platform: Software and Hardware Architecture |
| 3.4.2 Overview of ADAS/AD Algorithm Software (2) | Autonomous Driving Domain Controller X-BOX 3.0 |
| 3.4.3 3 Types and Development Cycle of ADAS/AD Algorithm Software | 3.7.2 Full-stack Autonomous Driving Software Platform: Middleware and Ecological Software |
| 3.4.4 Overall Market Penetration and Single Vehicle Value of ADAS/AD Functions (Software | Package |
| and Hardware System Integration Solutions) | 3.7.3 Autonomous Driving Domain Controller: M-Box ADAS Domain Controller Finds |
| 3.4.5 Market Size of ADAS/AD Functions (Software and Hardware System Integration Solutions) | Application in Mass-produced New Baojun E300 |
| (RMB100 Million) | 3.7.4 Automated ADAS Business: Autonomous Driving Products for L0-L3 |
| 3.4.6 China's Vehicle ADAS/AD Algorithm Application Software Market Size | 3.7.5 Automated ADAS Business: Autonomous Driving Software Platform |
| 3.4.7 Status Quo and Main Suppliers of Around View Monitor (AVM) | 3.7.6 Automated ADAS Business: Intelligent Driving Cloud Platform |
| 3.4.8 Status Quo and Main Suppliers of Automated Parking (APA/AVP) | 3.7.7 Automated ADAS Business: L4 Advanced Technology |
| 3.4.9 Status Quo and Main Suppliers of Passenger Car Autonomous Driving System Startups | |
| (Tier1s) | 3.8 Huawei |
| 3.4.10 Status Quo and Main Suppliers of Commercial Vehicle L1/L2 Driving Assistance System | 3.8.1 Overall Architecture of MDC Platform |
| Startups (Hardware + Software Algorithm) | 3.8.2 MDC Hardware Platform |
| 3.4.11 Status Quo and Main Suppliers of Commercial Vehicle L3/L4 Autonomous Driving | 3.8.3 MDC Software and Tool Chain |
| System Integrators (Hardware + Software Algorithm) | 3.8.4 MDC Automotive Security Platform |
| | 3.8.5 MDC Passed ISO26262 Functional Safety Certification and ASPICE Software |
| 3.5 NIU Map | Ceruncation |
| 3.3.1 TID MAD LAVELS AND UDDALE FLEQUENCY | |



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Table of Content (5)

3.9 TTTech & Technomous

3.9.1 Profile of TTTech

3.9.2 TTTech Autonomous Driving Solutions

- 3.9.3 Technical Advantages of TTTech Autonomous Driving Controller Platform
- 3.9.4 TTTech Autonomous Driving Security Software Platform: MotionWise (1)
- 3.9.5 TTTech Autonomous Driving Security Software Platform: MotionWise (2)
- 3.9.6 Cooperation between TTTech and SAIC: Development of Intelligent Electronic Control Unit (iECU)
- 3.9.7 Technomous Provides Customers with Domain Controller Hardware and Software Platform
- 3.9.8 MotionWise Software Platform for Technomous iECU Controller
- 3.9.9 Typical Customer Applications of Technomous iECU

3.10 Enjoy Move Technology

- 3.10.1 Profile
- 3.10.2 Technology and Products
- 3.10.3 Ecological Construction
- 3.10.4 High-performance Computing Software Platform: EMOS1.0
- 3.10.5 High-performance Computing Software Platform: Technical Features of EMOS1.0
- 3.10.6 High-performance Computing Software Platform: Multi-domain Integrated Software Platform
- 3.10.7 Multi-domain Integrated Computing Platform
- 3.10.8 Business Model

3.11 Nullmax

- 3.11.1 Profile
- 3.11.2 Advantages of Autonomous Driving Middleware
- 3.11.3 Details of Autonomous Driving Middleware Development

4 Intelligent Cockpit Software Architecture Overall Software and Hardware Architecture of Intelligent Cockpit

- 4.1 Composition and Trends of Intelligent Cockpit Software Platform
- 4.1.1 What is Intelligent Cockpit Software Platform
- 4.1.2 Future Cockpit Needs New Cockpit Software Architectures
- 4.1.3 Summary of Main Cockpit Software Solutions
- 4.1.4 Thundersoft's SOA-based Intelligent Cockpit Software Solution
- 4.1.5 Huawei HarmonyOS-powered Cockpit Software Platform: HOS-A
- 4.1.6 Zlingsmart's Intelligent Cockpit Solution
- 4.1.7 Megatronix's Cockpit Solution
- 4.1.8 Banma Zhixing's Heterogeneous Fusion Intelligent Cockpit OS
- 4.1.9 Neusoft Reach's SDV-oriented Complete Solution
- 4.1.10 Continental Creates a HPC-based Integrated Software Platform for Next Generation Automotive Electronics Architectures
- 4.1.11 UAES's AUTOSAR AP-based Open Software Platform
- 4.1.12 SAIC's SOA Software Platform

4.2 Intelligent Cockpit Operating System

- 4.2.1 Overview of Cockpit Operating System
- 4.2.2 Status Quo of Cockpit Operating System Market
- 4.2.3 Cockpit Operating System: Secondary Development Based on Underlying OS
- 4.2.4 Status Quo of Cockpit Operating System Market

4.2.5 Status Quo and Development Pattern of Intelligent Cockpit Operating System Inside and Outside China

- 4.3 Cockpit Hypervisor
- 4.3.1 Overview of Cockpit Hypervisor
- 4.3.2 Types of Cockpit Hypervisor
- 4.3.3 Status Quo of Cockpit Hypervisor
- 4.3.4 Global and Chinese Cockpit Hypervisor Players
- 4.3.5 Market Prospects of Cockpit Hypervisor
- 4.4 Cockpit Middleware

4.4.1 Status Quo of Cockpit Middleware Market



Table of Content (6)

4.4.2 Cockpit Middleware Software Architecture4.4.3 Major Global and Chinese Cockpit Middleware Players4.4.4 Market Prospects of Vehicle Cockpit Middleware

4.5 In-vehicle Voice Interaction

4.5.1 Overview of Human Computer Interaction
4.5.2 Overview of In-vehicle Voice Interaction Technology
4.5.3 Status Quo of In-vehicle Voice Interaction Market
4.5.4 Global and Chinese In-vehicle Voice Players
4.5.5 Market Prospects of In-vehicle Voice

4.6 DMS/OMS Software
4.6.1 Overview of DMS
4.6.2 DMS Software Technology
4.6.3 Status Quo of DMS Market
4.6.4 Major Global and Chinese DMS Software Technology Players
4.6.5 Market Prospects of DMS Software Technology

4.7 Other Interaction Software

4.7.1 Overview of Face Recognition Interaction Technology
4.7.2 Major Global and Chinese Face Recognition Players
4.7.3 Market Prospects of Vehicle Face Recognition
4.7.4 Overview of Gesture Recognition and Interaction Technology
4.7.5 Major Global and Chinese Gesture Recognition Players

4.8 HMI Design and User Experience
4.8.1 Overview of Vehicle Interface Design
4.8.2 Classification of HMI Design
4.8.3 Main HMI Design Software Tools
4.8.4 Varroc and Candera Cooperate to Develop HMI Software Solutions
4.8.5 Major Global and Chinese HMI UI/UX Designers
4.8.6 Market Prospects of Cockpit HMI UI/UX Design

- 4.9 Neusoft
- 4.9.1 Profile
- 4.9.2 Intelligent Cockpit System
- 4.9.3 Vehicle Computing Platform: Upgradeable Multi-Domain Control Platform
- 4.9.4 Dynamics in Intelligent Cockpit

4.10 Huawei

- 4.10.1 Intelligent Cockpit Solutions
- 4.10.2 Intelligent Cockpit Operating System: HOS
- 4.10.3 HarmonyOS-powered Intelligent Cockpit Platform
- 4.10.4 HarmonyOS-powered Intelligent Cockpit Ecosystem
- 4.10.5 CDC Intelligent Cockpit Platform
- 4.11 Megatronix
- 4.11.1 Profile
- 4.11.2 Product Lines
- 4.11.3 SmartMega? OS+ Vehicle Distributed Intelligent Operating System
- 4.11.4 SmartMega? Voice OS
- 4.11.5 Product Solutions: Intelligent Connected Gateway
- 4.11.6 Product Solutions: Intelligent Digital Cockpit
- 4.11.7 Product Solutions: Body Domain Controller
- 4.11.8 Product Solutions: Intelligent Vehicle Cloud and Big Data Platform as a Service (PaaS)
- 4.11.9 Product Solutions: Traditional Gateway
- 4.11.10 Product Solutions: T-BOX
- 4.11.11 Aftermarket Intelligent Product Line
- 4.11.12 Business Progress and Customers
- 4.11.13 Business Model
- 4.11.14 Competitive Edges

4.12 ThunderSoft

- 4.12.1 Profile
- 4.12.2 Overview of Intelligent Cockpit Business



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Table of Content (7)

- 4.12.3 Intelligent Connected Software Business Layout
- 4.12.4 Intelligent Cockpit Solutions
- 4.12.5 Intelligent Cockpit: TurboX Auto 4.5
- 4.12.6 Cockpit Domain Integrates Scenarios such as Automated Parking, DMS, and Front View ADAS
- 4.12.7 TurboX Auto 4.0
- 4.12.8 Cloud-pipeline-terminal Integrated SOA Software Platform
- 4.12.9 Rightware HMI Design Tool: KANZI HMI
- 4.12.10 Intelligent Vehicle Software Ecosystem Partners
- 4.13 ArcherMind Technology
- 4.13.1 Profile
- 4.13.2 Revenue
- 4.13.3 Product Lines of Automotive Division
- 4.13.4 Released EX5.0 Intelligent Cockpit Software Platform
- 4.13.5 Intelligent Cockpit Solution: EX4.0
- 4.13.6 EX4.0: Tool Set
- 4.13.7 SOA Technical Architecture
- 4.13.8 SOA Business Model
- 4.13.9 Became a Value-added Distributor of Elektrobit in China
- 4.13.10 Main Dynamics

4.14 Huizhou Foryou General Electronics

- 4.14.1 ADAYO Automotive Electronics Business
- 4.14.2 ADAYO Automotive Open Platform (AAOP): Helping to Build Intelligent Connected Ecosystem
- 4.14.3 AAOP2.0 Cockpit Open Platform: Hierarchical and Layered Technical Framework 4.14.4 AAOP2.0 Cockpit Open Platform: Infotainment and Intelligent Cockpit Integration
- 4.14.5 Features of AAOP2.0 Cockpit Open Platform (1)
- 4.14.6 Features of AAOP2.0 Cockpit Open Platform (2)
- 4.14.7 Features of AAOP2.0 Cockpit Open Platform (3)
- 4.14.8 Features of AAOP2.0 Cockpit Open Platform (4)

4.14.9 Features of AAOP2.0 Cockpit Open Platform (5) 4.14.10 AAOP Cooperation Cases

5 Telematics Software Architecture

5.1 V2X CVIS

5.1.1 The Value of V2X Telematics in China's Future Vehicle Industry Chain
5.1.2 Exploration of CVIS Payment Models
5.1.3 Traditional Cockpit Tier1s Will Be Transformed into Highly Integrated Solution Providers
5.1.4 Providers of V2X Software Stack and Application Services
5.1.5 V2X Cloud Control Basic Platform Software
5.1.6 Market Prospects of C-V2X in China
5.2 Cloud Service Platform
5.2.1 Overview of Cloud Platform
5.2.2 Status Quo of Cloud Service Platform Market
5.2.3 Global and Chinese Cloud Service Platform Players
5.2.4 Market Prospects of Cloud Service Platform

5.3 OTA

5.3.1 Overview of OTA
5.3.2 OTA Architecture and Cooperation Modes
5.3.3 Composition of Vehicle OTA Industry Chain
5.3.4 Status Quo of OTA Market
5.3.5 Vehicle OTA TO-B Business Model
5.3.6 Global and Chinese OTA Players
5.3.7 Market Prospects of OTA

5.4 Automotive Cyber Security5.4.1 Overview of Automotive Cyber Security5.4.2 Status Quo of Automotive Cyber Security5.4.3 Global and Chinese Automotive Cyber Security Players

5.4.4 Market Prospects of Automotive Cyber Security



Table of Content (8)

5.5 TSP Service5.5.1 Overview of TSP Service5.5.2 Status Quo of TSP Service Market5.5.3 Chinese TSP Service Players5.5.4 Market Prospects of TSP Service

5.6 Neusoft
5.6.1 V2X Business
5.6.2 V2X One-stop Solution
5.6.3 V2X CVIS Product Line
5.6.4 V2X CVIS Products: C-V2X OBU—V-NeX (C-BOX)
5.6.5 C-V2X OBU/RSU Products
5.6.6 Functions and Features of C-V2X Software Protocol Stack
5.6.7 Intelligent Communication Terminal (T-BOX)
5.6.8 T-Box Product Development and Technology Roadmap
5.6.9 V2X Product: VeTalk Vehicle-Infrastructure-Cloud Integrated Cooperative Platform
5.6.10 Successful C-V2X Cases
5.6.11 5G V2X Customers and Cooperation

5.7 ABUP5.7.1 Profile5.7.2 Development History5.7.3 OTA Solutions and Latest Features5.7.4 Major Partners





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