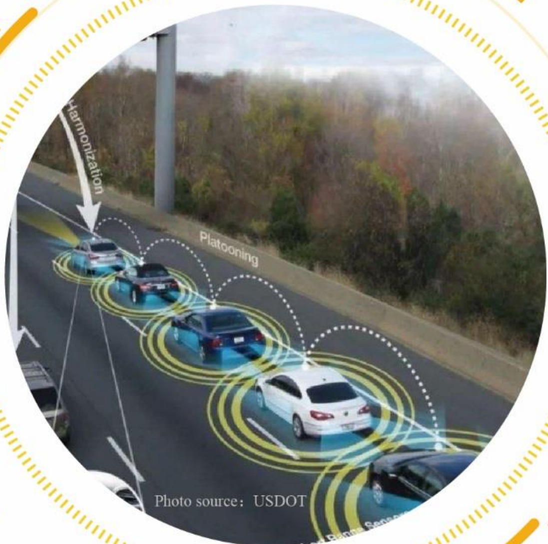

CONNECTED AUTOMATED VEHICLE HIGHWAY (CAVH): A VISION AND DEVELOPMENT REPORT FOR LARGE-SCALE AUTOMATED DRIVING SYSTEM (ADS) DEPLOYMENT

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Connected Automated Vehicle Highway (CAVH): A Vision and Development Report for Large-Scale Automated Driving System (ADS) Deployment

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Introduction

Intelligent Transportation Systems (ITS) has been considered instrumental methods to alleviate traffic congestions and improve traffic safety when the construction of new infrastructure or capacity increase are not viable. With the rapid development of artificial intelligence, mobile internet, big data, and other innovative information technologies, the next generation of ITS will feature the Automated Driving System (ADS) technologies and become the essential approach to ultimately address traffic problems. The vehicle-based ADS solutions are lead by Google, Tesla, Uber, and Baidu. Vehicle-based ADS systems use onboard high-resolution sensors to detect real-time driving conditions, and use on-board edge computing and Artificial Intelligence (AI) algorithms for driving decision making and vehicle control to achieve automated driving.

The main limitations of the vehicle-based technologies are the high concentration of onboard technologies and sensors, which make the large-scale deployment of technologies financially and societally difficult. The industry has come to realize that the large-scale deployment of ADS needs to take advantage of intelligent road infrastructure. Vehicle-based ADS sensing and computing systems can also be deployed along intelligent infrastructures to achieve ADS for all vehicles with less intensive resource deployment on the vehicle end compared with the vehicle-based approach. The interaction and coupling between the intelligent road infrastructures and intelligent vehicles have the potentials of facilitating or even replacing vehicle-based ADS technologies in large-scale deployment.

Under such vehicle-infrastructure integration paradigm, the development of the Connected Automated Vehicle Highway (CAVH) technologies will take the advantage of the rapid development and commercialization of ADS technologies, next-generation wireless communication, artificial intelligence(AI), Internet of Things (IoT), Cloud and Edge computing, Electric Vehicles and highway electrification, smart sensor and infrastructure, smart city, and other technologies to achieve ADS in large scales. The CAVH approach can also enable deep integration across different industrial sectors, including information technologies, intelligent manufacturing, transportation and logistics, and automobile industries to establish cross-industry ecosystems and supply chains for new scientific, technological, and industrial revolutions.

CAVH extends the existing applications of Connected Automated Vehicle (CAV) technologies into system-wide integration between vehicles and infrastructure. The development and deployment of the CAVH-based ADS technologies could be classified as four different stages:

- Stage I, information exchange and interaction: establish the Vehicle to Infrastructure & Infrastructure to Vehicle (V2I & I2V) connectivity.
- Stage II, collaborative sensing, prediction, and decision-making: share and integrate the sensing and prediction results between vehicles and infrastructure and execute coordinated

decision-making.

- Stage III, coordinated control: coordinate the real-time vehicle and infrastructure control with collaborative sensing, prediction, and decision-making results.
- Stage IV, vehicle-infrastructure integration: based on stage I, II and III, vehicles and infrastructure could achieve overall coordination and complete system functions to achieve global planning, control, and optimization of vehicle-infrastructure operations for ADS.

The CAVH-based ADS uses the advanced sensor, network, computing, and control technologies, to achieve the comprehensive sensing for the road and traffic environment, and the wide range and large capacity data sharing between multiple systems facilitating different vehicles and different traffic automation system at various integration levels. Based on CAVH, automated driving systems can be constructed from three dimensions: vehicle automation, network interconnection, and system integration. Such systems can efficiently execute the essential automated driving functions of sensing, prediction, decision-making, and control, and eventually forms intelligent systems that can integrate, coordinate, control, manage, and optimize all vehicles, information services, facilities, equipment, intelligent traffic management, and control. The CAVH is composed of four key subsystems, including traffic management subsystem, smart roadside infrastructure subsystem, intelligent vehicle subsystem, and intelligent communication subsystem, and four key functional modules: sensing module, prediction module, decision-making module, and control module. From a generalized perspective, the CAVH system covers the CAV system and the intelligent road infrastructure system. That is, the intelligent network vehicles, the Internet of vehicles, the active traffic management systems, the automated highway systems, and transportation entities are all included. The advanced CAVH is a more advanced stage of CAVH, which further enhances the intelligence of road infrastructure, which therefore accelerates the commercialization of automated driving, and eventually, achieves the integrated development of vehicles and roads for the automated driving.

Traditional technologies and industries are facing reconstruction and reengineering due to continuous innovations. As an emerging system, CAVH is bound to generate new technologies, industries, and businesses. The CAVH system covers automated vehicles, transportation environment, communication facilities, traffic management, and control system, and other entities, related to technologies of computer vision, communication, network security, vehicle collaboration with road, active control, human-vehicle-road-center collaborative service management, highway automation system, and system integration. These technologies are key to vehicle road collaborative automated driving toward commercialization. CAVH involves many industries, which are of multiple roles, complementing advantages, and prominent characteristics. Developing CAVH systems and promoting CAVH technology applications can advance the chip, software, information communication, data service, and other industry development and transformation, who are the suppliers of vehicle and infrastructure industries. The CAVH based automated driving ecosystem can enable the deployment of intelligent transportation and smart city solutions, a system of systems integration, and shared digital economy, to foster new economic growth.

This report presents the strategic plans and development directions of key technologies in CAVH, analyzes the development trends and CAVH industry positioning, and puts forward suggestions for the development of CAVH that is suitable for China based on an in-depth understanding of the concepts and connotation of CAVH.

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1 Automated Driving

1.1 Connotation of Automated Driving

1.1.1 Principle of Automated Driving

Automated driving means that the vehicle senses the surrounding environment through the sensors onboard, makes control decisions based on the information collected and fused, and makes vehicle control decisions, including both longitudinal control and lateral control. The process of automated driving mainly includes three stages: information collection, information processing, and instruction execution.

In the information collection stage, the automated vehicles detect the surrounding environment through the radar and camera mounted on the vehicle and collects information such as the position, speed, acceleration as well as pedestrians and vehicles nearby.

Information processing stage: the autonomous vehicle transmits the collected information to the automotive electronic control unit (ECU) for analysis, calculation, and control decision.

Instruction execution phase: the autonomous vehicle transmits the control decisions provided by the vehicle's electronic control unit to the engine/motor management system and the electric power steering system (EPS) to achieve vehicle acceleration, deceleration, and steering operations.

1.1.2 Automated Driving Classification

The SAE level of classification for automated driving is adopted in this report [1], as is shown in Figure 1 and Table 1.

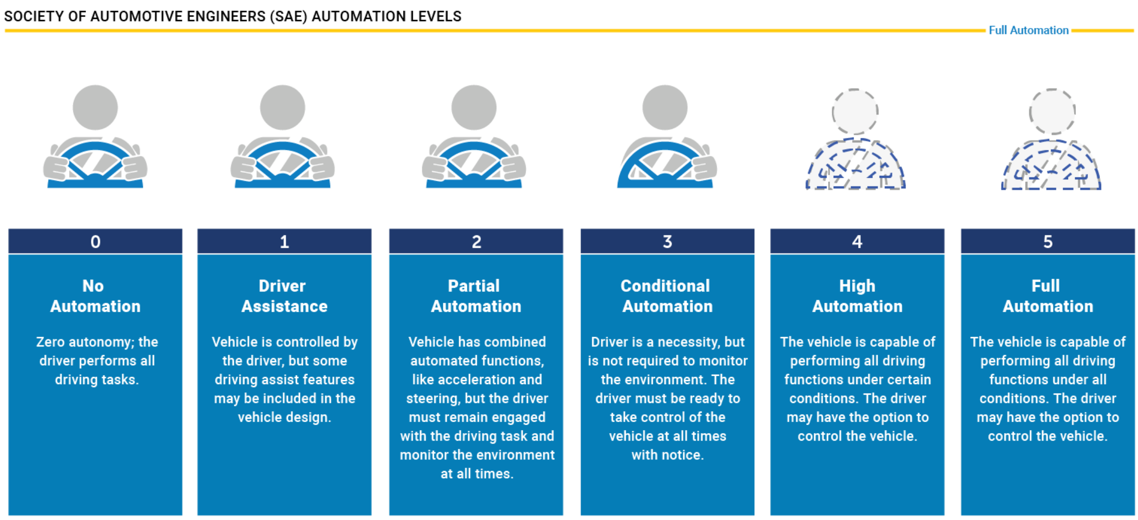

Figure 1 Automation Levels [1]

Table 1 Classification of Self-Driving Vehicles [1]

NHTSA	SAE	The degree of automation	Specific definition	Driving performance	Monitoring	Take over	Application scenes
0	0	No Automation	Zero autonomy; the driver performs all driving tasks.	Human driver	Human driver	Human driver	None
1	1	Driver Assistance	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Human driver and vehicle	Human driver	Human driver	Qualified scenes
2	2	Partial Automation	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Vehicle	Human driver	Human driver	
3	3	Conditional Automation	Driver is a necessity but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	Vehicle	Vehicle	Human driver	
4	4	Highly Automation	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	Vehicle	Vehicle	Vehicle	

	5	Fully Automation	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.	Vehicle	Vehicle	Vehicle	All scenes

- **Level 0**: The human driver does all the driving.
- **Level 1**: An Advanced Driver Assistance System (ADAS) on the vehicle can sometimes assist the human driver with either steering or braking/accelerating, but not both simultaneously.
- **Level 2**: An Advanced Driver Assistance System (ADAS) on the vehicle can itself actually control both steering and braking/accelerating simultaneously under some circumstances. The human driver must continue to pay full attention ("monitor the driving environment") at all times and perform the rest of the driving task.
- **Level 3**: An Automated Driving System (ADS) on the vehicle can itself perform all aspects of the driving task under some circumstances. In those circumstances, the human driver must be ready to take back control at any time when the ADS requests the human driver to do so. In all other circumstances, the human driver performs the driving task.
- **Level 4**: An Automated Driving System (ADS) on the vehicle can itself perform all driving tasks and monitor the driving environment – essentially, do all the driving – in certain circumstances. The human need not pay attention in those circumstances.
- **Level 5**: An Automated Driving System (ADS) on the vehicle can do all the driving in all circumstances. The human occupants are just passengers and need never be involved in driving.

1.2 Concept of Vehicle-Road Cooperative Automated Driving

The Connected Automated Vehicle Highway (CAVH) system detects high-resolution high-precision road environment in real-time by using advanced sensors such as radar, camera, LiDAR (Line Detection and Ranging), which are deployed on both vehicles and roadside. The CAVH system communicates and shares different levels of information among vehicles, between vehicles and pedestrians, and between vehicles and infrastructures according to the different communication protocols and data standards (Connectivity). It enables different levels of vehicle automation (Vehicle Automation) and accounts for different levels of integration and coordination based on the supply-demand dynamics among vehicle and infrastructure (System Integration). The main characteristics of CAVH systems can be designed and built from three different dimensions comprised of vehicle automation, connectivity, and system integration to efficiently and cooperatively perform the sensing, prediction, decision making, and control functions on vehicles and roads. Ultimately, the CAVH system can potentially form an intelligent transportation system that can integrate, cooperate, control, manage and optimize all vehicles, information services, facilities and equipment, intelligent traffic management and control. Generally, the vehicle-road cooperative automated driving system covers the two types of systems: Connected Automated Vehicle (CAV) and Intelligent Road Infrastructure System (IRIS). In other words, CAV, internet of vehicle, active traffic management system, automated highway system, could be considered as part of CAVH system.

The CAVH is a more advanced development form of the vehicle-infrastructure cooperative automated driving system. It can fulfill various functions such as vehicle-road integrated sensing, integrated prediction and decision-making, and integrated control. The CAVH sensing can provide a full-scale integrated sensing, to improve the limited capability of vehicle sensing by using the roadway sensing system to supplement the vehicle sensing. The vehicle-infrastructure integrated prediction and decision-making can make an optimized prediction and decision for the transportation system units, such as key nodes, segment layers and road network layers. The vehicle-infrastructure integrated control can optimize and allocate control instructions by considering the complexity of vehicle control and traffic environment [2][3][4]. Figure 2 shows three-dimensional development architecture of vehicle-road cooperative automated driving system.

- **Dimension 1**: Vehicle automation is the development dimension of connected automated vehicles in the connected automated vehicle highway;
- **Dimension 2**: Connectivity, is the development dimension of intelligent communication in the connected automated vehicle highway to achieve collaboration and interconnection among vehicles, pedestrians, and traffic environments;
- **Dimension 3**: System integration is the integrated development dimension of connected automated vehicle highway.

1.2.1 Vehicle Automation

The Vehicle Automation Level uses the SAE definition. [1]

- Level 0 – No Driving Automation. The performance by the human driver to perform the entire Dynamic Driving Task (DDT). Systems under this level are found in conventional automobiles.
- Level 1 – Driver Assistance. A driving automation system characterized by the sustained and operational design domain (ODD) specific execution of either the lateral or the longitudinal vehicle motion control subtask of the DDT. Level 1 does not include the execution of these subtasks simultaneously. It is also expected that the driver performs the remainder of the DDT.
- Level 2 – Partial Driving Automation. Similar to Level 1, but characterized by both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation

that the driver completes the object and detection and response (OEDR) subtask and supervises the driving automation system.

- Level 3 – Conditional Driving Automation. The sustained and ODD-specific performance by an ADS of the entire DDT, with the expectation that the human driver will be ready to respond to a request to intervene when issued by the ADS.
- Level 4 – High Driving Automation. Sustained and ODD-specific ADS performance of the entire DDT is carried out without any expectation that a user will respond to a request to intervene.
- Level 5 – Full Driving Automation. Sustained and unconditional performance by an ADS of the entire DDT without any expectation that a user will respond to a request to intervene. Please note that this performance, since it has no conditions to function, is not ODD-specific.

1.2.2 Connectivity

The Connectivity Level is defined based on the information volume and content:

(1) No Connectivity

Both vehicles and drivers do not have access to any traffic information.

(2) C1: Information Assistance

Vehicles and drivers can only access simple traffic information of certain accuracy, resolution, and with a noticeable delay from the internet, such as aggregated link traffic states.

(3) C2: Limited Connected Sensing

Vehicles and drivers can access live traffic information of high accuracy and unnoticeable delay, through connection with RoadSide Units (RSU), neighboring vehicles, and other information providers. However, the information may not be complete.

(4) C3: Redundant Information Sharing

Vehicles and drivers can connect with neighboring vehicles, traffic control device, live traffic condition map, and high-resolution infrastructure map.

The information has adequate accuracy, is provided almost in real time, and is complete and redundant from multiple sources.

(5) C4: Optimized Connectivity

Vehicles and drivers are provided with optimized information. Smart infrastructure can provide vehicles with optimized information feed.

1.2.3 System Integration

The System Integration Level is defined based on the coordination/optimization scope:

(1) SO: No Integration

There is no integration between any systems.

(2) S1: Key Point System Integration

System integration occurs at intersection or ramp metering area. However, coordination/optimization scope is very limited, e.g., RSU based control for intersections, ramp metering.

(3) S2: Segment System Integration

The scope becomes larger, and more RSUs, and vehicles are involved in the coordination and optimization. The traffic modes will remain the same.

(4) S3: Corridor System Integration

Coordination and optimization will be across different traffic modes, and an entire freeway or arterial will be considered. By sharing the information, RSUs and vehicles will achieve system optimal in the target scope (e.g., highway and local street integration, across different traffic modes).

(5) S4: Macroscopic System Integration

City or statewide coordination and optimization is achieved by connecting RSUs and vehicles in a very large scope.

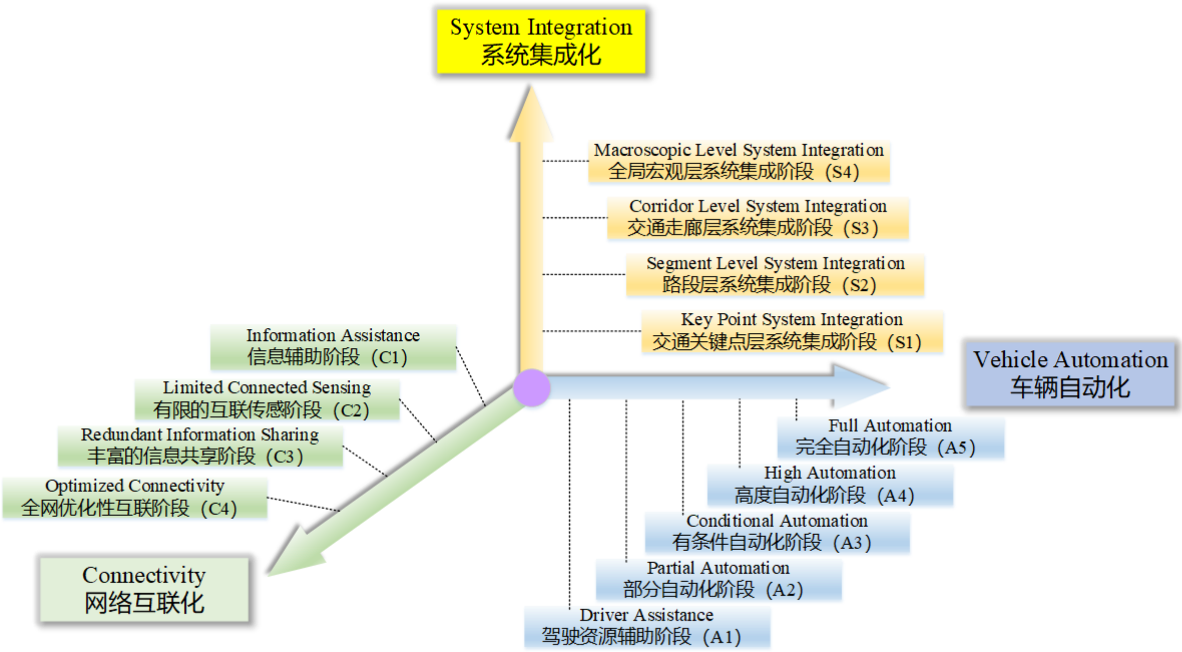

Figure 2 Three-Dimensional Development Architecture of Vehicle-Road Cooperative Automated Driving System

1.3 Development Level of Vehicle-Infrastructure Cooperative Automated Driving

The Connected Automated Vehicle Highway System has the following stages of development: (1) Level I - information interaction and synergy - information interaction and sharing between vehicles and infrastructures (V2I & I2V); (2) Level II - sensing, prediction, and decision-making cooperation – sensing, prediction and decision-making function of the vehicle based on Level I; (3) Level III - control cooperation - the advanced control cooperation function between vehicles and infrastructure based on Level I and II; (4) Level IV - vehicle-infrastructure integration - vehicles and infrastructure can fully cooperate on four functions: sensing, prediction, decision-making, and control based on Level I, II, and III.[5][6]

Level I: Using advanced wireless communication and next-generation internet technologies to enable dynamic interaction and sharing of real-time information between vehicles and vehicles, and between vehicles and roads, which is mainly reflected in the collection and fusion of environmental traffic information.

Level II: In addition to real-time interaction and sharing of information through communication technology, with the saturation of advanced vehicle technology and the complexity of traffic environment, the sensing and decision-making functions of automated driving depends not only on advanced in-vehicle devices (radar, camera, etc.), but also increasingly rely on intelligent road facilities to sense dynamic traffic environment, subsequent data fusion, prediction and decision-making functions, which are mainly reflected in comprehensive collection of environmental information and driving decision making.

Level III: In addition to collecting all-time dynamic environment information and implementing dynamic real-time V2I and V2V interactions, Level 3 can perform functions including prediction and decision-making, and moreover, it can facilitate the collaborative vehicle-infrastructure based automated driving control function so as to complete all the key tasks of automated driving on highways, urban expressways, and parking facilities. These applications are mainly reflected in the overall level of system participants' comprehensive collection of environmental information, driving decisions, and control execution.

Level IV: In addition to the functions of sensing, decision-making and control, it further enhances the application of intelligent road infrastructure, and then achieves intelligent cooperation between vehicles and roads at any given scenes. The system integration function of sensing, prediction, decision making, and control, will form an integrated path to improve automated driving by integrating vehicles and roads, as well as promoting the fast commercialization of automated driving.

1.4 Key Sub-systems and Modules

1.4.1 Key Sub-systems

The Connected Automated Vehicle Highway System includes four key sub-systems: intelligent traffic management subsystem, intelligent roadside subsystem, intelligent vehicle subsystem, and intelligent telecommunication subsystem [3].

(1) The intelligent traffic management subsystem includes a layered traffic control center and a traffic control unit for processing information and traffic control commands. The layered Traffic Control Center (TCC) and the Traffic Control Unit (TCU) include macro layer TCC, regional layer TCC, corridor layer TCC, road segment layer TCC, road segment layer TCU, and point layer TCU. For each layer, the control center and control unit can process the traffic control commands from the upper traffic control center and the traffic control unit and send control commands to the lower traffic control center and the traffic control unit.

(2) The intelligent roadside unit system is composed of roadside units, wherein the roadside unit mainly includes a sensing module, a data processing module, a communication module, a display module, and a power supply unit. The traffic and the vehicle driving environment information are collected by the sensing module, and the data processing module provides status data of the specific vehicle, and interact with the point layer TCU of upper level through the communication module, and sends specific driving instructions to the vehicle, and the display module is used to display data sent from the in-vehicle device.

(3) The intelligent vehicle sub-system includes mixed traffic flows of different degrees of network and automation. The vehicles mainly include at least one of the following components: a vehicle control module, traffic detection, and data acquisition module, a wireless communication module, data acquisition, and interaction module. Vehicles in the intelligent vehicle sub-system require the certification of networked safety, Vehicle Unit ID (OBU ID), Mobile Facility ID, Differential Global Positioning System (DGPS), Visual Detector, Mobile LiDAR (Light Detection and Ranging, laser detection and measurement) or fixed radar detectors for vehicle identification and tracking.

(4) The intelligent communication system includes one or more following modules, including OEM (Original Equipment Manufacturer) operators; communication service providers, such as China Mobile, China Unicom, and China Telecom and public agencies including transportation department. The communication system provides wired or wireless communication services for all entities in the system, including the following communication technologies: wireless communication technologies such as DSRC, 3G, 4G and 5G, Bluetooth; wired communication technologies, such as Ethernet.

1.4.2 Key Modules

The Connected Automated Vehicle Highway System includes four key functional modules [3][4]: sensing, fusion and prediction, planning and decision-making, and control.

(1) Sensing module: estimation of road line shape and environment perception, detection, and recognition of static and dynamic obstacle, estimation and motion compensation of vehicle state, detection of traffic signs, markings, signal lights and traffic infrastructures, vehicle positioning, and high-precision map or no map positioning.

(2) Prediction module: roadside and vehicle perception information fusion, multi-sensor forward information fusion, multi-sensor multi-directional information fusion, vehicle group information fusion, vehicle trajectory prediction, road segment, and network traffic state prediction. The information fusion between roadside and vehicle sensing devices can improve the sensing accuracy, and detect the traffic state accurately on a road segment based on the multi-vehicle information fusion.

(3) Planning and decision-making module: The planning, reasoning, and decision-making of vehicle motion are conducted by using the vehicle trajectory prediction results to calculate vehicle platoon sizes, speed, flow, and density, traffic merging, and diverging flow, and traffic

signals to optimize the mobility, safety, and energy consumption.

(4) Control module: vehicle path control, vehicle fleet control, and steering wheel, throttle, brake, and other actuator control by using onboard units based on the control commands. Under emergency situations such as when the communication is interrupted, vehicle control can be transferred to the onboard unit to ensure safety.

2 Key Technology and Development Trend of CAVH

2.1 Key Technology Analysis of CAVH

2.1.1 Environment Sensing Technology

ADS systems use the sensors such as cameras, millimeter-wave radar, and LiDAR to detect the surrounding environment, including road conditions, vehicles, pedestrians, and other obstacles that may affect driving to support the decision makings [7][8].

There are three prevailing types of ADS sensor technologies:

1) LiDAR-based sensing technologies used by Google Waymo, GM Cruise, and Baidu. In such systems, the LiDAR is the core sensor unit. The LiDAR-based sensing is supplemented by other supporting sensors such as radar and cameras.
2) Multi-sensors used by Apple, Uber, and Roadstar.
3) Camera-based computer vision sensors, used by Tesla, YuShi Micro, and Auto X. Such systems focus on using AI-based computer vision to collect real-time video data from the low-cost video cameras without the use of expensive LiDAR systems.

Among them, the LiDAR-based sensing technologies have been considered the mainstream solution. High-precision maps and positioning are used to complement the LiDAR-based sensing system data, especially in complex road conditions. Major map service providers are actively promoting high-precision maps for ADS applications.

2.1.2 Data Fusion and Prediction Technology

Data fusion and prediction technologies integrate data from multiple types of sensors to analyze the driving environment and predict the movement of vehicles, pedestrians, and other objects in the traffic stream. All sensor technologies have their advantages and disadvantages; no single sensor can perform well in all roadway conditions. For example, although the hardware technology of the camera is relatively mature, the software for objective recognition still has room for improvement. Meanwhile, the point cloud algorithm of LiDAR is easy to implement, but the cost of hardware LiDAR is still high and has limitations in fog, rain, and snow conditions. Therefore, it is necessary to integrate data feeds from multiple types of sensors, such as millimeter wave radar, LiDAR, and cameras. The vehicle movement status and surrounding environment information can be monitored in real time, and the driver behavior, traffic conditions, and vehicle trajectories can be identified and predicted.

2.1.3 Intelligent Decision Technology

Intelligent decision-making technologies aim to support ADS driving decision-making to improve safety, mobility, comfortability, and energy saving [9]. Two types of solutions have been proposed: the rule-based solution and the end-to-end solution. The rule-based solution needs to manually build a comparatively complicated decision architecture that is open-box and interpretable. On the other hand, the end-to-end solutions use black-box type of AI models such as neural network to imitate the driving decisions by human drivers. Some emerging end-to-end solutions can support collaborative decisions among AVs in different scenarios by taking advantage of stochastic processes, game theory, Markov processes, collaborative decision makings, and collaborative intelligence.

2.1.4 Control Execution Technology

The control execution technology analyzes the intelligent decision-making behavior command into a trajectory curve with time information to effectively control the automated driving vehicle's traveling speed and direction. Specifically, the control execution technique aims to solve the trajectory optimization problem of the automated driving vehicle, including vehicle trajectories and vehicle states (such as speed, acceleration, curvature). Most current ADS technologies adopt traditional control methods such as proportional-integral-derivative control, sliding mode control, fuzzy control, adaptive control, robust control [10].

2.1.5 I2X and V2X Communication Technology

Infrastructure to Everything (I2X) and Vehicle to Everything (V2X) are important information communication technologies that are used for realizing information interaction between roads, vehicles, and systems [11][12][13], where X covers any object, such as vehicles, people, traffic infrastructure, clouds, and networks. Specifically, I2X and V2X communication technologies can facilitate a series of traffic and driving information services, such as real-time road information and pedestrian information. All those information services can help improve the safety and travel efficiency of automated vehicles and provide onboard entertainment services [11][14]. DSRC, 4G LTE-V, and 5G are the most widely used I2X and V2X communication standards [15][16].

2.1.6 Network Security Technology

When onboard devices of a smart vehicle are wirelessly connected to other devices or the Internet, network security issues arise [14][17]. In 2013, the United States established the world's first automotive intelligent network information security standard SAE J3061 [15][18]. The main feature of this standard is about physical models and development processes which are proposed from the perspective of full information security life cycle. In Europe, the information security protection system is constructed from three levels: vehicles, open information platforms, and communication environment. Japanese Information-technology Promotion Agency plans to use the security model approaches as an essential reference to promote vehicle information security protection [16][19]. In China, the IDS Standards Committee of the Ministry of Transport has issued "Intelligent Networking Driving Information Security Standard System Framework," which provides clear definitions and specifications of network security for automated vehicles from the aspects of system architectures, test methods, and safety standards [17][18][19][20][21].

2.1.7 Collaborative Optimization Technology

Collaborative optimization technologies are to improve road safety and reduce traffic congestion by optimizing transportation system resources, which acquires real-time information of traffic participants such as vehicles and roadside facilities based on environment- awareness technologies vehicle-to-road interconnection through V2V and V2I communication technologies, and therefore integrate the advantages of both automated vehicles and infrastructure [22].

Collaborative optimization technologies involve V2V and V2I information interaction, collaborative sensing, collaborative prediction, collaborative decision-making, collaborative control technology, and vehicle road coordination simulation technology. Integrated optimization technologies use information transmission and coordination intelligent vehicle system and roadside control equipment, to control vehicles and vehicle groups collaboratively. The combined CV and traffic simulation platforms simulate the information interaction between the virtual roadside system and the virtual vehicle system through multi-mode wireless communication and routing protocols and apply the functional models to different simulation scenarios for safety evaluation and efficiency assessment of the vehicle road coordination.

2.1.8 Integrated Optimization Technology for Transportation System

The Integrated Optimization Technology for Transportation System is to make systematic decisions and optimization for the transportation system through continuous training and learning. The systematic decisions and optimization rely on real-time traffic status information on automated driving vehicles and their driving environment available through V2V and V2I communication technologies.

Traffic status information, traffic guidance, and control signals can be disseminated by the RSUs to coordinate vehicles and vehicle groups. The transportation system optimization mainly focuses on traffic management and control at highway entrance and exits and signalized intersections.

2.2 Future Direction of CAVH

2.2.1 Integrating High-Resolution and High-Reliability Positioning with RoadSide Unit based CAVH Applications

With the rapid development of intelligent transportation and automated driving, the existing ordinary navigation maps cannot meet the application requirements of CAVH in terms of content, accuracy, and integrity. The accuracy of the regular navigation maps is about five meters, which only depicts the location and shape of the road. It does not reflect the detailed information of the road. High-resolution maps, which can support automated driving, have the absolute accuracy of or better than one meter, and the relative accuracy about 10-20 cm. High-resolution maps contain rich geometry information such as lanes, lane boundaries, lane centerlines, and lane restriction. Compared with the upcoming next-generation GPS (Global Positioning System) in the US, the Beidou satellite navigation system can already provide high-precision, high-reliability positioning, navigation, and timing services for all kinds of users in all parts of the world, and it also has short message communication capabilities. Currently, Beidou has had preliminary regional navigation, positioning, and timing capabilities. In the future, Beidou satellites and roadside facilities will be integrated to build a high-resolution map for CAVH. At the same time, the low-cost, high-precision, high-reliability positioning sensor that combines satellite positioning and inertial navigation will be the most feasible way to achieve centimeter-level positioning for automated driving, which would be the foundations for real-time large-scale commercialization of CAVH.

2.2.2 Visual Recognition and LiDAR Becoming the Core of Sensing Technologies

Most of the information in vehicle driving is obtained from the vision for both human driving and automated vehicles. The camera has the most abundant linear density, and its data volume far exceeds that of other types of sensors. Due to the highest density of image information, video visual recognition is now at the center of the entire data fusion. However, such vision-based methods need to identify and estimate a large number of targets, resulting in complex learning algorithms for target monitoring and recognition. Compared with other sensors such as millimeter wave radar, LiDAR has the advantages of high resolution and good recognition effect. It has become a mainstream sensor for automated vehicles. However, the high cost has hindered the large-scale deployment and commercialization of ADS. Current development trends for LiDAR are toward low-cost, miniaturized solid-state scanning, and mechanical solid-state hybrid scanning, while there are still problems for mass production and cost reduction. Although the cost and performance of LiDAR keep improving, integration of multiple sensors is still the most feasible way to ensure high reliability in commercial automated driving. The bottom line is that how to implement multi-sensor fusion on both onboard systems and roadside systems is a more critical issue.

2.2.3 Cloud Platform Technologies

The cloud computing technology adopts distributed redundant storage, with the capability of processing large-scale data and data sharing. Services offered include cloud computing infrastructure as a service (infrastructure as a service, IaaS), Platform as a Service (platform as a service, PaaS) and software as a service (software and services, SaaS)[23][25]. The demand for a large amount of data storage and computing in the CAVH systems provides an opportunity for the cloud computing technology to move from the conceptual layer to the application layer, where the two can complement each other. The application of the cloud computing technology in CAVH is still in its early stage. The IaaS layer provides processing, storage, network and basic computing resources for CAVH systems, allowing the deployment at the levels of the road network, the road segment, and the individual roadside unit [24][26]. The PaaS layer provides services supporting applications for the road network, segment, and roadside unit to be deployed in the cloud. The SaaS layer allows access to service applications provided by cloud providers. How to establish a complete cloud-based intelligent transportation network distributed platform and improve the security of cloud services will be important directions for the development of CAVH communication technologies.

2.2.4 Connected Automated Vehicle Technologies

Compared with the unconnected AV's sensing of the surrounding environment, the Connected Automated Vehicle (CAV) technologies can obtain more traffic information from the time dimension and the spatial dimension, not only to improve the perception and decision-making for an individual vehicle but also facilitate collaborative sensing for all the vehicles as a whole. Based on V2X and I2X communication technologies, vehicle-to-vehicle, vehicle-to-infrastructure, infrastructure-to–cloud communication and data sharing, makes various automated driving application feasible at a large scale in time and space: to know or predict the surrounding vehicle movement, traffic control optimization, blind spot detection. The connected intelligence technology and automated intelligence technology are converging together, which therefore forms a new trend of automated driving technologies. However, the CAV technologies are limited by the communication range, latency, package loss in current wireless communication technologies. CAV’s needs for real-time situation awareness can only be fulfilled by large-bandwidth, low-interference, and low-latency communication, which may only be achieved by the upcoming 5G, 6G communication technologies.

2.2.5 CAVH Traffic System Optimization Technologies

The CAVH-based ADS systems have the functionalities of coordinated sensing, coordinated decision-making, and coordinated control between vehicles and infrastructure. The government’s efforts of transportation system control and management can more effectively integrate the automated driving efforts automobile manufacturers and IT enterprises, and provide safer and more effective services for travelers of different travel modes and technical levels at the systematic level. The CAVH collaborative sensing technology is based on roadside sensing devices and supplemented by onboard vehicle sensors, to achieve network-wide real-time holographic and high-resolution sensing. CAVH takes transportation system safety and energy consumption as the optimization goal and unified the planning and optimization of transportation system entities at various scales, such as intersections, corridors, and the entire network. CAVH based integrated control aims to find the network-wide global optimal solution for the transportation system.

3 Development Trend and Roles of CAVH

3.1 Development Trend of CAVH

The Connected Automated Vehicle Highway (CAVH) is a frontier for the transportation industry. With high market potentials, CAVH covers research areas such as vehicle networking and vehicle-infrastructure collaboration, automated driving, and smart highways. CAVH is a combination of deep integration of new technologies such as automobile, transportation industry, Internet, communication, artificial intelligence, intelligent manufacturing, and shared mobility services. It plays an essential role in the multidisciplinary integration of the transportation and automobile industry. CAVH covers a wide range of sectors, with a long industrial chain. Such industrial chains include the followings.

- The upstream: Sensors, high-precision map services, Internet, communications, chips, AI, automotive electronics, road facilities, and roadside equipment
- The mid-stream: system integration industry such as intelligent manufacturing, transportation enterprise, automated driving, system integration, data integration, etc.;
- The downstream: service industries such as public services, shared travel, logistics and distribution, and value-added services. Figure 3 shows the scheme of the connected automated vehicle highway chain, showing the main links and industrial distribution of the industry chain of connected automated vehicle highway.

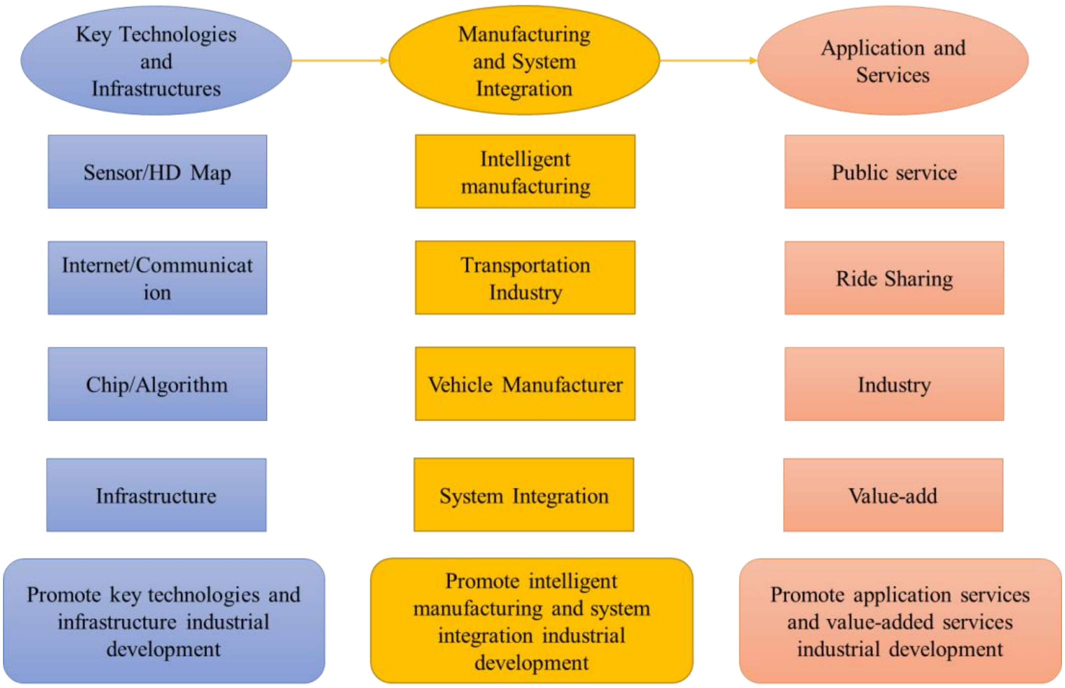

Figure 3 Industry Chain of CAVH

In recent years, a series of development plans for Connected Automated Vehicles, such as “The Medium and Long-term Development Plan of the Automobile Industry,” “Smart Vehicle

Innovation Development Strategy" and "Made in China 2025," has been initiated. The Internet, information, and communication industries are forerunners of the world too. Several world-class leading enterprises have emerged. The core technologies keep breaking through and playing an increasingly important role in the formulation of international 5G standards. In terms of the infrastructure industry, the freeway network has developed rapidly, which has become the largest in the world. In the application service industry, several new data and application service companies have emerged, and they have begun to dominate in fields of logistics, smart travel, and shared travel. However, the integration of the automobile, transportation industries, and the Internet and the information industry is still needed to be done. Key technologies still need to be broken through.

The rapid development of Artificial Intelligence, Data Science, information and communication technologies, the integrations need to be done. It includes the integration of Internet, automotive electronics, automated driving, roadside infrastructure, and other fields, the integration of the Internet, information and communication, intelligent manufacturing industry and transportation, and automotive industry. The construction of the CAVH system needs to be accelerated. New market entities, business models, and industrial forms, and its industrial chain has great potentials and need to be cultivated.

3.1.1 Key Technologies and Infrastructures (Upstream)

- **5G Communication to Promote CAVH Deployment**

5G provides comprehensive support for the Internet of Things, which will inevitably bring new intelligent technologies, and therefore offer exciting development opportunities for CAVH since 5G can meet the communication requirements of CAVH. Compared with 4G, the transmission speed of 5G is ten times faster, while 5G is compatible with various networking facilities. Compared with 4G, 5G has lower power consumption, relatively more reliable data transmission, real-time and low latency, which can allow users to obtain a much better communication experience than 4G.

5G can meet the high requirements of CAVH for communication and will form a basic consensus for CAVH across borders (communication, IT, automobile, transportation). Under the 5G Automobile Alliance (5GAA), the new market of CAVH will be promoted. With the help of 5G, CAVH application scenarios will be developed, CAVH commercial products will be available, and the next generation of transportation can be achieved.

- **Internet Technology Becoming The Engine of Rapid Development of CAVH**

The development of Internet technologies, such as cloud services and cloud computing, accelerates the development of the CAVH industry. Internet technology-related enterprises frequently take the lead in the field of CAVH and cooperate with traditional car companies on the development of automated driving. The new ecosystem of CAVH, which includes mutual assistance and cross-border cooperation, has begun to take shape and is actively innovating research and development (R&D) and business models [27]. Internet high-tech enterprises and traditional car companies can achieve cross-border cooperation and active cooperation through cooperative R&D, patent licensing and transfer, IP shares, and alliances to jointly promote the development of CAVH industry.

At present, Internet companies have joined the R&D, testing, and commercial strategic planning of the CAVH field [28]. Some IT enterprises have gained high competitiveness and influence in the core of the automobile industry, such as roadside testing, key algorithms, cloud computing, and cloud services for the automobile industry. Internet companies have become the engine to accelerated the development of the CAVH industry.

- **The Construction and Transformation of Smart Roads Becoming The Cornerstone and New Growth Point of CAVH**

It is difficult for individual vehicle intelligence to solve the safety and efficiency problems of the entire traffic. Smart cars and smart roads must work together to form vehicle road coordination intelligence to achieve L4+ automated driving. The basic principle of the construction of "smart road," intelligent road facilities, is to continuously improve the informatization and standardization of CAVH and fully explore and utilize the potential of CAV to improve safety, increase efficiency, energy economy, and reduce emission.

With the development of CAVH, the design, construction, management, operations, and maintenance of the automated highway will become a new industrial value-added point. At the same time, the transformation of intelligent road networks is the foundation to achieve CAVH: speeding up the construction of roadside units, monitoring facilities, traffic signals, traffic signages, the smart interconnection of infrastructures, and promoting the construction of smart roads.

- **Specialized Chips and Intelligent Algorithms Becoming The Key Technology of CAVH**

With the in-depth development of CAVH, intelligent algorithms, such as deep learning, have been widely used. Those algorithms require higher hardware computing ability and data transmission bandwidth for the vehicle computing platform. To meet the market demands, traditional PC enterprises have invested in the automotive computing platform R&D and manufacturing, and many Chinese start-up companies focus on improving the performance of AI chips. Traditional PC chip manufacturers, such as NVIDIA and Intel, mainly combine and upgrade the existing chips and apply them to the field of deep learning. Meanwhile, technology companies such as Google use customized machine learning chips to seek better performance, power consumption, and size. Chinese manufacturers are also actively promoting the domestic manufacturing for chips and computing platforms starting from the specialized chips for deep learning, computing architecture, and intelligent computing terminals, to break through the monopoly play of international manufacturers such as Intel, NVIDIA.

Multi-source information fusion, decision planning, and other vital links in CAVH require the AI algorithms such as deep learning. Different algorithms are encapsulated into different system modules (such as environmental awareness, central decision-making), embedded in the car, and then equipped with other sensor hardware to form a mass production, universal and complete automated driving solution. The aforementioned is the main development direction of current algorithm companies. Algorithms have become the most important entry point for entrepreneurs to enter the automated driving market at home and abroad. However, due to lack of their platforms, it is necessary for them to cooperate with mainframe manufacturers, component suppliers and so on to obtain the data and the opportunity of algorithm software applications, which makes it difficult to form a closed loop business in the short term.

- **Sensor and HD Map as The Decisive Factors for Large-Scale Commercialization of CAVH**

In CAVH, the sensors, such as vision, radar, positioning, attitude, hearing, collaboratively collect the information of the vehicle and its surrounding environment. The data is then extracted, processed, and fused by the algorithm. All those data and algorithms further build a complete driving situation map around the car, which provides the basis for decision-making of automated driving.

In the aspect of vision sensing, because of technical difficulties, most suppliers still concentrate on the application of products to the basic modules of the driver assistant system. There is still a long way to go to achieve the environmental awareness required for automated driving [29]. Start-up companies for ADAS and automated driving have their own technological and data accumulation, but they need to balance the current production and investment to the R&D. It is similar for startups that focus on visual algorithms. LiDAR still has high costs and difficulties in mass production, although the significant process has been made; the manufacturing threshold is high, but the application field is limited (automobile, resource survey), which makes the number of LiDAR suppliers is limited, lacking mature mass production schemes. To promote the LiDAR-based solutions, suppliers will have to master the core hardware technologies to control costs and develop efficient and reliable software/algorithms to make their solutions attractive in the market. All-solid-state, low-wire-beam LiDAR can reduce the cost, improving productivity, and thinning the cost of scale-benefit products through mass production, at the cost of minor precision loss. Millimeter-wave radar has the advantage of the round-the-clock and long detection range, but the market is monopolized by international manufacturers. The major Chinese suppliers of parts and components are working on the localization of on-board millimeter-wave radar. Whether it is a camera-based or a LiDAR-based computer vision scheme, it is still hard to detect everything.

Furthermore, information redundancy is considered critical for safety. Therefore, multi-sensor fusion has become a consensus in the automated driving industry. Different sensor technologies will all be worked on to support automated driving. On this basis, the sensor components required for automated driving should become more lightweight (including the weight of the product and the number of sensors) and of lower costs. However, multi-sensor fusion does not rule out the possibility that a single sensor will dominate the market. If the performance-price ratio of specific sensors is superior, it will be quickly adopted by car manufacturers and parts suppliers, occupy a larger market share.

High Definition Map (HD Map) is still in the commercial trial stage because the cost of R&D investment is high, and the technology development route is still unclear. Collecting road data through crowdsourcing and complete map drawing in the back end is now the critical concept of building high-precision map. Because developing high-precision maps need a long time and large investments, there is also another approach that uses low-precision, relatively simple technical solution with feature mapping. Incorporating other dynamic information into maps in real time is another difficult problem. As the largest cartographers in China, Navinfo and AutoNavi are the leaders of the industry, who have invested the most in automated driving and HD Map. BAT has also highly involved in the map market. Currently, the technology in this field has not yet matured, and it is still in the trial stage of commercialization. The capability of delivering low-cost, large-scale, and reliable map service will be the determinants of success. Relying on satellites and ground base stations for high-precision positioning is also an approach to be cooperated with high-precision maps to provide redundant and detailed information, for which Qianxun SI is the representative enterprise.

3.1.2 Intelligent Manufacturing and System Integration (Middle)

- **Car Manufacturers Actively Adopting Artificial Intelligence and Information Technologies for CAVH**

The automobile industry has apparent advantages in automobile design, automobile manufacturing, automobile production, and capital operation. They also have mature automobile production lines, supply, and marketing chains. However, traditional car companies need to consider the balance between corporate profits and technological innovation; most car companies adopt R&D strategies of either sequentially developing from L1 to L5 or directly starting from L3/L4. Leading automobile companies at home and abroad have set up R&D teams to carry out R&D and testing of L1 to L3 automated driving, and have developed their development plans.

Traditional automobile companies actively introduce artificial intelligence and information technologies to accelerate the integration of the automated driving manufacturing industry and the new generation of information technologies, which will eventually form self-perceiving and self-learning in all aspects of design, production, and service for CAVH. The new production model of self-execution and self-adaptation will create a modern intelligent manufacturing and integrated innovation for CAVH.

- **The Collaboration of Traditional Transportation Companies and Internet Companies To Foster New Innovation and Enterprises**

Traditional infrastructure and transportation companies are aware of the role of CAVH to achieve automated driving. The industry's cross-border cooperation has been unanimously recognized. The strong industrial alliance is the best choice, and there will be a complex ecosystem of multi-participation, competition, and collaboration [27]. With the construction of "smart roads" in the CAVH, new innovative mechanism and innovative enterprises will appear.

The strong combination of traditional transportation enterprises and Internet enterprises will promote the close cooperation and collaborative innovation of the infrastructure industry, transportation industry, and IT industry. The collaboration among those industries will gradually form with CAVH as the cornerstone. Such industrial ecosystem will cultivate a group of "professional, refined, and distinctive" innovative mechanism and innovations with the CAVH industry and professional characteristics.

- **New Data and System Integration Industry Fostered By The Demand of CAVH**

Vehicle-infrastructure collaboration intelligence is one of the key technologies for CAVH. The intelligence level of vehicle and road coordination determines the level of CAVH. The rapid development of CAVH calls for a high level of vehicle-road intelligence synergy. Internet companies are actively investing in automated driving leveraging their advantages in big data analysis, artificial intelligence, and information processing.

The collection and analysis of big data of CAVH will promote the construction, integration, and application of traffic big data, which will also facilitate the data services needed for production, research, and public. Big transportation data brought by CAVH will all generate new data and systems integration industries. In short, due to the demand of "Vehicle-infrastructure collaboration intelligence," part of CAVH, new data and system integration industries will be fostered, which will lead to new map services, big data applications, and system integration industries.

3.1.3 Application Services and Value-Added Services (Downstream)

- **The Automotive Industry Shifting From A "Car As Asset" Mode To A "Car As A Service" Mode With Diverse Business Models**

In the Internet sharing economy, customer behaviors have changed and shifted to the mode of subscription and usage payment. This trend is called "everything is service." Car-as-a-Service (CaaS) refers to that the car will no longer be an asset of an individual owner, but provide a series of diversified, innovative services such as car sharing, car rental, logistics and freight services, car network insurance, data monitoring platform and emergency rescue [27]. China has the highest adoption rate of using electronic payment in the world. With the completion of "technical pilot" in automated driving, shared travel, time-sharing logistics, and transportation will become the best application scenarios for CAVH in China. It is predicted that 20% of revenue and 36% of profits in the automotive industries will shift from car sales to services by 2030 since young consumers prefer the right to use the car instead of ownership.

- **Sharing Travel Will Become The Primary Point of Development, and The Online Car-Hailing and Time-Based Rental Will Have Huge Market Potential.**

The shared travel service has become the current trend. Shared travel reduces energy consumption and cost, for travelers, and alleviate traffic congestion, saving energy, and reducing emissions for society. By the end of 2018, the number of shared taxi users reached 330 million, and the number of shared and dedicated vehicles users reached 333 million, which is 40.2% of the total population. Due to the vast market potential, Uber, Didi, and other travel service providers are actively investing in the automated driving industry. In addition to the ridesharing, dedicated vehicles, taxi and time-based rental, other car services can also take advantage of the automated driving technology, providing a unified travel service and achieving a comprehensive vehicle sharing travel.

- **Strong Demand of Freight Transport in The Internet Economy as A Typical Application Scenario of Automated Driving.**

The freeway, on which most of the mileage of freight is, is a relatively simple operational condition for automated driving. Customized vehicles can be operated on fixed routes. In China, only state-owned enterprises, SF, Jingdong, and other enterprises have their fleets. Most of the traditional freight still rely on individually-owned trucks, which is unable to meet the increasing demand for freight transport. In April 2018, FAW Jiefang and Dongfeng Commercial Vehicles released L4 unmanned heavy-duty trucks; China National Heavy-Duty Truck, Tucson Future, and Suning's unmanned heavy trucks started trial operation. The development of China's e-commerce and world-leading mobile payment platforms have increased the demand for online and physical retail, which further asks for efficient, economical, and environmental-friendly logistics. The layout of the automated driving logistics system can save human costs and improve operational efficiency, which leads to higher profit margins.

- **CAVH Bringing More Intelligent and Efficient Traffic Emergency Rescue System to Reduce Congestions and Improve Safety.**

Thanks to advanced sensing and wireless communication technologies, the vehicle infrastructure cooperation system can achieve real-time dynamic interaction among vehicles and vehicle to infrastructure, improve the collection and integration of traffic information, and effectively detect accidents. It can provide the best rescue path for emergency vehicles based on different application scenarios after an accident. The Chinese industry is actively promoting related technology research. For example, China Information and Communication Research Institute is actively promoting the development of the standard series for vehicle emergency management. Changan, Chery, BYD and other independent entities and joint-venture car companies have launched services with partial vehicle emergency rescue functions.

- **New Opportunities and Challenges for Related Industries Brought by CAVH.**

The driving behavior of automated vehicles is different from traditional vehicles. Related business services, such as driver training, vehicle maintenance, and vehicle insurance, will change accordingly. Urban road infrastructure should be upgraded to match the development of automated vehicles, such as smart roads and smart parking lots. The planning, design, construction, operation, and maintenance services will also be changed. Benefits brought by automated driving vehicles in the transportation system will add values to and promote the development of other related industries.

3.1.4 CAVH Standardization

The rapid development of the industry and the active support of national policies can eventually converge to the standardization in the automated driving industry; while the rapid development of ADS technologies will also require the continuous update and improvement on related policies and regulations[29]. The deployment of automated driving involves many industries such as automobile, information communication, internet, constructions, transportation, and logistics. Different industrial sectors may have different understandings, interpretations, and strategies towards of ADS development and deployment. The development of CAVH standards needs to accommodate the diverse needs, goals, and strategies of related industrial sectors. The structure of the CAVH standards should adapt to different application areas. The CAVH standards also need to be compatible with standards and regulatory mechanisms in other related industries. The stages of CAVH standard development include the followings. (1) Stage 1 will focus on the series of technical and application standards on the information network and exchange in Level 1 of intelligence and network connection. (2) Stage 2 will develop a set of technologies and application standards on the perception, information networking, collaborative decision-making, and control in the Level 2 and 3 of intelligence and network connection.

In 2016, the Ministry of Industry and Information Technology carried out pilot demonstrations of automated vehicles called “the broadband mobile Internet-based automated driving and smart transportation applications” to promote automated driving test, in Shanghai, Zhejiang, Beijing, Hebei, Chongqing, Jilin, Hubei, and other cities. With the efforts of all parties, it is expected that the pilot demonstration and standard system will be completed within the next five years. Within the next 15 years, the automated driving lane backbone network will be built, when the commercial automated vehicles will be fully operational. By 2035 vehicle infrastructure cooperation based on "human-vehicle-road-cloud" will be fully implemented, when the plan of “nation of advanced transportation” is preliminarily established. By 2045, the completion of the construction of “nation of advanced transportation,” and Chinese vehicle infrastructure cooperation technology, facilities, standards will be compatible with the international standards.

3.2 Roles of Organizations, Agencies, and Enterprises in the Development of CAVH

3.2.1 Government Agencies

Government plays a supporting, guiding, and organizing role in the development of CAVH industry as follows.

- Policy Support and Strategic Guidance

Policies for CAVH need to address the needs and objectives of different stages in CAVH technology innovations. In the research and development stage of CAVH, we will introduce relevant policies and strategic guidance to promote and support the cooperative research and development of production, education, and research. In the stage of pilot-scale test, the government will introduce policies on cooperation among enterprises, universities, and research institutions. In the production stage of CAVH, the entrance certificate, and the policy of maintaining a competitive market is introduced. The government is at the top (organizational level) and plays a role in supporting, guiding, stimulating, and constraining the development of the CAVH alliance. Due to the different goals and interests of the participants, their responsibilities and obligations are different. The government should play its role in improving not only cooperation but also competition among various parties and protect the legitimate rights and defining responsibilities of all parties by using regulations and policies.

- Legislative Management and Market Supervision

Government is the supervisor of the CAVH industry and formulates relevant policies and documents. Governments at all levels should give full play to their advantages in policies, management, norms, standards, information, and services. By using legal formulation, policy guidance, information release, and industrial planning, the government can build platforms. At the same time, the government can take appropriate measures to regulate the market, determine the development direction of the CAVH industry, and establish relevant systems and laws. The government will support the CAVH innovation platform and develop applicable regulations and policies; leveraging the regulations and policies, innovations from the industry and university research can be put into practical applications and services in a fast pace, and therefore to speed up the development of CAVH.

3.2.2 Industry

The industrial sector plays the role of innovating, testing, and deploying the CAVH technologies. In the safety of research and development, the industry is the leading force in investing capital and dedicating R&D resources on CAVH technologies. In the stage of pilot-scale test, the industry will work with both public agencies to carry out intensive testing to achieve the system efficiency, safety, and reliability needed for the consumer market. In the production and deployment stage of CAVH, the industry will work with both the public agencies and consumers to improve the technical level and service quality of CAVH based on analyzing users' and operators’ feedbacks and suggestions.

3.2.3 Universities and Research Institutes

Universities and research institutes play an innovative, research, and service roles in the development of CAVH industry,

- Promoting Technical Innovation of CAVH

In the development of CAVH industry, universities and research institutes have the advantages of strong scientific research ability and advanced core technology. Therefore, they play the role as knowledge bases in the development of automated driving industry, and they are also essential subjects involved in technology research and development and service.

- Think Tank in the Development of CAVH Industry

Universities and research institutes have unique advantages in gathering, training, and preparing talents for CAVH innovations with their concentration of expert knowledge, technology, skills, and information. Universities and research institutes can participate in social practice and relevant decision-making by making full use of its dominant position in the development of the automated driving industry. Focusing on the major strategies, scientific research projects, medium-term and long-term goals, and major decision-making items of CAVH, universities and research institutes play a role as a think tank by organizing experts on conducting research and demonstration to provide scientific reference for the correct decision-making of CAVH.

- Service Promotion in the Development of CAVH

Universities and research institutes train high-quality technical innovation talents for enterprises and society. With the transformation of the advanced theory and knowledge of CAVH to enterprises, universities and research institutes provide talents for the development of CAVH, which play a service-promoting role in promoting the development of CAVH.

3.2.4 Associations

Associations play a supporting, serving, and communicating role in the development of CAVH industry. The specific roles of associations are as follow:

- Strong support for CAVH industry planning and standard formulation.

In the process of CAVH industry development, associations are the bonds and bridges among the government, enterprises, and scientific research institutes. They help the government strengthen the industry management, strengthen the research and development to reflect the needs and futures of CAVH research. They can actively provide policy recommendations and provide strong support for the formulation of CAVH industry planning and standards.

- Consulting services for the development of CAVH industry

Associations should take advantage of its abundant expert resources and actively provide policy, technology, and management advisory services for the government and enterprises.

Associations should promote the construction of industry and industry integrity, coordinate the relationship between associate members and enterprises, and promote the healthy development of the CAVH industry.

- Promoting the cooperation and exchange of CAVH industry

Associations should actively organize the special meeting, the technology forums, the product and equipment exhibition, and other activities of the CAVH industry development by combining its advantages. Associations should strengthen the link with international associations of CAVH industry, promote international cooperation and exchange, and actively assist enterprises in improving their global competitiveness.

3.2.5 Financial Capital and Investment Institutions

Venture capital and investment groups play the role of financial support and project financing in the development of CAVH industry. Their specific functions are as follows.

The financial support is crucial for the CAVH industry with the long cycles in technology innovations, development, testing, and deployment. Public-private partnership (PPP) is critical in leveraging different funding sources and financial tools to support the CAVH industry. As one of the most promising areas for the artificial intelligence technology evolution, automated driving has been favored by the capital market, and capital injection accelerates the development of enterprises. In 2018, under the pressure of the overall economic downturn and capital winter, the total amount of financing in automated driving had not decreased, but it has increased significantly. In 2018, the amount of funding for automated vehicle parts and solutions suppliers increased from 5.369 billion in 2017 to 16.231 billion yuan [29]. Government-led policy support and funding. All of the Ministry of Industry and Information Technology, the Ministry of Science and Technology, the Ministry of Transport, the National Natural Science Foundation of China, and relevant departments of local governments support the development of CAVH in different ways. Since 2011, the Ministry of Industry and Information Technology has released the Internet of Things project for many years, and automated vehicles are one of the key areas for its support; the Ministry of Science and Technology has carried out several national projects and policies for the “863 Program” in terms of vehicle-infrastructure cooperation and vehicle networking. The Ministry of Transport requires that “two passengers and one danger” vehicles and freight vehicles must install the vehicle network terminals that meet the requirements and report the data to form a large-scale management platform for nationwide networking. The Ministry of Industry and Information Technology conducts pilot demonstrations of automated vehicles in various places to promote automated driving test work.

In recent years, many IT companies in China have entered the automotive industry. Alibaba Group has signed strategic cooperation agreements with automobile groups including SAIC, Changan, and Shenlong to carry out cooperative development of Car on the Internet, Internet of Vehicles and smart car networking platforms. In October 2017, Baidu and Beiqi Group reached a strategic cooperation, and the two sides will achieve strategic cooperation at the group level in the fields of automated driving, vehicle networking, and cloud services. In November 2017, Tencent announced the launch of Tencent's "AI in Car" system. A total of five auto manufacturers which are Guangzhou Automobile, Changan, Geely, BYD and Dongfeng Liuqi have become the first batch of cooperative automobile manufacturers of Tencent Auto and built AI in Car ecosystem together.

4 Policies and Suggestions

CAVH can solve many social problems, as long as there are proper policies that support the integration of CAVH into the complex transportation system.

4.1 Government

4.1.1 Policies

(1) The policy should regulate the market behavior of CAVH. The government should speed up the deployment, establish the guide committee of CAVH, and clarify the functions and purposes of the committee. Also, the market order should be maintained, and the behavior of enterprises should be regulated [30][31].

(2) The government should support the development of CAVH industry, and coordinate the resources of various industries to promote industrial integration. At the same time, they should encourage the development of cross-domain and cross-industry development platforms.

(3) The government should support the transformation of intelligent transportation infrastructure, promote the deployment of devices and management platform of CAVH [32]. The government should promote demonstration of CAVH applications, regulate CAVH tests, and set up automated driving lanes in the demonstration area. Corresponding intelligent traffic lights, smart parking, and other applications should be deployed [33].

(4) The government should provide financial support for enterprises working on CAVH and encourage researches on CAVH [34]. The government should play an active and leading role to guide the CAVH to integrate into the transportation system.

4.1.2 Standards

(1) The government should play the leading role in setting standards and norms, especially in testing, evaluation, certification, access, and operations of CAVH. The government should promote the establishment of universal standards for CAVH and establish a cross-industry standardization system and cooperation mechanism [35].

(2) While standardizing various standards, the government should formulate and unify the safety standards of CAVH, with strict testing to ensure safety.

4.1.3 Laws and Regulations

The government should promulgate relevant laws and regulations for activities regarding the CAVH, such as the CAVH testing laws [36][37].

The government should lead in the public outreach about CAVH regarding the benefits and regulations of CAVH. In this way, the public could more accept the CAVH more smoothly. The main measures include the following:

(1) The government should define learning and driving rules for CAVH;

(2) The government should formulate the rules of the setting and applications for CAVH

(3) The government should monitor the development of emergency response manuals for possible incidents during CAVH testing and deployment.

4.2 Enterprises

(1) The enterprises should carry out the relevant commercial market behaviors of CAVH in compliance with government policies.

(2) The enterprises should coordinate with each other to define the implementation route of the industrialization development of CAVH and gradually form a new industrial integration system.

(3) The enterprises should increase investment in research and develop the key technologies or products, such as the operating systems, chips, and onboard units for CAVH.

(4) The enterprises should cooperate with relevant enterprises in the communication, automobile, transportation, and other industrial chains to conduct the practice and exploration of CAVH in various aspects. In this way, appropriate business models based on demonstration projects can be explored to make CAVH technologies mature.

(5) The enterprises should formulate the product specifications, interconnection interface, and the standard testing procedures, etc. The specifications prepare the industry for the commercial application and demonstration of CAVH technologies.

4.3 Universities and Research Institutes

(1) Universities and research institutes should strengthen collaboration with the government through financial subsidies, demonstration applications, and industrialization promotion. Besides, universities and research institute should focus on core research regarding key CAVH technologies, such as the intelligent infrastructure, communication facilities, and cloud service platforms;

(2) Universities and research institutes should actively encourage innovation and demonstration of the key technologies in relevant research fields, which can serve as the references for making correct strategic decisions for CAVH development.

(3) Universities and research institutes should educate next generation high-quality innovation talents for the CAVH industry.

5 Terminology

Terminology of this report is shown in Table 2.

Table 2 Terminology

No.	Term	Abbreviation
1	Target and Accident Detection and Response	TADR
2	Infrastructure to Everything	I2X
3	Vehicle to Vehicle	V2V
4	Infrastructure to Vehicle	I2V
5	Vehicle to Infrastructure	V2I
6	Road Side Unit	RSU
7	Infrastructure to Infrastructure	I2I
8	Dedicated Short Range Communications	DSRC
9	The 4th Generation Mobile Communication Technology-Long Term Evolution	4G-LTE
10	The 5^{th} Generation Mobile Communication Technology	5G
11	Adaptive Cruise Control	ACC
12	Cooperative Adaptive Cruise Control	CACC
13	Variable Speed Limit	VSL
14	Advanced Driver Assistance System	ADAS
15	Global Positioning System	GPS
16	Inertial Measurement Unit	IMU
17	Light Detection and Ranging	LiDAR
18	Proportional-Integral-Derivative	PID
19	Electronic Toll Collection	ETC
20	Vehicle Information Communication System	VICS
21	Infrastructure as a Service	IaaS
22	Platform as a Service	PaaS
23	Software as a Service	SaaS

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