Research on the Development of "Vehicle-Road-Cloud Integration"

Lingling Tan [1, 2, *], Bo Dong [1, 2]

[1] China Automotive Technology and Research Center Co., Ltd. Tianjin, China

[2] China Auto Information Technology (Tianjin) Co., Ltd. Tianjin, China

* Corresponding author: Lingling Tan (Email: tanlingling@catarc.ac.cn)

ABSTRACT

"Vehicle-Road-Cloud Integration" is key to solving the industrial development of intelligent connected vehicles and is also an important enabling technology for smart transportation. On July 3, 2024, the Ministry of Industry and Information Technology and four other departments released the list of pilot cities for the application of "Vehicle-Road-Cloud Integration" for intelligent connected vehicles, identifying 20 cities (alliances) as the first batch of pilot cities for "Vehicle-Road-Cloud Integration." The announcement of the pilot application list will accelerate the transition of intelligent driving from small-scale testing to large-scale implementation, further speeding up the widespread application and commercialization of advanced intelligent driving.

KEYWORDS

Vehicle-Road-Cloud Integration; Intelligent Connected Vehicles; Pilot Application.

1. OVERVIEW OF THE DEVELOPMENT OF "VEHICLE-ROAD-CLOUD INTEGRATION"

The vehicle-road-cloud integration system integrates the physical space and information space of people, vehicles, roads, and clouds through next-generation information and communication technology. It achieves safe, energy-efficient, comfortable, and efficient operation of the intelligent connected vehicle traffic system based on system-wide perception, decision-making, and control. Vehicle-road-cloud integration is a succinct description of the Chinese solution for the development of the intelligent connected vehicle industry, which has reached industry consensus. The system uses advanced technologies such as sensors, big data, artificial intelligence, and communication networks to collect and analyze real-time data from vehicles, road infrastructure, and the cloud to optimize traffic management, enhance road safety, and improve traffic efficiency. The core of the system lies in the organic integration of vehicles, roads, and clouds to form an intelligent transportation system. The implementation of this system marks a new stage in the development of intelligent connected vehicles in China. Unlike traditional single-vehicle intelligence or vehicle-road collaboration, the realization of vehicle-road-cloud integration relies on the support of the cloud. This means that vehicle driving not only depends on the vehicle's perception, decision-making, and control but also maps real-time vehicle traffic information to the cloud, including real-time information sensed by vehicles and roadside infrastructure. The cloud assists in collaborative analysis, decision-making, and control, making driving safer, more energy-efficient, comfortable, and efficient.

In recent years, with the joint efforts of the government, industry, academia, and research sectors, "Vehicle-Road-Cloud Integration" has gradually progressed from sporadic testing stages to large-

scale demonstration applications. Currently, 17 national intelligent connected vehicle test zones, 7 vehicle networking pilot zones, and 16 "Double Intelligent" pilot cities have been established nationwide. More than 32,000 kilometers of test roads have been opened, over 7,700 test licenses have been issued, and the test mileage has exceeded 120 million kilometers. Over 8,700 intelligent roadside units (RSUs) have been deployed in various regions, and many places have started constructing cloud control infrastructure platforms.

2. POLICY SUPPORT ACCELERATES THE DEVELOPMENT OF "VEHICLE-ROAD-CLOUD INTEGRATION"

In recent years, the state has highly valued the development of vehicle-road-cloud integration, viewing it as an important approach to developing intelligent connected vehicles and building a strong transportation nation. Since 2016, several policies have been successively issued, such as the "Implementation Plan for Promoting Intelligent Transportation through 'Internet+' Convenient Transportation," the "Technical Roadmap for Energy-saving and New Energy Vehicles," the "Action Plan for Promoting the Development of Intelligent Transportation," the "Action Plan for the Development of the Vehicle Networking (Intelligent Connected Vehicles) Industry," and the "Strategic Plan for the Innovative Development of Intelligent Vehicles." These policies have coordinated the planning of the vehicle-road collaboration industry and strengthened top-level coordination. With the national vehicle networking pilot zones in 2019 and the pilot for coordinated development of smart city infrastructure and intelligent connected vehicles in 2021, the work on "Vehicle-Road-Cloud Integration" has gradually deepened, experiencing rapid development since 2023.

In March 2023, the Ministry of Natural Resources released the "Guidelines for the Construction of the Standard System of Basic Maps for Intelligent Vehicles (2023 Edition)," strengthening the top-level design of basic map standards for intelligent vehicles and promoting the safe application of geographic information in the autonomous driving industry. In April, eight departments, including the Ministry of Industry and Information Technology, issued the "Implementation Opinions on Promoting the Evolution and Application Innovation of IPv6 Technology," supporting the digital and intelligent transformation of transportation infrastructure. In July, the Ministry of Industry and Information Technology and the National Standards Committee jointly released the "Guidelines for the Construction of the National Vehicle Networking Industry Standard System (Intelligent Connected Vehicles) (2023 Edition)," proposing to lead the coordinated development of "Vehicle-Road-Cloud" with intelligent connected vehicles as the core carrier and application carrier. In November, four departments, including the Ministry of Industry and Information Technology, issued the "Notice on Conducting Pilot Work on the Access and Road Traffic of Intelligent Connected Vehicles." The same month, the General Office of the Ministry of Transport released the "Guidelines for the Safe Transport Service of Autonomous Vehicles (Trial)." The policy combination promoting intelligent connected vehicles is being rapidly established, providing strong support for the large-scale and commercial application of high-level autonomous driving.

On January 15, 2024, five ministries, including the Ministry of Industry and Information Technology, jointly issued the "Notice on Conducting Pilot Applications of 'Vehicle-Road-Cloud Integration' for Intelligent Connected Vehicles," announcing the implementation of pilot applications of "Vehicle-Road-Cloud Integration" from 2024 to 2026. On May 20, the National Innovation Center for Intelligent Connected Vehicles and the China Society of Automotive Engineers, in conjunction with units from various professional fields such as automotive, transportation, communication, public security, and surveying, jointly compiled the "Reference Guide for the Large-scale Construction and Application of 'Vehicle-Road-Cloud Integration' for Intelligent Connected Vehicles (Version 1.0)," further supporting the construction of vehicle-road-cloud integration in various regions and ensuring the unified planning and implementation of "Vehicle-Road-Cloud-Network-Map-Security" in the

industrial development transformation. This provides advanced, systematic, phased, and operable promotion paths for relevant cities and enterprises. On July 3, five departments, including the Ministry of Industry and Information Technology, announced the list of pilot cities for the application of "Vehicle-Road-Cloud Integration," identifying 20 cities (alliances) and marking the entry of "Vehicle-Road-Cloud Integration" construction into the fast lane.

3. LOCAL ACCELERATION OF "VEHICLE-ROAD-CLOUD INTEGRATION" PROJECT IMPLEMENTATION

Under the guidance and support of national policies, various localities are accelerating the deployment of vehicle-road-cloud integration projects. Cities such as Beijing, Fuzhou, Wuhan, Ordos, and Shenzhen are actively promoting the construction of vehicle-road-cloud integration.

In April 2023, the "5G+Cloud Network+Vehicle-Road Collaboration" new infrastructure demonstration project for the Beijing section of the Jingxiong Expressway achieved full coverage of the dedicated 5G private network. Spanning 27 kilometers from the southern Fifth Ring Road in Beijing to the Hebei section, 45 5G base stations were built and activated. An "intelligent connected vehicle dedicated lane" has been reserved, supporting fully autonomous driving along the entire section in the future. In August 2023, the comprehensive construction of the vehicle-road-cloud integration in Shenzhen Pingshan officially began, deploying advanced networked equipment at 143 key locations across the district to create a comprehensive networked application environment. This supports application demonstrations in unique scenarios such as safe travel and high-quality bus priority throughout Pingshan District. In October, a holographic perception smart highway that meets the requirements for vehicle-road collaborative autonomous driving was put into operation in Suzhou. It covers 56 kilometers of the Sutai Expressway S17 (Huangdai Interchange to Xiangcheng Hub) and the Shanghai-Yi Expressway S48 (Xiangcheng Hub to Yangcheng Lake North Interchange), with 6.5 kilometers of road endpoints supporting L4-level autonomous driving test scenarios.

In May 2024, Beijing issued a tender announcement for the "Vehicle-Road-Cloud Integration" new infrastructure construction project with an investment of 9.939 billion yuan. The project is funded 70% by government investment and 30% by state-owned enterprises' self-financing, covering 2,324 square kilometers across 12 districts and the Yizhuang Economic Development Zone. It involves the intelligent transformation of 6,050 road intersections. On June 3, 2024, the Fujian Provincial Investment Project Online Approval and Supervision Platform announced the approval of the demonstration construction project for the Fuzhou Intelligent Connected Vehicle-Road-Cloud Integration startup area, making Fuzhou the second city after Beijing to take significant steps in vehicle-road-cloud collaboration. On June 14, 2024, the Wuhan "Vehicle-Road-Cloud" major demonstration project was approved by the Wuhan Municipal Development and Reform Commission with a filing amount of 17 billion yuan, starting construction in June. The project includes the construction of a citywide unified intelligent connected vehicle service platform, 15,000 smart parking spaces, the transformation of 5.578 kilometers of smart roads (Economic Development Zone), a 160,000-square-meter intelligent connected vehicle industry R&D base (Donghu High-tech Zone), a vehicle-standard chip industry park, and an unmanned driving industry park.

4. DEVELOPMENT STATUS OF KEY ENTERPRISES IN "VEHICLE-ROAD-CLOUD INTEGRATION"

(a) Baidu

Baidu began its layout in autonomous driving in 2013 and launched the world's first open autonomous driving platform, Apollo, in 2017. Currently, Baidu Apollo has industry-leading solutions in fields such as autonomous driving and intelligent vehicles. The autonomous driving travel service platform,

Luobo Kuaipao, has accumulated over 6 million orders. By 2024, Luobo Kuaipao's autonomous driving travel service has been opened to more than 10 cities. A decade of deep cultivation has endowed Baidu Apollo with safer technology and safer products. On Apollo Day, Baidu Apollo launched the world's first large model supporting L4-level autonomous driving, Apollo DFM (Autonomous Driving Foundation Model), along with the sixth generation of Luobo Kuaipao autonomous vehicles equipped with Baidu's sixth-generation intelligent system solution, priced at only 200,000 yuan. On December 19, 2023, Baidu officially launched the upgraded version of the Apollo Open Platform—Apollo Open Platform 9.0. The Apollo Open Platform gathers more than 160,000 developers from over 170 countries and regions worldwide. During the development from Apollo Open Platform 8.0 to 9.0, 120,000 lines of code were restructured, and 200,000 lines of code were added.

(b) Mogo AI

Since its establishment in 2017, Mogo AI has been committed to using artificial intelligence technology to serve intelligent connected and autonomous vehicles. Mogo AI has not only built a technologically advanced vehicle-road-cloud integration system but also launched a standard product package, MOGOPackage, covering the vehicle-road-cloud triad, integrating hardware and software, highly integrated and modular for rapid deployment. Mogo AI developed AI digital road base stations and systems (MRS), capable of real-time data twin at intersections and continuous road segments, with algorithm accuracy reaching the C4 standard and meeting the highest SL3 requirements in the industry, empowering all levels of intelligent connected vehicles and autonomous vehicles. Additionally, Mogo AI collaborated with Xiamen King Long to launch the world's first pre-installed mass-produced autonomous driving bus equipped with a vehicle-road collaboration system. Supported by effective technology and products, Mogo AI's vehicle-road-cloud integration projects have been deployed first in cities such as Beijing, Shanghai, Tianjin, Liaoning, Sichuan, Hunan, Yunnan, Shandong, and Hubei.

(c) Wanji Technology

Beijing Wanji Technology Co., Ltd., established in 1994, is a technology-based enterprise specializing in the research and development, product manufacturing, and technical services of intelligent transportation systems (ITS). The company has accumulated a large amount of independent innovation technology in fields such as the Internet of Vehicles, big data, cloud platforms, edge computing, and autonomous driving. It has developed various product series such as vehicle and road-end lidar, V2X vehicle-road collaboration, intelligent connected roadside intelligent perception systems, intelligent connected cloud control platforms, ETC, dynamic weighing, etc., providing comprehensive solutions, systems, products, and services for smart highways and smart cities. In recent years, Wanji Technology has built vehicle-road-cloud integration ecosystem capabilities, deploying core components such as perception, communication, and computing on the vehicle end, including vehicle-mounted lidar, V2X-OBU, and domain controllers, with scenario databases and testing simulation capabilities. In the road ecosystem, it has established software and hardware capabilities covering perception, computing, communication, and platforms. The company has participated in the construction of 21 smart highways, 45 digital twin tunnels, and 81 smart toll stations domestically, achieving large-scale application first in the country.

(d) Nebula Link

Beijing Nebula Link Technology Co., Ltd., established in 2015, is a global leader in full-stack vehicle-road collaboration technology and operational services. Its core technologies include a 100% self-developed V2X trusted interaction kernel, a production-grade V2X protocol stack achieving layered decoupling and cross-domain sharing, and a full-scenario algorithm library. The V2X protocol stack has been authorized for 5 million sets, covering over 30 car companies, including NIO, BMW, Great Wall, Volkswagen, and more, with the highest market share in the country. The company has deeply participated in all seven national vehicle networking pilot zones led by the

Ministry of Industry and Information Technology. Its technical application services cover 70% of the pilot cities for smart city infrastructure and intelligent connected vehicles by the Ministry of Industry and Information Technology and the Ministry of Housing and Urban-Rural Development, and 90% of national intelligent connected testing grounds. Its full-scenario solutions have been deployed and operated in over 50 cities, including Beijing, Shanghai, Changsha, and Hefei, deploying over 3,000 intersections. Applications cover urban open roads, highways, park roads, and more, deeply serving public transportation, taxis, freight, and unmanned vehicles such as unmanned vending, delivery, inspection, and cleaning, covering daily travel and urban public services.

5. DEVELOPMENT PROSPECTS OF "VEHICLE-ROAD-CLOUD INTEGRATION"

5.1. Clear Development Strategy

The implementation of pilot projects for "Vehicle-Road-Cloud Integration" in intelligent connected vehicles has provided a clear direction for the development of intelligent connected vehicles in China. "Vehicle-Road-Cloud Integration" has been elevated to a national strategic level. Compared to the single-vehicle intelligence technology route, "Vehicle-Road-Cloud Integration" can achieve comprehensive improvements in vehicle driving and traffic operation safety, efficiency, and performance, becoming an important development direction for intelligent connected vehicles in China.

5.2. Huge Market Potential

According to data from the CCID Consulting's Industry Research Institute, the market size of intelligent connected vehicles in China was nearly 600 billion yuan in 2022 and is expected to exceed 5 trillion yuan by 2030. The related market size of "Vehicle-Road-Cloud Integration" is expected to exceed 14 trillion yuan, indicating enormous potential and broad prospects. Promoting the development of "Vehicle-Road-Cloud Integration" is expected to drive investment in industries such as communications, computers, and chips, thereby stimulating more market vitality.

5.3. Industrial Integration and Development

"Vehicle-Road-Cloud Integration" offers a historic strategic opportunity for the deep integration and development of the automotive industry with information technology, energy, traffic management, and other fields. Through the application pilots of integrated development of "vehicle end, road end, and cloud end," the construction of digital cities and road infrastructure can be accelerated. This will help to overcome common key technologies in perception, decision-making, control, and networking, accelerate the research and mass production of intelligent connected vehicles, promote the development of cloud computing and big data technologies, and drive local industrial upgrades through cross-industry integration of vehicle-road-cloud.

6. DEVELOPMENT RECOMMENDATIONS FOR "VEHICLE-ROAD-CLOUD INTEGRATION"

6.1. National Level

On one hand, there needs to be continuous policy support. The state should strengthen the development strategy and top-level design of vehicle-road-cloud integration and introduce a series of related supporting policies. This should include steadfast and long-term promotion and support, while also formulating clear technological roadmaps to create sustainable industrial policies. On the other

hand, there should be leadership in establishing a unified standard system. By combining the technical architecture of vehicle-road-cloud integration and focusing on integrated systems, new architecture vehicles, intelligent infrastructure, cloud control platforms, communication networks, security, and test demonstrations, the standard system for vehicle-road-cloud integration should be improved. This will ensure compatibility and interoperability between different components and systems, thereby promoting the large-scale application and industrial development of intelligent connected vehicles.

6.2. Local Level

Seize the opportunity of vehicle-road-cloud integration pilot projects by actively applying to become pilot cities. Regions that have become pilot cities should formulate local support policies based on national policies and local actual conditions and characteristics. The development of vehicle-road-cloud integration should be promoted step-by-step by grade and scenario, exploring new business models for multi-party investment and joint operation by state-owned platforms, car companies, operators, and technology companies. Relevant projects should be implemented to drive the construction of digital cities and promote local economic growth.

6.3. Enterprise Level

The intelligent transportation system involves multiple fields of vehicles, roads, and clouds. While strengthening breakthroughs in key common technologies in each field, attention should also be paid to cross-industry collaboration between these fields. Promoting collaborative cooperation across the industrial chain's upstream and downstream sectors is essential. The integration of "smart cars," "intelligent roads," and "powerful clouds" should be achieved to form an intelligent transportation system.

6.4. Social Level

The public's general lack of understanding and low trust in new technologies such as intelligent transportation and autonomous driving limits their acceptance. Therefore, it is necessary to strengthen correct publicity and guidance to enhance society's scientific understanding and acceptance of intelligent transportation, thereby laying a solid social foundation for the industrialization of intelligent transportation.

REFERENCES

[1] Huafu Securities, "Forecast of Value-Added in the Vehicle-Road-Cloud Integration Intelligent Connected Vehicle Industry".
[2] CCID Consulting Industry Research Institute, "Data-Driven Era: 'Vehicle-Road-Cloud Integration' Accelerates the Commercialization of Autonomous Driving".
[3] Orient Securities, "'Vehicle-Road-Cloud Integration' Projects Continue to Heat Up.".