

From National Solution to Global Paradigm: Globalization Strategies and Practices of Vehicle- Road-Cloud Integration in Autonomous Driving

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Abstract: Amid the new wave of global technological revolution and industrial transformation, autonomous driving is transitioning from technical verification to large-scale commercial diffusion, emerging as a strategic high ground in the technological competition among major powers. Leveraging its distinctive technical pathway, vast market foundation, and complete industrial chain advantages, China's autonomous driving industry is poised to seize global development opportunities. This paper systematically compares divergent autonomous driving technical routes worldwide, clarifies that vehicle-road-cloud integration constitutes the core strategy of China's differentiated development, and constructs an analytical framework encompassing "domestic deployment—global expansion—regional implementation—challenge response." It proposes differentiated overseas strategies tailored to the European, Southeast Asian, and Middle Eastern markets, provides actionable pathways and practical recommendations for the globalization of Chinese solutions, and aims to secure China's dominant position in global intelligent transportation competition.

Keywords: Autonomous driving; Globalization; Vehicle-road-cloud integration; Intelligent transportation

1. The Strategic Significance of Autonomous Driving Going Overseas

The global spread of autonomous driving technology is not only a global market competition, but also a competition for vehicle-road-cloud integration technical standards and international discourse. China positions autonomous driving as the vanguard of its AI industry's global expansion, reflecting profound strategic significance.

According to Goldman Sachs and Bank of America Securities, the global autonomous driving market will achieve exponential growth, with the global Robotaxi market expected to reach \$40 billion to \$45.7 billion in 2030 and the total market size of autonomous vehicles to \$1.2 trillion in 2040 [1]. More importantly, the global road traffic electrification has entered an irreversible critical point, the European Union and China have gradually declined in fuel vehicle sales and rapid growth of electric vehicle production and sales since around 2019[2].

By setting up overseas R&D centers and participating in the formulation of local safety standards, Chinese enterprises have changed from "followers" to "participants" and "leaders" of industry rules, significantly enhancing China's voice and influence in the global intelligent car industry [3].

Overseas diversified road environments, traffic rules, and application scenarios provide "stress testing" scenarios for domestic technologies, feed back technology iterations with accumulated data and experience, drive the coordinated development of the entire industry chain such as sensors, chips, high-precision maps, and cloud services, and form a "technology-manufacturing-service" full-chain overseas empowerment system [4].

China's autonomous driving enterprises possess three distinctive competitive advantages. First, scenario-driven algorithmic robustness: exposure to the world's most complex and diverse urban traffic environments has endowed Chinese models with exceptional adaptability, enabling rapid calibration for overseas markets across Southeast Asia, the Middle East, and Europe. Second, data-driven iteration velocity: leveraging the world's largest new energy vehicle market, Chinese firms have accumulated massive real-world road-test datasets and edge-case libraries, establishing a high-efficiency closed loop of data collection, algorithmic training, and deployment validation that outpaces international competitors in model iteration speed [5]. Third, supply-chain cost leadership: China's complete intelligent connected vehicle ecosystem enables high-performance driving solutions at competitive cost structures, constituting a core competitive asset—particularly in price-sensitive emerging markets.

2. Vehicle-Road-Cloud Integration as the Core of Autonomous Driving China's Solution

Presently, two dominant technical paradigms define global autonomous driving: the US-led intelligent vehicle-centric approach, which relies on onboard sensors and algorithms for autonomous decision-making, and China's original vehicle-road-cloud integration approach, which enhances safety and traffic efficiency through the synergistic collaboration of vehicle, road, and cloud systems [6]. In contrast, vehicle-intelligence has perception blind spots in long-tail scenarios and extreme road conditions, and vehicle-road-cloud integration significantly improves system reliability through roadside blind spotting, cloud decision-making, and global collaboration, and is more suitable for large-scale commercial needs [7].

The vehicle-road-cloud integration solution leverages 5G, C-V2X, and next-generation information and communication technologies to achieve deep convergence among intelligent vehicles, smart infrastructure, and unified cloud platforms. This constructs an efficient, collaborative cyber-physical system encompassing three tiers: autonomous vehicles equipped with high-performance onboard sensors for advanced perception; roadside sensing equipment and communication base stations for environmental monitoring and connectivity; and cloud platforms delivering data processing and AI algorithmic services. Through real-time closed-loop data flows, the architecture effectively overcomes inherent limitations of single-vehicle perception and insufficient multi-agent coordination, substantially enhancing both autonomous driving safety and overall traffic operational efficiency.

Globalization of the vehicle-road-cloud integration solution carries strategic significance extending far beyond commercial exports. First, it enables China to compete for technical standard dominance: by promoting this solution globally, China's communication protocols, data interfaces, and security standards can become the international mainstream, thereby securing China's commanding position in the next-generation intelligent transportation industry chain. Second, it shapes national brand image by transforming export paradigms from product-centric to systematic solutions encompassing "technology + standards + infrastructure + business models," thus amplifying China's voice in global science and technology governance [7]. Third, aligned with the global sustainable development agenda, it demonstrates strong synergy with worldwide smart city initiatives and positions China at the ethical and technological forefront of international cooperation, securing

strategic high ground in both domains.

3. Implementation Pathways for Vehicle-Road-Cloud Integration in China

This pathway advances through phased, region-specific deployment—progressing from technical verification to scenario-based application and systematic operation at the city scale—ultimately yielding a replicable, generalizable, and scalable Chinese model.

(1) Nationally, vehicle-road-cloud integration is elevated to a strategic priority within intelligent connected vehicles and new infrastructure agendas. A tiered governance model—central steering, cross-departmental coordination, and local implementation—is instituted. Joint action plans from key ministries define technical routes, construction goals, operational standards, and safety requirements. Local governments tailor implementation to urban transport assets, industrial bases, and digital infrastructure, mapping pilot areas, schedules, and investors. Supporting regulations are concurrently updated, covering road testing, demonstration operations, data security, and accident liability, thereby delineating stakeholder responsibilities across the vehicle-road-cloud ecosystem and securing institutional foundations for scaled rollout [7].

(2) The deployment follows a phased trajectory: vehicle-road-cloud integration solutions will be initiated with closed-course validation, progressed to open-road piloting, and ultimately scaled to city-wide operation. Pilot demonstrations are rolled out incrementally across batches. Within closed campuses and dedicated test facilities, a vehicle-road-cloud integrated test environment is established at national intelligent connected vehicle demonstration zones, enabling rigorous reliability verification of core functions—including multi-sensor fusion, C-V2X communication, and cloud-based collaborative decision-making [2]. In key cities such as Beijing, Shanghai, Guangzhou, Shenzhen, Wuhan, and Chongqing, smart parks, high-speed rail new cities, and airport economic zones are selected to deploy roadside perception, edge computing, 5G base stations, high-precision maps and other facilities to realize real-time interaction between autonomous vehicles and smart roads. Large-scale deployment at the city level will promote the extension of pilots to central urban areas, intercity highways, and key hubs, achieve full coverage of main roads, secondary roads, and branch roads, open up a "point-line-surface" global collaborative network, and support the normal operation of multiple scenarios such as Robotaxi, intelligent buses, unmanned distribution, and smart logistics [5].

(3) Based on the principles of independent controllability, international compatibility, and industrial use, a full-chain technical standard system of Vehicle-Road-Cloud Integration solutions will be built to solve problems such as equipment incompatibility, data incompatibility, and inefficient collaboration. The standardization effort unifies interfaces and communication protocols across vehicle terminals, roadside perception devices (including radar and cameras), and associated equipment, while formalizing C-V2X frequency bands and data transmission formats. Functional specifications for cloud-based management platforms and edge computing nodes are codified, establishing clear protocols for traffic data collection, transmission, storage, and sharing. A tiered certification framework covering functional safety, cybersecurity, and data security is instituted, supplemented by third-party testing to ensure system reliability. Concurrently, alignment between domestic and international standards is advanced to establish interoperability and lay the groundwork for global market entry [7].

(4) An infrastructure-first approach underpins the construction of Vehicle-Road-Cloud Integration solutions which deploys a three-tier architecture: smart roads, connected vehicles, and unified clouds. Roads are instrumented with LiDAR, millimeter-wave radar, high-definition cameras, edge nodes, and RSUs. Vehicles ship with factory-installed 5G+C-V2X units, accelerating L2+ adoption. National and

municipal traffic-brain platforms at the cloud layer fuse traffic, vehicle, and road data to enable network-wide scheduling, algorithm training, and simulation—completing the vehicle-road-cloud closed loop [8].

(5) End-to-end supply-chain localization is achieved through industrial ecosystem orchestration. Leveraging China's comprehensive intelligent connected vehicle ecosystem, a vertically integrated architecture spanning silicon, onboard units, roadside infrastructure, cloud platforms, operational systems, and end-user services is built. Strategic indigenous R&D focuses on automotive-grade silicon, vehicle operating systems, LiDAR, high-definition mapping, and AI algorithms to reduce supply-chain exposure and optimize total cost of ownership. Cross-sector alignment among OEMs, technology vendors, telecom carriers, municipal authorities, and mobility operators harmonizes development, deployment, and service timelines. Deep embedding in smart city, logistics, port, and campus environments accelerates scenario validation and revenue realization, establishing a sustainable flywheel of adoption and monetization [4-6].

(6) Security assurance and regulatory compliance anchor a comprehensive, multi-dimensional safeguard architecture. Grounded in principles of security primacy, data sovereignty, and risk prevention, the framework institutes a holistic security mechanism. Multi-layered redundancy across perception, decision, and control subsystems ensures fault tolerance and effective risk isolation. A unified vehicle-road-cloud cybersecurity architecture defends against cyberattacks, data tampering, and unauthorized intrusion. Data governance operates through classification and tiered management, standardizing the collection and use of geospatial data, traffic telemetry, and user privacy information. Localized data residency and auditable cross-border flows ensure full conformance with national data security statutes and personal information protection regulations [9-10].

(7) By the end of 2025, more than 20 cities across the country have carried out open road testing and demonstration operations, with a total of more than 4,060 kilometers of smart roads and more than 5,580 smart intersections. More than 3 million 5G and C-V2X units have been assembled, more than 35,000 kilometers of demonstration roads have been opened for testing, more than 11,000 sets of intelligent roadside units have been deployed, and the total test mileage of intelligent connected vehicles has exceeded 200 million kilometers. Beijing, Shanghai, Shenzhen, Wuhan and other cities have achieved city-level vehicle-road-cloud collaborative coverage, and scenarios such as Robotaxi, unmanned buses, and intelligent logistics are operated normally.

4. Implementation Pathways for Globalizing Vehicle-Road-Cloud Integration

Promoting the "China Plan" to the "World Plan" is a systematic project that requires the concerted efforts of central and local governments, technology enterprises, automobiles and solution manufacturers.

(1) Strengthen the government's top-level design and overseas escort. The government plays the dual roles of "chief designer" and "overseas escort": incorporating Vehicle-Road-Cloud Integration into key national foreign cooperation projects, integrating into multilateral cooperation frameworks such as the "Belt and Road", BRICS, and China-ASEAN, and signing intergovernmental cooperation memorandums to clear policy obstacles; leading standards are docked and mutually recognized, promoting domestic mature technical standards to become the international mainstream, and grasping the initiative in rule-making[7][9]; Give full play to the role of policy-oriented financial institutions, provide long-term preferential loans to support overseas infrastructure construction, cover political and default risks through export credit insurance, and resolve non-tariff barriers such as data security.

(2) Give full play to the role of technology enterprises in technology empowerment and ecological construction. As the technical base, Baidu, Huawei, Alibaba, Tencent and other enterprises output modular and decoupled cloud control platforms to form a rapidly adaptable "urban traffic brain" solution to support localized deployment to meet data sovereignty requirements; open API interfaces and cooperate with local enterprises to develop applications such as smart parking and logistics optimization to build a win-win ecosystem; strictly abide by global data regulations, integrate "privacy design" and "security design" to ensure cross-border data compliance [10].

(3) Rely on car companies and solution manufacturers to develop terminal markets. As the front-end carrier of the market, car companies and solution manufacturers actively participate in the construction of overseas demonstration zones, establish demonstration operation zones with local governments and Chinese partners, and carry out market education with practical results. Deeply optimize autonomous driving algorithms and interactive interfaces based on local traffic culture, driving habits, and typical road conditions, and transform technical advantages into excellent experiences that users can perceive, thereby leveraging market demand [5][8].

(4) Promote global layout by regional differentiation. The European market takes compliance as the core, prioritizes meeting GDPR data localization requirements, promotes mutual recognition of certifications, and focuses on high-end demonstration projects and technical cooperation [10]. The Southeast Asian market relies on the advantages of vehicles going overseas and promotes the large-scale penetration of L2-L3 intelligent driving solutions with low cost and fast implementation [4]. The Middle East market is dominated by government cooperation and city-level projects, promoting the implementation of overall solutions such as Robotaxi, smart parks, and vehicles-road-cloud [11]. Latin America, Africa and other markets give priority to closed scenarios such as ports, mining areas, and parks, and establish demonstrations with low-investment, high-certainty projects

5. Challenges and Strategic Responses in Globalizing Autonomous Driving

The global diffusion of vehicle-road-cloud integration confronts significant barriers, necessitating proactive planning and adaptive countermeasures.

(1) Data sovereignty and compliance barriers. EU GDPR and other regulations have strict requirements for localized storage of geographic information and biometric data. The Chinese government should vigorously promote the pilot models of "data enclave" and "data sandbox". Establish a specially regulated compliance data area in the target market to realize the localization of data in the "enclave", which not only meets local laws but also supports enterprise technology iteration [10]. At the same time, actively promote the negotiation of bilateral data compliance agreements.

(2) Geopolitics and trust deficits. Core technology output may be politicized and face "technical security" review. The Chinese government should invite third-party international institutions to participate in technical audits and security certifications through a transparent and open cooperative attitude. Encourage cooperation with influential local enterprises in the form of joint ventures and technology alliances to build a "community of interests" and resolve the crisis of trust.

(3) Huge investment and long commercial return cycle. The investment in smart road infrastructure construction is huge and the return is slow. Chinese enterprises should vigorously promote innovative investment and financing models, and attract multiple capital through public-private cooperation, construction-operation, and transfer. In the early stage, they could focus on closed/semi-closed scenarios such as airports, ports, and industrial parks, or specific transportation corridors in cities, to achieve small-scale breakthroughs and attract social capital with a model effect.

(4) Fragmentation of technical standards. The global landscape of autonomous driving is complicated by heterogeneous communication frequency allocations, technical protocols, and certification frameworks. Capitalizing on the industrial convergence achieved through China's extensive domestic application base, enterprises should strategically promote a focused portfolio of core common standards, with C-V2X as a flagship candidate, to establish international mainstream acceptance. Simultaneously, China must assume an influential role in international standardization fora—notably the United Nations and 3GPP—to attenuate fragmentation at the normative source [13].

6. Conclusion

Centered on vehicle-road-cloud integration, China's autonomous driving solution represents not merely a technological breakthrough, but strategic inflection points for securing discourse power in global intelligent transportation, shaping national brand identity, and steering future development trajectories. The global mobility landscape is being reshaped by two irreversible megatrends: first, electrification has crossed a cascading tipping point, progressively eroding the resilience of fossil-fuel vehicle systems; second, the locus of intelligence is migrating from isolated vehicle autonomy toward collaborative ecosystems [14]. By deploying an overseas architecture of state facilitation and private-sector execution—cultivating tripartite synergy among government, technology enterprises, and automotive manufacturers—China possesses the full capability to globalize this deeply integrated intelligent solution. This marks a historic evolution from merchandise exports to systemic solution provision, ultimately establishing China's autonomous driving paradigm as a globally competitive benchmark and contributing Chinese expertise to the intelligent transformation of world mobility.

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