

Application and Construction of Vehicle-Energy-Road-Cloud Data Platform for Expressway Scenarios

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Abstract: The integrated development of the vehicle–energy–road–cloud (VERC) system organically integrates automotive facilities, energy supply systems, transportation infrastructures, and cloud computing technologies. This paradigm facilitates the establishment of an intelligent, low-carbon, safe, and efficient ecosystem for transportation and daily mobility, thereby advancing the high-quality development of the automotive industry. This paper investigates the current construction status and foundational conditions of VERC integrated platforms. On this basis, it proposes the construction requirements and implementation schemes for the expressway-oriented VERC data application platform. The platform aims to realize data sharing, information interaction, and intelligent decision-making across vehicle, energy, transportation, and cloud terminals, and further improve the overall operational and management level of expressway traffic systems.

Keywords: Expressway; Vehicle-Energy-Road-Cloud Platform; Data Access.

1. Introduction

Under the national strategy of "Building a Strong Transportation Nation," the cooperative vehicle-infrastructure intelligent transportation system has become a core component of the intelligent transportation system. The "Vehicle-Energy-Road-Cloud" industry integrates automobiles, energy, transportation, and communications, enabling vehicle-energy integration, vehicle-infrastructure cooperation, and vehicle-cloud interconnection, with tremendous social benefits[7]. As one of the first pilot provinces for building a strong transportation nation, Jiangsu has made significant progress in related construction[1]. However, the existing data system still has three core problems: first,

heterogeneous data fusion; second, inadequate depth of data value mining; third, limited service model innovation. These problems constrain the optimal allocation of transportation resources and the improvement of service efficiency. Based on the achievements of digital transformation and upgrading of Jiangsu expressways, this research uses the digital foundation of new energy and heavy-duty vehicles to efficiently integrate and connect the Jiangsu expressway network, energy, and cloud computing infrastructure, empowers industrial collaborative development through intelligent applications, improves road network operation quality, and provides high-quality travel services for the public.

2. Construction Background and Significance

2.1 Construction Background

As early as June 2023, the State Council executive meeting pointed out that an industrial ecosystem integrating the development of "Vehicle-Energy-Road-Cloud" should be built to enhance the independent and controllable capability of the entire industrial chain and the level of green development. On November 17, 2023, the Ministry of Industry and Information Technology, the Ministry of Public Security, the Ministry of Housing and Urban-Rural Development, and the Ministry of Transport issued the "Notice on Carrying Out Pilot Work on Access and Road Traffic of Intelligent Connected Vehicles," which explicitly proposed supporting the further promotion and application of advanced technologies and products, feasible solutions, and innovative mechanisms of "Vehicle-Energy-Road-Cloud" integration that have been verified through pilots and refined. On January 16, 2024, the Ministry of Industry and Information Technology, the Ministry of Public Security, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, and the Ministry of Transport (five

ministries) issued the "Notice on Carrying Out the Pilot Work of Vehicle-Road-Cloud Integrated Application for Intelligent Connected Vehicles," which explicitly proposed promoting the construction of intelligent road-side infrastructure and cloud-controlled basic platforms, facilitating large-scale demonstration applications and the exploration of new business models, and vigorously promoting the industrialization of intelligent connected vehicles.

In July 2024, the "Notice on Announcing the List

of Pilot Cities for Vehicle-Road-Cloud Integrated Application of Intelligent Connected Vehicles" was issued, among which Nanjing, Suzhou, and Wuxi in Jiangsu Province were selected. This is the first batch of pilot cities announced by the state following the release of the "Notice on Carrying Out the Pilot Work of Vehicle-Road-Cloud Integrated Application for Intelligent Connected Vehicles" by the five ministries in January this year.

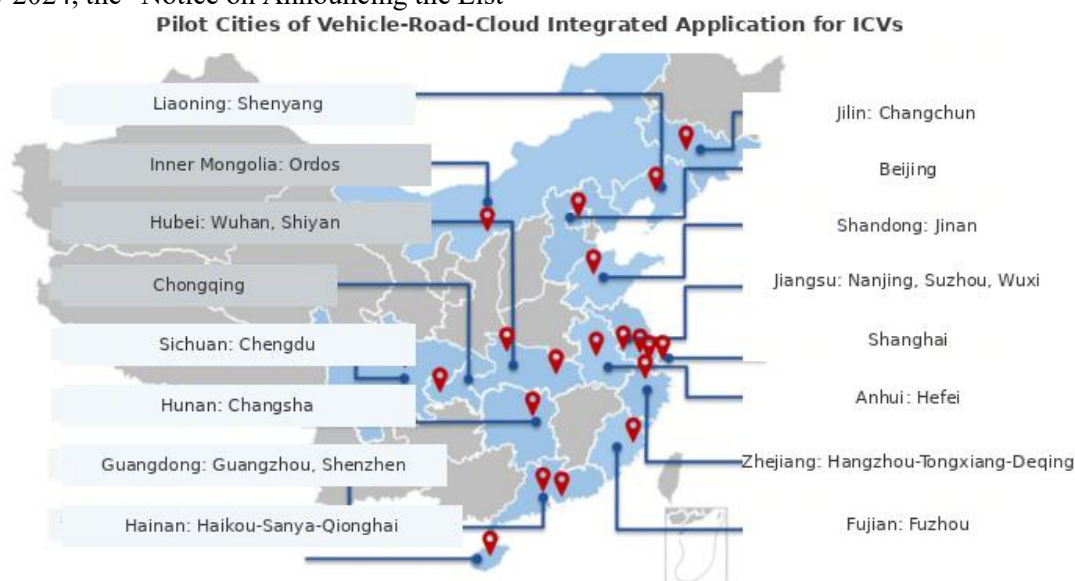


Figure 1. Pilot Cities of the Vehicle-Road-Cloud Integrated Application for Intelligent Connected Vehicles

2.2 Construction Significance

First, the "Vehicle-Energy-Road-Cloud" integrated industry spans multiple fields such as communications, roads, energy, and cloud services. It is capital- and technology-intensive with enormous market demand. The integrated development of "Vehicle-Energy-Road-Cloud" will provide benefits and functional services for vehicle manufacturers, autonomous driving enterprises, traffic management departments, and multiple parties. Jiangsu has relatively complete industrial clusters in automobile manufacturing, electronic information, and new energy. The development of the "Vehicle-Energy-Road-Cloud" industry will promote in-depth integration and collaborative innovation among these industries, providing key support for Jiangsu to build a modern comprehensive transportation system.

Second, the integrated fusion of "Vehicle-Energy-Road-Cloud" data can comprehensively enhance the precise perception capability of road network operation status, the proactive

intervention capability for traffic accidents and events, and the safety control capability at important nodes and locations[8]. Through the exploration of key technologies for integrated data applications, it meets the needs of safety control operations, fully empowers expressway operation safety management, and improves the road network's capability to ensure safety and smooth traffic.

Finally, relying on the construction of the "Vehicle-Energy-Road-Cloud" integrated cloud-control platform, it can connect and fuse the perception, traffic events, traffic control, construction and maintenance, accident rescue, and other related data of the existing road network, enrich the business scenarios of construction, management, maintenance, operation, and service, and promote large-scale scenario applications based on the digital transformation of the Jiangsu road network.

3. Current Status and Foundation of Jiangsu's Vehicle-Energy-Road-Cloud Integrated Construction

Jiangsu started early in supporting facilities such as the Internet of Vehicles and new energy, with good foundations and conditions:

(1) Vehicle side:

Commercial vehicles: Commercial vehicles within Jiangsu Province have achieved full coverage of satellite positioning systems, and were the first to apply AI-based active safety intelligent prevention and control systems on "two types of passenger vehicles and one type of hazardous chemical vehicle" starting in 2017, and are now gradually expanding to heavy-duty trucks of 12 tons or more.

Passenger vehicles: According to statistics from the Traffic Management Bureau of the Ministry of Public Security, by the end of December 2023, the national number of new energy vehicles reached 20.41 million, accounting for 6.07% of the total vehicle ownership. Among them, Jiangsu Province has over 1.5 million new energy vehicles, ranking third nationwide, and is expected to have nearly 3 million new energy vehicles by the end of 2025.

(2) Energy side:

To date, the Jiangsu expressway network has built 202 charging stations, 1,299 charging piles, and 1,735 charging guns, of which over 70% are ultra-fast chargers of 120kW and above; over 43 battery swapping stations have been cumulatively built on the expressway network. The charging and swapping equipment data collected by road network energy supply facilities includes the status, power, occupancy, charging status, and fault conditions of service area charging and swapping equipment.

(3) Road side:

Jiangsu has completed intelligent upgrading of over 8,000 kilometers of national and provincial trunk roads, with the digitalization rate of trunk roads reaching 60%. All newly built expressways are synchronously equipped with digital facilities, while existing expressways are being intelligently upgraded using "video cloud networking." All 5,087 kilometers of expressways in the province have achieved 100% "intelligent transformation and digital upgrading," ranking first nationwide in scale.

(4) Cloud side:

Jiangsu has carried out digital transformation construction around the full life-cycle scenarios of expressway "investment, construction, maintenance, operation, management, and service." All business systems have moved to the cloud, and the "Expressway Cloud" has been built

using a hybrid cloud architecture, achieving effective aggregation of information infrastructure and data resources. A number of vehicle-road-cloud-related applications have been built, such as the "Dispatch Cloud," "Expressway Brain," and "Intelligent Road Network Cloud Control Platform." Construction and research on high-precision maps and transportation large models are also underway, providing strong support for the "Vehicle-Energy-Road-Cloud" integration.

4. Key Technology Research

4.1 Data Access

Data access technology refers to the technical means of collecting, transmitting, and integrating data from various data sources into a target system or data platform. Common data access technologies include: ETL[2], message queue, RESTful API[3], etc. When selecting data access technology, factors such as data volume, data update frequency, diversity of data sources, system performance requirements, scalability, and cost need to be considered. The main process of data access includes four steps: data preparation, connection configuration, data transmission, and data validation.

4.2 Data Storage

After completing data access, massive data needs to be stored. When selecting a data storage method, it is necessary to comprehensively evaluate and choose an appropriate storage method based on business requirements, data volume, access speed requirements, and data characteristics, from multiple aspects including secure data preservation, efficient data access and utilization, cost-effectiveness optimization, scalability and adaptability, as well as compliance and management convenience. Common data storage methods include: distributed file system (DFS)[4], columnar storage[5], cloud storage, etc.

4.3 Data Cleaning

According to the implementation method and scope of data cleaning, data cleaning generally includes four strategies: (1) Manual cleaning: manually modifying dirty data directly; (2) Automatic cleaning: detecting and correcting errors by writing dedicated application programs; (3) Domain-specific cleaning: for example, finding numerically abnormal records based on probability statistics principles and then

correcting them; (4) Domain-independent data cleaning: mainly focusing on the detection and deletion of duplicate records. Different stages of data loading have different cleaning tasks, and different cleaning strategies should be selected for them. Data cleaning includes three items: similar duplicate record cleaning[6], outlier cleaning, and missing value handling.

5. Implementation Path for the Construction of the Vehicle-Energy-Road-Cloud Integrated Data Application Platform

5.1 Platform Construction Approach

The position of Jiangsu's high-value "Vehicle-

Energy-Road-Cloud" integrated data application platform within the Jiangsu Transportation Holding data middle platform is shown in Figure 2: The construction of the high-value "Vehicle-Energy-Road-Cloud" integrated data application platform refers to the relevant requirements of the Jiangsu Transportation Holding data middle platform. The new energy National VI standard heavy-duty truck related data in the high-value "Vehicle-Energy-Road-Cloud" integrated data application platform can support Jiangsu Transportation Holding in deploying multi-scenario applications such as construction, management, maintenance, operation, and service

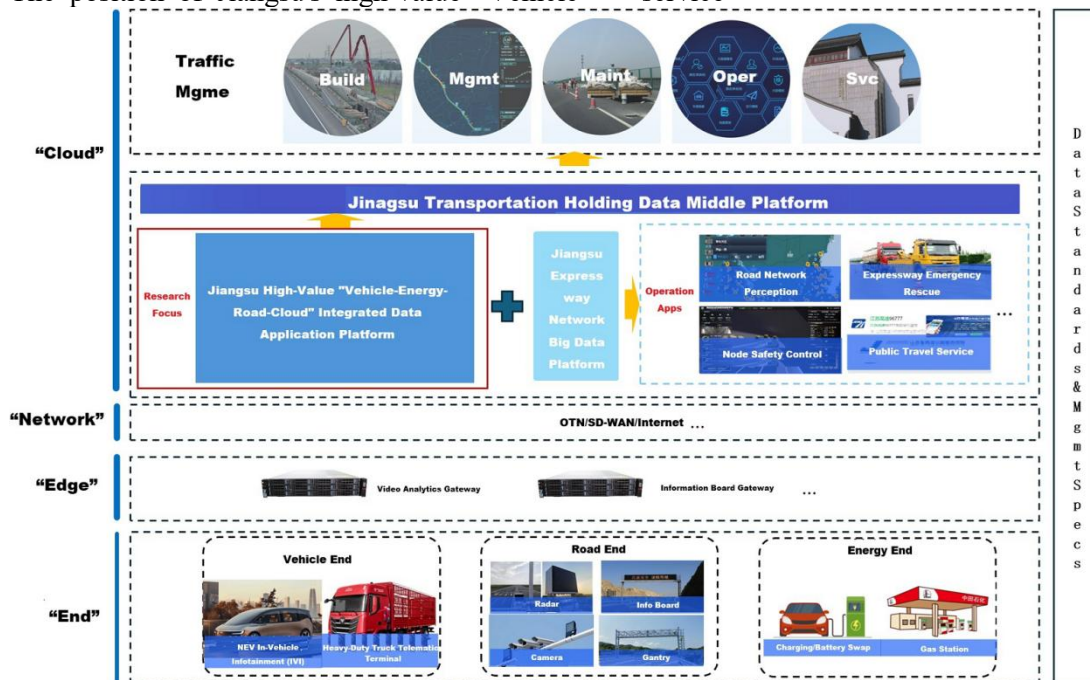


Figure 2. High-Value "Vehicle-Energy-Road-Cloud" Integrated Data Application Platform Construction Approach

End: The "end" refers to endpoint devices, which are devices that users directly interact with. The vehicle end mainly includes new energy vehicle in-vehicle infotainment systems and heavy-duty truck intelligent terminals; the road end includes road-side radar, information boards, cameras, gantries, and other devices; the energy end includes new energy vehicle charging piles, battery swapping stations, and gas stations. These devices connect to the cloud and edge computing nodes through the network, serving as the source of data and the carrier of final applications.

Edge: Edge Computing refers to a computing model that performs data processing near the data source or user (i.e., at the network edge). Specifically, it includes video analytics gateways and information board gateways.

Network: This mainly refers to communication networks, including Wide Area Network (WAN), Metropolitan Area Network (MAN), and Local Area Network (LAN), etc. It is the infrastructure connecting various devices, systems, and data centers, enabling data transmission and communication. It can be based on wired (such as optical fiber, twisted pair, etc.) or wireless (such as Wi-Fi, 4G/5G, etc.) communication methods.

Cloud: "Cloud" is the abbreviation of Cloud Computing. It is a model for providing computing services (including servers, storage, databases, networks, software, analytics, etc.) through the Internet. Jiangsu's high-value "Vehicle-Energy-Road-Cloud" integrated data application platform can directly empower the Jiangsu Expressway Network big data platform, supporting

operational services such as road network operation perception, expressway emergency rescue, important node safety control, and public travel services. It can also connect to the Jiangsu Transportation Holding data middle platform to realize "construction, management, maintenance, operation, and service" related applications.

5.2 Platform Construction Content

The specific construction framework of Jiangsu's high-value "Vehicle-Energy-Road-Cloud" integrated data application platform is shown in Figure 3:

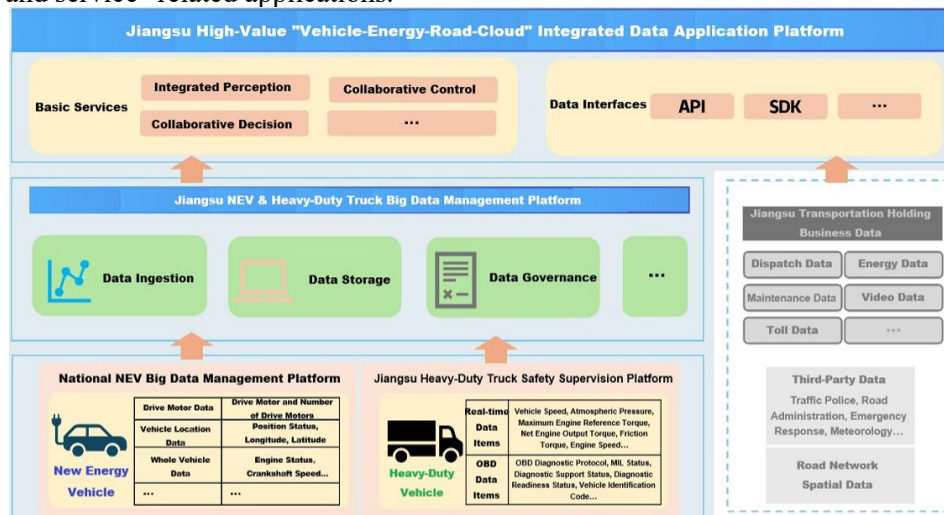


Figure 3. High-Value Vehicle-Energy-Road-Cloud Integrated Data Application Platform Construction Framework

5.2.1 Data Sources

Based on the Jiangsu Province transportation industry data foundation, according to the business needs of "Vehicle-Energy-Road-Cloud" integrated services, data from various sources is cleaned, aligned, and integrated to carry out the construction of the "Vehicle-Energy-Road-Cloud" integrated data warehouse, providing data support for various upper-layer applications and services.

1) With the National New Energy Vehicle Big Data Management Platform and the Jiangsu Provincial Law Enforcement Bureau's heavy-duty truck safety supervision platform as technical and data support, through real-time collection covering 100 core data items such as operation safety, charging behavior, and mileage, real-time data docking of millions of new energy vehicles and heavy-duty loading vehicles across the province is realized, providing data support for industry work such as vehicle operation safety supervision, vehicle service facility layout construction, and aftermarket services.

2) Jiangsu Transportation Holding business data: including road network rescue/maintenance/work vehicle data (including vehicle type, work plan, current location, speed, heading angle, work route, etc.), high-precision map data of the provincial expressway network, road network dynamic control information (including traffic restrictions,

variable emergency lanes, dynamic speed limits, traffic guidance, traffic events, severe weather, traffic accidents, construction and maintenance operations, etc.), energy data (including the status, power, occupancy, charging status, and fault conditions of service area charging and swapping equipment), parking lot data, etc.;

3) Third-party data:

Internet data: crowdsourced data obtained through service purchase or data exchange.

External data: horizontal data from departments such as logistics and meteorology; vertical data shared and exchanged from provincial departments and the Ministry of Transport.

5.2.2 Implementation Path

Provides technical capabilities, including data access, data storage, data governance, platform forwarding, and protocol management, fully supporting the data middle platform's full data lifecycle management.

(1) Data Access

According to the data sources being accessed, data is ingested from application systems (such as road asset management, maintenance business operations, toll collection systems, operation monitoring, etc.) through data interface services, HTTP, FTP, Socket, or ETL and other methods, achieving comprehensive aggregation of industry application system data. For existing systems and new business systems, data access can be

achieved through the following methods: First, structured data access: for lightweight tables or large-scale real-time data, file exchange, database data exchange, and dedicated interfaces (Socket, HTTP, JMS, WebService, etc.) are used through FTP and ETL tools for service exchange. Second, unstructured data access: unstructured data is ingested via FTP and extracted to the data resource center. Third, video stream data access: video stream data is ingested through standard interfaces; although the data resource center does not store video data, it has monitoring and visualization display capabilities.

(2) Data Storage

Select appropriate data strategies to store raw data and processed data, forming a data warehouse. The data warehouse, for different scenario applications, fuses the raw data accessed from the national platform and related data from vehicles, roads, and energy according to unified coding rules, forming thematic data model databases that meet the needs of different scenario applications.

(3) Data Governance

The raw data accessed from the national platform may have related issues, requiring cleaning, transformation, and other steps to convert the problematic data into a data format that meets the relevant requirements of the management platform.

5.2.3 Data Interfaces

The high-value "Vehicle-Energy-Road-Cloud" integrated data is based on the four-end data of "Vehicle-Energy-Road-Cloud," processed through a technical support platform. On one hand, it can directly empower the Jiangsu Expressway Network data service and control platform to carry out scenario applications such as road network operation status perception, expressway emergency rescue, important node safety control, and public travel services. On the other hand, it can support Jiangsu Transportation Holding in exploring "construction, management, maintenance, operation, and service" scenarios. The API open platform provides customized interface development services, realizing data sharing with different internal business systems.

5.2.4 Data Applications

Upgraded based on the Jiangsu Transportation Holding road network operation-related platforms, providing users with data, model, and other service capabilities needed for perception, decision-making, control, management, and big data empowerment.

(1) Road Network Operation Monitoring

Through the analysis of real-time location data of new energy and heavy-duty loading vehicles, combined with multi-source data fusion algorithms, precise perception of road network operation status such as traffic flow, speed, and congestion is achieved[9], providing capability support for scenarios such as efficient command and dispatch, road network traffic flow guidance, and precise vehicle control.

(2) Proactive Traffic Event Detection

Through the analysis of fault data of new energy and heavy-duty loading vehicles, combined with the Jiangsu expressway road-side video AI monitoring capability, intelligent prediction and early warning of abnormal events related to new energy and heavy-duty loading vehicles are achieved.

(3) Intelligent Vehicle Rescue

For rescue events involving new energy vehicles running out of power (such events account for 60% of new energy vehicle rescue events), the in-vehicle battery status of the rescued vehicle is analyzed in advance to assist rescuers in accurately selecting dedicated rescue equipment, improving on-site rescue efficiency, and eliminating safety risks such as deflagration, electric leakage, and reverse charging during the rescue process.

For heavy-duty loading vehicle accident rescue events, it is confirmed in advance whether the vehicle is a hazardous chemical vehicle, and the nearest rescue vehicles and dedicated rescue equipment are dynamically dispatched to the scene. Rescuers can prepare corresponding rescue tools and protective measures in advance based on the vehicle information provided by the system, ensuring efficient and safe on-site rescue.

(4) Vehicle Safety Control

Through the analysis of status data and in-vehicle fuel cell data of new energy and heavy-duty loading vehicles, the safe operation status of vehicles at important nodes such as key bridges, tunnels, and service areas can be clearly mastered. Service area safety control: by mastering real-time charging data of new energy vehicles, dynamic monitoring of in-vehicle battery status is achieved, and linkage with the smart service area management platform or intelligent charging pile systems eliminates battery combustion accidents caused by battery overcharging damage, improving the safety management capability of service area plazas. Through monitoring of the location, real-time parameters, and other data of "two types of passenger vehicles and one type of

hazardous chemical vehicle," the status monitoring of key vehicles in service areas is achieved.

Key bridge and tunnel safety control: through monitoring of battery status such as new energy vehicle battery temperature, safety warning of in-vehicle battery temperature is achieved, preventing major safety risk accidents where new energy vehicle deflagration caused by traffic accidents leads to structural damage of key bridges and tunnels, providing important, real-time, and accurate data support for emergency safety management of key bridges and tunnels. Through real-time monitoring of the real-time location, load, and other data of heavy-duty loading vehicles, real-time monitoring of heavy-duty loading vehicles at key bridges and tunnels is achieved.

(5) Intelligent Vehicle Services

Appointed Travel

Combined with precise monitoring and calculation of the location, license plate, and other information of new energy and heavy-duty loading vehicles, it provides appointed travel services such as service area parking, charging, refueling, and free passage at toll stations.

Cooperative Vehicle-Infrastructure Information Dissemination

Currently, new energy and heavy-duty loading vehicles are factory-equipped with IoT cards and high-precision positioning devices. Based on the vehicle-side information reach capability for new energy and heavy-duty loading vehicles, real-time in-route information services for the road network are realized, achieving refined and accompanying vehicle-infrastructure cooperative dissemination of information including safety warnings and proactive guidance.

6. Conclusion

In response to the needs for refined and humanized intelligent management of future expressways, the construction of the "Vehicle-Energy-Road-Cloud" data application platform can not only unify existing data resources and break down data silos, solving the pain points of large amounts of data assets lying dormant, difficulty in achieving data reuse, and insufficient mining of data value, but also meet the urgent application needs within expressway management systems, providing technical hosting and data support capabilities for multiple applications. In addition, as the "Vehicle-Energy-Road-Cloud" data application platform is

implemented and applied in the future, it can provide travel users with more precise, multi-dimensional, and personalized services, improving satisfaction with expressway travel services.

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