Journal of Highway and Transportation Research and Development
2024,18(1):54-62
ISSN 2095-6215
DOI: 10.26599/HTRD.2024.9480007

Research on New Framework Based on Existing Smart Expressway Construction Guides

Zhuocheng Yang*[1], Liang Hao[1], Yu-chen Liu[1], Longmei Duan[2], Chunfu Jia[2]

(1. Beijing GOTEC ITS Technology Co., Ltd., Beijing 100088, China;
2. Jilin Provincial Transportation Planning and Design Institute, Changchun, Jilin 130021, China)

Abstract: This article aims to introduce an innovative framework and associated construction content for the modern smart highway, and to succinctly provide viable recommendations for its rapid development. This study examines the construction frameworks and guidelines across 13 provinces and cities, identifying their commonalities and variations. The new framework is categorized into five layers: Perception, Support, Data, Computing, and Application. The construction key points in these layers are concisely explained and the Application layer is further segmented into six facets: Safety, Efficiency, Green, Convenience, and Toll Collection. This study analyzes the critical application scenarios in various provinces and cities. It aids in rectifying the disparity in understanding during actual construction across these provinces, providing a classification criteria for smart highway construction content. These guidelines will significantly influence future project construction improvements.

Key words: intelligent transportation; smart expressway; construction guide; framework

1 Introduction

Smart expressway is a digital and intelligent expressway based on the business needs of managers and users' travel needs. It's data-centric and make full use of the new generation of technology to realize intelligent perception, intelligent service, and intelligent management. It promote the deep integration and coordination of people, vehicles, and road environments. Finally realize the digitalization and intelligence of the whole process of construction, management, maintenance, operation and service.

As of March 2023, according to the release time of the construction guides for smart expressway, 13 provinces and cities including Zhejiang Province, Jiangsu Province, Shandong Province, and Beijing have issued construction guides. All guides have given answers on how to build smart expressway from different focuses based on the experience of smart expressway construction in provinces/cities. However, the phenomenon of "bulk version-smart expressway" is serious. The situation of "a diversity of ideas" leads to the inability to form a unified construction framework system. Only refer to the construction guide of the province (city) or take the advantages of each guides when actually construct smart expressway is a question worth exploring at present. This article aims to sort out the 13 guides, compare their similarities and innovations, and give relevant suggestions for the future construction of smart expressway.

2 Summary of Guides

2.1 Scope of application

In the past three years, all provinces and cities have reached an agreement on the scope of application of the guides. That is to say the construction of new and renovated (expanded) smart expressway, and the intelligent upgrading and transformation of operational expressway.

2.2 Guides overview

Because different provinces and cities have summarized their experience in the construction of smart expressways according to the actual characteristics of their provinces and cities, their requirements are different.

Zhejiang Province: As the first guide in China, it is comprehensive, giving basic application scenarios and innovative application scenarios, as well as the construction experience of Shanghai-Hangzhou-Ningbo Expressway, Hangzhou Ring West Double Line, and Hangzhou-Shaoxing-Ningbo Smart Expressway, but lacks an overall

Received 15 March 2023; Revised 26 May 2023; Accepted 10 June 2023

* *E-mail address*: 984862589@qq.com

framework of smart expressway that dominates the whole text[1].

Jiangsu Province: Focusing on the functional requirements, equipment performance requirements and layout requirements of the perception layer and the application layer. The service, management and support layer are relatively simple The detailed overall framework is proposed in the guide for the first time. The concept of all-factor perception is proposed for the first time, which was later used by the guides of many provinces and cities[2].

Shandong Province: The idea of the overall framework is different from other guidelines and relatively simple, focusing on the full life cycle of smart expressway. It build a system from the aspects of construction, maintenance and operation, focusing on the smart construction and maintenance of the smart construction and maintenance system, and the road network control and travel services of the smart operation system[3].

Beijing: For the first time, the classification of smart expressway intelligence levels is proposed in the guide. The overall framework is relatively perfect, which elaborates on the content of intelligent perception, the functions of intelligent middle platform, the equipment and functions of intelligent services, and intelligent management covering smart expressway construction, operation, maintenance and decision-making[4].

Sichuan-Chongqing area: The guide was divided into four releases, including overall technical requirements, intelligent grading, roadside facility setting specifications, and data exchange of vehicle-road coordination system. The level division, grade evaluation and grade requirements of smart expressway are given in further detail. The guide covers a relatively comprehensive area, with the construction experience of the Rongcheng Second Ring and Chengyi Expressway[5-8].

Yunnan Province: The guide covers the technical requirements, functional requirements and construction requirements of perception, service, management, application and support layer. It adds smart expressway construction requirements, construction processes, industry management systems and enterprise operation systems, and improves the smart expressway level and application configuration[9].

Gansu Province: Focusing on the perception layer, data layer and application layer. Including the data collection requirements of all-factor perception, facility layout requirements, comprehensive transportation data center functions, typical applications and innovative application functions. Compared with other guidelines, it is a "basic version"[10].

Henan Province: It comprehensively covers the functions and layout requirements of monitoring facilities, the functions of application support environment, the data transmission requirements of construction and maintenance links, and the functions of basic business applications, special scenarios and innovation scenarios[11].

Hebei Province: Focusing on the technical requirements and layout requirements of the application layer. It is only a brief introduction to other levels and is accompanied by the construction experience of Yanchong Smart Expressway, Jingxiong Smart Expressway, Rongwu Expressway New Line, and Jingde Smart Expressway, as well as key technical and product index references[12].

Shanghai: The relatively simple cloud-edge-end framework gives in great detail the requirements for information collection and layout of roadside facilities. It gives the requirements for the cloud control platform at the road network level and the regional or road section level, the requirements for edge computing functions and layout, and the application function requirements and comparison tables at the road network level, region or road section level[13].

Guangdong Province: In addition to the technical framework, the overall framework also adds data flow framework and road network collaboration framework, focusing on the requirements of general business scenarios and innovative business scenarios, with requirements for the whole process management of smart expressway construction and smart expressway innovation ecosystem[14].

Jilin Province: Lacking the overall framework and the classification of smart expressway, the guide is relatively simple. The layers are briefly introduced and the application layer focuses on road network control[15].

Guizhou Province: There is business framework, data framework, technical framework. According to digital infrastructure, converged communication facilities, green energy supply facilities, intelligent cloud platform, intelligent applications, etc. to organize the smart expre-

ssway construction process, with typical application scenarios of smart expressway, preliminary research work requirements of construction projects, and sub-project division tables[16].

3 Guide framework

As shown in Table 1, the frameworks of the 13 guides are classified, except for Zhejiang Province and Jilin Province. The other 11 provinces and cities have proposed the overall framework, except for Shandong Province (smart construction and maintenance system, smart operation system, support system), the remaining 10 provinces and cities can be further summarized into 2 categories, that is, the "perception-service-management-support-application" framework represented by 7 provinces and cities such as Jiangsu Province and the "cloud-edge-end" framework represented by 3 provinces and cities such as Sichuan-Chongqing area.

Table 1 Comparison of the framework of the construction guides of each province and city

Provinces	Jiangsu	Beijing	Yunnan	Gansu
Architecture	All-factor perception, all-round service, full-service management, vehicle-road coordination and autonomous driving, support and guarantee, and new technology application	Intelligent perception, intelligent service, intelligent management, intelligent middle office, cloud platform, support and guarantee	All-factor perception, all-round service, full-service management, innovative application, support and guarantee, new technology application	All-factor perception, support and guarantee, typical applications, innovative applications
Provinces	Henan	Hebei	Guangdong	
Architecture	Information infrastructure, application support environment, basic business applications, special scenarios, and innovation scenarios	Digital perception layer, converged communication layer, cloud control resource layer, control and collaboration layer, application service layer	1 perception transmission system, 3-level data center, and N-class application scenarios	
Provinces	Sichuan-Chongqing	Shanghai	Guizhou	
Architecture	Roadside facilities, cloud control platforms, application services, infrastructure digital support environment, information security	Cloud-controlled platforms, edge computing facilities, roadside facilities	Cloud-network-edge-end	

In the "perception-service-management-support-application" framework, the perception layer is the foundation for building smart expressway and realizing the collection of multi-dimensional data information. The service layer includes lane-level services, all-weather traffic, free-flow toll collection, in-transit information release, and smart service areas. Which mainly for drivers and passengers, realizing Mobility as a service (Maas). The management includes construction management, operation monitoring, emergency command, toll collection management, maintenance management, decision support, etc., mainly for management personnel to achieve management quality and efficiency. The support layer includes facility power supply, converged communication, service middle platform, and data middle platform to ensure the effective transmission and efficient processing of various types of data and provide support for business applications. The application layer uses the unified data and capabilities of the platform to provide upper-layer applications related to expressway control, safety, and services.

The "cloud-edge-end" framework refers to the expressway cloud control system composed of cloud subsystem, edge subsystem, and end device, with bottom-up step-by-level data processing and control instruction transmission logic framework. The cloud subsystem refers to the expressway operation control center of cloud computing technology architecture, that is, the cloud control center. It can be divided into road segment cloud, regional cloud and road network cloud. Edge subsystem re-

fers to facilities with edge computing capabilities deployed along expressways, the main roadside edge computing control station (ECCS) and the road section cloud control center (road section cloud). End equipment refers to terminal equipment that has a stable and reliable network connection on the expressway and can be online in real time, mainly including roadside terminal equipment and vehicle-side intelligent terminal equipment[17].

Combined with the characteristics of the two types of architectures, and the European Cooperative Intelligent Transport System (C-ITS), Japan's next generation smart road program "Smartway" and other foreign smart expressway experience, the following compares the similarities and differences of the construction guides of various provinces and cities according to the "perception-support-data-computing-application" framework. This new framework summarizes the characteristics of different provinces and cities and is suitable for future expansion, standardization and innovation.

4 Specific content of the guide

4.1 Perception layer

All provinces and cities have basically reached a consensus on the content that the perception system needs to perceive, and put forward relevant data collection requirements, layout requirements, functional requirements, performance requirements, etc. The perception content is divided into three categories. The first category is the monitoring of expressway subjects and ancillary facilities, including bridge condition monitoring, tunnel condition monitoring, road condition monitoring, traffic engineering and facility status monitoring along the route. The second category is traffic operation status monitoring, including traffic flow/parameter monitoring, license plate recognition/video monitoring, traffic incident monitoring, and vehicle operation monitoring. The third category is expressway meteorological environment monitoring.

4.2 Support layer

The support layer includes communication system, power supply and distribution system, information security, etc.

Converged communication systems, including wired/wireless communication networks and high-precision positioning. By building a basic network architecture integrating 4G, LTE-V, 5G, WiFi, and optical fiber, it provides a strong guarantee for the transmission of data, voice, image, and video. The communication system provides network communication and data transmission services for smart expressway, including two-way data transmission between the perception layer and the computing layer, high-speed data transmission between edge computing server-edge cloud-central cloud, bus data communication between edge computing server and perception layer, and remote wireless communication between application layer-edge computing server-vehicle equipment and user terminal.

The power supply and distribution system carries out real-time distributed monitoring and centralized management of high and low voltage power distribution equipment, generators, transformers, UPS, EPS, on-site lighting, ground transformation and lighting, ventilation and drainage and other mechanical and electrical equipment in substations along the expressway. So as to realize unattended operation, ensure expressway safety, improve the level of automatic management, and reduce the operation and maintenance costs of mechanical and electrical equipment.

4.3 Data layer

The data layer mainly includes high-precision maps and big data centers.

High-precision maps consist of static and dynamic data layers. The static data layer is structured and processed based on static data, which includes road data, lane data, road facility data (traffic sign markings, guardrails, speed bumps, roadside facilities, bridges and tunnels, toll stations, service areas, roadside buildings, etc.), with attributes, geometry, association relationships and other features. Dynamic data layers include layers such as traffic flow status, traffic events, road meteorological environment, road infrastructure status, traffic control information, and warning information.

The big data center has data aggregation functions, data storage functions, data quality management functions, data analysis and processing functions, data service functions, and data backup functions.

4.4 Computing layer

As shown in Table 2, the computing layer mainly includes cloud control platform, intelligent middle plat-

form, and edge computing. The main functions of this layer are based on the computing and data resources provided by the edge cloud and the center, processing, integrating and analyzing the raw data perceived by roadside devices, and providing traffic information services and auxiliary decision-making for vehicles based on the requirements of application scenarios. At the same time, the computing layer is also responsible for the condition monitoring, communication control and task scheduling of roadside sensing devices. The computing layer integrates sensing, computing and communication, and adopts a multi-level storage mechanism to store input and output data locally, in edge clouds and central clouds, reducing the consumption of the overall communication bandwidth of the system by data transmission within the computing layer, and avoiding the impact of communication delay caused by multi-level data transmission on the real-time performance of local computing.

Table 2 Comparison of the specific requirements of the computing layer of the construction guides of each province and city

Provinces	Cloud control platform	Intelligent middle platform	Edge computing
Zhejiang	Functions and construction requirements of provincial-level cloud control platforms, road sections/regional cloud control platforms	—	—
Jiangsu	Relevantly simple	—	—
Shandong	—	The IoT control platform, algorithms and models of the intelligent middle office	—
Beijing	Functional requirements of the cloud control platform	Basic middle platform, knowledge middle office functional requirements	—
Sichuan-Chongqing	Functional requirements	—	Facility requirements
Yunnan	Functional requirements of the cloud control platform	Expressway Digital Twin System Functional Requirements	—
Henan	—	Functional requirements of data centers, GIS+BIM, video platforms, and data service platforms	—
Hebei	Technical requirements, layout requirements	—	—
Shanghai	Road network level cloud control platform, regional or road section level cloud control platform requirements	BIM+GIS	Functional requirements, layout requirements
Jilin	Relevantly simple	—	—
Guizhou	A series of middle platforms for intelligent cloud platforms		Edge computing facilities, infrastructure information models

4.5 Application layer

As shown in Table 3, the basic and innovative applications of each province and city are classified according to safety, efficiency, green, convenience, toll collection, and others, with a total of 17 scenarios in 6 categories. Group according to the number mentioned in the guide: 1-4 occurrences are personalize scenes, 5-7 occurrences are improved scenes, and 8-13 occurrences are required scenes.

Sort the scent by heat, as shown in Figure 1. Information services, service areas, vehicle-road coordination, traffic control, emergency management, and all-weather traffic are the popular scenarios for reaching consensus on smart expressway, this section explains the fo-

cus of each guide on mandatory scenarios.

Table 3 Comparison of the specific requirements of the application layer of the construction guides of each province and city

Application	scenario	remark
Safety	All-weather running	Required
	Emergency management	Required
	Vehicle-road coordination	Required
	Autonomous driving	Improved
	Infrastructure	Improved
Efficiency	Traffic control	Required
	Active management	Personalize
	Vehicle Platooning	Personalize
Green	Energy	Personalize
Convenience	Information Service	Required
	Service Area	Required
Toll Collection	Free flow toll collection	Improved
	Network access charges	Improved
Others	Construction	Personalize
	Management	Improved
	Maintenance	Improved
	Operation	Improved

(1) Safety

① All-weather traffic

There are two categories: all-weather traffic and almost-all-weather traffic. Jiangsu and Shandong provinces, which proposed the definition of all-weather traffic, did not give an explanation. The remaining five provinces and cities proposed almost-all-weather traffic, which is defined as: automatically collecting road weather data and using this data to formulate short-term warnings or recommendations that can be provided to drivers to improve traffic safety under specific adverse weather conditions such as foggy weather, ice and snow. Including foggy driving guidance, intelligent ice and snow removal, specific to application points, equipment and layout, functional requirements and other aspects.

② Emergency management

Emergency management includes emergency support, emergency rescue, emergency command and dispatch, emergency handling, etc. The guide of Shandong Province put forward requirements for tunnel traffic safety monitoring, emergency handling (secondary accident

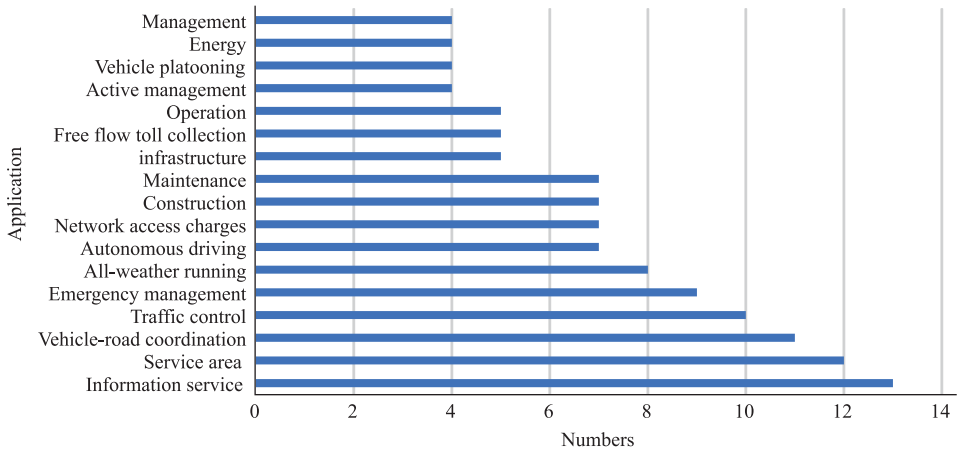

Fig. 1 Scenario sorting

Table 4 Comparison of all-weather traffic requirements for construction guides in various provinces and cities

Provinces	All-weather traffic	Requirements
Zhejiang	Almost all-weather traffic	Requirements for the layout of vehicle-side and roadside equipment
Jiangsu	All-weather traffic	Roadside equipment layout requirements
Shandong	All-weather traffic	Device functional requirements
Beijing	Almost all-weather traffic	Brief introduction
Sichuan-Chongqing	Almost all-weather traffic	Traffic information services, vehicle-road coordination, autonomous driving, and traffic under adverse weather conditions
Yunnan	Almost all-weather traffic	Requirements for the layout of vehicle-side and roadside equipment
Gansu	Almost all-weather traffic	Roadside equipment layout requirements

prevention) and major activity guarantee. The guide of Yunnan Province put forward functional requirements and construction requirements for disaster early warning and emergency rescue. Some provinces and cities have also put forward functional requirements: Shanghai (emergency management and management), Guangdong Province (emergency command and dispatch), Jilin Province (emergency response), Guizhou Province (emergency rescue and command and dispatch). The rest is only a brief introduction: Gansu Province (emergency command and dispatch), Henan Province (emergency command dispatch and disposal), Hebei Province (traffic safety risk identification).

③ Vehicle-road coordination and autonomous driving

As shown in Table 5, the vehicle-road coordination in the guide includes requirements such as scene classification, equipment and layout, and functional requirements, while the requirements for autonomous driving are relatively simple.

Table 5 Comparison of road coordination and autonomous driving requirements in construction guides for provinces and cities

Provinces	Vehicle-road coordination		Autonomous driving
	Scenes, Data	Functions, Layout	Functions, Application points
Zhejiang			
Jiangsu	3 categories 11 scenes	Device capabilities	Simple requirements
Shandong	—	Equipment function and layout requirements	Simple requirements
Beijing	—	Equipment function and layout requirements	Simple requirements
Sichuan-Chongqing	Vehicle-road coordination system data exchange		Simple requirements
Yunnan	11 scences	Device capabilities	Functions, application points
Gansu	10 scences	Device capabilities	—
Henan	3 categories 13 scenes	Equipment function and layout requirements	Simple requirements
Hebei	—	Equipment function and layout requirements	—
Shanghai	—	Device capabilities	—
Guangdong	3 categories 31 scenes	—	—

④ Infrastructure

Upgrading scenarios mainly focus on bridge and tunnel operation and control. Including bridge and tunnel safety improvement (Zhejiang Province), infrastructure status monitoring and intelligent management (Gansu Province), infrastructure management, smart bridge, smart tunnel (Henan Province), smart tunnel (Hebei Province), bridge and tunnel operation control facilities (Guizhou Province), etc.

(2) Efficiency

① Traffic control

As shown in Table 6, traffic control includes lane-level traffic control, including main line control, ramp control, and ramp diversion service functions, layout requirements.

② Active management

That is active traffic control. Shandong Province, Beijing, Sichuan-Chongqing and Guangdong Province have all put forward requirements.

③ Platooning

It mainly include truck platooning, cargo transportation control, special vehicle control, and important operating vehicle control.

(3) Green

It refers to the requirements of green energy, including energy management (Beijing), condition monitoring and intelligent operation and maintenance of mechanical and electrical facilities (Gansu Province), energy monitoring and management (Henan Province), new energy application, energy conservation and carbon reduction measures (Guizhou Province).

(4) Convenience

① Information services

As shown in Table 7, information services are divided into two categories, companion information services and travel information release.

Table 6 Comparison of traffic control requirements of construction guides by province and city

Provinces	Traffic Control	Requirements
Zhejiang	Lane-level traffic control	Traffic control requirements, equipment layout requirements
Jiangsu	Lane-level service	Main line control, ramp control, and ramp shunt and merge service functions, layout requirements
Beijing	Lane-level service	Functional requirements for main line lane guidance and ramp diversion area guidance
Sichuan-Chongqing	Lane-level control	Functional requirements for lane-level control and active traffic control
Yunnan	Lane-level traffic control	Functional requirements, construction requirements
Gansu	Lane-level service	Control sign laying requirements
Henan	Lane-level control and service	Functional requirements
Shanghai	Dynamic lane control, smooth speed limit adjustment, and coordinated control of entrances and exits	Functional requirements
Guangdong	Congestion section management	Measures to control congested road sections
Guizhou	Lane-level traffic control	Functional requirements

Table 7 Comparison of information service requirements of construction guides by province and city

Provinces	Companion information services	Travel information release
Zhejiang	Information release content, timeliness, release method requirements; Facility layout requirements	—
Jiangsu	—	Smart information board, Internet
Shandong	Application points	—
Beijing	Requirements for smart information boards, intelligent calls, Internet, FM broadcasting, and vehicle intelligent terminals	
Sichuan-Chongqing	Simple requirements	—
Yunnan	Functional requirements	—
Gansu	—	Content timeliness requirements, release method requirements, and smart information board layout requirements
Henan	—	What to publish, how to publish it
Hebei	Technical requirements for transportation service systems	—
Shanghai	Application capability requirements at the road network, region, or segment level	—
Guangdong	—	Beidou navigation application requirements
Jilin	—	Travel Service Requirements
Guizhou	Regulations on the construction of location based travel service facilities	Intelligent application functions and regulations of travel services

② Service area

All provinces and cities have put forward functional requirements for smart service areas, and build expressway service areas that provide users with intelligent services such as vehicle services and travel information services.

(5) Toll collection

① Free flow toll collection

On toll roads without physical isolation facilities, electronic toll collection technology is used to automatically complete the toll processing of free-moving vehicles on multiple lanes, also known as multi-lane electronic

toll collection method or all-electronic toll collection method.

② Online toll collection

It is current method in China. Including toll collection, toll management (Beijing), smart toll operation (Yunnan Province), cloud toll collection, online toll audit and credit management (Gansu Province), online toll management, smart toll station (Henan Province), ETC network toll collection (Shanghai), toll station congestion control, toll audit, ETC extended application (Guangdong Province), intelligent charging, charge management (Guizhou Province), etc.

5 Conclusions and Recommendations

(1) All guides set out corresponding construction requirements at 5 different layers. ① Covering the perception layer of expressway main body and ancillary facilities monitoring, traffic operation status monitoring, expressway meteorological environment monitoring. ② Covering the support layer of communication system, power supply and distribution system, information security and other systems. ③ Cover the data layer of high-precision maps and big data centers. ④ Computing layer covering cloud control platform, intelligent middle platform and edge computing. ⑤ Application layer covering safety, efficiency, green, convenience, toll collection, etc.

(2) With the process of expressway intelligence, different provinces and cities have also shown different points. There are differences in functional requirements, performance requirements, layout requirements, construction requirements, etc.. Due to the influence of the smart expressway pilot project carried out by the province, there are inconsistencies in the details of the technical and construction understanding of different levels of the overall framework. The complex interconnection poses a challenge to the seamless integration and large-scale development of the future smart expressway system's "point-line-surface" infrastructure.

(3) Need to track whether the guide is actually being used. We cannot blindly guide for the sake of guide, fall into a passive, involuted release guide, and ignore its real role after release. It is urgent to build a smart expressway system framework and standard system with broad consensus, interoperability, scalability and upgradeability on the basis of extensive consulting and research, so as to promote the healthy development of the industry and improve the utilization rate of investment.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

References

[1] ZJ/ZN 2020-01, Guide to the Construction of Smart Expressways (Provisional) [S].

[2] JSITS/T 0001—2020, Technical Guide for Smart expressway Construction in Jiangsu Province [S].

[3] DB37/T 4541—2022, Guide to the Construction of Smart Expressways [S].

[4] BJJT/0060—2021, Guidelines for the Construction of Smart Expressways (Trial) [S].

[5] DB50/T 10001.1—2021 DB51/T 10001.1—2021, Smart Expressway Part 1: General Technical Requirements [S].

[6] DB50/T 10001.2—2021 DB51/T 10001.2—2021, Smart Expressway Part 2: Intelligent Classification [S].

[7] DB50/T 10001.3—2021 DB51/T 10001.3-2021, Smart Expressway Part 3: Code for Roadside Facility Installation [S].

[8] DB50/T 10001.4—2021 DB51/T 10001.4—2021, Smart Expressway Part 4: Data Exchange of Vehicle-road Coordination System [S].

[9] Broadvision Engineering Consultants Co., Ltd. Guide to the Construction of Smart Expressway in Yunnan Province (trial) [S].

[10] Gansu Provincial Department of Transportation. Technical Guide for Smart Expressway Construction in Gansu Province [S].

[11] Henan Provincial Department of Transportation. Technical Guide for Smart Expressway Construction in Henan Province (Trial) [S].

[12] Hebei Provincial Department of Transportation. Smart Expressway Construction Guide (Trial) [S].

[13] Shanghai Municipal Transportation Commission, Shanghai Municipal Road Transport Administrative Bureau. Technical Guidelines for the Construction of Smart Expressway in Shanghai [S].

[14] GDJT 001-07—2022, Guide to the Construction of Smart Expressways in Guangdong Province (trial) [S].

[15] DB22/T 3428—2023, Technical Guide for Smart expressway Construction [S].

[16] JTT52/01—2022, Guidelines for the Construction of Smart Expressways in Guizhou Province (trial) [S].

[17] CEN Yan-qing, SONG Xiang-hui, WANG Dong-zhu, et al. Establishment of Technology System of Smart Expressway [J]. Journal of Highway and Transportation Research and Development, 2020, 37 (7): 111-121.