System architecture and basic platform for intelligent high-speed railway

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Received 12 April 2023
Revised 23 April 2023
Accepted 23 April 2023

Abstract

Purpose – This paper aims to provide top-level design and basic platform for intelligent application in China high-speed railway.

Design/methodology/approach – Based on the analysis for the future development trends of world railway, combined with the actual development needs in China high-speed railway, The definition and scientific connotation of intelligent high-speed railway (IHSR) are given at first, and then the system architecture of IHSR are outlined, including 1 basic platform, 3 business sectors, 10 business fields, and 18 innovative applications. At last, a basic platform with cloud edge integration for IHSR is designed.

Findings – The rationality, feasibility and implementability of the system architecture of IHSR have been verified on and applied to the Beijing–Zhangjiakou high-speed railway, providing important support for the construction and operation of the world's first IHSR.

Originality/value – This paper systematically gives the definition and connotation of the IHSR and put forward the system architecture of IHSR for first time. It will play the most important role in the design, construction and operation of IHSR.

Keywords System architecture, Intelligent high-speed railway, Railway transportation

Paper type Research paper

1. Introduction

High-speed railway (HSR) is an important sign of transportation modernization and a concentrated reflection of a country's industrialization level. China has built the world's largest and most modern HSR network. By means of introduction, digestion, absorption, re-innovation and independent innovation, China has established a complete HSR technology system covering such three fields as engineering construction, equipment manufacturing and operation management (Wang, 2018; Shi & Peng, 2021). The HSR technology in China has generally strode into the top rank in the world and has reached the world's leading level in some fields.

Since the twenty-first century, new-generation information technologies such as BIM, cloud computing, big data, Internet of Things (IoT), 5G and artificial intelligence have witnessed their accelerated development, promoting the digital transformation of traditional industries such as manufacturing, energy, transportation and finance. Railways in major developed countries and regions in the world are actively using new information technologies to make strategic deployments for railway digitalization and intelligence. In order to realize the continuous leadership of China's HSR technology, promote the coordination of the whole life cycle and the whole industrial chain, comprehensively improve the service quality, efficiency, benefits and safety level of China's HSR, the development of intelligent high-speed railway (IHSR) has become an inevitable course (Ma, Li, Ma, & Shao, 2020).

This work was supported by the Science and Technology Research and Development Program of China State Railway Group Co. Ltd. (K2021X010).

Railway Sciences
Vol. 2 No. 2, 2023
pp. 257-272
Emerald Publishing Limited
e-ISSN: 2755-0915
p-ISSN: 2755-0907
DOI 10.1108/RS-04-2023-0017

2. The definition and scientific connotation of IHSR

IHSR is a new-generation IHSR system in which new technologies such as cloud computing, big data, IoT, mobile interconnection, artificial intelligence, BeiDou navigation and BIM are widely used and resources are comprehensively and efficiently utilized to achieve the features presented in Figure 1, namely, the comprehensive perception of information among mobile HSR equipment, fixed infrastructure and internal and external environments, ubiquitous interconnection, fusion processing, active learning and scientific decision-making, and realizing integrated life cycle management (Wang, 2019).

The typical characteristics of IHSR mainly include three aspects:

- Driving business decision-making based on the integration of models and data, that is, supporting the scientific decision-making of HSR construction (manufacturing), operation and maintenance, service, and safety through the integrated application of characterization model, mechanism model and massive dynamic and static data;
- Realizing the life cycle management of infrastructure and equipment, that is, realizing the unified management of the whole life cycle from design and construction (manufacturing) to operation;
- Using intelligent technology to reduce costs, raise efficiency, improve services and ensure safety. IHSR is a means of transport aiming at making travelling "more convenient, faster, safer, more reliable, warmer, more comfortable, more energy efficient, more environmentally friendly, more economical and efficient" by means of the deep integration of intelligent technology with HSR business, instead of the simple accumulation and application of intelligent technology.

3. The system architecture of IHSR

3.1 Dimensional design of IHSR system architecture

IHSR is a complex cyber-physical system covering multiple disciplines, fields and new technologies. Its construction is not accomplished overnight, but needs to be promoted in stages and steps under the guidance of a unified system architecture. The IHSR system architecture is a guiding framework for the construction and operation of IHSR based on the systematic summary of the intelligent innovation practice in Beijing–Zhangjiakou High-Speed Railway and Beijing–Xiongan Intercity Railway, covering the technical system framework, standard system framework and data system framework of IHSR. With the continuous development of technologies and application needs related to IHSR, the IHSR system architecture can be continuously optimized and expanded according to actual needs in the future. The specific content is shown in Figure 2.

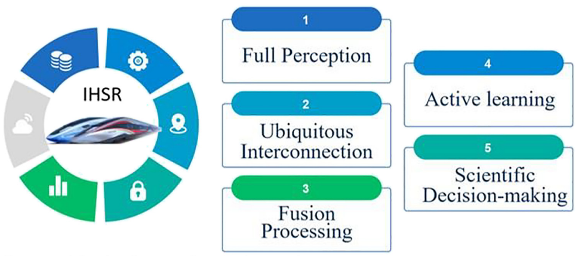

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Figure 1.
The typical characteristics of IHSR

The technical system framework of IHSR is the core of the IHSR system architecture. It defines the technical composition of three sections, namely intelligent construction, intelligent equipment and intelligent operation, and provides guidance for the formulation of the data system framework and standard system framework.

The standard system framework of IHSR provides standard support for the implementation and application of the technical system framework and data system framework in terms of data, technology and management, and defines general basic and management standards, technical standards of IHSR, platform and supporting technology standards, etc.

The data system framework of IHSR defines services such as data collection, storage and analysis, and application display for the data generated by innovative applications of intelligent construction, intelligent equipment and intelligent operation defined in the technical system framework and other related internal and external data, with the life cycle management of data as the focus, to provide data driving for the technical system framework and feedback for the standard system framework.

3.2 Technical system framework of IHSR

The system architecture of IHSR is a systematic, hierarchical and standardized design of the various components and their interrelationships included in IHSR. Based on the principle of classification and hierarchical design, the system architecture of IHSR includes five levels from top to bottom, namely section, field, direction, innovation and support platform, totally involving 3 sections, 10 fields, 18 directions, N innovations and 1 platform (Li, Luan, & Liu, 2022). The detailed composition is shown in Figure 3.

The three sections refer to intelligent construction, intelligent equipment and intelligent operation. Intelligent construction integrates technologies such as BIM, GIS, digital twins, construction robots, automated quality inspection, prefabrication and assembly with advanced engineering construction technologies, achieving refined and intelligent management of the entire process of HSR. Intelligent equipment integrates technologies such as comprehensive situational awareness, autonomous driving, operational control, fault

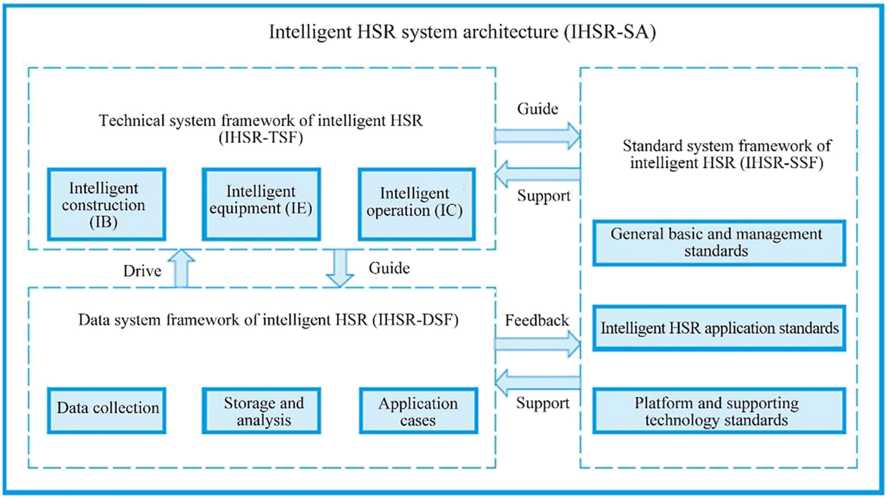

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Figure 2. IHSR system architecture

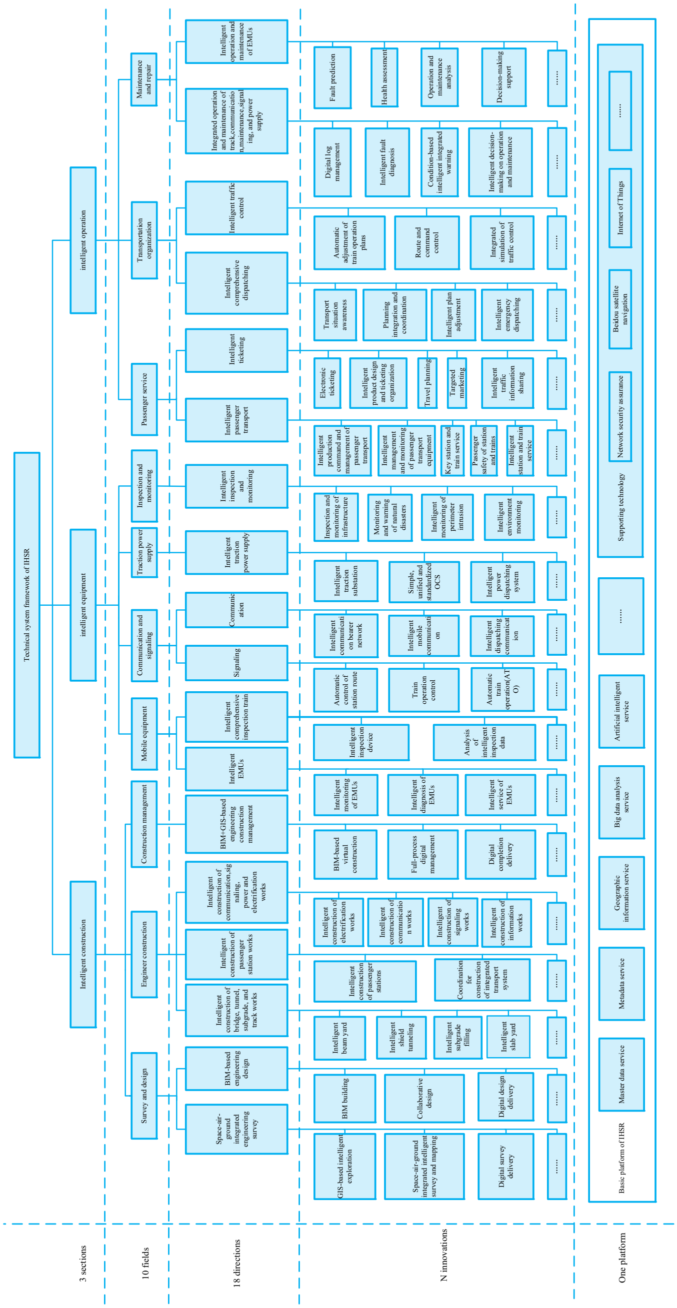

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Figure 3.
The system architecture of IHSR

diagnosis and health management (PHM) with advanced equipment technology to achieve safe, efficient and intelligent management of HSR mobile equipment and infrastructure throughout their entire life cycle. Intelligent operation combines technologies such as ubiquitous perception, intelligent monitoring, augmented reality, intelligent video, accident prediction and smart networking with HSR operation technology to achieve personalized services, predictive operation and intelligent maintenance.

The ten fields refer to survey and design, engineering construction, construction management, mobile equipment, communication and signaling, traction power supply, inspection and monitoring, passenger service, transport organization, maintenance and repair under the framework of three sections.

The 18 directions refer to the innovative application scenarios of intelligent technology and railway service under the framework of three sections and ten fields.

(1) Space-air-ground integrated engineering survey

For HSR engineering survey scenarios, GIS, BeiDou satellite navigation system, aerial photogrammetry, LIDAR measurement and other advanced technology means are integrated applications to achieve space-air-ground integration of geological investigation, drilling and touching. GIS-based technology provides digital elevation model data and 3D display of terrain along the railway line to support the estimation of earth and land volume. The survey and design information related to the construction and operation of HSR will be stored, managed and delivered digitally.

(2) BIM-based engineering design

Build a unified environment for 3D BIM design to carry out collaborative scheme design through video, VR/AR, BIM and other technologies. Form a BIM-based collaborative design system to effectively support the collaborative design of surveying and mapping, railway line, bridge, tunnel, subgrade, catenary system, signal and other professional BIM, and finally achieve the integration of survey and design multisource data (Xie, Ma, & Meng, 2021).

(3) Intelligent construction of bridge, tunnel, subgrade, and track works

For bridges, tunnels, subgrade, tracks and other engineering, the intelligent construction of bridges such as steel beam multipoint synchronous push, automatic state monitoring, factory fabrication of bridge deck structures and prefabricated assembly is achieved through the integrated use of BIM, BeiDou satellite navigation system, image recognition, robotics and other technologies. Realize tunnel intelligent construction such as complex multi-domain construction technology, tunnel structure health monitoring and tunnel visualization management. Realize intelligent construction of railway line such as visualized subgrade filling and intelligent construction robots. Realize intelligent construction of railway track such as sleeper intelligent detection and sleeper industrial Internet production management system (Wang, 2020).

(4) Intelligent construction of passenger station works

Based on BIM technology to realize the deepening design and green design of passenger station decoration, steel structure, electromechanical pipeline, customer service room, etc. BIM + IOT technology is used to realize construction information management of construction raw material traceability and deep foundation pit monitoring, tower crane collision prevention, steel structure welding seams, etc. Build a BIM-based construction organization optimization simulation system to realize construction refinement management (Yao, Shi, & Duan, 2022).

(5) Intelligent construction of railway communication, signaling, power supply and electrification

BIM + GIS technology as the core, RFID electronic tags, two-dimensional code and other IoT technology as a means to achieve data collection and integration of communication, signal, power, electrification and other equipment in the process of design, manufacturing, installation, commissioning and acceptance. Provide information means for the railway communication, signaling, power supply and electrification equipment whole life management. Provide information technology for the whole life management of railway communication, signaling, power supply and electrification equipment.

(6) BIM + GIS-based engineering construction management

Around the HSR engineering construction process, such as human, machine, material, method, environment and other elements, to achieve the digital twin HSR through BIM + GIS-based multisource data fusion and model lightweight technology.

(7) Intelligent EMUs

Based on comprehensive information and situational awareness, automatic driving, operation control, fault diagnosis, fault prediction and health management and other technologies, intelligent monitoring, intelligent diagnosis and intelligent service of EMUs are realized.

(8) Intelligent comprehensive inspection train

Installing railway track, catenary system, wheel–rail relationship, communication, signal detection and comprehensive system equipment to achieve comprehensive inspection train high-speed travel in the process of instant transmission and analysis of detection data can be intelligent perception of HSR infrastructure status.

(9) Signaling

Based on CCTS-3 train operation control system, automatic train operation (ATO) and affiliated equipment are added to realize automatic train driving at 350 km/h. By adding the ground precise location transponder in the train track, the train can stop automatically and accurately. Realize automatic departure, automatic operation, automatic parking, automatic opening, and door and platform door linkage.

(10) Communication

Through intelligent communication network, intelligent mobile communication, intelligent dispatching communication and other technologies, transmission and exchange of various information in the process of HSR construction, operation and maintenance. Provide multimedia, personalized, broadband communication services to satisfy the needs of typical application scenarios (Dong, Li, Sun, & Wang, 2022).

(11) Intelligent traction power supply

Digital equipment is adopted to realize the integrated display, self-healing reconstruction, information sharing and active operation and maintenance of traction substation, improve the operation and maintenance efficiency of traction power supply, and optimize the catenary system from the aspects of system parameters, wrist arm and positioning device, unified material to improve the service performance of parts, anti-loose and anticorrosion.

(12) Intelligent inspection and monitoring

Realize the monitoring, alarm and disposal of natural disasters such as wind, rain, snow, earthquake and perimeter human intrusion events along the HSR, and access to the disaster monitoring center system to realize the intensive configuration of disaster monitoring resources, monitoring information sharing, facility and equipment quality defects diagnosis and state assessment (Yu *et al.*, 2021).

(13) Intelligent passenger transport

The intelligent passenger transport covering "personnel-train-equipment-environment-operation" is constructed to realize the synergy of production and service links of the intelligent railway station, and to provide information support for accurate passenger service, efficient production organization, reliable safety guarantee, green, energy-saving and environmental protection (Li, Li, Dai, Ma, & Li, 2022; Li, Shi, Ma, Yang, & Zhang, 2022).

(14) Intelligent ticketing

Implement comprehensive electronic ticket; Relying on AI, industrial Internet technology, image recognition technology, intelligent semantic analysis and other advanced technologies, passengers can enter and exit the railway station efficiently and conveniently; Combined with group portrait technology, intelligent travel planning and precision marketing for passengers can be realized; Combining with the demand of elastic passenger flow, the passenger train plan is dynamically optimized to realize the dynamic adaptation of the plan; Electronic ticket authentication and mutual recognition across a variety of transportation modes.

(15) Intelligent comprehensive dispatching

Through the comprehensive use of big data, artificial intelligence, network optimization and other technologies, realize the integration of production information, the integrated preparation of transport production plans and the collaborative linkage of operations in all transportation disciplines. Realize the intelligence of perception, decision, manipulation and evaluation of the whole process of scheduling and command. Realize accurate and automatic prediction of transportation situation (Wang, Li, & Yang, 2020).

(16) Intelligent traffic control

Ability to provide matching adjustment strategies for different emergency situations; Expand the existing self-regulatory control conditions and self-regulatory inspection scope of the railway traffic dispatching system; Realize simulation of dispatchers; Realize the expansion of information sharing with professional systems such as passenger transportation, power supply, construction section and rolling stock depot.

(17) Integrated operation and maintenance of track, communication, maintenance, signaling, and power supply

For HSR infrastructure of construction section, electricity and power supply, realize the centralized and unified management of BIM + GIS-based equipment and asset data of maintenance-electricity-power supply infrastructure, and improve the access and processing capability of mobile and fixed facilities and equipment inspection data. Realize quantitative analysis and comprehensive evaluation of integrated equipment unit of maintenance-electricity-power supply; Realize unified management of joint production and scheduling of maintenance-electricity-power supply; Realize intelligent operation and maintenance of integrated maintenance-electricity-power supply based on big data.

(18) Intelligent operation and maintenance of EMUs

By gathering data from EMUs manufacturing, operation and maintenance, automatic equipment testing, EMUs monitoring and operating environment, using data analysis, data cleaning, data fusion, data modeling and deep mining technology to achieve fault prediction, health assessment, operation and maintenance analysis and decision support for EMUs, providing decision basis for EMUs operation and maintenance.

One platform refers to the basic platform of IHSR providing support and services for the technical innovation of IHSR. The basic platform provides master data, metadata, geographic information, big data analysis, artificial intelligence and other services for N innovations in 3 sections (namely intelligent construction, intelligent equipment and intelligent operation), 10 fields and 18 directions, and adopts supporting technologies such as network security assurance, BeiDou satellite navigation and IoT.

3.2.1 Framework of intelligent construction technology system. According to the construction process of infrastructure, the intelligent construction section is divided into three fields, namely, survey and design, engineering construction and construction management.

The field of survey and design includes space-air-ground integrated engineering survey and BIM-based engineering design. The space-air-ground integrated engineering survey mainly includes GIS-based intelligent exploration, space-air-ground integrated intelligent survey and mapping, and digital survey delivery; BIM-based engineering design mainly includes BIM modeling, collaborative design and digital design delivery.

The engineering construction field includes intelligent construction of bridge, tunnel, subgrade, and track, intelligent construction of passenger station, and intelligent construction of communication, signaling, power and electrification projects. The intelligent construction of bridge, tunnel, subgrade and track mainly includes intelligent beam yard, intelligent shield tunneling, intelligent subgrade filling and intelligent slab yard; intelligent construction of passenger station mainly includes intelligent construction of passenger stations and coordination for construction of integrated transport systems; the intelligent construction of communication, signaling, power and electrification projects mainly includes intelligent construction of electrification projects, communication projects, signaling projects and information projects.

The field of construction management includes BIM + GIS-based engineering construction management, mainly involving BIM-based virtual construction, full-process digital management and digital completion delivery.

To sum up, the intelligent construction section can be summarized into 3 fields, 6 directions and 19 innovations, and the innovation content can be expanded as needed in the future. The specific content is shown in Figure 4.

3.2.2 Framework of intelligent equipment technology system. Intelligent equipment can be divided into mobile equipment, communication and signaling, traction power supply and inspection and monitoring according to the classification of main business objects. The field of mobile equipment includes intelligent EMUs and intelligent comprehensive inspection trains. The intelligent EMUs mainly include intelligent monitoring of EMUs, intelligent diagnosis of EMUs and intelligent services of EMUs; intelligent comprehensive inspection train mainly includes intelligent inspection equipment and intelligent inspection data analysis (Wang, 2021a, b).

The communication and signaling field includes signaling and communication. The signaling field mainly includes automatic control of station route, train operation control and ATO; the communication field mainly includes intelligent communication bearer network, intelligent mobile communication and intelligent dispatching communication.

The field of traction power supply includes intelligent traction power supply and others, mainly involving innovations such as intelligent traction substation, simple, unified and standardized OCS and intelligent power supply dispatching system.

The field of inspection and monitoring includes intelligent inspection and monitoring and others, mainly involving inspection and monitoring of infrastructure, monitoring and warning of natural disaster, intelligent monitoring of perimeter intrusion and intelligent monitoring of environment.

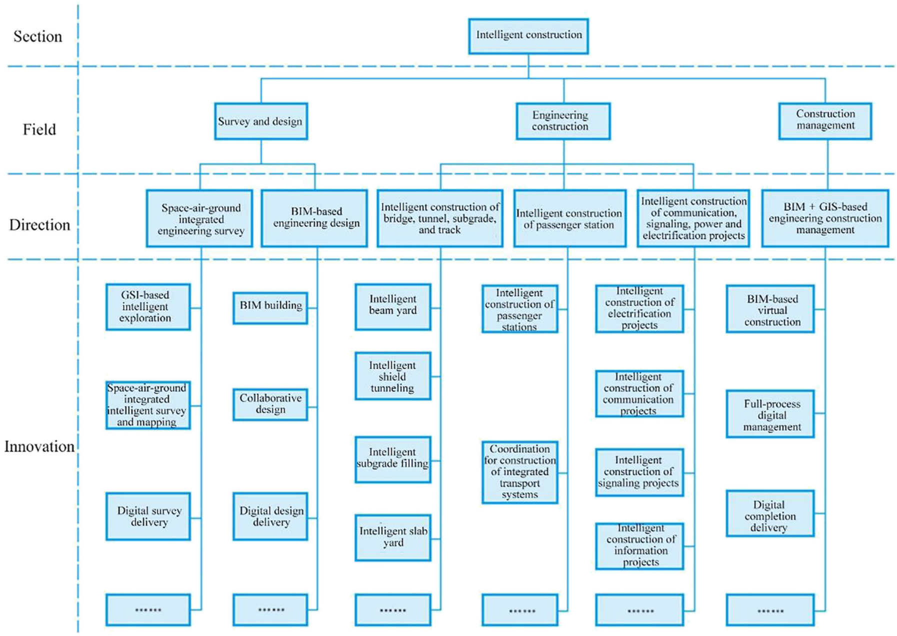

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Figure 4. Framework of intelligent construction technology system

To sum up, the intelligent equipment section can be summarized into 4 fields, 6 directions and 18 innovations, and the innovation content can be expanded as needed in the future. The specific content is shown in Figure 5.

3.2.3 Framework of intelligent operation technology system. The intelligent operation can be divided into passenger service, transport organization, maintenance and repair according to the main business classification of operation (Wang, 2021a, b).

Passenger service includes intelligent passenger transport and intelligent ticketing. The intelligent passenger transport mainly includes integrated production command and management of passenger transport, intelligent management and monitoring of passenger transport equipment, key station-and-train service, passenger safety of stations and trains, and intelligent station and train service; intelligent ticketing mainly includes electronic ticketing, intelligent product design and ticketing organization, travel planning, targeted marketing, and integrated traffic information sharing.

The field of transport organization includes intelligent comprehensive dispatching, intelligent traffic control, etc. The intelligent comprehensive dispatching mainly includes transportation situation awareness, planning integration and coordination, intelligent plan adjustment, and intelligent emergency dispatching; intelligent traffic control mainly includes automatic adjustment of train operation plan, route and command control, and integrated simulation of train operation control.

The maintenance and repair field includes the integrated operation and maintenance of track, communication, signaling and power supply, and intelligent operation and maintenance of EMU. The integrated operation and maintenance of track, communication, signaling and power supply mainly includes digital record management, intelligent fault diagnosis, integrated condition-based warning and intelligent decision-making on operation

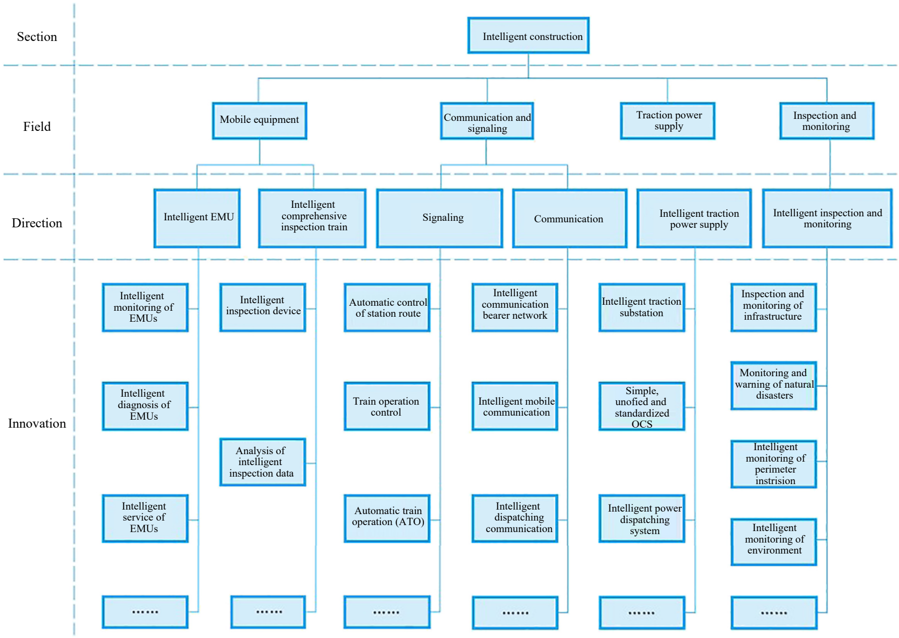

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Figure 5.
Framework of intelligent equipment technology system

and maintenance; intelligent operation and maintenance of EMUs mainly include fault prediction, health assessment, operation and maintenance analysis, and decision-making support.

To sum up, the intelligent operation section can be summarized into 3 fields, 6 directions and 25 innovations, and the innovation content can be expanded as needed in the future. The specific content is shown in Figure 6.

4. The basic platform of IHSR

The basic platform of IHSR provides characterization models, mechanism models, dynamic and static data, and other model-data integration services for N innovations in 3 sections (intelligent construction, intelligent equipment and intelligent operation), 10 fields and 18 directions (Ma, 2022; Li, Li *et al.*, 2022; Li, Shi *et al.*, 2022).

The basic platform is deployed in the mode of cloud-edge collaboration for realizing the collaborative application of the cloud platform deployed in the Main Data Center and the edge platforms deployed in stations, trains and lines. The overall architecture of basic platform of IHSR integrates the physical dimension, management dimension and collaborative dimension, as shown in Figure 7.

(1) Physical dimension

The cloud platform is deployed in the Main Data Center of CHINA RAILWAY for realizing the functions of cloud data access, model management, model-data governance, model-data storage, model-data annotation, model training, model release, model deployment, resource management, cloud-edge collaborative management, cloud task orchestration and scheduling management, etc. The edge platforms are deployed in stations, trains and

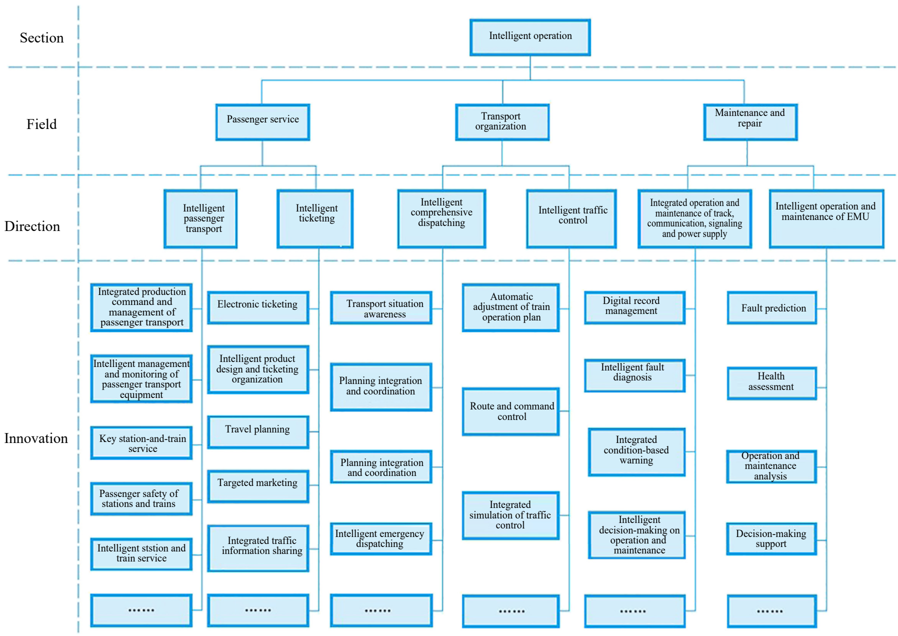

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Figure 6. Framework of intelligent operation technology system

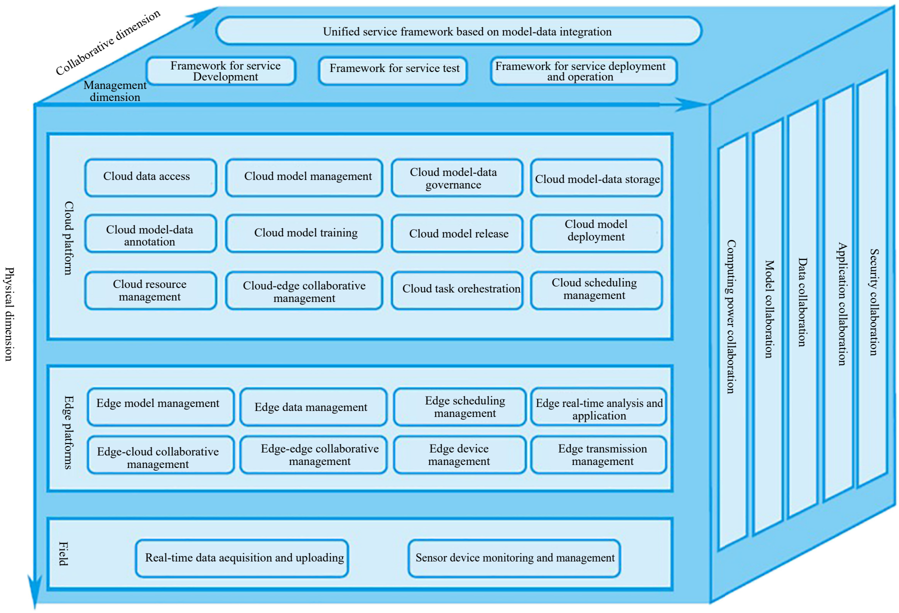

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Figure 7. Overall architecture of basic platform of IHSR

beside tracks, mainly for realizing the functions of edge model management, data management, scheduling management, real-time analysis and application, edge-edge collaborative management, edge device management, transmission management, etc. Field devices mainly include sensor network, the IoT and other kinds of sensor devices deployed in stations and trains and beside tracks, for acquiring data in real time and uploading them to edge platforms and cloud platform.

(2) Management dimension

The basic platform will have a unified service framework based on model-data integration in the whole process of service development, service test, and service deployment and operation, to ensure the consistency of models and data in the whole life cycle. In the platform development stage, ensure that the basic coding, version management and authority design of models and data are consistent, relevant and dynamically related; in the platform test stage, ensure that the model-data integrated storage, model-data fabric and model-data standards are consistent; in the platform deployment and operation stage, ensure that the model and data grow synchronously with the IHSR system and are organically related.

(3) Collaborative dimension

The cloud-edge collaboration mainly realizes the collaboration between cloud platform and edge platforms in terms of computing power, models, data, application and security.

(1) Computing power collaboration. Facing the computing requirements of a variety of complex task scenarios under the cloud-edge collaborative architecture, the cloud platform can allocate the overall computing power resources and provide task processing priority policies for different task scenarios according to their attributes and response requirements. The edge platform automatically identifies and processes the tasks that require high real-time detection but low model computing power. The cloud platform uses large-scale computing power to analyze the tasks that require massive models or data to be processed and high accuracy. In addition, according to the priority policy, tasks with high real-time requirement are prioritized, while non-real-time tasks are processed in idle time, thus the overall computing power resources of the system can be optimally utilized.

(2) Model collaboration. According to the requirements of application scenarios, the cloud platform integrates the real-time data and massive historical data acquired by the field IoT and sensor network, makes them become stable and reliable models through training and optimization, and then distributes these models to edge platforms. Edge platforms complete the model deployment of edges, use models for real-time analysis based on the data acquired by the edge IoT, and upload the analysis results to the cloud platform. The cloud platform continuously optimizes and improves models according to the operation results fed back by models, and distributes the optimized models to edge nodes to continuously improve the accuracy and timeliness of models.

(3) Data collaboration. Edge nodes can effectively acquire data related to production and monitoring generated by IoT terminals, as well as all kinds of data formed during the production, management and operation process, and then locally store the data in a limited space-time range. According to the requirements of task scenario, the edge platform will first use the local data stored in its node for analysis. To achieve data collaboration between the cloud platform and edge platforms, it is necessary to timely schedule the enormous amounts of data stored in the cloud platform for joint analysis

and application when the accuracy is insufficient or more data are required to support the application of the algorithm.

(4) Application collaboration. The cloud platform is responsible for the integration and unified management of different model-data integrated analysis models, provides deployment, invocation and other interface services for edge platforms, supports the rapid deployment of simple and portable applications, such as container images, micro-services and micro-applications on the edges, and provides high-availability guarantee and live migration. In daily application, the cloud platform can continuously enrich the sample library according to the data acquired by edges, and iteratively train the machine learning algorithm model and deep neural network model according to the error loss feedback of the models, thus improving the adaptability of each business scenario and the accuracy of intelligent analysis. Edge nodes have the conditions and operating environment for implementing network applications, and can realize powerful intelligent analysis and fast output response for various terminal applications. In case of downtime of central server or interruption of network transmission, edge nodes can realize closed-loop management to ensure the normal operation of the edge business model, and cooperate with the cloud in upgrading and maintaining the application system.

The deployment architecture of the basic platform of IHSR is shown in Figure 8. The cloud platform, deployed in the Main Data Center of CHINA RAILWAY or the cloud data center of each railway administration, is used to acquire all-discipline models and data from infrastructure, mobile equipment and external environment in the whole life cycle, completes the analysis of compute-intensive and complex scenario requirements, and ensures the safe and efficient operation. Edge platforms mainly include station edge platform, train edge platform and trackside edge platform. The station edge platform is used to monitor the status of station equipment and facilities, carry out integrated analysis of models and data, and guarantee the stations are comfortable, energy-saving and environment-friendly. The train edge platform is used to acquire data from onboard sensors, and study and judge the train operation safety status in real time to ensure train operation safety. The trackside edge platform is mainly used to acquire the status information of infrastructure and mobile

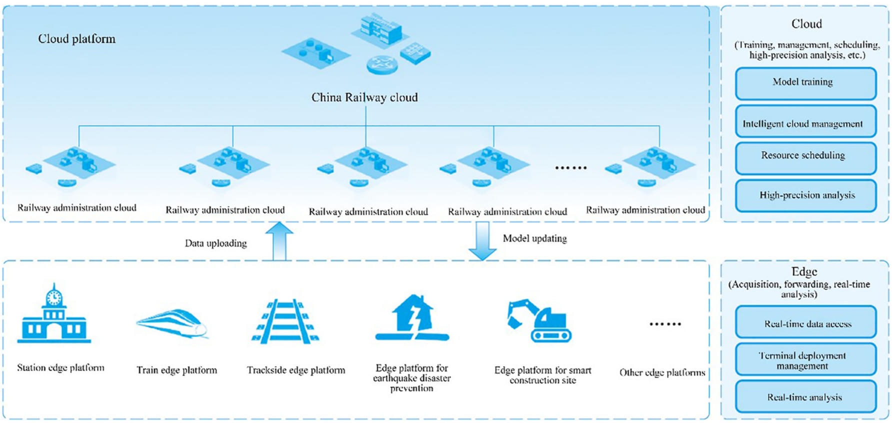

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Figure 8. Deployment architecture of basic platform of IHSR

equipment, and analyze the risks affecting operation safety based on machine vision data and structured data in real time to ensure operation safety.

The hardware configured for edge platforms mainly includes storage computing devices and data transmission devices. The storage computing devices mainly include edge AI computing nodes, edge gateways, edge controllers and store-and-forward devices. The software configured for edge platforms mainly include edge resource management, edge platform management, edge software service management and edge basic platform. Edge resource management mainly includes the local data resources transmitted from field devices, and the models and data resources distributed from the cloud. Meanwhile, edge platforms provide all edges with operating system, device driver and virtual mirror environment, and provide the basic operating environment for all kinds of software services. Edge software services are mainly used for the scheduling management of edge devices and storage devices. The edge basic platform is responsible for the deployment management of specific edge applications and the analysis and processing of models and data.

The hardware configuration type of the cloud platform is basically the same as the functional attributes of edges, but it is more complex in terms of data scale and the corresponding data processing scale. Especially in terms of software configuration, on the one hand, the cloud platform realizes the tasks of application management, data resources, task scheduling and model management, to ensure the execution of the entire cloud-edge collaborative business model; and on the other hand, after the cloud basic platform is configured to acquire and store massive global production data, data storage and management can be realized on the cloud platform, and large-scale AI algorithm model training can be carried out, including data set annotation, model training, model release and model deployment.

5. Conclusion

In 2022, the Winter Olympic and Paralympic Games were hosted in Beijing and Zhangjiakou. In order to ensure the safety, convenience and punctuality of transportation between the two cities and three competition areas, China began construction of the Beijing–Zhangjiakou high-speed railway in 2017. As the first IHSR, 5G, BIM, big data, AI, ATO and other latest technologies are used in its design, construction and operation. Beijing–Zhangjiakou high-speed railway was opened in 2019 and played a critical role in the transportation guarantee for the Winter Olympics.

The latest achievements of IHSR under the guidance of the system architecture are systematically demonstrated in Beijing–Zhangjiakou high-speed railway. In the field of intelligent building, space-air-ground integrated intelligent survey and BIM-based collaborative design have been realized, digital factories such as intelligent beam yard, intelligent track slab yard, intelligent double-block sleeper yard and intelligent machine-made sand processing yard have been built, complete intelligent construction technologies for bridges, tunnels, subgrade, tracks, passenger stations and communication, signaling, power and electrification have been established, and a BIM + GIS-based engineering management platform has been developed and applied. In the field of intelligent equipment, intelligent EMUs with functions such as intelligent driving, intelligent safety and intelligent service have been developed, the automatic driving of 350 km/h high-speed trains based on CTCS3+ATO has been realized for the first time, restrictions have been shattered for new train operation control technology with functions such as moving block and station-area integrated remote control, an intelligent traction power supply system with holographic perception, multidimensional fusion, reconstruction and self-recovery, and intelligent operation and maintenance has been built, an intelligent communication system composed of 5G-R, bearer network and multimedia dispatching communication has been proposed, and an intelligent inspection and monitoring system covering infrastructure, mobile devices, perimeter intrusion, external environment and natural disasters has been established. In the field of intelligent operation, intelligent passenger stations with functions such as automatic information service and intelligent management control have been innovated, an intelligent ticketing system with the characteristics of perceptual automation, service networking and autonomous execution has been developed, key technical problems have been solved for intelligent preparation of train diagram, intelligent centralized traffic control and intelligent comprehensive dispatching, and the intelligent operation and maintenance system of infrastructure, PHM and intelligent operation and maintenance system of EMUs have been built. In terms of basic platform, the first main data center based on cloud computing in the railway industry has been built, the railway data service platform has been developed and deployed, the data lake of "temperature-granularity-sensitivity" integration and the data analysis algorithm of "general-private" combination have been innovated, and the railway BIM service platform has been established.

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