Research on Innovation Strategies and Practice of China iHSR

Ping Li and Hong-fei CAO
China Academy of Railway Sciences Co. Ltd., China

Keywords: iHSR, Development strategy, Innovation practice, CPS.

Abstract. This paper introduces the development status of China Railway and the medium- and long-term railway network plan, analyzes the opportunities and challenges brought by the new technology development to the railway, and combines the factors influencing the development of the world high-speed rail in the 2035 and beyond, and presents the intelligent high-speed rail conceptual model based on the CPS structure. At the same time, the definition, objectives, composition and system structure of China intelligent high-speed railway are put forward. Secondly, this article introduces the innovative practice of China's intelligent high-speed rail, the construction of Beijing-Zhangjiakou high-speed rail and the phased development plan. Finally, based on the Internet of things, mobile Internet, cloud computing, edge computing, data lake and artificial intelligence technology, the construction of intelligent high-speed rail connected by man, station and vehicle is the future development direction of intelligent high-speed rail.

Introduction
Railway is the main artery of the national economy, key infrastructure and major livelihood projects. China attaches great importance to the development of the railway industry. The mileage of railway operation had increased from 22,000 kilometers in the early days of the founding of New China in 1949 to 127,000 kilometers (including more than 25,000 km HSR operation mileage) at the end of 2017. With 2,654 EMUs and 3034 standard trains, China is a country with the longest mileage of high-speed railways and the largest number of EMU trains in the world. China has established a complete high-speed railway technology system. Survey and design, equipment development, construction, personnel training and operation management are all at the international advanced level.

Some typical HSR lines includes: Beijing-Tianjin Intercity High-speed Railway-China’s first railway with a design speed of 350 kilometers per hour and crossing the soft soil area. Beijing - Shanghai High-speed Railway - the railway involving the operation trains with the highest speed during operation tests in the world and with a speed up to 486.1 km/h. Harbin-Dalian Railway -the first railway that traverses the coldest area in the world. Beijing-Guangzhou High-speed Railway -the railway with the longest operation mileage in the world. Lanzhou-Urumqi High-speed Railway -the railway that has the longest one-time construction mileage and crosses the desert and strong wind areas. Hainan Island-looping High-speed Railway - the first island-looping high-speed railway and also the southernmost high-speed railway in the world to date.

More than 5,200 EMU trains run on high-speed railways every day. In 2017, a total of 3.04 billion passengers were transported, of which 1.71 million passengers were transported by high-speed railways, with a year-on-year growth of 18.7%, accounting for 56.4% of the total passengers transported.

China has multiple units with various speed levels from 200 km/h to 350 km/h. For the big MU family featuring the highest number of categories and the most complete spectrum, the world’s advanced technologies have been integrated and high-end products with independent intellectual property rights have been created through digestion, absorption and re-innovation.

In the process of high-speed railway development, China has explored and established a set of high-speed railway safety protection system based on information technology. From the operation monitoring of EMUs to the infrastructure condition monitoring, natural disaster monitoring, perimeter intrusion alarm, and emergency handling, a complete protection system has been formed to ensure the safe and stable operation of high-speed railways.
According to the national medium and long-term railway network plan, by 2020, the high-speed railway will reach 30,000 kilometers, and in 2025, it will reach 38,000 kilometers. The high-speed railway network is basically connected to the provincial capital city and the large and medium-sized cities with a population of more than 500,000 achieving 1 to 4 hours traffic circle, 0.5 to 2 hours living circle within the urban agglomeration. On the basis of the four vertical and four horizontal high-speed railways, a high-speed railway network with the main channels of the eight vertical and eight horizontal railways as the framework, regional connection lines as the links and inter-city railways as supplements will be formed. [1]

Figure 1. National medium and long-term railway network plan.

Opportunities and Challenges of Global Railways

The development of the railway is inseparable from the support of advanced technology, so it is well known that the emerging new technologies will bring new opportunities for the development of high-speed railways. [2] Secondly, high-speed railways face the challenge of providing better services, such as more convenient, more personalized, integrated with other modes of transportation, and providing door-to-door service worldwide. Thirdly, high-speed railways face the challenge of more efficient and greater capacity. In the future, passenger traffic will increase exponentially, requiring high-speed rail to provide more transportation capacity, higher operational efficiency, and lower operation and maintenance costs while ensuring safety. Finally, high-speed railways face more security challenges. High-speed rail operation requires active safety protection, safety factor correlation analysis, cyber and information security, intelligent image recognition, etc.

Figure 2. Opportunities and challenges.
According to the predictions of the authorities, there are 4 major factors affecting the development of high-speed rail in the world in 2035 and beyond.

1. The accelerating urbanization process will bring more demands for intercity high-speed rail transportation. The aging population is intensifying and the young labor force is decreasing. There is an urgent need for the intelligence of railway equipment, building and operation.

2. The frequency and intensity of extreme weather events will increase further climate change, high-intensity storms, and sea level rise will have a significant impact on the design, operation and maintenance of high-speed rail infrastructure, increasing the risk of interference and harm to the safety of high-speed rail systems.

3. Global greenhouse gas emission control will be more stringent, and high-speed rail design and operation should consider more about environmental protection.

4. High-speed rail passenger traffic will grow exponentially, requiring high-speed rail to provide sufficient capacity for growing passenger traffic. In addition, passenger demands are diversified, high-ended and personalized.

![Figure 3. Factors affecting the development of high-speed rail.](image)

To cope with these challenges and opportunities facing the current and future global high-speed rail development, the future high-speed rail should be safer, more reliable, more cost-effective, warm and comfortable, convenient and fast, energy-saving and eco-friendly. The next generation of high-speed rail should be smart with brain and capable of sensing, diagnosing, learning, and making decisions like human beings.

Fig. 4 is the conceptual design of the intelligent high-speed railway. The intelligent high-speed railway is the deep integration of the physical high-speed rail network and the digital high-speed rail network. The physical network is a real world composed of multiple visible physical entities such as EMUs, lines, bridges, communications, and power supply. The digital network is an invisible digital world composed of an accurate digital model of the entity, a data-based knowledge discovery system, and a capability output system with self-perceived, self-diagnosing and self-decision. The two spaces guide each other, map each other, interoperate, and deeply integrate. Through the comprehensive utilization of data and knowledge in the digital high-speed rail space, the specific activities of the physical high-speed rail space are guided, and finally a closed-loop system of mutual iteration is formed.
System Architecture of China’s Intelligent High-Speed Railways

Intelligent high-speed railways are the new generation of intelligent high-speed railway systems for which new technologies such as cloud computing, big data, Internet of Things, mobile interconnection, artificial intelligence, Beidou navigation, and BIM are widely used and resources are comprehensively and efficiently utilized to achieve the comprehensive perception, ubiquitous interconnection, fusion processing, active learning and scientific decision-making of high-speed rail mobile equipment, fixed infrastructure and internal and external environment information, and realize integrated lifecycle management. The Features and Goals of Intelligent High-speed Railways are including more convenient and faster, more cost-effective and efficient, more energy saving and environmentally friendly, warmer and more comfortable, safer and more reliable.

The Overall Composition of Intelligent High-speed Railway includes 3 parts: Intelligent construction, Intelligent equipment and Intelligent operation.
Intelligent operation includes 6 parts: intelligent stations, travel services, intelligent dispatching, detection and monitoring, security, operation and maintenance.
Intelligent building includes 3 parts: intelligent building of Passenger stations; bridge, tunnel and tracks; BIM-based building management.
Intelligent equipment includes 4 parts: intelligent EMUs, traction power supply, train operation control, and next-generation communication.
The intelligent high-speed rail brain platform includes big data and AI decision-making platforms.
The architecture of intelligent high-speed railway consists of five layers, from bottom to top they are intelligent sensing layer, intelligent transmission layer, data resource layer, intelligent decision layer and intelligent application layer. [3]

Figure 6. The system architecture of China’s intelligent high-speed railways [4,5].

Innovation Practices of China’s Intelligent High-speed Railways

Beijing-Zhangjiakou high-speed railway is an important guarantee project for the Beijing Olympics in 2022, with a design speed of 350 km/h and a total length of 174 kilometers. Chongli Railway is led from the Xiahuayuan North Station of Beijing-Zhangjiakou High-speed Railway to the Taizicheng Station, with a main line length of 53 kilometers. The total length of the two railways is 227 kilometers. The Innovation Practices includes: intelligent construction, intelligent equipment, intelligent operation.
Intelligent construction includes BIM-based engineering construction management platform, Intelligent construction of bridges of special spans, Intelligent construction of tunnel engineering - Badaling Underground Station, Intelligent construction of tunnel engineering – Qinghuayuan Tunnel, Intelligent construction of subgrade, Intelligent laying of ballastless track, Intelligent construction of passenger stations and etc.

Intelligent equipment includes Intelligent EMU, Independently-developed China Train Control System (CTCS3), Automatic Train Operation (ATO), 4G-based Railway Radio Communication (LTE-R), Intelligent traction feeding - intelligent substation and Intelligent traction feeding - new type of pantograph-OCS system.

Intelligent Operation includes Smart Station, Intelligent Disaster Prevention, Intelligent Detection and Monitoring, Intelligent Integrated Dispatching, Intelligent Ticketing, Intelligent Station Service, Intelligent O&M.

Development Prospects of China Intelligent High-speed Railways

The Development Strategies of China Intelligent High-speed Railway is divided into 2 phases. First phase: Till 2025, The entire industry chain technologies involved intelligent high-speed railway design, building and operation will be developed. It includes 5 aims. BIM-based full life cycle system, Full spectrum of intelligent EMU of self-learning and self-adaption, Unattended train operation of full sensing (Crew on duty, DTO), Intelligent integrated cooperative command for multiple modes of transportation, Passenger travel intelligent service system.

Second phase: Till 2035, upgraded from assistance, the intelligent high-speed railway is fully auto controlled. It also includes 5 aims. Wide application of intelligent construction technology, Self-repairing intelligent EMU, Exploration on unattended train operation (UTO), Theory and technology on intelligent fault tolerance of high-speed railway in extremely complicated situations, Intelligent security system based on new technologies such as quantum and blockchain.

The entire industry chain Technologies involved intelligent high-speed railway design, building and operation will be developed.

2025
- BIM-based life-cycle system
- Self-learning and adaptive pedigree intelligent EMU
- Fully aware of auto driving (Driving duty, DTO)
- Intelligent integrated cooperative command for multiple modes of transportation
- Passenger travel intelligent service system

2035
- Widely used intelligent building technology
- Self-repairing intelligent EMU
- Explore unattended train operation (UTO)
- Intelligent high-speed railway fault tolerance theory and technology in extremely complicated situations
- Intelligent security system based on new technologies such as quantum and blockchain

Figure 7. Route sketch of Beijing-Zhangjiakou high-speed railway.

Figure 8. Development strategies of intelligent high-speed railway.
Based on the IOT, the Internet and the agent technology, the passengers, the high-speed railway stations and trains are fully connected. And through integration of cloud computing and edge computing, big data lake and the AI platform are formed to construct intelligent high-speed railway brain based on Cyber-physical system.

![Figure 9. Intelligent high-speed railway “brain”](image)

Intelligent high-speed railway is the future of railway development, and the ternary human-cyber-physical integration will bring infinite possibilities for the future.

Acknowledgement

This research was financially supported by China Academy of Engineering and China Railway Corporation.

References


