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Key technologies and applications of intelligent dispatching command for high-speed railway in China

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Abstract

Purpose – The intelligent Central Traffic Control (CTC) system plays a vital role in establishing an intelligent high-speed railway (HSR) system. As the core of HSR transportation command, the intelligent CTC system is a new HSR dispatching command system that integrates the widely used CTC in China with the practical service requirements of intelligent dispatching. This paper aims to propose key technologies and applications for intelligent dispatching command in HSR in China.

Design/methodology/approach – This paper first briefly introduces the functions and configuration of the intelligent CTC system. Some new servers, terminals and interfaces are introduced, which are plan adjustment server/terminal, interface for automatic train operation (ATO), interface for Dynamic Monitoring System of Train Control Equipment (DMS), interface for Power Supervisory Control and Data Acquisition (PSCADA), interface for Disaster Monitoring, etc.

Findings – The key technologies applied in the intelligent CTC system include automatic adjustment of train operation plans, safety control of train routes and commands, traffic information data platform, integrated simulation of traffic dispatching and ATO function. These technologies have been applied in the Beijing-

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Zhangjiakou HSR, which commenced operations at the end of 2019. Implementing these key intelligent functions has improved the train dispatching command capacity, ensured the safe operation of intelligent HSR, reduced the labor intensity of dispatching operators and enhanced the intelligence level of China's dispatching system.

Originality/value – This paper provides further challenges and research directions for the intelligent dispatching command of HSR. To achieve the objectives, new measures need to be conducted, including the development of advanced technologies for intelligent dispatching command, coping with new requirements with the development of China's railway signaling system, the integration of traffic dispatching and train control and the application of AI and data-driven modeling and methods.

Keywords High-speed railway, Intelligent dispatching command, Intelligent centralized traffic control, Key technologies and application

Paper type Research paper

1. Introduction

The intelligent railway is the comprehensive application of modern new technologies in the railway field, and it represents the inevitable development direction of railway transportation (Wang, 2018). Currently, China has the longest high-speed railway (HSR) operation mileage, highest transportation density, largest passenger flow and most complex network operation scenarios in the world. By the end of 2022, the total operating mileage of China's HSR has reached 42,000 km, which accounts for about 70% of the HSR length worldwide. China's "Four Verticals and Four Horizontals" HSR network has been established.

The Centralized Traffic Control (CTC) system is a technological equipment used by railway dispatchers in a control center to centrally control signal equipment within a specific dispatching section and directly manage train operations. As one of the important technical equipment of the railway dispatching command system, CTC is widely used in HSR in China and has been promoted in conventional railway. The CTC system is developed based on Dispatch Management Information System (DMIS)/Train Dispatching Command System (TDCS). It has achieved the functions of automatic triggering of station control, automatic routing arrangement and station signaling equipment (e.g. computer interlocking equipment) (Wen, Feng, Hu, Yang, & Tian, 2020).

However, the intelligence level of existing CTC systems is still relatively low, and there are some issues in practical applications (Qiao, 2023). For example, the adjustments of train operation plans are mainly made manually by dispatchers, and the efficiency and optimality of the adjustments are difficult to guarantee. Emergency response on HSRs often requires coordination among multiple railway specialties, including train operation, locomotive, track maintenance, signal and communication and rolling stock. Currently, relying mainly on manual work can result in a high workload for dispatchers and low efficiency in emergency response.

As the nerve center of HSR transportation command, the intelligent CTC system is a new HSR dispatching command system that integrates the widely used CTC in China HSR with the practical service requirements of intelligent railway dispatching (Wang, 2022). The intelligent CTC system is crucial for constructing an intelligent HSR system to improve transportation efficiency, passenger service and operation safety. Building an intelligent HSR dispatching command system is necessary for intelligent HSR traffic management (dispatching) and transportation organization, improving transportation quality, ensuring driving safety and operational efficiency.

The intelligent CTC is divided into three levels according to the intelligence level: Level 1, which achieves functions such as assisting in adjusting train operation plans and safety control of train operations; Level 2, which achieves functions such as automatic adjustment of train operation plans and predicting delays; and Level 3, which achieves functions such as utilizing big data for traffic information and intelligent adjustment of train operation plans (China State Railway Group Corporation Limited, 2019). Currently, level 1 is being developed and applied in practice, while the systems and functions of the other two levels are still under development.

The key technologies applied in the intelligent CTC system include automatic adjustment of train operation plans, safety control of train routes and commands, traffic information data platform, integrated simulation of traffic dispatching and automatic train operation (ATO) function (China State Railway Group Corporation Limited, 2019). Implementing these key intelligent functions has improved the train dispatching command capacity, ensured the safe operation of intelligent HSR, reduced the labor intensity of dispatching operators and enhanced the intelligence level of China's dispatching command system. These technologies have been applied in the Beijing-Zhangjiakou HSR, which is the world's first HSR designed based on the concept of the intelligent railway. It is an important part of China's "Eight Vertical and Eight Horizontal" HSR network and a critical transportation facility for the 2022 Beijing Winter Olympics. The line commenced operations at the end of 2019, providing intelligent transportation services for passengers (Wang, 2021).

In this paper, we first introduce the intelligent CTC system with its system functions and configuration. We then introduce newly added servers, terminals and interfaces. Next, we discuss the five key technologies of the intelligent CTC and review their real-world application. Finally, we provide a conclusion and some prospects.

2. System functions and configuration of intelligent CTC

With the development of emerging technologies such as artificial intelligence (AI), big data, cloud computing, Internet of Things, etc., the intelligent CTC system was developed based on the existing CTC system, with new features and components to meet the requirement of the "Intelligent Railway" (China Railway Corporation, 2016; China State Railway Group Corporation Limited, 2019; Wang, 2018, 2019, 2022; Zhang, Wang, Huang, & Chen, 2021). Compared with the CTC, the intelligent CTC is a supplement and improvement without structural changes to the center, station and network system of the CTC. The system configuration of the intelligent CTC is shown in Figure 1.

The HSR dispatching system is mainly divided into the CTC center system, the CTC station system and the CTC network system. The CTC center system includes supporting systems such as the CTC center dispatching subsystem, query subsystem, operation and maintenance subsystem, simulation and testing subsystem, etc. Other signaling systems, such as Radio Block Center (RBC), Global System for Mobile Communications-Railways (GSM-R) and Temporary Speed Restriction Server (TSRS), are connected through related interface servers. The CTC station system includes equipment such as the CTC station autonomous machine, station terminal, maintenance terminal, network equipment, etc. Station interlocking and Train Control Center (TCC) are connected to the station autonomous machine. The CTC network consists of the Local Area Network (LAN) in CTC centers, the CTC stations and the Wide Area Network (WAN) between them.

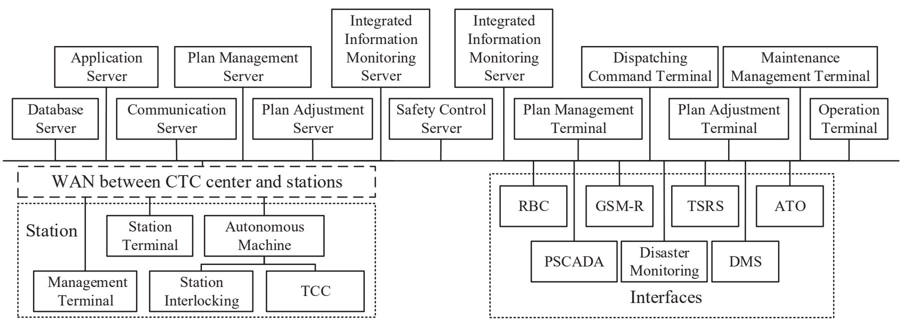

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Figure 1.
System configuration of the intelligent CTC

The intelligent CTC adds some new servers, terminals and interfaces, which are the plan adjustment server/terminal, interface for ATO, interface for Dynamic Monitoring System of Train Control Equipment (DMS), interface for Power Supervisory Control and Data Acquisition (PSCADA), interface for Disaster Monitoring, etc. These new components further enhanced technologies: automatic adjustment of train operation plans, safety control of train routes and commands, traffic information data platform, integrated simulation of traffic dispatching and ATO function. As a result, the CTC's intelligence level has been greatly improved. The functions of the newly added servers, terminals and interfaces are described as follows.

(1) Plan adjustment server/terminal. The plan adjustment server automatically and dynamically generates the train operation plan. The plan adjustment terminal provides the dispatcher with manual access to automatic adjustment.

(2) Interface for ATO. The interface server for ATO is mainly responsible for uploading the adjusted train operation plans to the onboard ATO system and receiving the train operation status information issued by the onboard ATO system.

(3) Interface for DMS. The interface server for DMS receives real-time train information from the DMS system, such as train position, locomotive number, speed, driver name, etc.

(4) Interface for PSCADA. The interface server for PSCADA obtains real-time information on the power supply section provided by the PSCADA system.

(5) Interface for Disaster Monitoring. The interface server for disaster monitoring receives real-time alerts of natural disasters such as wind, rain and snow. It also includes the automatic generation of temporary speed restriction dispatching commands and temporary speed restriction control commands.

The integrated simulation system for train operation is physically isolated from the intelligent CTC system applied in the real world. The simulation system is connected to the intelligent CTC system and related signal systems through independently set hardware simulations. This system aims to familiarize dispatchers with the functions of the intelligent CTC system, standardize operation procedures and improve emergency response capabilities.

3. Key technologies and applications

With the newly added servers, terminals and interfaces, technologies such as the automatic adjustment of train operation plans, safety control of train routes and commands, traffic information data platform, integrated simulation of traffic dispatching, and ATO function have been developed. These have supported the application of the intelligent CTC in Beijing-Zhangjiakou HSR.

3.1 Automatic adjustment of train operation plans

In the daily operation of railways, trains usually run according to original operation plans. However, unforeseen events such as communication interruptions, track circuit failures, severe weather and foreign object intrusions can cause the actual operation of trains to deviate from the planned schedule. In such situations, trains may encounter new conflicts on the operational line, including temporal and spatial conflicts between trains, resource conflicts between trains and equipment, etc. To avoid the propagation of conflicts that can cause widespread train delays, or even severe consequences such as train collisions, and to ensure the safety of train operations while maximizing the operational efficiency of the entire railway network, it is critical to adjust the train operation plans. This process is also known as train timetable rescheduling in academic research.

The influence of train operation under emergency circumstances can be summarized in three aspects, which are influence degree, scope and time (Wang, 2022). The train operation plan will be adjusted according to these aspects. The number and types of affected trains, the range of affected areas and the duration of delays should be determined to obtain an adjusted train operation plan. Different dispatching measures are utilized to adjust the train operation plan, such as retiming, reordering and canceling. Several optimization objectives are considered, such as minimizing the total number of affected trains, minimizing the total delay time of affected trains, etc. The adjusted train operation plan is verified manually by the dispatcher before finally being executed. As a result, the train operation will recover to the original plan with the least deviation. An expert knowledge base for HSR train operation plan adjustments will be established, delays and adjustment plans caused by different factors will be categorized, and adjustment cases and experiences will be accumulated.

In order to solve the problem of operation plan adjustment, it is necessary to confirm the facilities involved in the railway network, traffic state and other information to establish the optimization model. Common models include linear programming, mixed integer linear/nonlinear programming, alternative graph model, etc. (Fang, Yang, & Yao, 2015). The adjustment problem of the train operation plan involves huge variables, multiple objectives and complex constraints, which is NP-hard. For this problem, the common solving methods mainly refers to operation research, intelligent optimization (evolutionary computation) and AI algorithm (e.g. reinforcement learning) (Ding, Zhang, Liu *et al.*, 2022; Ding, Zhang, Wang, & Yuan, 2022; Wang, Zhang, Zhang, Wang, & Ding, 2022; Yan, Zhang, Ding, & Wang, 2022). In order to realize conflict detection and resolution in the dynamic environment, the model and framework of automatic adjustment are constructed. Human interaction is introduced into the intelligent CTC system utilizing human-machine interaction. Human intervention actively adjusts parameters to give satisfactory problem-solving. The framework of automatic adjustment is shown in Figure 2.

During the plan adjustment process, the plan adjustment terminal requests the latest train operation plan from the plan adjustment server and displays it. The terminal automatically checks all conflicts when it detects plan changes and adjusts them according to the adjustment model. In addition, in an emergency, such as a section blockage, speed restriction, or train failure, the dispatcher may set the fault conditions and input the adjustment intention in the plan adjustment terminal, and the system will automatically adjust all subsequent plans. The automatically adjusted plan is returned to the plan adjustment server, which sends the latest adjusted plan to the operation terminal, achieving the goal of automatic adjustment of the train operation plans.

Since the HSR in China is operated as a network, the CTC system conducts the dispatching command of train operations of different sections under jurisdiction. The global adjustment

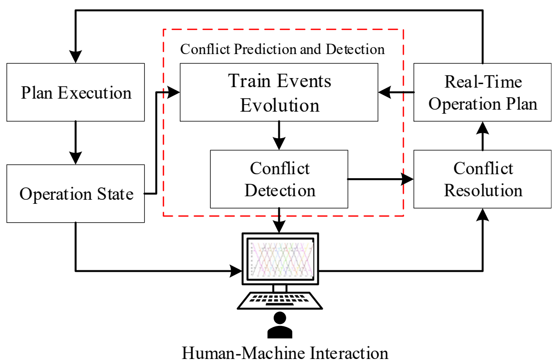

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Figure 2.
Automatic adjustment framework of train operation plans

terminal and global adjustment server are used to achieve global adjustment of the operation plans. The global adjustment database is deployed, and a data check is performed based on the adjacent dispatching consoles' operating line splicing around the global basic train operation plan or daily plan to achieve correct splicing of cross-console operating plan data. When a station or section experiences a sudden failure that is expected to have a significant influence for a long period, and the influence scope is relatively large, exceeding the scope that the train dispatcher can handle, the emergency command center of the railway bureau's dispatching office uses the global adjustment terminal to send the adjusted plans to the affected dispatching stations and neighboring bureaus.

3.2 Safety control of train routes and commands

The management of train operations is a highly safety-related business, which essentially involves planning and reallocating train operation resources under safety constraints. Dispatching must strictly comply with railway regulations and operating procedures in this process. Train operation plans are generated with rigid constraints such as infrastructure and mobile equipment to ensure the safe, reliable and efficient operation of trains. Safety control is carried out from the perspective of the operational process and critical business of the HSR train dispatching command. Based on the safety constraints of the signal system and transportation organization regulations, safety functions such as fixed route control, safety control of station operation, safety control of station tracks fully occupied, optimization control of complex station route triggering, wireless approaching signal for departure route, automatic updating of train number, automatic triggering of siding passing route with manual confirmation, and other safety functions are implemented to ensure the safety and feasibility of the dispatching decisions.

The safety control functions of train routes and commands are briefly described as follows.

(1) Fixed route control. The station autonomous machine obtains the basic train operation plan or daily plan from the plan management server and retains it locally as a fixed route. The fixed route updates with changes in the daily plan in real-time. The system will alarm if the routes of the train operation plan differ from the daily plan.

(2) Safety control of station operation. Some types of station operations are added to the track properties of the station. The system will alarm if the station operations cannot be conducted, including water feeding, sewage suction, boarding/alighting, etc.

(3) Safety control of fully occupied station tracks. The system will alarm when the station tracks are fully occupied during the execution of the train operation plan.

(4) Optimization control of complex station route triggering. The routes for arrival and departure trains at the station will trigger automatically.

(5) Wireless approaching signal for departure route. The approaching signal for the departure route will be automatically sent to drivers. The route signal will send again when the status of the route changes. The system will alarm when the system fails to send the approaching signal for the departure route.

(6) Automatic changing of train number. The train number will be changed automatically with the updated train number in the train operation plans. When a train reaches its terminal and turns back, the system can automatically change the train number based on the train operation plan.

(7) Safety control of dispatching command. The dispatching command will be calibrated and confirmed by both the train and assistant dispatchers.

3.3 Traffic information data platform

Train dispatching command requires comprehensive use of information from multiple railway specialties and dispatching jobs, such as train operation, locomotive, track maintenance, signal and communication and rolling stock. An integrated platform of train operation information with big data is constructed to provide emergency response processes and an integrated display of train operations. Through the deep integration of the CTC system and the integrated platform for railway transportation information, the information sharing and real-time interaction between the CTC and passenger transportation, power supply, construction and disaster prevention systems can be improved to realize the display of passenger tickets, driver and passenger information, automatic control of power transmission, automatic drawing of construction command symbols, automatic extraction of disaster prevention and speed restriction information, etc. The traffic information data platform covers the following aspects.

(1) Integrated management of traffic data. The platform provides functions for querying and editing train names, train attributes, routes, tracks, stations, locomotives, etc.

(2) Process management of emergency response. The platform provides functions for setting and querying emergency handling processes.

(3) Information sharing of passenger transportation. Information such as ticketing (number of passengers, seats) and crew are obtained from the ticketing system.

(4) Information sharing of power supply. Information on the power supply section is obtained by interaction with the PSCADA system. Dispatchers can change the status of the relevant equipment.

(5) Information sharing of disaster monitoring. The platform obtains alarm information for wind, rain, snow and foreign object intrusion provided by the disaster monitoring system. It automatically generates corresponding dispatch commands and system alarms according to the alarm information.

3.4 Integrated simulation of traffic dispatching

The integrated simulation of traffic dispatching for HSR realizes intelligent CTC functional and performance tests, fault analysis, use and maintenance personnel training and other practical application needs. The simulation system facilitates the realization of simulation tests and training goals for traffic dispatching. It also includes scenarios such as scene setting and fault injection in normal, abnormal and emergency situations.

The simulation system provides all functions of the CTC system, including operation plans, dispatching commands, temporary speed restrictions, train number tracking, etc. The station autonomous machines in the simulated train operations of dispatching sections utilize actual software with the same data and configurations as those in real applications. The simulation system connects the simulated computer-based interlocking (CBI), TCC, TSRS, ATO, RBC, GSM-R, etc., with the intelligent CTC system by CTC interfaces.

The simulation system provides the function of train operation simulation. The simulated trains operate based on predefined scenarios. During train operation, corresponding signals are generated and exchanged with connected CBI, TCC, RBC, GSM-R, etc. The simulated trains are automatically generated or manually added based on the train operation plans and move according to the constraints of the signaling system. The velocity of the trains is set as predefined and can decrease automatically based on the speed restriction value. Disruptions and emergency scenarios can also be generated in the simulation system. The simulation of a train's operation status, such as the speed curve, acceleration and current position of the EMU, is achieved through time-based calculations based on the track parameters and the traction and braking performance of the train during the operation simulation. The traction calculation of the EMU is primarily based on the EMU type, calculating the traction, resistance and braking forces to simulate the train's acceleration, steady-state operation, coasting and braking processes. Fault-state simulation is achieved by setting natural disasters, equipment and train failures through human factors to simulate the impact on train operations. Through train operation simulation, the algorithms of train operation plan adjustment and train control can be verified.

The simulation system provides training and examination of traffic dispatching services for dispatchers. Dispatchers can experience the actual operating environment and operate the actual equipment since the software used in the simulation system is the same as those used in real applications. The system can simulate the conversation between dispatchers and relevant personnel, including drivers, signal and communication personnel, track maintenance personnel, duty managers, etc. During the training, dispatchers will practice on normal operations, under actual train operation plans, under disruption and abnormal scenarios, etc. As for examination, when exam questions are selected from the database, the system automatically generates a train timetable and simulates train movements. Basic operations, complex operations and abnormal scenarios are automatically selected for testing dispatchers. The framework of integrated simulation is shown in Figure 3.

3.5 ATO function

The ATO system boasts features such as precise train parking, automatic door opening/closing, train operation according to predefined operation plans, smooth speed control of the train, etc. The intelligent CTC system transmits the train operation plans to the train based on its current position and provides passenger boarding and alighting information. Meanwhile, the intelligent CTC system obtains information on the station platform door status and ATO operation status through interface devices.

The control of train operation based on the operation plans achieves automatic train control through the CTC and ATO interface servers and the GSM-R system. The train operation plans are automatically transmitted to the onboard ATO system, and the trains are running automatically and controlled by the ATO system. The trains are controlled according to the scheduled running time for each section and station stop specified in the train operation plans. The onboard equipment automatically accelerates, brakes and coasts under

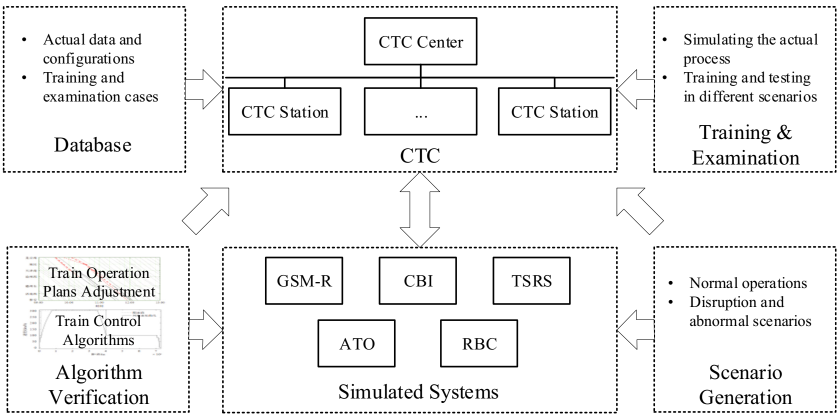

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Figure 3. Integrated simulation framework of traffic dispatching

the train operation plans, achieving precise control of train operation based on the train operation plans and controlling train speed through the operation plan. Through the ATO interface, traffic dispatching and train control are integrated. The performance of the train operation has been improved in terms of safety, comfort, energy saving and punctuality.

3.6 Applications

The intelligent CTC system conducted integrated tests on the Beijing-Shenyang HSR between June and September 2018, successfully completing tests on various aspects such as automatic adjustment of train operation plans, safety control of train routes and commands, traffic information data platform, integrated simulation of traffic dispatching, ATO interface and basic functions of CTC for all scenarios. Later, in December 2019, the Intelligent Beijing-Zhangjiakou HSR implemented the system, achieving the objectives of precise train parking, automatic control of section running speed and smooth train operation.

Intelligent transportation services have been provided for passengers on the line by implementing intelligent dispatching technologies. Applying these series of key intelligent functions has improved the train dispatching command capacity, ensured the safe operation of intelligent HSR, reduced the labor intensity of dispatchers and enhanced the intelligence level of China's dispatching system.

4. Conclusion

The key technologies and application of the intelligent dispatching command of HSR in China have been presented in this paper. With the rapid development of the intelligent railway in China, intelligent dispatching command is receiving increasing attention. The five key technologies of the intelligent dispatching command of HSR, which are automatic adjustment of train operation plans, safety control of train routes and commands, traffic information data platform, integrated simulation of traffic dispatching and ATO function, with the application in Beijing-Zhangjiakou HSR, improve the train dispatching and operation safety assurance capabilities and intelligence level, maintain the advanced level of China's HSR technology internationally and provide support for the construction of intelligent railways. In order to further develop the technologies of the intelligent CTC, some topics and challenges worth further study are listed below:

(1) Advanced technologies of intelligent dispatching command. The current intelligent CTC is still in its initial stage. Those technologies are still in the upgrading process. For example, it is important to make full use of the information obtained from various system interfaces to form a big data platform. Utilization of the information on the big data platform for predicting delays, optimizing and adjusting train operation plans should be fully explored. The development from assisted adjustment of train operation plans to automatic and intelligent adjustment of train operation plans should also be promoted.

(2) New requirements with the development of China's railway signaling system. With the rapid development of railway communication technology, automatic driving technology, autonomous train control, train positioning technology, etc., new systems such as the Next Generation Train Control System and the Future Railway Mobile Communication System have been carried out (Wang, Wang, Roberts, & Chen, 2015; Lin, Ni, & Liang, 2023; Song, Gao, Li, Liu, & Dong, 2023; Hu, *et al.*, 2022). There will be less trackside equipment and the realization of real-time positioning, moving blocks and virtual coupling will improve the capacity of the railway. Besides, the integration of four networks of urban rail (mainline rail network, intercity rail transit network,

city (suburban) railway (rail transit) network and urban rail transit network) is also promoted. These require the intelligent CTC system with new development by developing the corresponding functions and interfaces.

(3) Integration of traffic dispatching and train control. The daily operation of the HSR system can be broadly divided into two core systems, the CTC system and the train control system, to keep its safety and efficiency (Dai *et al.*, 2022). The integration of traffic dispatching and train control is realized by applying advanced perception, transmission, control methods and technologies (Dong *et al.*, 2022). Real-time information and future status can be obtained and the integrated adjustment of train operation plans and recommended train speed trajectories can be generated. It can manage train speeds for punctuality, operation safety, energy saving and comfortability (Peng, Yang, Ding, Wu, & Sun, 2023).

(4) Application of AI and data-driven modeling and methods. AI has become popular in many fields, such as natural language processing, automatic speech recognition, computer vision, etc. (Bešinović *et al.*, 2022). The use of AI technologies in intelligent dispatching command is still in its early stage, which needs further investigation. Meanwhile, with the large amount of data obtained from the system, a more realistic modeling of HSR operation can be formulated, providing more detailed real-time information and prediction of the railway. The system may achieve more advanced functions (Tang *et al.*, 2022). For example, AI and data-driven modeling methods can help handle uncertainties arising from data collection, variation of the data and imperfection of the models. Using neural network models can help formulate intelligent dispatching command generation models (Peng, Hu, & Lu, 2020). In addition, as the conductor of HSR operations, especially in emergency scenarios, dispatchers integrate their intentions and preferences into intelligent dispatching command through AI, achieving human-machine cooperation between dispatchers and the intelligent CTC system.

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