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The Real-time Application Analysis of Highs-peed Train Scheduling System

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Abstract: Based on the scheduling problem of the high-speed train, this study introduces a real-time scheduling model. Combining with the dynamic behavior controlling of train, the feedback of the optimal speed and the algorithm optimization of the real-time scheduling, the feasibility of the model is studied at the end, this study gives the real-time application analysis of high-speed train scheduling system.

Key words: High-speed train, intelligent controlling, real-time scheduling, corrective feedback, speed governing

INTRODUCTION

In recent years, great progress has been made in Chinese railway construction and the growing of high-speed train has pushed new vigor into the national economy. However, the high-speed railway 7.23 events and the high-speed metro rear-end accidents in Shanghai rang the alarm bells-it is of great importance to study how to strengthen the safety of high-speed train scheduling and the real-time response.

Huaping *et al*. (2004) put forward the problem of the multi targets and objects while controlling the running train, made a series of researches on the integration of intelligent control (Huaping *et al*., 2004; Huashen and Junfeng, 2009) studied some key technologies, such as the compatibility of track circuit system and the information transmission of GSM-R in controlling system of high-speed train, the station interval and the Interlocking and Train Controls System (Huashen and Junfeng, 2009); In order to improve the relatively static scheduling model of train operation, (Zhou *et al*., 2011) established an integration model of station and block section (Zhou *et al*., 2011). Such series of researches have an important influence on the controlling system of the high-speed train scheduling. But they neither gave a total discussion on the entire integrated controlling system nor made the practical, systematic and comprehensive analysis on the real-time problem of the intelligent scheduling control of high-speed train.

In this study, the real-time problem of scheduling control of the high-speed train is discussed. Combining with the intelligent controlling and speed governing, this paper gives a real-time controlling system model of high-speed train scheduling through controlling the dynamic behavior and correcting the feedback of the optimal speed.

THE OPTIMIZATION NEEDS OF HIGH-SPEED TRAIN

The more improvement of the trains' speed, the higher requirements of intelligence have been made for the real-time controlling of high-speed train scheduling.

Establishing the rapid response mechanism of high-speed train scheduling: Because of the constraint conditions of the railway lines, the time interval of the high-speed trains' departure shrinks. While the passing rate of the train increases rapidly and it has brought unprecedented challenges for controlling of high-speed train scheduling. According to the traditional scheduling, the train operation is under the control diagram made by the control center. Therefore, when unpredictable conditions happen, it is difficult to change the real-time scheduling control, while there are always the unpredictable risks during the high-speed train operation. How to transfer the scheduling information and feedback accurately in microseconds has become the bottleneck on the safety of high-speed train. To achieve the aim of real-time controlling and quick scheduling of the busy railway

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lines, the safety mechanism of high-speed train must be improved and the controlling mechanism of the high-speed train must be strengthened. Building the real-time response mechanism of high-speed train is in urgent need.

Strengthening the flexibility of the automated scheduling system: The scheduling model needs to be more flexible for high-speed train, while the present scheduling system needs to coordinate the route line and calculate the waiting time at the stations of each train so as to prevent the conflict of train operation in the existing railway lines. Owing to the shorter intervals of every high-speed train, there may be something wrong with the train operation as long as the scheduling system of high-speed train has any deviation, thus, it is crucial to strengthen the real-time character and flexibility of the intelligent scheduling of high-speed train.

Strengthening intelligent control of the train furtherly: The high-speed train needs higher requirements for the train security. The quick response of the controlling system and the flexibility of the automated scheduling of high-speed train have become the main way of the intelligent development of high-speed train. Through the construction of the intelligent information system, enhancing the trains' ability of getting information automatically and strengthening the intelligence of real-time scheduling, the accidents of the highspeed train can be avoided and the safety maintenance of the high-speed train can be strengthened. All these measures can make the highspeed train operation more efficient and flexible.

In conclusion, strengthening intelligent controlling of the train is the kernel of the quick and flexible scheduling of the high-speed train. The basis of enhancing the intelligent controlling of high-speed train is to improve the real-time character of high-speed train. Without, the efficient real-time controlling, the safety performance of high-speed train can't be fully guaranteed. Therefore, the problems of real-time controlling of high-speed train need to be studied in depth.

THE REAL-TIME CONTROLLING MODEL OF HIGH-SPEED TRAIN SCHEDULING

With the development of modern technology, the researches on the scheduling and controlling system of high-speed train are also improving. Honggang *et al.* (2005) proposed a model of high-speed train scheduling based on UML and this model realized the informatization of the scheduling and controlling system efficiently (Honggang *et al.*, 2005). Yong-jun and Lei-shan (2008) solved the scheduling problem of the heavy railway of Qinhuangdao through Decentralized and Autonomous CTC System which gives a guide of developing the intelligent scheduling of high-speed train (Yong-jun and Lei-shan, 2008). Zhou *et al.* (2011) set up the dynamic model of train operation. These models have given certain guidance to the train operation and scheduling system, but most of the researches put weight on the single train system, which did not focus on the problems of the real-time scheduling and intelligent controlling among the high-speed trains.

The background of the proposed model: At present, the maximum speed of Chinese high-speed train has been up to 350 km per h. Moreover the Beijing-Shanghai high-speed railway has the maximum speed of 380 km h^{-1}. The automatic monitoring system, automatic protection system and automatic operation system of high-speed train have developed rapidly. However, there still needs to be improved in coordination aspects. Therefore, the system needs a coordinating security mechanism which can realize the intelligent control of the train interval and train speed, get the present running speed and the current position of the train in time and achieve the real-time control in high-speed train operation (Alhassan and Ben-Edigbe, 2011; Xuedong and Yin, 2011; Xuedong *et al.*, 2011).

Aiming at the existing problems of high-speed train, this study gives a real-time controlling model of high-speed train scheduling. This model combines the scheduling system of the high-speed train with the controlling system. It promotes the quick response of the high-speed train scheduling, improves the intelligent controlling system and enhances the real-time controlling of high-speed train, thus, the safety performance of high-speed train is also further enhanced.

The framework of the model: Combining with the train scheduling and intelligent controlling system, this system model mainly includes the ground equipments, on-board equipments and data transmission channels. The structure of the system model is shown in Fig. 1 and 2.

The ground equipments: The ground equipments are composed of Roving Block Center, Train Control Center, transponder and interface devices of GSM-R. The transponder can transmit located information, parameters of railway line and information of temporary speed limits to the on-board equipments in order to meet the needs of back-up system; Train Control Center has the function of track circuit coding, transponder message storage and transferring circuit status of track interval. According to track circuit status and the information of temporary

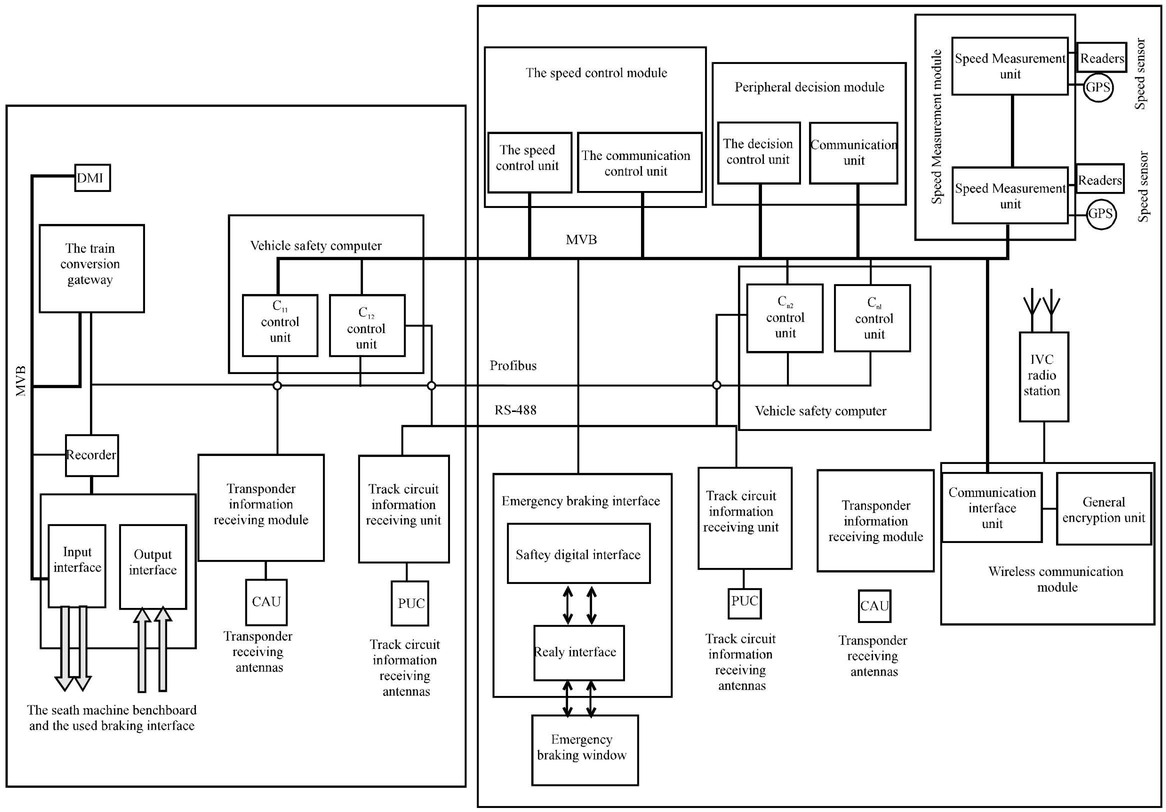

Fig. 1: The system structure of on-board equipments

speed limit, traveling license of the train can be permitted to on-board equipments by the track circuit and wireless devices (Lo and Keh, 2011; Fen-Ling and Dan, 2012).

In this model, the ground control center doesn't calculate the speed that train allows but the status of railway line, the location of running train and the space between the neighboring running trains in the rail are transferred to trains. According to the received information, the maximum speed can be calculated by the on-board computer which is in charge of controlling the speed of the train.

The on-board equipment: The on-board equipments are composed of the on-board computer, wireless communication unit of GSM-R, speed-measuring module, speed-controlling module, record unit, human-machine interface and interface unit of the train. According to the information transferred by the track circuit, the reliable speed commands are provided for drivers to control the actual speed of train. Therefore, the on-board equipment is the core part of the real-time controlling model of the high-speed train scheduling. According to the parameters of railway line and the trains, the temporary speed limit and other information that the ground equipments offers, the on-board computer can generate dynamic speed curves to monitor the safe operation of trains. Speed control module can automatically detect the speed of the nearby train by wireless communication and speed-measuring module. The on-board equipment will activate the speed governing system automatically if there is no manual controlling of the speed. Through the wireless communication with the nearby-running train and base station, the real-time character of the high-speed train scheduling system are further enhanced.

Data transmission channel: Data transmission channel, which is composed of the concentrated-checking communication network, communication network of train control center, communication network of CTC system, MVB and wireless communication network, is the bridge to connect the ground equipments and the on-board equipments. It is also the main way of the communication between the high-speed running trains. Through the technology of radar and GPS, the resources are saved and the precise three dimensional positions, speed of the running train can be continually provided at any time or in any weather condition (Sasikala and Srivatsa, 2006; Viswacheda *et al*., 2007; Salem *et al*., 2011).

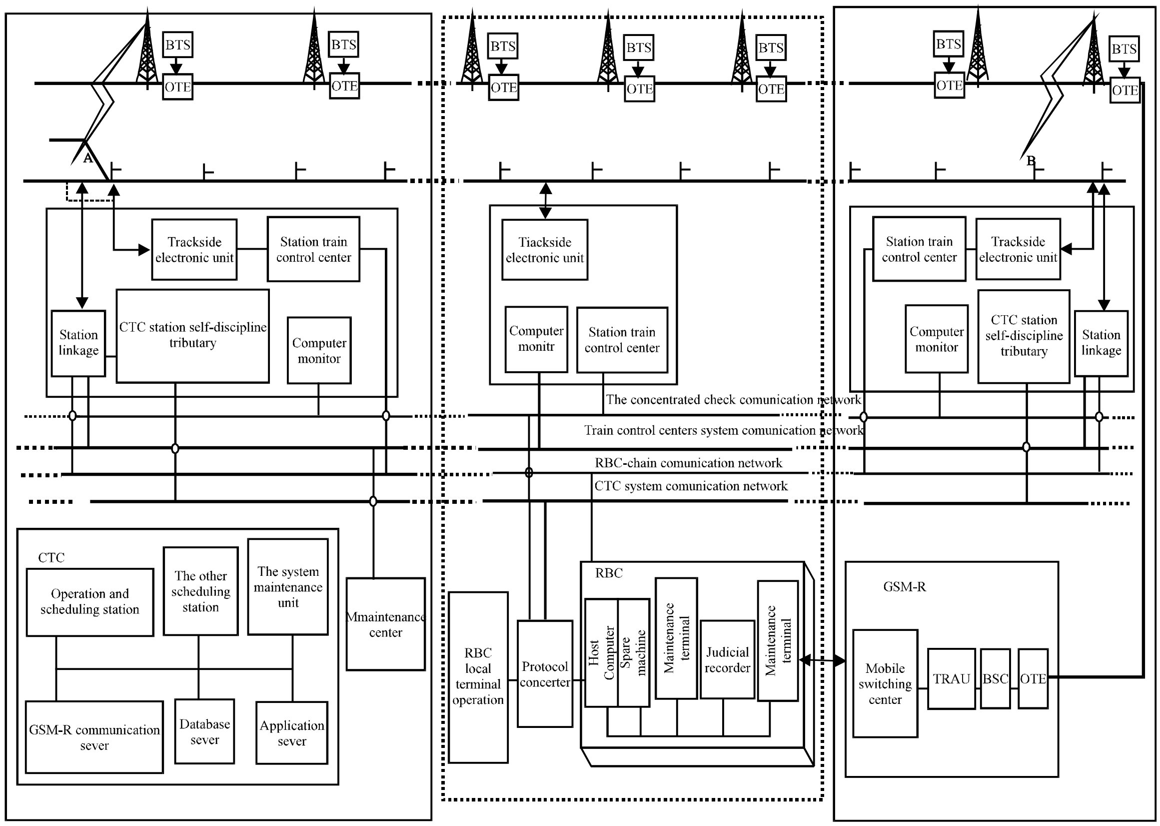

Fig. 2: The system structure of ground equipments

In the model, the operation of the train is controlled by the intelligent control system. When, there is something wrong with the intelligent control system, emergency warning system will be activated and it will adjust the state of the running train automatically and send a warning at the same time. In order to avoid the time consumption of scheduling for the emergency, the model adopts the rolling scheduling strategy which can further improve the real-time character of the high-speed train scheduling system.

THE BASIC THEORY OF THE REAL-TIME SCHEDULING SYSTEM OF TRAIN

The real-time character requires that the control system can make speed adjustments and transmit the related information to the control center rapidly when there is some unpredictable interference, so as to guarantee the safety of the high-speed train. In order to reduce the time consumption of information transmission, combining with the existed scheduling and control system of the high-speed train, the model can predict the running state of train through analysis of the dynamic behavior of train, get the optimal speed by the objective function and enhance the accuracy of speed adjustment through corrective feedback, so as to strengthen the response ability and intelligent control between the trains.

The analysis of dynamic behavior of the train: Usually the status of train operation can be divided into five parts: Starting, accelerating, normal running, decelerating and emergency braking. In the traditional railway system, the running of the train is usually controlled by fuzzy inference which is mostly determined by the driver's operation to control the train through receiving and analyzing the outside information and combining with the common experience. However, the process of train operation is extremely complex. The operation of the train has been affected by many factors, such as emergencies and the conditions of railway line. Therefore, the accurate mathematical model of train operation system is often hard to be established. Thus, the train operation can't be effectively studied in the traditional control theory and it is difficult to realize the high-quality requirements of train scheduling. Limin *et al.* (1996) gave a dynamic motion equation to predict the behavior of the train. It can be described as follows:

$$\frac{dv}{dt} = \varepsilon \times f(n,r,v) = \varepsilon \times \frac{F(n,r,v)}{P+G} \quad (1)$$

where, ε is the acceleration coefficient of the train operation; v is the current speed; n is the control function applied to the train, including traction level and electronic braking level; r is the reduction of train pipe pressure; P is the weight of locomotive; G is the weight of vehicle; f (n, r, v) refers to the unit force of train; F(n, r, v) refers to the resultant force of the train, including traction force of the locomotive, braking force, running resistance and the additional force caused by the environment.

The corrective feedback and optimization algorithm: The real-time scheduling algorithm of high-speed train is essentially an algorithm which needs to select an optimal speed-governing method and mostly related with the correct feedback. The feedback of the actual running status of the train detected by the track circuit can be transmitted by the GSM-R network in time which makes the speed and position of the train more accurate. Therefore, the deviation which is caused by the influence of environment, can be further corrected. For example, the optimal speed calculated by the algorithm is v_1 and then the message of the optimal speed is sent to the CTC system via GSM-R wireless network to implement control commands of the high-speed train. But due to the interference of the external environment, the actual speed of the train only reaches v_2. Because of the limit of the safety braking distance, the actual speed of the train needs to be transmitted to the control center and the related parameters needs to be corrected, so as to enhance the reliability of the model. Therefore, the feedback can guarantee the security of train scheduling.

Zhou *et al.* (2011) put forward the performance index of the optimal scheduling strategy in period T which is the offset value of the future timetable and the default timetable of the train. Because real-time character needs the speed to be improved higher, the speed is applied into the formula. the expression is described as follows:

$$\min J = \sum_i \sum_j w_{i,j} \sqrt{[(t_0 + s/v_1) - (T_{i,j} + s/v_2)]^2 + (t_{i,j} - E_{i,j})^2} \quad (2)$$

where, $w_{i,j}$ expresses the weight coefficient; t_0 and $T_{i,j}$ represents the actual and planning initial time, respectively; s is the distance; v_1 and v_2 are, respectively the actual and planning speed when the train i gets to the station j; $t_{i,j}$ and $E_{i,j}$ are, respectively the actual and planning time when train i leaves the station j; The objective function is to calculate the minimum offset value.

The specific steps of Optimization algorithms are as follows:

- **Step 1:** Detecting the Surrounding potential conflict of train in period T. If there are conflicts in period T, the algorithm turns to Step 2, otherwise the algorithm turns to Step 4
- **Step 2:** Calculating the optimal speed of the train, the main operations of the step are as follows:
  - Saving the current information of the railway network and listing all possible scheduling strategies of the current train
  - According to the different scheduling strategies, calculating the objective function values by formula 2 in order to obtain the offset value J of the future timetable and the fault timetable of the train, and defining an array to store the different return values
  - By comparing the values of the different objective functions, selecting the scheduling solution with the minimum offset value J and adjusting the speed of the train according to the selected scheduling solution
- **Step 3:** Judging whether detections of all surrounding trains are completed in this period. If so, then turn to Step 4, otherwise return to Step 2. According to the default timetable, the detections of other trains are given in this period
- **Step 4:** Updating locating information and running speed of the train
- **Step 5:** Giving the real-time feedback according to the information of the train operation
- **Step 6:** Calculating the value of the objective function and returning the corresponding information of train timetable

The analysis of the algorithm: At present, the research of train scheduling is developed rapidly and the optimization algorithms are also constantly updated with the innovations of technologies. In order to evaluate the potential advantages of the proposed algorithms, we have a further research on the algorithms of FCFS (First Come First Served), FLFS (First Left First Served) and AMCC (Avoid Maximum Current Cost).

The main idea of FCFS is to give priority to the train which first request to reach the block section and FLFS is give priority to the train which first request to leave the block section. They both are the simple scheduling algorithms of the train operation. AMCC is a heuristic algorithm based on global information and the principle of fungibility. The scheduling models of the three algorithms are relatively static which are based on the fixed running time and speed information of the train for scheduling. Actually, the optimization scheduling of train operation often predicts the future information of train travel (Ayanzadeh *et al*., 2009; Baklizi *et al*., 2012).

On the basis of these algorithms, we propose an algorithm which considers the scheduling strategy in the five cases of train running conditions. The dynamic and real-time characteristics of the scheduling model are also enhanced greatly.

CONCLUSION

Through discussing the intelligent control of high-speed train and analyzing the real-time character of train scheduling, this study introduces an intelligent scheduling system model of high-speed train. It strengthens the coordination of the scheduling between trains and the rapid response capability of high-speed train scheduling system and enhances the safety of the high-speed train operation effectively.

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