Scalable Computing: Practice and Experience, ISSN 1895-1767, http://www.scpe.org

Volume 25, Issues 5, pp. 4274–4282, DOI 10.12694/scpe.v25i5.3196

APPLICATION OF PHYSICAL MODELING AND VIRTUAL SIMULATION TECHNOLOGY IN MEASURING THE PERFORMANCE OF SUBWAY TRAIN TRACKING AND OPERATION

XIUXUAN WANG* AND HONGWEI LIANG†

Abstract. The purpose of this paper is to study the application of virtual simulation technology in the measurement of subway train tracking performance. Firstly, the safety braking model required by virtual reconnection technology is discussed around the operation simulation and performance measurement of virtual reconnection. The two trains are combined into "one virtual reconnection train set", the tracking train and the head train run with relative moving block, and the two run with the front train set with moving block. Then, according to the characteristics of Metro train tracking operation, a virtual reconnection model and an improved station tracking model are proposed for the bottleneck area of the station. Finally, the proposed model is verified by numerical calculation and computer simulation modeling. The simulation results reproduce the dynamic characteristics of train flow during metro train operation. The results show that the departure interval and minimum tracking interval of the train are all 58 s. The improved station tracking model has the moderate passing capacity as the relative moving block, and the virtual reconnection model has the largest passing capacity. After the initial delay of the system, the delay recovery ability of the virtual reconnection model is the strongest.

Key words: virtual reconnection, relative moving block, train tracking interval, performance measurement, simulation system, Subway operation system

1. Introduction and examples. Virtual simulation technology is Simulation technology and virtual reality technology combined product. It builds the whole system A complete virtual environment is typically characterized and integrated and controlled through the virtual environment Make a large number of entities. Entities interact in a virtual environment, or with a virtual Environmental effects are the real characteristics of the objective world.Virtual simulation means "true Real people manipulate virtual systems in a virtual environment while conducting simulations, in the most In recent years, the development has been very rapid, and a series of successful in a wider range of fields Apply.

Driven by information technology, simulation technology has developed into a universal and strategic technology for human beings to understand and transform the objective world, which requires it to further absorb and integrate other related technologies on the original basis. Virtual simulation technology is the combination of simulation technology and virtual reality technology. It is typically characterized by a unified and complete virtual environment of the whole system, and integrates and controls a large number of entities through the virtual environment [1]. The interaction between entities in the virtual environment or with the virtual environment is the real characteristics of the objective world. Virtual simulation refers to the simulation conducted by "real people manipulating virtual systems in virtual environment". It has developed very rapidly in recent years and has been successfully applied in a wide range of fields. Metro train operation system can ensure safe and smooth train operation. But it is a systematic process from design, construction to system commissioning, involving large quantities, high investment and complex system. So it is difficult to quickly find and handle problems only by virtue of experience. We combine virtual simulation technology with Metro train operation system to simulate a real subway operation environment on computer, which can be used for train operation control strategy, system integration scheme analysis, key subsystem testing and driving training. It has the characteristics of controllability, safety, repeatability and economy, which is of great significance for urban traffic development [2].

*Zhengzhou Railway Vocational &Technical College, Zhengzhou, Henan, 451460, China (Corresponding author, XiuxuanWang@163.com)

†Zhengzhou Railway Vocational &Technical College, Zhengzhou, Henan, 451460, China(HongweiLiang7@163.com)

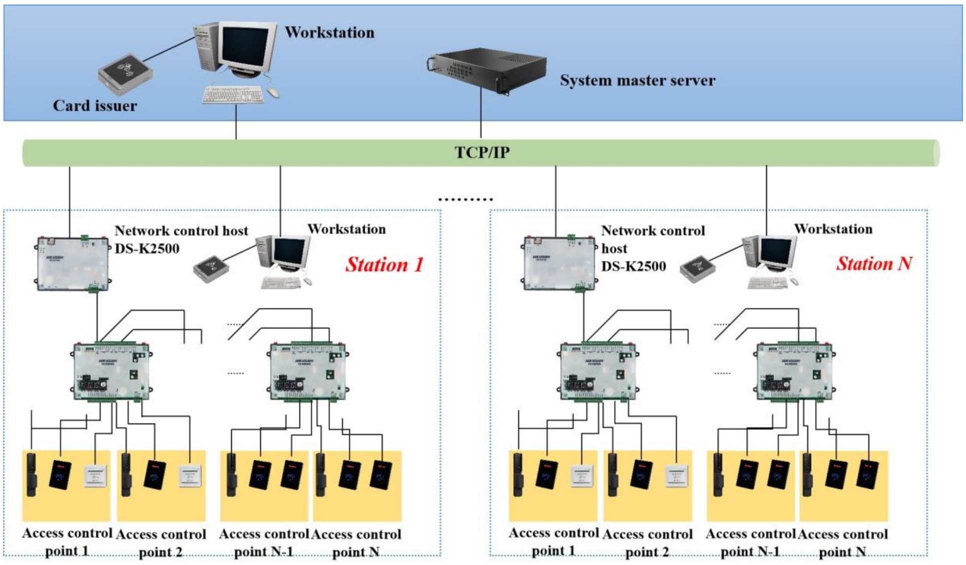

Fig. 1.1: Metro train tracking operation

The subway train operation system can ensure the safe and smooth operation of the train, but it is a systematic process from design, construction to system trial operation, which involves a large amount of engineering, high investment and complex system, and it is difficult to quickly discover and master the problem just by relying on experience.We combine virtual simulation technology with subway train operation system To carry out research, simulate a real subway operating environment on the computer, can It is used for train operation control strategy, system integration scheme analysis, key subsystem test and driving training. It is controllable, safe, repeatable and economical Sex and other characteristics are of great significance to the development of urban traffic.

In terms of the current development of the railway, on the main trunk lines of the railway line, with the increase of speed and traffic density, there will be mixed trains of different speed grades on the line at the same time, and their body weight and speed are different to some extent. Due to the different speeds of trains, it is impossible for trains to operate in an undisturbed environment. In most cases, multi-trains tracking operation with mutual influence (Fig. 1.1).

In this process, the operation of the two trains will affect each other. In case of failure or speed restriction of the current train during operation, the recommended speed curve and train schedule of ATO system are no longer applicable to the following train [3]. At this time, if the following train still operates according to the speed curve generated offline before leaving the station, it may produce unnecessary braking or parking, or even more serious accidents when receiving the fault information of the preceding train. After braking or parking, increasing speed or starting again will produce traction energy consumption, which increases the total energy consumption of the train.

According to the characteristics of section tracking operation, the following train obtains the position, speed and other information of the front train in real time through communication. Therefore, the impact of the front on the following should be taken into account in the energy-saving and optimized driving of the following train. So that it can update its target speed curve in time according to the actual situation, avoiding unnecessary deceleration or waiting. So as to reduce the total energy consumption of the train [4]. When the current train is disturbed during operation and has an impact on the following train, the ATO system of the following train will adjust or re-plan its operation speed curve in real time according to its current information and the information of the front train. It will adopt corresponding intelligent control methods to make the train take the updated speed as the operation basis, reducing delay and unnecessary energy consumption.

2. Literature review. The VR virtual simulation operation system of rail transit trains can help train operators to deal with various emergency situations, such as train accidents, equipment failures and so on. By simulating the actual situation, the operator can be trained in the virtual environment, familiar with the emergency handling procedures and operating procedures, improve the emergency response capacity and processing capacity, and greatly improve the operation safety.The VR virtual simulation operation system of rail transit trains can monitor and analyze the operation of trains in real time, identify potential faults and problems in advance by predicting and analyzing the operation status of trains, help dispatchers make reasonable operation plans and maintenance plans, and improve the reliability and operation efficiency of trains.The traditional training method needs to spend a lot of manpower, material resources and financial resources, and the VR virtual simulation operation system of rail transit trains can be trained in the virtual environment, which greatly reduces the training cost, and can also avoid accidents and losses caused by improper operation.

For this study, considering the constraints such as the actual line condition and speed limit of train operation, Z L *ü* et al. constructed the train operation strategy using genetic algorithm (GA), and gave the form of the optimal solution in ATO system and the minimized energy consumption of train driving control [5]. Liu, Y. et al. use the Lagrange multiplier and maximum principle method to obtain a set of optimal control and control conversion points of the train, and optimize the running time [6]. Song, H. et al. proposed a global optimal driving strategy for the train running on the track with different slopes, and calculated the local optimal switching point on each slope using the principle of local energy minimization. The algorithm can continuously update the optimal speed profile [7]. Considering the utilization of train regenerative braking energy, Zhang, M. et al. proposed a semi-analytical solution to discretize optimization problem of the train energy consumption, and applied the Lagrange multiplier algorithm to solve the speed optimization [8]. Dong, J. et al. proposed a distance based train speed trajectory search method, which uses the speed level of each preset position obtained during operation, and uses the search method combined with ant colony algorithm, GA and dynamic programming to search the train speed [9].

Based on the analysis of train energy-saving operation strategy, Zhanjun, W. proposed a fusion algorithm to optimize the global optimal operation strategy of train. The fusion algorithm is based on energy saving, meets the requirements of passengers, and can obtain the optimal timetable and optimal driving strategy of the train at the same time [10]. For multi train joint control, Li, Z. et al. proposed the corresponding controller and stability criteria. And the stability conditions of the proposed algorithm are given using Lyapunov stability criterion. The controller can use the information of the nearest train to ensure the operation performance of multi-train sequence [11]. Gao, R. et al. mainly studied the absorption of energy consumption generated by train regenerative braking and proposed the method of multi-train combination. That is, the energy consumption generated by the braking of the front train can be absorbed by other trains on the line [12]. Zheng, P. and others mainly used GA and particle swarm optimization algorithm to determine the train speed and minimize the error between it and the actual running speed. At the same time, Kalman filter is used to determine the position of transponder according to the changed parameters. When the transponder position reaches the optimum, the train speed error is also reduced [13]. Aiming at the train optimal control, Zhou, H. et al. firstly analyzed the stress of the train and established the train analysis model. Then, according to the selection principle of optimal coasting point and the energy-saving of regenerative braking, the single train interval operation optimization model and multi-train energy-saving operation model are established respectively. The particle swarm optimization algorithm based on Gaussian white noise disturbance variation is used to solve the above model, and the optimal control strategy of the train in each case is obtained. Finally, the energy-saving adjustment scheme under the condition of train delay is discussed [14].

3. Virtual simulation of train operation system. Scene model is the basis of simulation. Modeling is an essential part in the construction of virtual simulation system which needs to model the physical attributes and motion laws of virtual environment and virtual objects like visual appearance and surface friction. Its purpose is to give drivers and customers a sense of immersion in the actual scene around the current train.

(1) Scene modeling content. The modeling quality of scene model has a direct impact on the analysis and evaluation of the whole simulation system. After a high-quality model runs, users will have a strong sense of immersion [15]. Therefore, the three-dimensional model of subway track and trackside ancillary facilities must

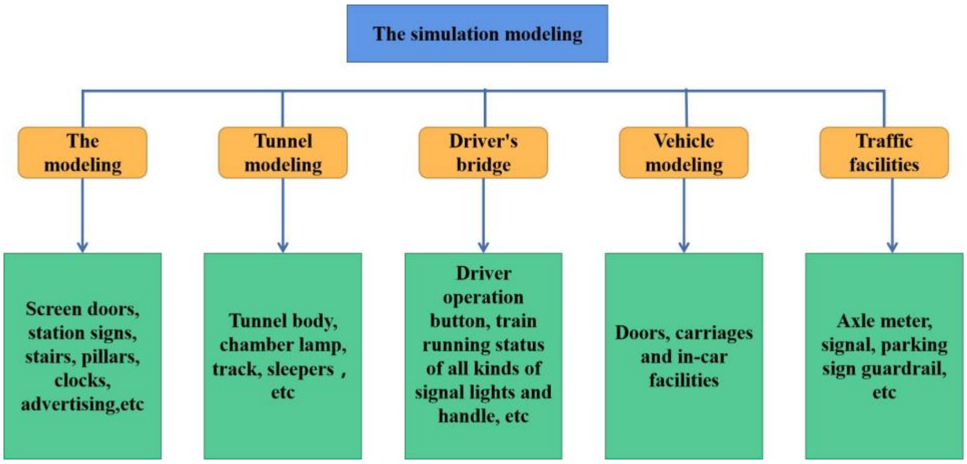

Fig. 3.1: Scene Modeling content

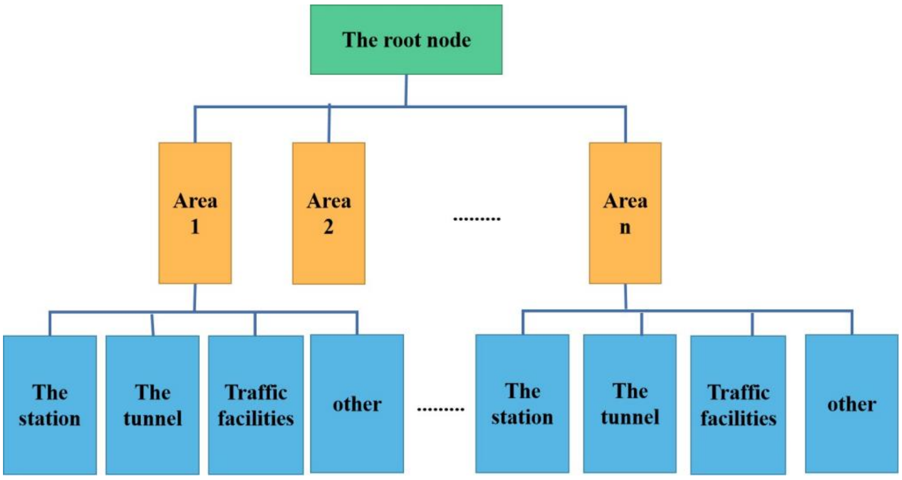

Fig. 3.2: organizational structure of scene model

be established according to the reconstructed line drawings of Beijing Metro Line 2. The design results can be observed and displayed from any angle, so as to realize the roaming function by interactively changing the position of viewpoint or preset motion route. We use the modeling software creator launched by American MultiGen paradise company for modeling. The virtual simulation modeling of the system mainly includes the following six modules, as shown in Figure 3.1.

(2) Organizational structure of the model. The organizational structure of scene model directly affects the operation efficiency of the system. The scene model is generally expressed in a multi-level tree structure. According to the characteristics of banded distribution of subway lines [16], the tree structure based on spatial location relationship is adopted to realize the establishment of scene model. The basic idea is to divide the whole scene into several regions along the line direction, which correspond to the first-level nodes in the scene model tree (Figure 3.2).

The idea of hierarchical modeling method is generally adopted for the modeling of the underlying facilities. It uses the tree structure to represent each component of the object. It not only provides a convenient natural segmentation method, which can arrange various levels of the database from large to small, but also is very

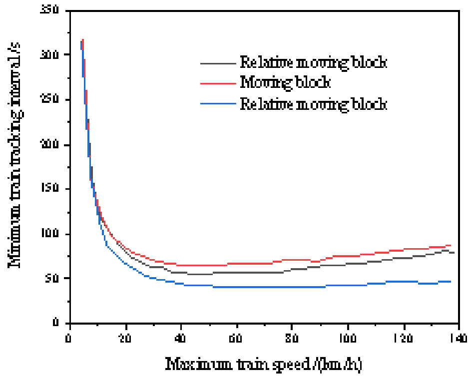

Fig. 4.1: Influence of station tracking interval on maximum operation speed under different tracking modes

beneficial to the modification of complex models [17]. Take the subway station model as an example: the independent modules such as platform, wall, roof, column and annunciator can be placed at the same level, while the stairs can be placed at a lower level than the platform because they are on the platform. The stair nodes include handrails, steps, etc., which are the next node of the stairs. This tree hierarchical scene modeling based on spatial location relationship can quickly realize various convenient operations on the scene model of the specified area from top to bottom, reduce mutual restraint and interference, have clear structure and clear hierarchy, and greatly improve the operation efficiency of the system.

The whole scene is divided into static scene and dynamic scene. The static scene is the fixed part of the scene, and the dynamic scene is the part that changes in the scene. In the simulation process, the dynamic scene should be controlled. The screen door, train door, signal and train operating status indicator in the station are all dynamic scenes, and we need to control them in real time according to the operation of the train, such as controlling the opening of the screen door and the train door, the color change of the signal and the indicator, and the movement of the virtual handle. The control of dynamic scenes can be achieved through the Switch node and DOF provided by Creator.

The system software mainly includes three parts: the model system initialization, the 3D model loading and management and the main program of vision generation.The initial configuration of the model was completed through the Vega graphical interface LynX, and the.adF file was formed. After the initialization work is completed, the virtual simulator loads the required 3D model from the file into the memory, and at the same time reads the signal device description file and determines the state of the device and the position of the moving object to operate the model accordingly.

4. Performance measurement and result analysis.

4.1. Steady state performance measurement. The simulation parameters are set as follows: train length $L_T = 140m$, protection section length, $L_S = 15m$, train starting acceleration $a = 1m/s$, train braking deceleration $b = 1m/s$, braking reaction time $T_R = 3s$ and stop time $T_R = 3s$. Based on formulas 4.1 to 4.4, the relationship between station tracking interval and train speed of moving block, relative moving block, virtual reconnection model and improved station tracking model can be obtained [18]. The simulation results are shown in Figure 4.1.

Under the condition of train tracking operation, the general formula for calculating the passing capacity of the line is:

$$T_1 = \frac{2a(L_T + L_S) + v_{max}^2}{2av_{max}} + T_R + T_D \tag{4.1}$$

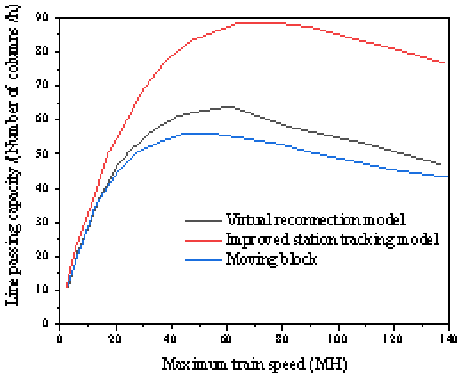

Fig. 4.2: Influence of passing capacity on maximum speed under different tracking modes

Table 4.1: Comparison of station tracking interval and passing capacity under different tracking modes

Block system	The station tracking interval/s	Passing capacity/ (cars/h)
Moving block	60.21	54
Relative moving block	54.35	58
Virtual reconnection model	33.26	86
Improved station tracking model	54.46	88

$$T_2 = \sqrt{\frac{2b(L_T + L_S)}{a^2 + ab}} + T_R + T_D + \frac{v_{max}}{b} \tag{4.2}$$

$$T_1 = \frac{4a(L_T + L_S) + v_{max}^2}{2av_{max}} + T_R + T_D + \frac{v_{max}}{b}/2 \tag{4.3}$$

$$T_4 = T_2 \tag{4.4}$$

$$N = \frac{3600}{t} \tag{4.5}$$

where: N refers to the maximum number of trains that can pass through the line within 1h, t is the minimum tracking interval of the train. The control value of the minimum tracking interval of the train generally occurs during the parking operation of the front train. When multiple trains travel in sequence along the same track and the same direction [19], there must be sufficient tracking interval between the follow-up train and the front train to ensure a certain safe distance between adjacent trains, so as to avoid abnormal braking, parking or collision of the follow-up train. Therefore, the tracking interval of the station is used to calculate the line passing capacity. The line passing capacity ignores many factors affecting the capacity in the actual line operation, so it is only discussed here as the upper bound of the theoretical capacity. The relationship between the line capacity and the maximum train speed under different tracking modes is shown in Figure 4.2.

See Table 4.1 for station tracking interval and passing capacity under different tracking modes when $v_{max} = 72km/h$. It can be seen from Figure 4.1 and Figure 4.2 that the station train tracking interval is not the greater the speed, the smaller the interval, but the minimum tracking interval under a special speed [20]. After exceeding this speed limit, the greater the speed is, the greater the tracking interval will be, and the corresponding

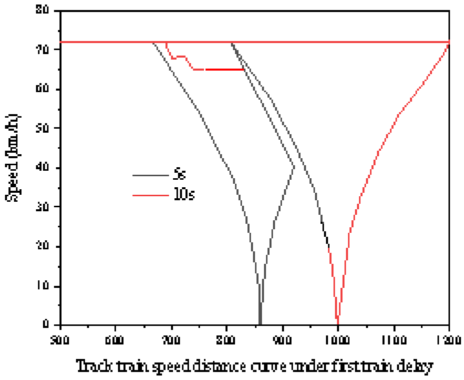

Fig. 4.3: Speed distance curve of tracking train under head train delay

theoretical passing capacity will be smaller and smaller. According to the simulation data in table 4.1, under the same maximum driving speed limit, the tracking interval of the moving block station is the largest, and the tracking interval of the improved station tracking model is the same as that of the relative moving block, while the station tracking interval of virtual reconnection model is the smallest. For the corresponding passing capacity, virtual reconnection model is the largest, the relative moving block is equal to the improved station tracking model, and the moving block is the smallest.

It can be seen that under the moving block system, adding the concepts of virtual reconnection model and improved station tracking model, will theoretically improve the line passing capacity (in the data in Table 4.1, the passing capacity of virtual reconnection model is 64.1% higher than that of moving block, and the passing capacity of improved station tracking model is 11.3% higher than that of moving block). This is only two train formation. If more trains are formed, the line passing capacity will be further improved [21,22,23]. But correspondingly, the train control system will be more complicated.

4.2. Dynamic performance measurement. The simulation scene and simulation parameters of the system are set as follows:$L_T = 140m$, $L = 2000m$. The total evolution time of the system is 2000 s, the acceleration and deceleration of the train are $1m/s^2$, maximum operating speed $v_{max} = 72km/h$, safety interval $L_S = 15m$. The system sets up a station at 1000m in the center, and the parking position of the locomotive in the station is 1000m. In particular, the simulation scene in this paper is that only the storage line and turn back line (or arrival departure site) are set at the end station, one station line is reserved in the upper and lower directions of the section transfer station, and there is no turnout connection with the section main line. Therefore, there is no "station arrival departure interval" at the station.

Figure 4.3 is the speed distance curve of follow-up tracking trains when the initial delay of the first train occurs at the station under moving block (the departure interval and minimum tracking interval of trains are all 58s). As can be seen in Figure 4.3, when the first train has no initial delay, the follow-up tracking train will slow down and stop evenly, and accelerate to leave the station after arriving at the station without interference by the first train [24]. However, when the head train is delayed, the tracking train will deviate from the planned speed distance curve. The longer the head train is delayed, the farther the tracking train deviates from the planned speed distance curve, and even stops outside the station waiting for the outgoing train, which is consistent with the actual situation.

In order to evaluate the delay propagation of initial delay in different systems under different tracking modes, the number of delayed trains caused by initial delay is calculated during simulation. Figure 4.4 is the relationship between different departure intervals and the number of train delays when the initial delay of the first train is 120s.

It can be seen from Figure 4.4 that appropriately increasing the departure interval can effectively reduce

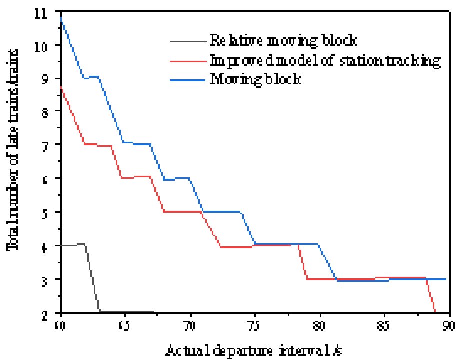

Fig. 4.4: Relationship between departure interval and train delay number under different tracking modes

the number of follow-up train delays caused by the initial delay of the first train [25]. On the premise of a certain actual departure interval, the number of delayed trains is reduced to a certain extent compared with moving block under the conditions of improved station tracking model in most cases. The number of delays in the improved station tracking model is basically the same as that in the relative moving block. The virtual reconnection model has the least number of delayed disturbed trains.

5. Conclusion. Virtual reconnection technology is a technology to control the tracking operation of trains on the track in formation. This technology uses vehicle-to-vehicle communication to coordinate the operation of each train, so as to realize the operation of "safe space dimension and closer time dimension". It improves the flexibility of urban rail transit operation, so as to adapt to the changing traffic demand and improve the passing capacity of the line. Aiming at the bottleneck area of the station, a tracking interval model based on virtual reconnection is proposed: that is, the combination of two trains is "one virtual reconnection train set". The relative moving block is used between the tracking train and the head train, and between the train set and the front train set. Then an improved station tracking model is proposed: relative moving block tracking is adopted only in the station area and moving block tracking is adopted in the section.

Therefore, on the premise of large space in the station platform, the design of virtual reconnection technology for the station area is an effective and feasible method to improve the overall line passing capacity. Under the condition of limited space in the station platform, the improved station tracking model can further improve the line passing capacity. In the aspect of running time optimization, the train running time in the section is only required within the allowable error range. In actual operation, when the train runs in multiple stations (multiple sections), it cannot only ensure that a certain section meets the requirements of operation time, but also need to adjust the overall operation time. For example, when the train runs ahead, it needs to redistribute the excess time. Or when laging behind, it needs to speed up to reduce the delay, Therefore, optimizing the timetable can better achieve the purpose of optimizing the speed of the train. This system can not only meet the needs of the subway train running simulation system, but also provide various reference information for the subway line designers to make decisions about its design. It has high fidelity and credibility to provide drivers with simulation training for driving under various signal systems on different lines.

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Edited by: Bradha Madhavan
Special issue on: High-performance Computing Algorithms for Material Sciences
Received: Jan 17, 2024
Accepted: Mar 26, 2024