Research on High-speed Train Tracking Simulation Based on Multi-Agent

Bingquan Sha, Lei Yuan*, and Guodong Wei

School of Automation and Intelligence, Beijing Jiaotong University, Beijing, 100091, China
*lyuan@bjtu.edu.cn.

Abstract. Based on the multi-agent theory, a multi-train tracking model is established. According to the train control system structure and the high-speed train tracking function requirements, the train agent, RBC agent and station agent functional models are defined, and a blackboard communication mechanism is proposed to realize the train-ground information interaction. By simulating the operation of the train in the Beijing South-Jinan West section of the Beijing-Shanghai High-Speed Railway, the train operation curves at different tracking intervals are obtained. The simulation results show that when the tracking interval is smaller, the train operation is affected by the preceding train, and the operation curve is jagged. Based on the train operation data, the tracking interval time of each section of Beijing South-Jinan West is calculated. The results show that the arrival interval time is the main factor affecting the train tracking interval time. The simulation results prove the effectiveness of the simulation method proposed in this paper.

Keywords: Multi-agent, Multiple train tracking, Quasi-moving block

1 INTRODUCTION

The interaction between the various subsystems in the train tracking process is very complex. It is difficult to accurately describe the train tracking process through analytical methods. Field tests are also very costly in terms of economy and time. Selecting appropriate methods to analyze the characteristics of train operation control systems can help improve the level of train operation safety control and provide support for train tracking interval control calculations [1] and line capacity analysis.

In recent years, many studies have been conducted at home and abroad on train operation simulation: Germany's RailSys[2] train simulation software can simulate train operation and train scheduling. OpenTrack[3] developed in Switzerland is used to analyze, simulate and optimize railway systems. In China, Yuhang Ma [4] developed a high-speed field simulation system for Beijing South Railway Station based on C# to study the train arrival and departure process. Zhongyi Zhu [5] established a simulation model for the tracking interval of mobile, block and quasi-mobile block based on an agent, and quantitatively analyzed the advantages and disadvantages of different blocking methods. Yong Chen [6] et al. established a mobile block train tracking model based on an agent method to analyze the reliability of train scheduling. Hai Zhang [7] established

G. Chen et al. (eds.), *Proceedings of the 2024 International Conference on Rail Transit and Transportation (ICRTT 2024)*, Advances in Engineering Research 254,
https://doi.org/10.2991/978-94-6463-610-9_33

a train station turnaround model based on cellular automata. Existing studies on high-speed railway train operation simulation have little consideration of the characteristics of the train itself, the influence of actual line conditions, and the information interaction between the signal system and the train.

Based on the multi-agent theory, this paper proposes a train tracking simulation method, establishes a vehicle-ground information interaction model and a train agent model to realize train tracking operation control. The method proposed in this paper is used to simulate the train tracking behavior based on the Beijing-Shanghai high-speed railway line data, analyzes the train tracking operation effect at different tracking intervals, and verifies the tracking interval time of the Beijing-Shanghai high-speed railway Beijing South-Jinan West section based on the operation data.

2 TRAIN TRACKING INTERVAL CALCULATION

The train tracking interval is divided into station departure tracking interval, section tracking interval and station arrival tracking interval [8], and the calculation formula is as follows.

（1）Station departure tracking interval

$$I_{dep} = \frac{L_m + L_{th} + L_t}{V_{dep}} + t_{dep} \tag{1}$$

Where: L_m: the distance from the stop mark to the exit signal; V_{dep}: the station departure speed; t_{dep}: the station departure additional time; L_{th}: the throat area length; L_t: the train length。

（2）Section tracking interval

$$I_{\sec} = \frac{L_b + L_s + L_{th} + L_t}{V_{\sec}} + t_{\sec} \tag{2}$$

Where: L_b: braking distance; L_s: safety protection distance; L_b: block section length; $V_{\sec}$: section running speed; $t_{\sec}$: section tracking additional time.

（3）Station arrival tracking interval

$$I_{arr} = \frac{L_b + L_s + L_{th} + L_t}{V_{arr}} + t_{arr} \tag{3}$$

Where: V_{arr}: the running speed of the train when it stops at the station; t_{arr}: the additional time for the train to arrive at the station.

3 MULTI-AGENT TRAIN TRACKING MODEL

Agent-based modeling is divided into environment modeling, agent modeling and operation logic modeling. Environment modeling mainly refers to railway network modeling. Agent modeling establishes train agent, RBC agent and station agent models according to the composition of the train control system and the requirements of train tracking simulation functions. The RBC agent sends MA to the train according to the track occupancy status and station approach status; the train agent receives the MA sent by the RBC agent, and generates a train operation protection curve based on the comprehensive processing of line data. The station agent is mainly used to handle operational scenarios such as train arrival, passing, and departure. High-density train tracking operation can be achieved based on the operation logic and the interaction between agents. Fig 1 is a schematic diagram of multi-agent train tracking.

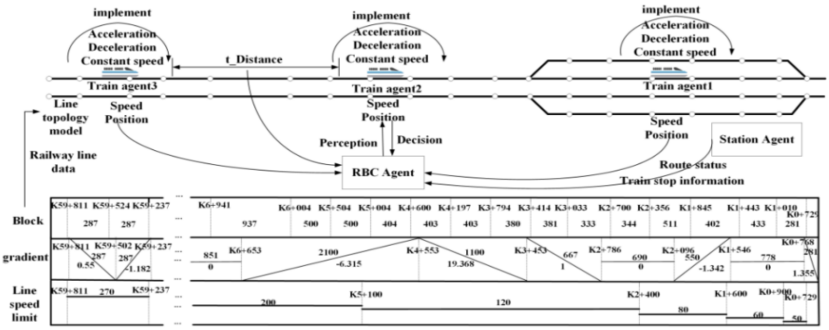

Fig. 1. Schematic diagram of multi-agent train tracking

3.1 Railway Network Modeling

The railway network model is converted into a topological network. As shown in Fig 1, the turnouts are regarded as nodes at the station, and the tracks between the turnouts are regarded as arcs. The demarcation points of two adjacent block partitions in the section are regarded as nodes, and the section tracks are regarded as arcs. When the head of the train reaches a certain arc, it means that the section of the track is occupied by the train until the tail of the train passes the end of the arc and the track is cleared. For specific sections of the actual railway line, the line information is determined. When modeling the railway network, the slope, curve, tunnel and block partition information of the railway line are read into the shared database through an Excel document as line attributes.

3.2 Train Agent Dynamics Model

The most important function of the train agent is to generate the train permissible speed curve based on the control information obtained in real time [8]. The traction braking characteristic curve of the CR400AF EMU is shown in Fig 2. The train acceleration and braking deceleration methods are as follows [9]:

Basic resistance: $W_0 = 4.5 + 0.0146v + 0.000543v^2$ (4)

Additional resistance: $W_i = 1000\tan\alpha = i(N/kN)$ (5)

Train traction acceleration: $TrainAcc = \dfrac{g(fi + W_0 + W_i)}{1000(1+\gamma)}$ (6)

Train braking deceleration: $TrainAcc = \frac{g(b+W_0+W_i)}{1000(1+\gamma)} = a + \frac{g(W_0+W_i)}{1000(1+\gamma)}$ (7)

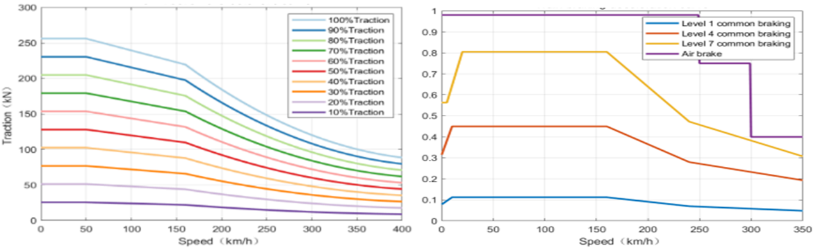

Fig.2. CR400AF traction and brake characteristic curve

Where: i is the converted slope in thousandths, γ is the rotational mass coefficient, fi is the traction force of the train, and b is the braking force of the train.

The vehicle control curve includes two parts: the roof speed monitoring curve and the target speed monitoring curve. The roof area speed is obtained according to the maximum speed limit curve (MRSP):

$$V_{i,p} = MRSP \quad P_{i,p} \in \{P_{i,t}, P_{target} - S_{bi}\} \tag{8}$$

Where: $P_{i,t}$ is the position of the train at time t; P_{target} is the target position of the train; S_{bi} is the braking distance.

The target speed monitoring curve is obtained by reverse calculation from the target point. Based on the time step, the train continuous braking curve is calculated. The train speed change ΔV_p and distance increment ΔS_p within Δt are:

$$\Delta V_p = (a + \frac{g(W_0+W_i+W_r+W_s)}{1000(1+\gamma)}) \times \Delta t \tag{9}$$

$$\Delta S_p = (\frac{500(1+\gamma)(V_0^2-V_1^2)}{1000 \times a \times (1+\gamma) + g \times (W_0+W_i+W_r+W_s)}) \times \Delta t \tag{10}$$

The train braking distance is the sum of the actual braking distance and the idling distance of the train:

$$S_{bi} = V_0 \times t_0 + \sum_{i=1}^{n} \Delta S_p \quad (i = 1,2,3,\ldots,n) \tag{11}$$

According to the braking curve, the discrete points are calculated by reverse calculation. ($V_{i,p}$, $P_{i,p}$)

$$V_{i,p} = V_{i,p-1} + \Delta V_{p-1} \qquad P_{i,p} = P_{i,p-1} + \Delta S_{p-1} \tag{12}$$

Where: $P_{i,0}$:the target position of the train; $V_{i,0}$:the target speed of the train, $V_{i,p}$:the allowed speed of train i at position P; $P_{i,p}$: the position p of train i.

The linear interpolation method is used for curve fitting to obtain the train target speed monitoring curve calculation formula:

$$V_{i,p} = V_{i,p-1} + t \times (V_{i,p} - V_{i,p-1}) \tag{13}$$

$$t = (P_{i,p-1} - P) / (P_{i,p-1} - P_{i,p}) \;\; P_{i,p} \in \{P_{target} - S_{bi}, P_{target}\} \tag{14}$$

3.3 Multi-Agent Communication Mechanism

The RBC agent sends MA to the train according to the occupancy of the block ahead. In the simulation model, the multi-train agent group composed of trains is a distributed structure, as shown in Fig 3(a). If direct communication is adopted, the simulation resources are consumed more and the flexibility is not high. In this study, the train and RBC adopt the blackboard communication mode [10], as shown in Fig 3(b). RBC is regarded as a blackboard, which provides an area for train-ground information interaction. This method can greatly improve the communication efficiency between agents. The train operation data storage module stores the real-time data of the train through Hashmap type variables.

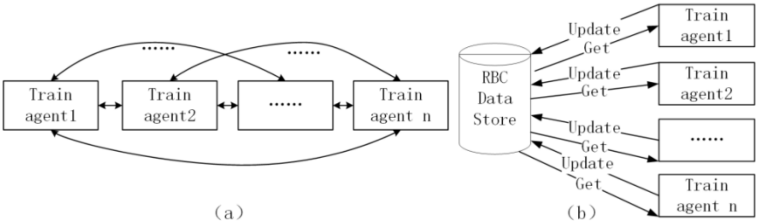

Fig.3. Multi-agent communication mechanism

3.4 Train Tracking Logical Model

The high-speed railway train tracking operation logic is shown in Fig 4. The train operation process is decomposed into three processes: exit, section and entry. The train continuously executes the above three processes and makes operation decisions based on the station's receiving and dispatching orders and the MA sent by the RBC, thus realizing the complete train operation process.

When the train is running, in addition to meeting the speed constraint of the train control curve, it should also meet the tracking interval constraint. The train interval tracking constraints are as follows:

$$P_{i+1,t} + L_b^0 + L_s + L_{add} + L_{bl} \le P_{i,t} \tag{15}$$

$$P_{i+1,t} + L_b^v + L_s + L_{add} \le P_v \tag{16}$$

Where: $P_{i+1,t}$:the position of the rear vehicle at time t, $P_{i,t}$:the position of the front vehicle at time t, P_v :the starting point of the section with a speed limit of v, L_b^0 :the braking distance of the train when it brakes to speed 0, L_b^v : the braking distance of the train when it brakes to speed v.

The station departure constraints are as follows:

$$P_{i+1,t} + L_s + L_{th} + L_{add} + L_t \le P_{i,t} \tag{17}$$

The station pick-up constraints are as follows:

$$P_{i+1,t} + L_b^0 + L_{th} + L_{add} + L_t \le P_{i,t} \tag{18}$$

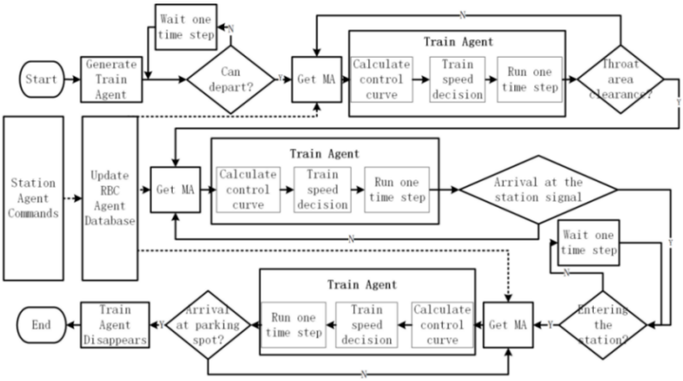

Fig.4. Train tracking operation process

4 SIMULATION VERIFICATION

In order to verify the effectiveness of the multi-agent train tracking simulation model proposed in this paper, this paper uses AnyLogic combined with Java extension programming for simulation modeling. The line data selected for the study is the Beijing-Shanghai High-Speed Railway from Beijing South to Jinan West. The simulation train data comes from the CR400AF EMU, the train length is 209m, and the simulation step is set to 0.5s. The train tracking logic model established based on the above analysis is shown in Fig 5.

Fig 6 is a train tracking operation curve under quasi-moving block system. The train departure intervals are 150s, 180s, and 240s respectively. It can be seen that the front train runs according to the line speed limit; when the tracking interval is large, the operation curve of the rear train coincides with the front train, and when the tracking interval is small, the operation of the rear train is affected by the front train, and the operation curve is sawtooth.

The tracking interval calculated according to the results of the train simulation tracking operation is shown in Table 1. The Beijing South section tracking interval in the table represents the Beijing South - Langfang section tracking interval. As can be seen from Table 1, first of all, by comparing the departure tracking interval, the arrival tracking interval and the section tracking interval, it can be seen that the arrival tracking interval is the bottleneck of the train tracking interval. The design tracking interval of the Beijing-Shanghai High-speed Railway is 3 minutes, but the current station pick-up tracking interval is generally greater than 3 minutes. Reducing the station arrival tracking interval is an important research direction for improving the line's throughput capacity. Secondly, it can be seen that the departure tracking interval of Beijing South is much greater than that of other stations. This is because Beijing South is a double-throat area station, and the departure tracking interval is increased. As the starting station of the Beijing-Shanghai High-speed Railway, Beijing South Station's departure capacity affects the throughput capacity of the entire line.

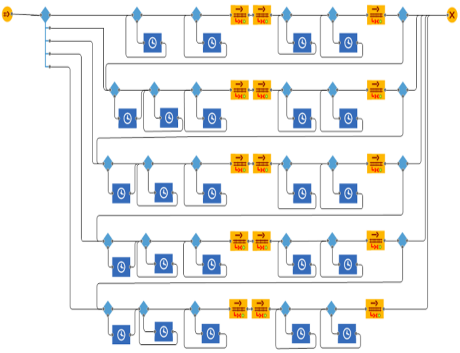

Fig.5. Anylogic train tracking logic model

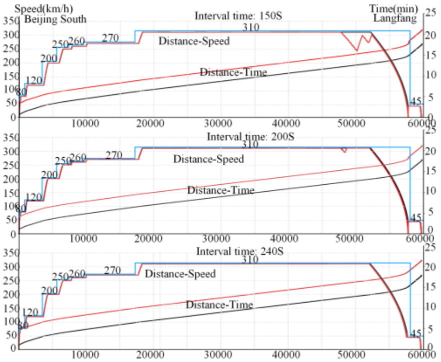

Fig.6. Train running curve

Table 1. Beijing South-Jinan West tracking interval

Time	Beijing South	Langfang	Tianjin South	Cangzhou West	Dezhou East	Jinan West
I_{dep}	185	148	146	143	168	-
I_{arr}	-	227	221	220	219	226
I_{sec}	164	153	159	158	160	-

5 CONCLUTION

This paper applies multi-agent theory to establish a multi-train tracking operation simulation model under moving block, defines the functions of train agent, RBC agent and station agent, and defines the information interaction principle between multi-agents. The train operation process is decomposed into departure, section operation and train reception to achieve multi-station continuous operation of trains. Finally, the system is verified by taking the actual line data of Beijing-Shanghai High-speed Railway as an example. The following conclusions are drawn through the simulation of train tracking operation under quasi-moving block: When the tracking interval is small, the operation of the train is affected by the preceding train, and the operation curve is jagged. The arrival interval of trains at different stations is greater than 3 minutes, which is the main factor affecting the train tracking interval time, that is, the station is the main bottleneck limiting the train's capacity. In view of the saturation of the capacity of some high-speed lines in my country, how to take favorable measures to compress the high-speed railway train tracking interval time, and verify it through the train tracking operation simulation experiment, and study the relevant characteristics of tracking operation, is an important direction for future research and application.

ACKNOWLEDGMENT

Supported by the Fundamental Research Funds for the Central Universities (Science and technology leading talent team project 2022JBXT000) and China State Railway Group Co. Ltd. Science and Technology Research and Development Program Project (L2022X003).

REFERENCES

1. Tian, C.H. (2015). Study on the Train Headway on Automatic Block Sections of HighSpeed Railway. J. China Railway Society,37(10),1-6. doi:10.3969/j.issn.1001-8360.2015.10.001.
2. Jansen, J. (2019). ERTMS/ETCS Hybrid Level 3: A simulation-based impact assessment for the Dutch railway network. D. Delft University of Technology. https://resolver.tudelft.nl/uuid:639015a7-d633-4b73-b782-9b9a153eae11
3. Lordieck, J. Nold, M., & Corman, F. (2024). Microscopic railway capacity assessment of heterogeneous traffic under real-life operational conditions. J.Rail Transport Planning & Management, https://doi.org/10.1016/j.jrtpm.2024.100446.
4. Ma, Y.H. (2022). Simulation study on the arrival and departure process of trains at Beijing South Railway Station. D. China Academy of Railway Sciences. doi:10.27369/d.cnki.gtdky.2022.000030.
5. Zhu, Z.Y., Peng, Q.Y. (2020). Comparative analysis of train tracking interval simulation under quasi-moving block and moving block conditions. J. Railway Economic Research, (06), 27-33. doi:10.3969/j.issn.1004-9746.2020.06.006.
6. Chen, Y., Dang, J.W., & Hu, X.H. (2014). Modeling and simulation of train tracking operation based on multi-agent theory. J. Computer Applications, 34(05), 1521-1525. doi:10.11772/j.issn.1001-9081.2014.05.1521.
7. Zhang, H., Ni, S.Q, & Lv, M.M. (2021). Analysis of subway train turnaround interval based on motivation model. J. Transportation Engineering and Information, 19(02), 37-45. doi:10.3969/j.issn.1672-4747.2021.02.004.
8. Jiang, M., Zhang, W.Q., & Zhang, J.Y. (2023). Decomposition and impact analysis of train tracking interval time. J. Railway Communication Signal Engineering Technology, 20(07), 1-9. doi: 10.3969/j.issn.1673-4440.2023.07.001.
9. Zhuang, H.H., Cui, J.T. (2023). Train traction calculation and simulation. J. Science and Technology and Innovation, (19), 16-18. 10.15913/j.cnki.kjycx.2023.19.005.
10. Li, C. P. (2013). Research on the implementation method of multi-agent system based on blackboard structure. D. Northeastern University. doi:10.7666/d.J0103224.