# A Parallel Intelligent System for Optimizing High-Speed Railway Rescheduling by Learning

Pengxin Yang[1], Dongliang Cui[1], Xuewu Dai[*1], Yisheng Lv[2], Hairong Dong[3], Xinghao Wang[1], Ruiguang Liu[1]

1. State Key Laboratory of Synthetical Automation for Process Industries, Northeastern University, Shenyang, China
2. State Key Laboratory for Management and Control of Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing, China
3. State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China

***Abstract*—The railway system is a complex system because of many constraints, randomness and high security requirements, so it is difficult to establish an accurate mathematical model for it, which brings great challenges to railway scheduling. Parallel intelligence theory can effectively solve the modeling, analysis and control of complex systems, so it has a wide range of applications in the field of intelligent transportation. In this paper, we build an artificial system according to the actual system, and use the surrogate modelling to carry out the calculation experiments, and proposed a parallel scheduling system based on the parallel intelligence method. Select a case to design scenario and perform computational experiment, the scheduling strategy is given and the scheduling strategy is analyzed.**

***Keywords—parallel intelligence, high-speed scheduling system, ACP approach.***

## I. INTRODUCTION

Railway traffic scheduling is a complex system with multiple coupling of sub-systems such as operation control scheduling and interlocking. Especially as the large-scale construction of high-speed railway network, higher demand for railway transport capacity have been put forward. Therefore, train scheduling through intelligent scheduling algorithm has become an important research topic. Because the railway simulation platform can better reflect the real information of the railway, more and more researchers focus on the simulation system of high-speed railway.

Chen *et al*. [1] used Open Track to simulate the Beijing-Shanghai line under different headways, and analyzed the carrying capacity of the line. M. Shakibayifar *et al*. [2] proposed an object-oriented event-driven simulation method for train scheduling, and used variable neighborhood search algorithm to adjust the running order of all trains to address shortage of capacity near the blockage.

In recent years, with the development of Intelligent Transportation System(ITS), a series of theories and methods have been put forward. In order to solve the modeling, analysis and control of complex systems, Prof. F.-Y. Wang proposed the ACP approach[3], which includes Artificial Systems, Computational Experiments and Parallel Execution. ACP approach provides an application platform for all kinds of algorithms in artificial intelligence, and it can provide a solution for complex problems in different fields. So it has a wide range of practices and applications in intelligent transportation, smart city, smart medical care and other fields. Parallel system based on ACP approach also shows obvious advantages in the management and control of high-speed railway system compared to other methods[4]. Ning *et al.* [5] introduced a framework of high-speed railway systems based on ACP method, which use multi-agent to build the artificial system and perform different kinds of computational experiment to obtain control and management strategies applicable to the actual system. Guo *et al.* [6] introduced a calculation architecture for railway emergency management system based on ACP approach and multi-agent modeling method, which provided a solution for the complex problems in emergency management.

## II. ACP FRAMEWORK FOR RAILWAY SCHEDULING (ACP-RS)

The parallel system based on ACP approach mainly includes: 1) using artificial system to model the high-speed railway system;2) conduct several computational experiments based on the artificial system, analyze and evaluate the data of experiments to get a better strategy;3) through the parallel execution of artificial system and the real system, the artificial system parameters are constantly updated to generate better control results. Fig. 1 is the framework of parallel system based on ACP approach, in which the artificial system is obtained by analyzing and modeling the actual system, and the appropriate learning agent is selected to generate better solutions.

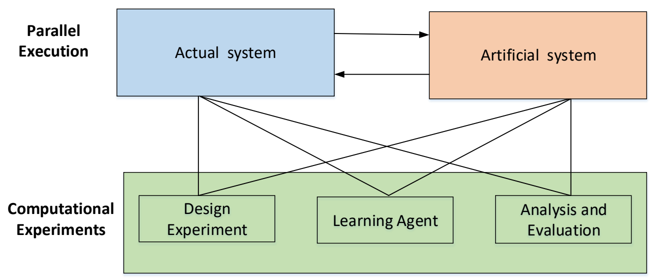


Fig. 1. The framework of parallel system based on ACP approach

In railway scheduling, because of the complexity of the railway line and many constraints, using ACP approach to establish parallel system can effectively improve the scheduling efficiency. The ACP framework for railway scheduling is shown in Fig. 2.

Due to the inevitable impact of environment or human factors during the train operation, such as disaster weather, passenger flow, equipment failure and other random events, the actual operation of the train will deviate from the plan, resulting in a delay. Therefore, the computational experiments can be set in different scenarios. The artificial system carries out simulation for several times according to the specific scenarios designed by the experiment and the line information of the actual system, and transmits the reward of each experiment to the learning agent. The agent constantly explores and searches for the optimal scheduling strategy according to the reward of artificial system.

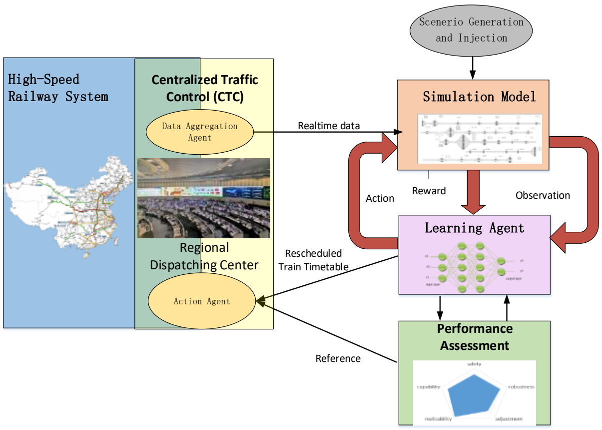


Fig. 2. The ACP framework for railway scheduling

Through several computational experiments, the learning agent can calculate the final scheduling strategy and send it to the actual system to adjust trains with initial delay. The artificial system needs to be updated according to the current state of the train and line by interacting with the actual system. Then it run according to the final scheduling strategy to synchronize with the actual system, and the two systems learn from each other to realize parallel execution.

In addition, the train scheduling system can evaluate and analyze different scheduling strategies. Because different scheduling algorithms can get different train running schedules, it is necessary to evaluate the train scheduling strategy to select or improve the scheduling algorithm. A good scheduling strategy not only depends on the total delay time of the train but also includes the robustness of the schedule, the energy consumption of the train and so on. Therefore, the train scheduling strategy can be evaluated with different indexes through multiple experiments, and the evaluation results can be used for reference in actual scheduling.

## III. Construction of High-Speed Railway Scheduling System Based On ACP Approach

In order to construct the high-speed railway dispatching system, an artificial system is first established according to the actual system. Then, the scheduling algorithm is selected to generate the scheduling strategy, and the calculation experiment is designed to provide data support for the scheduling algorithm. Finally, integrate the artificial platform and actual system to execute scheduling strategy in parallel.

### *A. Establishment of artificial system*

The manual system is used to replace the actual system for performing experiments. Using the simulation software can consider various factors such as lines, trains, personnel, etc., and better reflect different traffic behaviors. Besides, it is not necessary to establish an accurate mathematical model of the real system. The artificial system mainly includes train scheduling, simulation core, operation control, data storage, interactive interface and user interface. Fig. 3 shows the structure of artificial system.

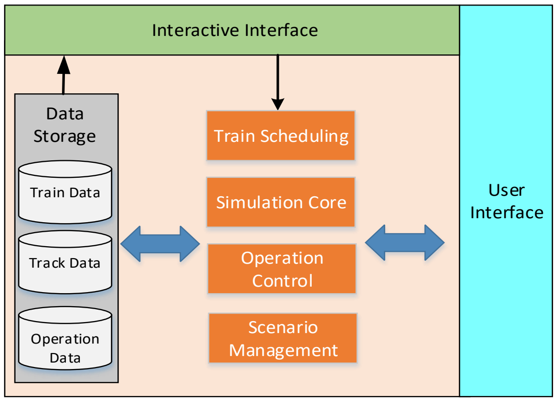


Fig. 3. structure of artificial system

*1) Train Scheduling:* Receiving the train timetable and scheduling command from the interactive interface, importing the timetable into the data storage module of the system to determine the arrival and departure time of the train, and receiving the scheduling command to control the train speed and line status.

*2) Simulation Core:* By adjusting the simulation speed, multiple cycles can be carried out in unit time to accelerate the simulation, which reduces the time of several computational experiments and quickly gets the simulation results of lines and trains.

*3) Operation Control:* The train operation is modeled based on the actual train operation data. When the train is ready to depart, the train operation curve is calculated through the data-driven operation model, and the train is controlled to run according to the curve. Besides, Automatic Train Protection (ATP) is introduced to deal with emergency braking in case of emergency.

*4) Scenario Management:* Setting the state of the line according to the computational experiment can simulate the section blockade caused by the damage of the line. Adding the disturbance to station and line to simulate the delay caused by human factors of passengers and drivers in daily driving.

*5) Data Storage:* Storing train data such as train number, timetable; the track information such as position, length, occupancy state and train operation data includes train speed, position, delay time, etc.

*6) Interactive interface:* In computational experiments, the artificial system will continuously communicate with others through interactive interfaces, including receiving schedules, scheduling commands and sending simulation results, operation information. The artificial system also needs to be calibrated by interacting with actual system in parallel. In this paper, the artificial system interactive interface is developed based on TCP/IP protocol, which has good practicability and compatibility.

*7) User Interface:* When the artificial system is running, the user interface will display line conditions and current running status of trains. Meanwhile, the researcher can also design experiments and control the system through UI.

## B. Computational Experiments

The impact of emergencies on train operation and line status can be simulated through the design of computational experiments. A mass of simulations can provide data support for actual scheduling. The scheduling strategies given by intelligent scheduling algorithms can be analyzed and evaluated through computational experiments.

*a)Learning Agent*

Many scheduling algorithms, such as reinforcement learning and optimization based on surrogate modelling, can learn information from a large number of simulation results to give a better scheduling strategy. In the experiment, the artificial system will send the current time, train speed and position, line status information to the learning agent. According to the feedback of the experimental data, the agent will update the model and calculate the new timetable for the artificial system. Learning agent can constantly improve the behavior in the interaction and finally get optimal solution.

*b) Surrogate-driven Experiment Design*

Because the railway lines are interlaced into a network, using single line delay as the objective function to scheduling may not generate the best strategy without considering the influence of train transfer. But it is difficult to construct an accurate mathematical model of the objective function for railway network. Although the artificial system proposed in this paper can be used to evaluate the objective function, but it is very expensive in terms of computation time and computation resource demands. In order to have an efficient evaluation of the complex objective function, a Gaussian Process model may be used for the experiment design, which has the features of guiding the selection of experiment sample and provide an efficient evaluation of the objective function. The GP process can be expressed as:

$$y(S) \sim GP\left(m(S), k\left(S_i, S_j\right)\right) \tag{1}$$

where S is the input set, $y(S)$ is the output set , $m(S)$ is the mean function of $y(S)$, and $k\left(S_i, S_j\right)$ is the covariance function.

According to the active learning method, the next experiment sample can be selected as the one that has the maximum expected value E(I) lower than the current observed $y_{min}(S)$, E(I) can be expressed as (2):

$$\mathrm{E}[I] = \int I(S) p(y(S)) d(y(S)) \tag{2}$$

where $p(y(S))$ is the probability density function of Gaussian distribution, $I(L)$ is the difference between $y(S)_{min}$ and $y(S)$ which is expressed by (3):

$$I(L) = \begin{cases} y(S)_{min} - y(S), & y(S) < y(S)_{min} \\ 0, & y(S) \geq y(S)_{min} \end{cases} \tag{3}$$

With the aid of GP surrogate model, the amount of data required for build approximation of the objective function is greatly reduced.

*c) Performance Assessment*

There are many indexes to evaluate the scheduling scheme, including delay of trains, robustness of timetable, train energy cost, passenger satisfaction, etc. According to the experimental results of the scheduling strategy in the artificial system, actual timetable, delay time, the number of delayed trains and conflicts can be obtained, and those indexes can be calculated based on these information. We can also use statistical methods to analyze the mean and variance of experimental results.

## C. Parallel Execution

The interaction between the artificial system and actual system enables the high-speed railway scheduling system to transform the traditional passive scheduling into active adjustment on the basis of parallel execution and parallel management. The artificial system constantly updates model parameters and state variables in the interaction with the actual system. Through a number of computational experiments, the high-speed railway scheduling system not only can provide the adjustment for emergency but also predict the state of line based on the data in different scenarios, and provide the active control strategy and visual interface.

# IV. CASE STUDY

In this paper, a section of high-speed railway in China is selected as the case analysis scenario. Using high-speed railway scheduling system to adjust timetable of trains and analyzing the result. The layout is constructed in the artificial system according to the line information of the actual system. As shown in Fig. 4, the railway track and interval length of the station are consistent with the actual system.

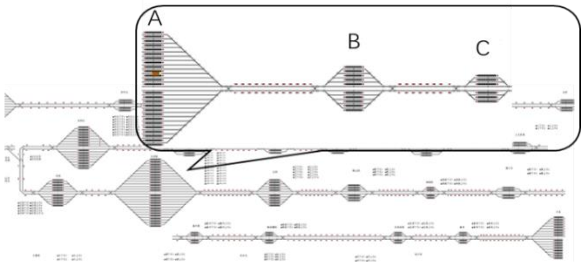


Fig. 4. layout in artificial system based on actual system

## A. Scheduling Policy Generation

In actual scheduling, it is hard to obtain the optimal solution if only the current line delay is taken as the goal, without considering the influence of the train on other lines after the transfer. Especially in the stations with busy trains, it is difficult to model the scheduling objective function accurately, which also a great challenge to dispatchers. In this paper, a large junction station is taken as an example, and the agent model is introduced to carry out the junction station scheduling. Considering the delayed train in the local line and the performance of the transferred trains in the subsequent lines, the surrogate modelling is used to effectively predict the location of the optimal solution. Fig. 5 shows the process of finding the optimal solution based on the surrogate modelling.

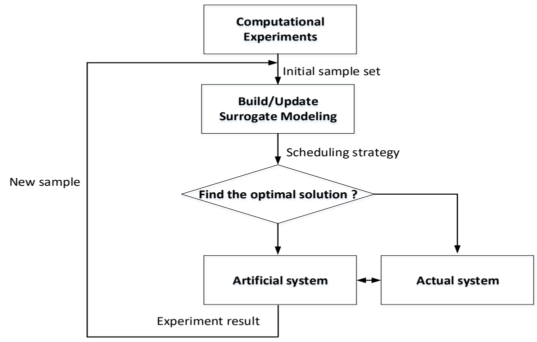


Fig.5. the process of finding the optimal solution based on the surrogate modelling

In order to verify the ability of the scheduling system to the initial delay, this paper selects 10 high-speed trains and conducts experiments in 11 stations. We assumed that 2 trains have the initial delay. Assume that two trains have an initial delay: train T4 has 10 minutes late at station A, and train T6 has 12 minutes late at station A. Due to the section selected is busy, the scheduling system comprehensively considers the number of affected vehicles and the total delay time in giving the scheduling strategy. The total delay time of all trains at the final station is 347 minutes. Fig. 6 shows the initial timetable and rescheduling timetable of trains.

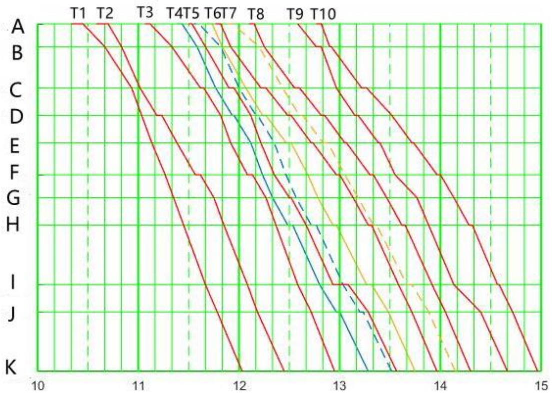


Fig. 6. initial timetable and rescheduling timetable of trains

### B. *Analysis and Evaluation*

For high-speed railway scheduling, a good scheduling strategy not only has a small total delay and less affected vehicles, but also needs to have anti-interference ability. We added disturbance to stations and the interval between stations, and tested the ability of late recovery and robustness of the scheduling strategy through a large number of disturbance experiments

Let

$a(i,j)$ = actual arrival time of train j at station i;

$d(i,j)$ = actual departure time of train j at station i;

$a_0(i,j)$ = scheduled arrival time of train j at station i;

$d_0(i,j)$ = scheduled departure time of train j at station i;

The total number of stations is $m$, the total number of vehicles is $n$, the number of experiments is $N$, the number of delayed trains in the s-th disturbance experiment is $c_s$.

*1)* The arrival time of the train at each station was considered as the total delayed time of each train. Count the total delay time for each experiment to calculate the mean and variance according to (4):

$$T_{ave}(j) = \frac{\sum_{s=1}^{N}\sum_{i=1}^{m} a(i,j) - a_0(i,j)}{N}$$

$$\sigma^2(j) = \frac{\sum_{s=1}^{N}(\sum_{i=1}^{m} a(i,j) - a_0(i,j))^2 - T_{ave}(j)^2}{N-1} \quad (4)$$

*2)* Count the number of delayed trains according to (5)

$$P = \frac{\sum_{s=1}^{N} c_s}{n \times N} \times 100\% \quad (5)$$

*3)* The scheduling policy will adjust several of trains when late occurs. However, in the case of disturbance, due to the interaction between vehicles and the conflict of track, the final number of delayed trains may be greater than initial. The propagation of delay can be reflected by counting the number of subsequent trains affected. The proportion of affected trains R is defined as follows:

$$R = \frac{\sum_{s=1}^{N} c_s - c_{adj}}{n \times N} \times 100\% \quad (6)$$

We add the disturbance which obeys the exponential distribution to the line, and use the generated scheduling strategy to carry out a large number of calculation experiments, and record the experimental results. The mean value and variance of train delay are calculated respectively, and the statistical values of train delay under multiple disturbance experiments are obtained, as shown in Table 1:

TABLE I. DELAY STATISTICS UNDER DISTURBANCE EXPERIMENTS

| Train | $T_{ave}(j)$ | $\sigma^2(j)$ |
|---|---|---|
| T1 | 0.05 | 0.05 |
| T2 | 0.45 | 0.75 |
| T3 | 0.5 | 0.55 |
| T4 | 1.95 | 2.65 |
| T5 | 6 | 4.20 |
| T6 | 1.3 | 2.41 |
| T7 | 2.05 | 0.35 |
| T8 | 0.75 | 0.59 |
| T9 | 0.4 | 0.54 |
| T10 | 1 | 0.50 |

The number of delayed trains in each disturbance experiment was counted, and the statistics results are shown in Table 2:

TABLE II. STATISTICS OF LATE TRAINS

| | |
|---|---|
| The number of trains adjusted by scheduling strategy | 3 |
| Average number of delayed trains per experiment | 5.7 |
| Percentage of delayed trains ($P$) | 57% |
| Percentage of trains affected（$R$） | 27% |

## V. CONCLUSION

In this paper, we proposed a high-speed railway parallel scheduling system based on ACP approach. Firstly, the artificial system is constructed according to the actual system, and it provides an experimental platform for computational experiments. By designing experiments, selecting leaning agent, establishing evaluation index of scheduling strategy and performing a lot of experiments, the scheduling strategy can be obtained quickly and the scheduling results can be analyzed.

We selected a case to verify the implementation of the high-speed parallel scheduling system. According to the actual system, the experimental scenarios of 10 trains and 11 stations are designed. Through several computational experiments, the scheduling strategy under initial delay is obtained. According to a large number of disturbance experiments, the scheduling strategy is analyzed statistically from the total delay time, the number of affected trains and other indicators.

At present, the continuous development and improvement of new intelligent technology, data analysis and other theories provide more abundant algorithm support for ACP method. Parallel intelligent system will also play a greater role in high-speed railway scheduling decision-making, data analysis, prediction and other aspects.

## References


[1] Chen Z, et al., “Simulation Study Based on OpenTrack on Carrying Capacity in District of Beijing-Shanghai High-Speed Railway”. Applied Mechanics & Materials, pp. 505-506, 2014.

[2] Shakibayifar M , Sheikholeslami A , Corman F, “A simulation-based optimization approach to reschedule train traffic in uncertain conditions during disruptions”. Scientia Iranica, 2017.

[3] F.-Y. Wang, “Artificial societies, computational experiments, and parallel systems: An investigation on computational theory of complex social-eco- nomic systems,” Complex Syst. Complexity Sci., vol. 1, no. 4, pp. 25–35, 2004.

[4] H. Dong et al., "Parallel Intelligent Systems for Integrated High-Speed Railway Operation Control and Dynamic Scheduling," in IEEE Transactions on Cybernetics, vol. 48, no. 12, pp. 3381-3389, Dec. 2018

[5] B. Ning et al., “An introduction to parallel control and management for high-speed railway systems,” IEEE Trans. Intell. Transp. Syst., vol. 12, no. 4, pp. 1473–1483, Dec. 2011.

[6] G. Guo, et al., "Research on computational architecture for railway emergency management system based on ACP theory," 2010 8th World Congress on Intelligent Control and Automation, 2010, pp. 5331-5336.

[7] Y. Lv et al., "Generative Adversarial Networks for Parallel Transportation Systems," in IEEE Intelligent Transportation Systems Magazine, vol. 10, no. 3, pp. 4-10, Fall 2018.

[8] Mevludin, et al. "Reinforcement Learning for Electric Power System Decision and Control: Past Considerations and Perspectives." Ifac Papersonline, vol 50, Issue 1, pp. 6918-6927, 2017.