

Model and Algorithm Research on High-speed Railway Intelligent Traffic Dispatching

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Abstract: According to the characteristics of high-speed railway traffic dispatching in holiday, analyses the strategy of traffic dispatching and sets up the intelligent traffic dispatching model of high-speed railway in holiday. Multi-objective particle swarm optimization algorithm that based on exterior archive is adopted to solve the intelligent traffic dispatching model. At last, the actual data of Chengdu, Mianyang, Leshan intercity high-speed railway in Chengdu railway bureau during the May Day is used as experimental data to do the simulation. The result shows that the intelligent traffic dispatching model of high-speed railway and the algorithm adopted are feasibility and effectiveness.

1. Introduction

Traffic dispatching in holiday is the important part of high-speed railway traffic dispatching. With the increase of China railway lines and the operating distance, high-speed railway makes travel faster and more convenient. Especially in holiday, it will induce a greater amount of passenger flow. This is a tremendous pressure and challenge to high-speed railway traffic dispatching. Therefore it is urgent to study on high-speed railway traffic dispatching in holiday. Shi [1] studied on passenger train plans optimization based on elastic demands. Dou [2] did the research on trains deployment model and algorithm during the holiday. Cheng [3] set up a passenger volume prediction model that considering holiday effects. In this paper, research the traffic dispatching strategy in the situation of outburst mass passenger flow in holiday. Determine the number of additional passenger trains, the running sections and the stop schedule according to the situation of outburst mass passenger flow. Setting up the high-speed railway intelligent traffic dispatching model offers a complete solution for traffic dispatching in holiday.

2. Strategy analysis of high-speed railway traffic dispatching in holiday

Under the situation of outburst mass passenger flow, there are two main countermeasures. One is that adding a number of temporary passenger trains in the proper train operation section to satisfy passenger's travel demand. And the existing train operation schedule plan remains unchanged. The other is not adding a number of temporary passenger trains. By changing the train running sections or the stop schedule plan in the existing train operation schedule plan and adjusting the train operation schedule plan to satisfy the requirement of the outburst mass passenger flow.



(1) In order to deal with the outburst mass passenger flow, complete the passenger transportation safely and rapidly, ensure the safety of passengers' life and their property and minimize the adverse effects of the outburst mass passenger flow, we should adjust the train operation schedule plan and add a number of temporary passenger trains timely. The number of additional passenger trains depends on the passenger flow directly. Its number is usually calculated by the formula (1).

$$m_{add} = \frac{\Delta C_p}{\bar{M} \cdot \mu} \quad (1)$$

m_{add} represents the number of additional passenger trains. ΔC_p represents the increase passengers in holiday. \bar{M} represents the average value of rated each train capacity. μ represents the overloading rate, $1 < \mu \leq 1.3$.

(2) Determine the stop schedule plan of additional passenger trains. The stop schedule plan will fall into four categories as follows.

Through train: There is larger passenger OD flow in originated station and terminal station. As this kind of train does not stop along the way, it has highest travelling speed and train class.

The train only stops at the large station: As this kind of train does not stop at the middle and small station along the way, it has higher travelling speed and comfort level. There are a lot of passengers whose travel aim is travelling and official business at the larger station. As they have higher comfort requirement, this kind of train will meet travelling requirement of the people in large station along the way.

The train stops at the station alternately: This kind of train stops at the larger station fixedly and stops at the small station alternately. It can reduce the passenger losses along the way, realize the passenger transfer between small cities and larger cities and ensure the travelling speed.

The train stops at every station along the way: This model of stop schedule is similar to bus. It can attract the passenger along the way wholly. It is a great convenience for short riders. As this kind of train stops at every station along the way, its train class is lower and travelling time is longer.

(3) Train operation diagram generation method of the additional passenger trains. It makes full use of the reserved space and add the additional passenger train lines in the basic train operation diagram. It pulls out some freight train lines and add the additional passenger train lines. It adjusts some train lines schedule and make use of the existed space to add passenger train lines in the basic train operation diagram.

3. Intelligent traffic dispatching model of high-speed railway in holiday

3.1. Model specification and parameter definition

In order to meet the requirement of outburst mass passenger flow in holiday, it will arrange four types of the additional passenger trains in this paper. Type A: The number of through train that does not stop along the way is Num_A . Type B: The number of the train that only stops at the large station is Num_B . Type C: The number of the train that stops at the station alternately is Num_C . Type D: The number of the train that stops at every station along the way is Num_D .

Type: Train type, $Type = \{A, B, C, D, TD\}$. Num_A : The number of train which type is A. Num_B : The number of train which type is B. Num_C : The number of train which type is C. Num_D : The number of train which type is D. $OD_{j,k}$: The passenger flow volume that between station j and station k . $\delta_{type,j \rightarrow k}$: The attraction degree of each type train that between station j and station k . M : The rated capacity value of each train. *Station*: The station that along the high-speed railway. The number of stations is n . $Station = \{Station_1, Station_2, \dots, Station_j, \dots, Station_k, \dots, Station_n\}$, $j, k \in (1, n)$, $j < k$, $Station_1$ is the originated station, $Station_n$ is the terminal station. *Train*: The trains that runs in this high-speed railway. The number of trains is m . The number of additional trains is m_{add} . The number

of existed trains is m_{td} . $m_{add} + m_{td} = m$, $Train = \{Train_1, Train_2, \dots, Train_i, \dots, Train_l, \dots, Train_m\}$, $i, l \in (1, m)$, $i < l$, $m_{add} = Num_A + Num_B + Num_C + Num_D$. $T_{Ai,j}$: The time that train i arrivals at station j . $i \in (1, m)$, $j \in (1, n)$. $T_{Di,j}$: The time that train i departs from station j . $i \in (1, m)$, $j \in (1, n)$. $T_{TAi,j}$: The basic time that train i arrivals at station j . $i \in (1, m)$, $j \in (1, n)$. $T_{TDi,j}$: The basic time that train i departs from station j . $i \in (1, m)$, $j \in (1, n)$. λ_{start} : The train starting additional time. λ_{stop} : The train parking additional time. $Track_j$: The track number of station j , $j \in (1, n)$. $T_{SECI,s}$: The time that train i runs in section s . $i \in (1, m)$, $s \in (1, n-1)$. I_{Aj} : The minimum arrival interval time of the adjacent trains at the station j , $j \in (1, n)$. I_{Dj} : The minimum arrival departure time of the adjacent trains at the station j , $j \in (1, n)$. $T_{Ti,j}$: The minimum task time that train i completes at station j , $i \in (1, m)$, $j \in (1, n)$.

$$Task_{type,j} = \begin{cases} 1, & \text{type of train has task in station } j \\ 0, & \text{others} \end{cases}, T_{SEC} = \begin{bmatrix} T_{SEC1,1} & T_{SEC1,2} & \dots & T_{SEC1,s} & \dots & T_{SEC1,n-2} & T_{SEC1,n-1} \\ T_{SEC2,1} & T_{SEC2,2} & \dots & T_{SEC2,s} & \dots & T_{SEC2,n-2} & T_{SEC2,n-1} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{SECI,1} & T_{SECI,2} & \dots & T_{SECI,s} & \dots & T_{SECI,n-2} & T_{SECI,n-1} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{SECM-1,1} & T_{SECM-1,2} & \dots & T_{SECM-1,s} & \dots & T_{SECM-1,n-2} & T_{SECM-1,n-1} \\ T_{SECM,1} & T_{SECM,2} & \dots & T_{SECM,s} & \dots & T_{SECM,n-2} & T_{SECM,n-1} \end{bmatrix}$$

$$T_A = \begin{bmatrix} T_{A1,1} & T_{A1,2} & \dots & T_{A1,j} & \dots & T_{A1,n-1} & T_{A1,n} \\ T_{A2,1} & T_{A2,2} & \dots & T_{A2,j} & \dots & T_{A2,n-1} & T_{A2,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{Ai,1} & T_{Ai,2} & \dots & T_{Ai,j} & \dots & T_{Ai,n-1} & T_{Ai,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{Am-1,1} & T_{Am-1,2} & \dots & T_{Am-1,j} & \dots & T_{Am-1,n-1} & T_{Am-1,n} \\ T_{Am,1} & T_{Am,2} & \dots & T_{Am,j} & \dots & T_{Am,n-1} & T_{Am,n} \end{bmatrix}$$

$$T_D = \begin{bmatrix} T_{D1,1} & T_{D1,2} & \dots & T_{D1,j} & \dots & T_{D1,n-1} & T_{D1,n} \\ T_{D2,1} & T_{D2,2} & \dots & T_{D2,j} & \dots & T_{D2,n-1} & T_{D2,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{Di,1} & T_{Di,2} & \dots & T_{Di,j} & \dots & T_{Di,n-1} & T_{Di,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{Dm-1,1} & T_{Dm-1,2} & \dots & T_{Dm-1,j} & \dots & T_{Dm-1,n-1} & T_{Dm-1,n} \\ T_{Dm,1} & T_{Dm,2} & \dots & T_{Dm,j} & \dots & T_{Dm,n-1} & T_{Dm,n} \end{bmatrix}$$

$$T_{TA} = \begin{bmatrix} T_{TA1,1} & T_{TA1,2} & \dots & T_{TA1,j} & \dots & T_{TA1,n-1} & T_{TA1,n} \\ T_{TA2,1} & T_{TA2,2} & \dots & T_{TA2,j} & \dots & T_{TA2,n-1} & T_{TA2,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{TAi,1} & T_{TAi,2} & \dots & T_{TAi,j} & \dots & T_{TAi,n-1} & T_{TAi,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{TAm-1,1} & T_{TAm-1,2} & \dots & T_{TAm-1,j} & \dots & T_{TAm-1,n-1} & T_{TAm-1,n} \\ T_{TAm,1} & T_{TAm,2} & \dots & T_{TAm,j} & \dots & T_{TAm,n-1} & T_{TAm,n} \end{bmatrix}$$

$$T_{TD} = \begin{bmatrix} T_{TD1,1} & T_{TD1,2} & \dots & T_{TD1,j} & \dots & T_{TD1,n-1} & T_{TD1,n} \\ T_{TD2,1} & T_{TD2,2} & \dots & T_{TD2,j} & \dots & T_{TD2,n-1} & T_{TD2,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{TDi,1} & T_{TDi,2} & \dots & T_{TDi,j} & \dots & T_{TDi,n-1} & T_{TDi,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{TDM-1,1} & T_{TDM-1,2} & \dots & T_{TDM-1,j} & \dots & T_{TDM-1,n-1} & T_{TDM-1,n} \\ T_{TDM,1} & T_{TDM,2} & \dots & T_{TDM,j} & \dots & T_{TDM,n-1} & T_{TDM,n} \end{bmatrix}$$

$$T_T = \begin{bmatrix} T_{T1,1} & T_{T1,2} & \dots & T_{T1,j} & \dots & T_{T1,n-1} & T_{T1,n} \\ T_{T2,1} & T_{T2,2} & \dots & T_{T2,j} & \dots & T_{T2,n-1} & T_{T2,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{Ti,1} & T_{Ti,2} & \dots & T_{Ti,j} & \dots & T_{Ti,n-1} & T_{Ti,n} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ T_{Tm-1,1} & T_{Tm-1,2} & \dots & T_{Tm-1,j} & \dots & T_{Tm-1,n-1} & T_{Tm-1,n} \\ T_{Tm,1} & T_{Tm,2} & \dots & T_{Tm,j} & \dots & T_{Tm,n-1} & T_{Tm,n} \end{bmatrix}$$

3.2 Objective function

Objective1: Minimize the number of additional passenger trains. As a prerequisite that meeting the travelling requirement in holiday, the number of additional passenger trains should be minimized as far as possible for reducing the waste of transportation capacity. The formula of objective 1 is as follows:

$$Z_1 = \min(Num_A + Num_B + Num_C + Num_D)$$

Objective2: Minimize the total trains' travelling time. The formula of objective 2 is as follows:

$$Z_2 = \min \sum_{i=1}^m (T_{Ai,n} - T_{Di,1})$$

Objective3: Minimize the total delaying time. The formula of objective 3 is as follows:

$$Z_3 = \min \sum_{i=1}^m \sum_{j=1}^n (|T_{Ai,j} - T_{Ti,j}| + |T_{Di,j} - T_{TDi,j}|)$$

Combining the three optimization objectives, the multi-objective optimization problem is transformed into a cooperative single objective optimization problem. In practical use, the weight value of w_1 , w_2 , w_3 are set flexibly by the different condition of stations and railway lines and the specific dispatching requirement of China railway company.

$$Z = w_1 Z_1 + w_2 Z_2 + w_3 Z_3, \quad w_1 + w_2 + w_3 = 1$$

3.3 Constraint condition

(1) The constraint that the departure interval time of the adjacent trains at the originated station.

$$\min |T_{Di,1} - T_{Di,l}| \geq I_{Dj}, \quad i, l \in (1, m), \quad i < l$$

(2) The constraint that the arrival interval time of the adjacent trains at the terminal station.

$$\min |T_{Ai,n} - T_{Ai,j}| \geq I_{Aj}, \quad i, l \in (1, m), \quad i < l$$

(3) The constraint that the arrival and departure interval time of the adjacent trains at station.

$$\min |T_{Ai,j} - T_{Ai,j}| \geq I_{Aj}, \quad \min |T_{Di,j} - T_{Di,j}| \geq I_{Dj}, \quad i, l \in (1, m), \quad i < l, \quad j \in (1, n)$$

(4) The constraint that the train stopping time at station.

$$T_{Di,j} - T_{Ai,j} \geq Task_{type,j} (T_{Ti,j} + \lambda_{start} + \lambda_{stop}), \quad i \in (1, m), \quad j \in (1, n), \quad type \in Type$$

(5) The constraint that the train running time in section.

$$T_{Ai,j+1} - T_{Di,j} \geq T_{SECI,j}, \quad i \in (1, m), \quad j \in (1, n-1)$$

(6) The constraint that the use of arrival and departure tracks.

$$\sum occupy(i, j) \leq Track_j, \quad occupy(i, j) = \begin{cases} 1, & T_{Ai,j} \leq t \leq T_{Di,j} \\ 0, & others \end{cases}$$

(7) The constraint that the travelling requirement between station j and station k .

$$\begin{aligned} Num_A \cdot M &\geq OD_{1 \rightarrow n} \delta_{A,1 \rightarrow n} \\ Num_B \cdot M \cdot \theta &\geq \sum_j \sum_k OD_{j \rightarrow k} \delta_{B,j \rightarrow k} Task_{B,j} \cdot Task_{B,k} \\ Num_C \cdot M \cdot \theta &\geq \sum_j \sum_k OD_{j \rightarrow k} \delta_{C,j \rightarrow k} Task_{C,j} \cdot Task_{C,k} \\ Num_D \cdot M \cdot \theta &\geq \sum_j \sum_k OD_{j \rightarrow k} \delta_{D,j \rightarrow k} Task_{D,j} \cdot Task_{D,k} \end{aligned}$$

$$Num_A, Num_B, Num_C, Num_D \in \text{postive integer}$$

$$\delta_{A,j \rightarrow k} + \delta_{B,j \rightarrow k} + \delta_{C,j \rightarrow k} + \delta_{D,j \rightarrow k} = 1, \quad j, k \in (1, n), \quad j < k$$

θ represents the possible coefficient that the seat is sold by passengers many times in different travelling sections.

(8) The constraint that the carrying capacity of each train.

$$\begin{aligned} Num_A \cdot M &\geq OD_{j \rightarrow k} \cdot \delta_{A,j \rightarrow k} \cdot Task_{A,j} \cdot Task_{A,k}, \quad Num_B \cdot M \geq OD_{j \rightarrow k} \cdot \delta_{B,j \rightarrow k} \cdot Task_{B,j} \cdot Task_{B,k} \\ Num_C \cdot M &\geq OD_{j \rightarrow k} \cdot \delta_{C,j \rightarrow k} \cdot Task_{C,j} \cdot Task_{C,k}, \quad Num_D \cdot M \geq OD_{j \rightarrow k} \cdot \delta_{D,j \rightarrow k} \cdot Task_{D,j} \cdot Task_{D,k} \\ Num_A, Num_B, Num_C, Num_D &\in \text{postive integer} \end{aligned}$$

$$\delta_{A,j \rightarrow k} + \delta_{B,j \rightarrow k} + \delta_{C,j \rightarrow k} + \delta_{D,j \rightarrow k} = 1, \quad j, k \in (1, n), \quad j < k$$

(9) The constraint that the departure time can't be earlier that the scheduled departure time [4].

$$\text{If } T_{Ti,j} \neq 0, \text{ then } T_{Di,j} \geq T_{TDi,j}.$$

4. Multi-objective particle swarm optimization algorithm based on exterior archive

Particle swarm optimization algorithm is a kind of swarm intelligence algorithm. Multi-objective particle swarm optimization algorithm (short for MOPSO) is that particle swarm optimization algorithm is applied to solve the multi-objective optimization problem. The optimal solution set that is Pareto optimal solution set is obtained in multi-objective particle swarm optimization algorithm. The optimal solution set is consist of many uncorrelated Pareto optimal solution.

Definition. $V_{i,t}$: The velocity of particle i at time t . $P_{i,t}$: The position of particle i at time t . N : The size of population, $i \in (1, N)$. S_t : The particle swarm at time t . P_{iBest} : The best position of particle i . P_{gBest} : The global best position in population.

The basic flow that the MOPSO algorithm based on exterior archive is shown in Figure 1.

(1) The formula of updating the velocity and position of particle.

$$V_{i,t+1} = \omega \cdot V_{i,t} + \eta_1 \cdot rand_1() \cdot (P_{iBest} - P_{i,t}) + \eta_2 \cdot rand_2() \cdot (P_{gBest} - P_{i,t}), \quad P_{i,t+1} = P_{i,t} + V_{i,t+1}$$

(2) The maintenance of exterior archive[6]. The maximum quantity of exterior population is N . The non-inferior set in population S_t is copy to exterior set NP_{t+1} . Eliminating the solution that controlled by S_t in NP_{t+1} . If the number of non-inferior solution exceed N , NP_{t+1} will be trimmed by cluster analysis to eliminate superfluous solution. The procedure of cluster is as follows:

Step1: Initializing the cluster set, each particle is regarded as a type.

Step2: If $Num_{Cluster} \leq N$ ($Num_{Cluster}$ represents the number of cluster types), then jump to step 5, otherwise jump to step 3.

Step 3: Calculating the distance between the types, the formula that the distance between NP_1 and

$$NP_2 \text{ is } d_{NP} = \frac{1}{|NP_1| + |NP_2|} \cdot \sum_{i_1 \in NP_1, i_2 \in NP_2} d(i_1, i_2).$$

Step 4: NP_1 and NP_2 which distance is the shortest will be combined one type. $Num_{Cluster} = Num_{Cluster} - 1$. Jump to step 2.

Step 5: Selecting one representative in each class and removing the rest ensures the number of the individuals less than N .

(3) The best position of individual. According to the control relationship between the solution of particle and the best position at present, decides the best position individual. If the former controls the latter, then updates the new solution of particle as the best position. Otherwise, the best position is unchanged.

(4) The best global position. In the case of multi objective optimization, P_{gBest} is not unique. There are a number of unrelated global best positions usually. Double particles swarm algorithm, Sigma method and grid method [5] are used to get the effective best global position.

(5) Ensure the particles move in the search space. The motion of the particles is likely to leave the feasible region in MOPSO algorithm. There are three methods to ensure the particle move in the search space. Firstly, when the particle files out of the boundary of a decision variable, let the particle stays on the boundary and change the movement direction of particle. Secondly, when the particle files out of the boundary of a decision variable, slowing down the velocity of particle makes it stay on the boundary and not change the movement direction of particle. Thirdly, change the value of $rand_1()$ and $rand_2()$ repeatedly until the particle moves into the search space.

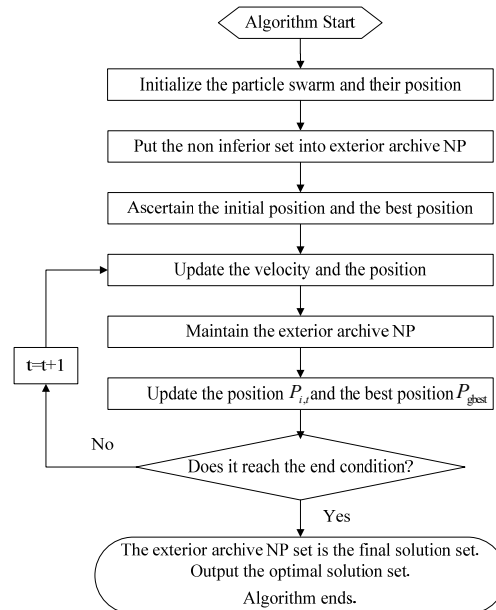


Figure 1 the basic flow that the MOPSO algorithm based on exterior archive

5. Example and Result analysis

Based on the background that the application of Chengdu, Mianyang, Leshan intercity high-speed railway in Chengdu railway bureau during the May Day, constructs an experiment example. There are nineteen stations in this railway line. JiangYou, MianYang, DeYang, ChengDuDong, ChengDuNan, MeiShanDong, LeShan and EMeiShan are the larger stations. Others are the small station. The basic diagram of train operation schedule is shown in Figure 2.

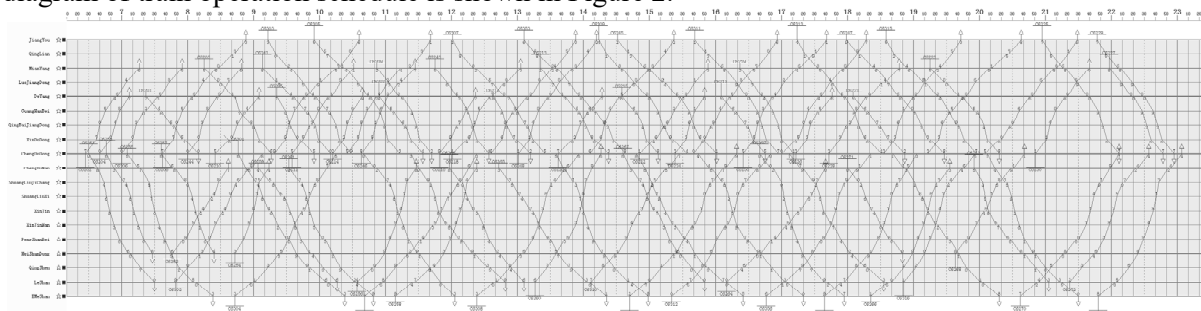


Figure 2 the basic diagram of train operation schedule

High-speed railway traffic intelligent dispatching strategy and MOPSO algorithm based on exterior archive are adopted to solve the model of intelligent traffic dispatching model of high-speed railway in holiday. The result is shown in Figure 3.

From the result, we can see that twelve trains are added in May Day. There are six trains (C1, C2, C3, C4, C5 and C6) that only stop at the large station. There are two trains (C7 and C8) that stop at every station along the way. There are four trains (C9, C10, C11 and C12) that stop at the station alternately. The stopping schedule of the twelve additional trains is shown in Figure 4. The results correspond to anticipation. The model and the algorithm adopted can meet the effectiveness and reliability requirement.

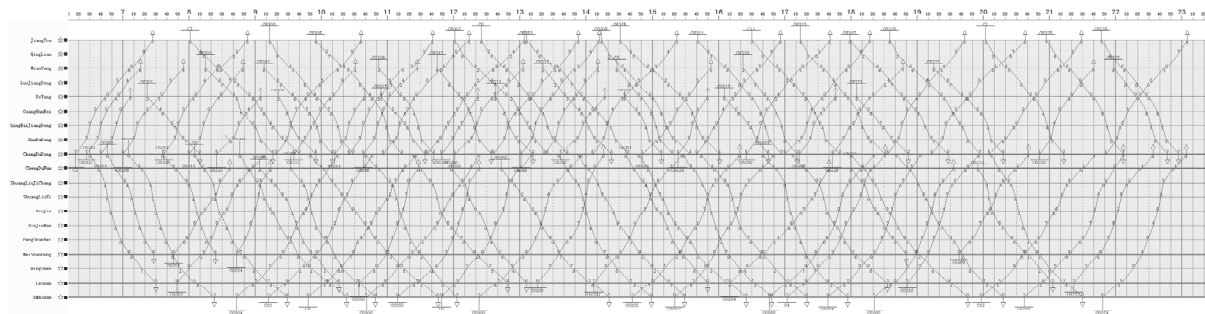


Figure 3 the new diagram of train operation schedule that added the temporary trains

S1 represents JiangYou station. S2 represents QingLian station. S3 represents MianYang station. S4 represents LuoJiangDong station. S5 represents DeYang station. S6 represents GuangHanBei station. S7 represents QingBaiJiangDong station. S8 represents XinDuDong station. S9 represents ChenDuDong station. S10 represents ChengDuNan station. S11 represents ShuangLiuJiChang station. S12 represents ShuangLiuXi station. S13 represents XinJin station. S14 represents XinJinNan station. S15 represents PengShanBei station. S16 represents MeiShanDong station. S17 represents QingShen station. S18 represents LeShan station. S19 represents EMeiShan station.

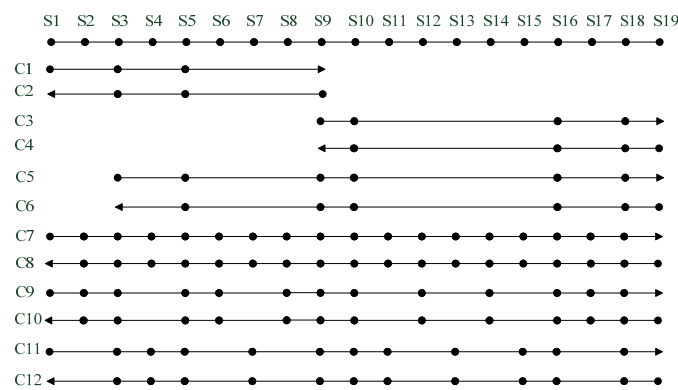


Figure 4 the stopping schedule of the twelve additional trains

6. Conclusion

This paper analyses the high-speed railway traffic dispatching strategy and set up the intelligent traffic dispatching model in holiday. MOPSO algorithm is adopted to solve the model. The experimental result shows that the intelligent traffic dispatching model of high-speed railway and the algorithm adopted are feasibility and effectiveness.

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References

- [1] Shi F, Zhou W L, Chen Y, et al. Optimization Study on Passenger Train Plans with Elastic Demands [J]. Journal of the China Railway society, 2008, 30(3): 1-6.
- [2] Dou F. Study on Train Deployment Model and Algorithms during Holidays [D]. Beijing Jiaotong University, Beijing, 2011.
- [3] Cheng C, Du Y C, Liu X. A Passenger Volume Prediction Model of Transportation Hub Considering Holiday Effects [J]. Journal of Transportation Systems Engineering and

- Information Technology, 2015, 15(5): 202-207.
- [4] Zhou X Z. Application Research of Immune Genetic Algorithm for High-speed Railway Train Operation Adjustment [D]. Beijing Jiaotong University, Beijing, 2014.
 - [5] Zhang T. Research on Intelligent Optimization Control Method Based on Operation Dispatching of Train Group[D]. China Academy of Railway Sciences, Beijing, 2015.
 - [6] Chen J K, Wei W. Optimization of the MVB Period Polling Table based on Multi-objective Particle Swarm Optimization [J]. Journal of the China Railway society, 2012, 34(11): 60-66.