


## Research Article

# Coordinated Optimization of Departure Time Domains of Multiple Trains at a Station Based on Passenger Satisfaction

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In order to optimize the passenger train working diagram and improve the passenger satisfaction towards a coordinated optimization problem of departure time domains of multiple passenger trains at a station, the optimization model is designed to maximize the overall passenger travel satisfaction based on the quantification of the level of passenger travel satisfaction. The simulated annealing algorithm is then used to solve the model. Finally, 23 pairs of passenger trains from Chengdu Railway Station are selected as examples to verify the feasibility and effectiveness of the algorithm. The result shows that the model and algorithm proposed in this paper can realize the coordinated optimization of the departure time of multiple trains at a station while considering the passengers' travel satisfaction, which can provide an effective reference for the compilation of passenger train working diagram.

## 1. Introduction

The passenger train-operation plan is designed to solve the problem of the layout of the passenger train scheduling line. It is mainly to determine the departure time of the passenger train-operation line after obtaining the reasonable departure time domains of each passenger train and then to provide a reasonable framework for the drawing of the passenger train working diagram. It is also one of the main technical indicators to measure the strengths and weaknesses of the train working diagram. For Chinese common-speed railway lines with long running time, the compilation result will directly affect the feasibility and compilation quality of the passenger train working diagram. Therefore, it is particularly important to determine the departure time of the passenger trains on the common-speed railway lines reasonably in the process of compiling the train working diagram.

The optimization of passenger train timetable has attracted wide attention in the past decades. Cordeau et al. [1] and Caprara et al. [2] have comprehensively reviewed the general train timetabling problem and passenger train

timetabling problem, respectively. In order to improve the quality of passenger transport service, train service operators have gradually shifted their focus from operation-oriented decision-making to market-oriented decision-making, including the shortest total travel time and the shortest waiting time of passengers at the station [3–5], among which the frame and core component of train timetable, departure time of departure station determines the operation plan of passenger train and affects the overall performance of train service. In the literature, many scholars have studied the departure time domain of trains. Some literature studies the optimization of train departure time from the perspective of improving passenger travel convenience. Li et al. [6] proposed an improved train scheduling simulation method to reduce the total train running time and optimize the train departure time. In order to improve the quality of passenger train service, Vansteenwegen and Oudheusden [7] designed a waiting cost function to calculate different types of waiting time and delaying time and then carried out research work to minimize them. Standard linear programming is used to optimize the train timetabling. Fu [8] reduced the

quantitative optimization of passenger train timetable to a multiobjective programming problem and proposed an optimization algorithm to optimize convenient passenger travel. Zhou and Zhong [9] studied the passenger train scheduling problem with the objective of minimizing the expected waiting time of passenger trains and the total travel time of trains and solved it by branch and bound algorithm. Ni et al. [10] starting from the aspects of passenger travel convenience and economy, considering the occupancy of the train's inbound and outbound tracks and stop tracks, studied the optimization of passenger train departure time domain.

There are also some studies on the optimization of train departure time from the perspective of railway operation departments. Ni et al. [11] took the optimal time domain of trains in and out the station as the objective function and, with the constraints of the basic capacity of the track in and out of the station in unit time (such as the departure capacity and receiving capacity), established an optimization model of passenger train departure time domain and proposed a heuristic priority strategy algorithm for the optimal solution. Chen et al. [12] set up a model to satisfy the expected arrival/departure time of passengers with the constraints of arrival and departure capacity of stations, genetic algorithm with conflict detection was used to solve the optimal arrival and departure time of trains, and the Chengdu Station was taken as an example to verify the model and algorithm.

Although there are a lot of in-depth studies on the optimization of the departure time of passenger trains, most of the literature fails to take into account the long east-west direction, large north-south span, and obvious seasonal variation characteristics in common-speed railway network in China, which makes the departure and arrival time of passenger trains determined by the current time (Beijing time) reference standard cannot meet the passengers travel need in certain cities very well. For this reason, based on the previous studies, this paper takes passenger travel satisfaction considering time zone deviation as the main evaluation index and puts forward the coordinated optimization of multitrain departure time at a station based on passenger satisfaction.

The rest of the paper will proceed as follows. The authors will first calculate the overall passenger satisfaction of any pair of passenger trains based on the number of passengers getting on and off the train at each station along the travel route with the estimated travel time. Section 3 establishes an optimization model of departure time of multiple passenger trains at a station based on passenger satisfaction. Section 4 introduces the simulated annealing algorithm. Section 5 includes 23 pairs of passenger trains from Chengdu Station as an example to verify the feasibility of the model and algorithm. Finally, the concluding remarks will be noted in the last section.

## 2. Overall Passenger Satisfaction Calculation of Paired Passenger Train

The passenger satisfaction discussed in this paper refers to the passenger satisfaction with the departure or arrival of a

train at a certain time in the city and is an important indicator to measure the overall satisfaction of all passengers on the train. Due to the fact that a passenger train has passengers getting on and off at every station passing along the route, it is necessary to investigate and study the passenger satisfaction in different travel periods of each station (city).

Before drawing up the passenger train working diagram, it is impossible to accurately judge the frequency, location, and corresponding stop time of the train meeting and overtaking along the route. Therefore, it would be impossible to get an accurate travel time for each train. Hence, when calculating the overall satisfaction of passenger trains, it is necessary to use the estimated travel time and the number of passengers getting on and off at different stations.

In order to ensure that the passenger trains departing from the station and returning to the station both have higher overall satisfaction, the total satisfaction value of paired trains is taken as the main parameter of optimization in this study. The calculation of the overall satisfaction of paired passenger train is made up of the following parts.

*2.1. Passenger Train Travel Time Estimation Based on Existing Train Working Diagram.* For common-speed railway lines, the uncertainties of the passenger train meeting and overtaking along the route usually in operation process make the whole travel time of the train deviate greatly from the pure running time. Therefore, before calculating the arrival/departure time and the overall passenger satisfaction of the train, it is necessary to first determine a more reasonable train travel time.

Through the analysis of Chinese common-speed railway network, the main large-scale stations (or hubs) are used as the key nodes to divide the network into several smaller sections, and the travel time of specific types of trains in each section is analyzed, respectively, so as to estimate the travel time of all kinds of the trains between any station in the entire network [13]. On this basis, as long as the departure time of the train at the departure station can be obtained, the arrival and departure time of the train at any station along the route can be calculated according to the passenger train operational time in each section.

*2.2. Fitting of the Number of Passengers Getting on and off the Train and Passenger Satisfaction Survey.* The passenger is the main object of passenger train service. Therefore, when calculating the overall passenger satisfaction of a passenger train, it should take into account the number of passengers getting on and off the train at each station along the route and the passenger satisfaction of the corresponding station (city) at different time.

By analyzing the ticket sales data of passenger trains obtained from the Academy of Railway Sciences and the ticket allocation data of the existing passenger train working diagram, it is found that the majority of passengers get on and off the train mainly concentrated in the large-scale stations along the route. For a certain passenger train, the

number of passengers getting on and off in small stations is small, while the workload of investigating the satisfaction of passengers at these stations is very large. In addition, the deviation of latitude and longitude between the small stations and their nearby large station is relatively small, the arrival and departure time of the stop trains are close, and then the satisfaction value of passengers getting on and off the train at the small stations is basically the same as the one of nearby large stations. Therefore, when calculating the number of passengers getting on and off the train at the stations along the route, the passenger flow of the small stations along the route is integrated into the nearest adjacent large station, so as to simplify the calculation process of the overall passenger satisfaction of the passenger trains. The fitting process of the number of passengers getting on and off the train from small stations to the large stations is shown in Figure 1.

In Figure 1, the number of passengers getting on and off at station  $f$  is 32 and 34, respectively, which is far less than adjacent large stations  $C$  and  $D$ . Since station  $C$  is closer to station  $f$  than station  $D$ , the passenger flow of station  $f$  is then added to station  $C$  to simplify the calculation process. That is to say, the number of passengers getting on and off at station  $f$  turned to be zero, while the number of stations  $C$  increased to 172 and 162, respectively.

Furthermore, according to the results of the classification of railway passenger transport nodes in document, a representative city (station) to design questionnaire was selected from each type of city to conduct satisfaction survey by letting a large number of passengers to score different time periods of getting on and off according to their travel experience and willingness. The score range is 0 to 10, where 0 represents very dissatisfied, while 10 represents very satisfied. The Grubbs criterion is used for denoising analysis to obtain the passenger satisfaction of each time period of the representative city. Taking the representative cities as the benchmark, time zone deviation is introduced to calculate the travel satisfaction of passengers in other cities with in the same type, which can obtain the travel satisfaction of passengers of all cities in different time periods. So far, combined with the number of passengers getting on and off the train at each station along the route, the overall satisfaction of a passenger train departing at any time can be calculated.

**2.3. Calculation of Overall Passenger Satisfaction of Paired Trains.** For the convenience of description, the train  $i$  departure from station  $S$  is defined as updirection, while its opposite train  $i'$  is defined as downdirection. It is assumed that the departure time of the train  $i$  from the station  $S$  is  $k$ , and the number of passengers getting on and off at the  $j$  th station is  $n_{ij}^{ss}$  and  $n_{ij}^{sx}$ , respectively, and the satisfaction value of passengers getting on and off the train at the departure and arrival time of this train is  $n_{jk}^{ss}$  and  $n_{jk}^{sx}$ , respectively. Therefore, the overall passenger satisfaction  $S_{ik}^f$  for train  $i$  departing from station  $S$  at time  $k$  can be expressed as follows:

$$S_{ik}^f = \sum_{j=1}^N n_{ij}^{ss} s_{jk}^{ss} + n_{ij}^{sx} s_{jk}^{sx}, \quad i = 1, 2, \dots, M; k = 1, 2, \dots, T. \quad (1)$$

Similarly, the overall passenger satisfaction  $S_{i'k}^d$  of passenger train  $i'$ , which runs in pairs with train  $i$  and ends to station  $S$ , can be obtained as follows:

$$S_{i'k}^d = \sum_{j=1}^N n_{i'j}^{xs} s_{jk'}^{xs} + n_{i'j}^{xx} s_{jk'}^{xx}, \quad i' = 1, 2, \dots, M; k' = 1, 2, \dots, T, \quad (2)$$

where  $n_{i'j}^{xs}$  and  $n_{i'j}^{xx}$ , respectively, represent the number of passengers getting on and off the downdirection train  $i'$  at the  $j$  th station along the route (here, it is assumed that the paired passenger train adopts the same stopping scheme and therefore uses the same station subscript);  $s_{jk'}^{xs}$  and  $s_{jk'}^{xx}$ , respectively, indicate the satisfaction of the passengers getting on and off the train at the corresponding arrival/departure time.

The main consideration in this paper is how to avoid the time resource competition of different types of passenger trains for favourable departure time when running multiple passenger trains at station  $S$ , so as to have better coordination of departure time for multiple trains with different grades. To simplify the calculation, the time resource constraints of the turn back station are not considered here; that is, the overall passenger satisfaction of all the opposite downdirection passenger trains  $i'$  can achieve the best value. Therefore, the optimal value of the overall satisfaction of the passengers on the downdirection train  $i'$  can be expressed as  $\max\{S_{i'k'}^d \mid k' = 1, 2, 3, \dots, T\}$ .

Let  $S_{ik}$  denote the total passenger satisfaction of the paired passenger trains  $i$  and  $i'$ ; then it can be expressed as

$$S_{ik} = S_{ik}^f + \max\{S_{i'k'}^d \mid k' = 1, 2, 3, \dots, T\}. \quad (3)$$

Thus, through formula (3), we can calculate the overall satisfaction of any pair of passenger trains at station  $S$  with the departure time  $k$ .

### 3. Optimization Model of Multitrain Departure Time at a Station Based on Passenger Satisfaction

After obtaining the overall satisfaction value of each passenger train pair corresponding to any departure time, coordinating and optimizing the reasonable departure time of multiple trains are essential to deal with the resource conflict between each train and the departure time with higher satisfaction and assign the multiple departure trains to the corresponding departure time on the basis of considering the constraints of departure interval of trains in a station so as to maximize the satisfaction of all passengers.

**3.1. Objective Function.** Take  $x_{ik}$  to indicate whether train  $i$  departs at time  $k$ ,  $M$  represents the number of paired trains related to station  $S$ , and the number of departure times  $T$

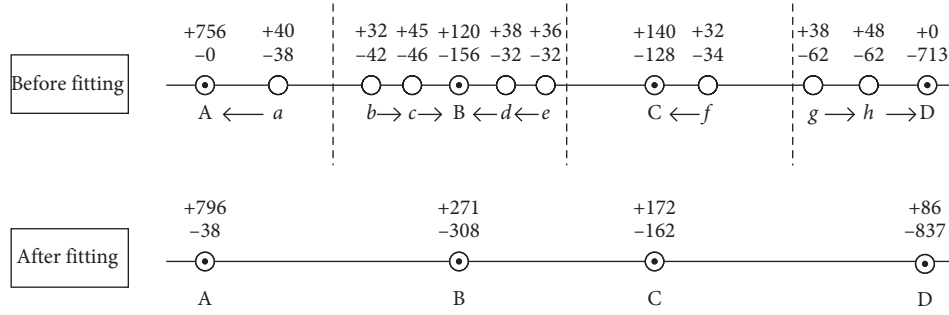


FIGURE 1: The fitting process of the number of passengers getting on and off the train.

takes 1440 that is per 1 minute set corresponding to a departure time. And  $\alpha_i$  is the train class adjustment coefficient, which is used to measure the difference in passenger satisfaction between different classes of trains. It is generally considered that the higher the train class, the larger the coefficient. Then, at a hub station  $S$  in the common-speed railway network, the objective function which maximizes the overall satisfaction of all passengers from the train journey can be expressed as follows:

$$Z = \max \sum_{i=1}^M \sum_{k=1}^{1440} x_{ik} S_{ik} \alpha_i. \quad (4)$$

### 3.2. Constraint Conditions

- (1) For any passenger train, it must be guaranteed that there is only one departure time:

$$\sum_{k=1}^{1440} x_{ik} = 1, \quad i = 1, 2, \dots, M. \quad (5)$$

- (2) At any time, there shall be no more than one train departure at that time:

$$\sum_{i=1}^M x_{ik} \leq 1, \quad k = 1, 2, \dots, 1440. \quad (6)$$

- (3) Ensure that the departure time interval between any two trains at station  $S$  is not less than the specified time interval standard  $t_b$ . Since the train origination time is cycled in unit of 1440 minutes, in order to correctly describe the constraint relationship between the two days before and after, a special representation method is adopted here:

$$\sum_{i=1}^M \sum_{k=h}^{h+t_b-1} x_{ik} \leq 1, \quad \forall h + t_b - 1 \leq 1440, \quad (7)$$

$$\sum_{i=1}^M \left( \sum_{k=h}^{1440} x_{ik} + \sum_{l=1}^{t_b-1440+h-1} x_{il} \right) \leq 1, \quad \forall h + t_b - 1 > 1440.$$

- (4) 0-1 variable constraint  $x_{ik}$  equals 1 if train  $i$  departure is at time  $k$  and 0; otherwise,

$$x_{ik} \in \{0, 1\}, \quad i = 1, 2, \dots, M; k = 1, 2, \dots, 1440. \quad (8)$$

## 4. Algorithm Design

Simulated annealing algorithm is a random search method suitable for solving large-scale combinatorial optimization problems. It has the characteristics of flexible use, simple description, wide application, and high computational efficiency. Due to the large number of train pairs involved, Hungarian algorithm may not be able to find the optimal solution of the problem. Considering the particularity of the model constructed and the advantages of the simulated annealing algorithm for solving the combined optimization problem, this paper uses the simulated annealing algorithm to solve the above model. The theoretical basis of the simulated annealing algorithm is derived from the principle of solid annealing, which is a heuristic random search process based on Monte Carlo iteration. According to the Metropolis criterion, the iterative process of generating new solution, evaluation (calculating the increment of cost function), judging whether to accept or not is carried out repeatedly to obtain the optimal or better solution of the problem at the end of iteration. The algorithm flow is shown in Figure 2.

Based on the iterative solution idea of simulated annealing algorithm, the solving process of the above model in this paper is as follows:

- (i) *Step 1 (Initialization)*. Under the condition that the train departure interval is satisfied, the random number generates the initial solution  $x_0$  (i.e., the departure time of 23 passenger trains), sets the number of iterations as  $k = 1$ , and calculates the corresponding satisfaction value  $Z_0$  of the initial solution.
- (ii) *Step 2 (Disturbance)*. Change the departure time of a train in the current solution. The specific method is to randomly select a train from 23 trains, generate the random number within the interval (1-1440) as the candidate departure time, and judge whether the time satisfies the departure interval constraint. Replace the old departure time value if the

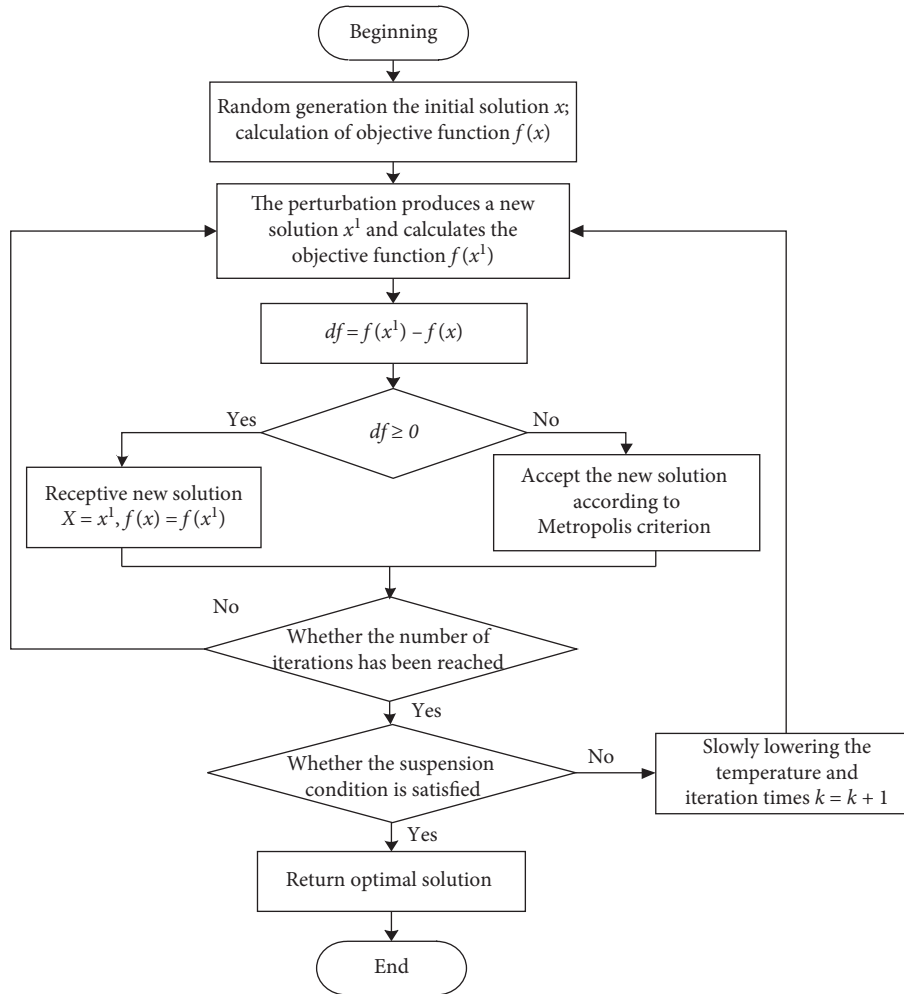


FIGURE 2: Algorithm flowchart.

constraint is satisfied; otherwise, regenerate a new departure time and judge again.

- (iii) *Step 3 (Exchange)*. Select two passenger trains randomly and exchange their departure time.
- (iv) *Step 4 (Calculating the Satisfaction)*. Calculate the total satisfaction value  $Z_t$  by summing up the satisfaction value of all trains corresponding to their own departure time, and let  $k = k + 1$ .
- (v) *Step 5 (Judgment)*. The satisfaction value of the current solution is compared with that of the optimal solution up to now. If the satisfaction value of the current solution is larger, the solution is accepted as the optimal solution up to now. Otherwise, the current solution will be accepted according to the Metropolis guideline.
- (vi) *Step 6 (Termination)*. To determine whether the algorithm reaches the critical temperature or the number of iterations  $k$  reaches the maximum number, if the termination condition of the algorithm is satisfied, the iteration best solution is output as the optimal solution and the algorithm stops; otherwise, return to Step 2.

## 5. Computational Experiments

In order to verify the feasibility and effectiveness of the above-mentioned model and algorithm, this paper selects 23 pairs of passenger trains with Chengdu Station as the departure and arrival station as the example to coordinate the departure time of all trains. Among them, there are 5 pairs of nonstop (Z) passenger trains, 4 pairs of special fast (T) passenger trains, and 14 pairs of fast (K) passenger trains. The specific information is shown in Table 1. First, the data of train working diagram executed from July 1, 2018, is selected to estimate the travel time of each train in divided segments. Then, the number of passengers getting on and off the train at the main stations along the route is fitted, and the satisfaction of the passengers getting on and off along the route is calculated. As the passenger satisfaction survey takes hours as a unit, the satisfaction calculation results of some consecutive moments are the same. The passenger satisfaction for arrival/departure of all stations along the route at all times of the day is shown in Table 2. At the same time, priority should be given to the passenger trains with higher grade and longer travel distance. In order to show their priority, the satisfaction value coefficient of the nonstop (Z)

TABLE 1: 23 pairs of passenger train information with Chengdu as the starting/terminal station.

Number	Level	Train-operation section
1	K	Chengdu–Guiyang
2	T	Chengdu–Wuhan
3	K	Chengdu–Wuhan
4	Z	Chengdu–Wuhan
5	T	Chengdu–Xi’an
6	K	Chengdu–Xi’an
7	K	Chengdu–Lanzhou
8	K	Chengdu–Kunming
9	Z	Chengdu–Zhengzhou
10	K	Chengdu–Zhengzhou
11	Z	Chengdu–Guangzhou
12	K	Chengdu–Guangzhou
13	K	Chengdu–Nanchang
14	T	Chengdu–Nanchang
15	K	Chengdu–Hangzhou
16	K	Chengdu–Changsha
17	T	Chengdu–Beijing
18	K	Chengdu–Nanjing
19	K	Chengdu–Beijing
20	Z	Chengdu–Beijing
21	K	Chengdu–Shenyang
22	K	Chengdu–Shanghai
23	T	Chengdu–Changsha

TABLE 2: Passenger satisfaction of getting on and off at all stations along the route throughout the day.

Time period (minutes)	Chengdu (off)	Chengdu (on)	Xi’an (off)	Xi’an (on)	...	Shijiazhuang (off)	Shijiazhuang (on)	Tianjin (off)	Tianjin (on)	Shenyang (off)	Shenyang (on)
0	0.5	1.2	0.2	0.5	...	0.9	2.4	0.2	0.5	0.2	0.5
1	0.5	1.2	0.2	0.5	...	0.9	2.4	0.2	0.5	0.2	0
2	0.5	1.2	0.2	0.5	...	0.9	2.4	0.2	0.5	0.2	0
...	...	...	...	...	...	...	...	...	...	...	...
70	0.9	2.4	0.2	0.0	...	1.3	3	0.2	0	0	0.2
71	1.3	3	0.2	0.0	...	1.3	3	0.2	0	0	0.2
...	...	...	...	...	...	...	...	...	...	...	...
420	7	6.5	2.5	2.9	...	6.6	6	2.5	2.9	2.5	2.9
421	7	6.5	2.5	2.9	...	6.6	6	2.5	2.9	4.1	4.4
...	...	...	...	...	...	...	...	...	...	...	...
699	6.6	8.5	9.2	8.6	...	6.5	7.9	10	9.2	10	9.2
700	6.8	8.5	9.2	8.8	...	6.5	7.9	10	9.2	10	9.2
...	...	...	...	...	...	...	...	...	...	...	...
1428	0.5	1.2	1.1	2.4	...	2.5	2.4	0.2	0.5	0.2	0.5
1429	0.5	1.2	1.1	2.4	...	2.4	2.4	0.2	0.5	0.2	0.5
...	...	...	...	...	...	...	...	...	...	...	...
1438	0.5	1.2	1.1	2.4	...	1.0	2.4	0.2	0.5	0.2	0.5
1439	0.5	1.2	0.2	0.5	...	1.0	2.4	0.2	0.5	0.2	0.5
1440	0.5	1.2	0.2	0.5	...	0.9	2.4	0.2	0.5	0.2	0.5

passenger train is set to 1.2, while the satisfaction value coefficient of the special fast (T) passenger trains is set to 1.1. Based on this, we can get the passenger satisfaction of each train. Finally, formula (3) is used to calculate the overall passenger satisfaction of the 23 pairs of passenger trains. The results obtained are shown in Table 3.

After obtaining the overall satisfaction of 23 pairs of passenger trains, C language programming is used to solve the passenger train departure time optimization model

based on passenger travel satisfaction, and the train departure interval is set to 20 min, 15 min, and 10 min, respectively. The calculation process is shown in Figures 3–5.

The comparison of the optimization results with different departure interval constraint is shown in Table 4.

From the above table, it can be seen that, with the decrease of departure interval, the number of possible maximum departure trains increases, and the increase of

TABLE 3: Overall satisfaction of 23 pairs of passenger trains departure at each time.

Departure time from Chengdu	Opposite station and train level						
	Guiyang (K)	Beijing (T)	Beijing (Z)	...	Changsha (K)	Hangzhou (K)	Shenyang (K)
1	23624.7	19536.1	27422.6	...	22943.3	23512.4	32331.1
2	23624.7	19536.1	27422.6	...	23100.6	23512.4	32331.1
3	23624.7	19536.1	27422.6	...	23100.6	23512.4	32251.6
...	...	...	...	...	...	...	...
101	24883.1	24825.7	27498.2	...	22942.8	26612.2	31313.1
102	24514.3	24825.5	27498.2	...	22942.8	26612.2	31313.2
...	...	...	...	...	...	...	...
641	23443.1	33101.9	40075.3	...	31107.9	28174.3	35544.5
642	23039.7	33101.7	40075.3	...	31107.9	28174.3	35544.7
...	...	...	...	...	...	...	...
1121	27774.3	26350.1	37438.2	...	29852.2	27646.4	35873.5
1122	28095.1	26350.1	37438.0	...	29852.2	27646.4	35873.5
...	...	...	...	...	...	...	...
1435	23624.7	27191.7	19536.3	...	22943.3	23512.4	32331.1
1436	23624.7	27191.6	19536.1	...	22943.3	23512.4	32331.1
1438	23624.7	27191.6	19536.1	...	22943.3	23512.4	32331.1
1439	23624.7	27191.6	19536.1	...	22943.3	23512.4	32331.1
1440	16537.9	27191.6	19536.1	...	22943.3	23512.4	32331.1

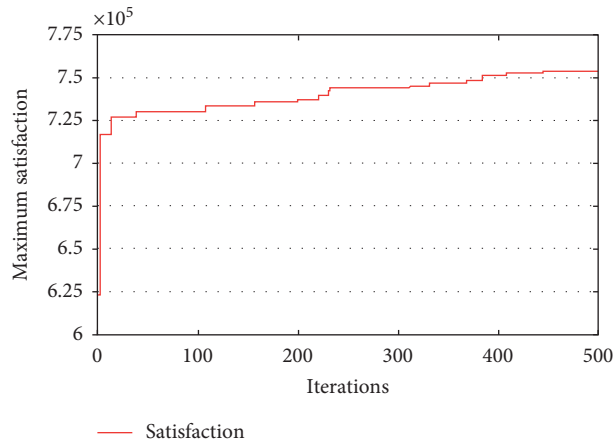


FIGURE 3: Algorithm iteration result graph with 20 min departure interval.

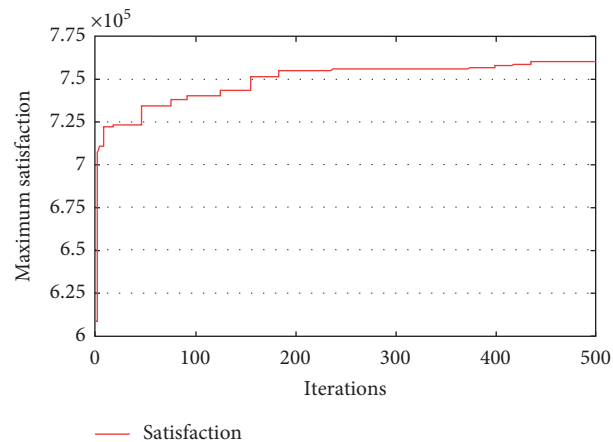


FIGURE 4: Algorithm iteration result graph with 15 min departure interval.

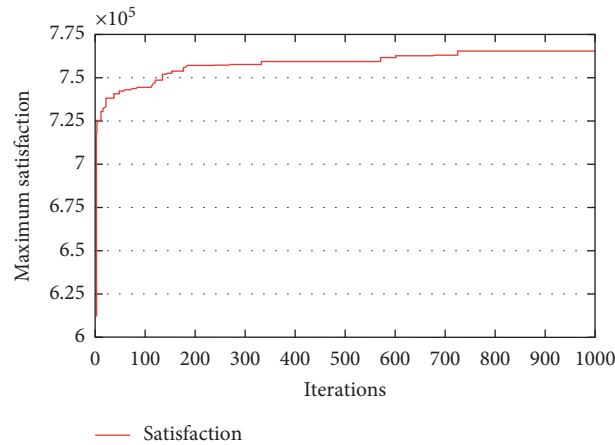


FIGURE 5: Algorithm iteration result graph with 10 min departure interval.

TABLE 4: Scheme comparison with different departure interval constraint.

Minimum departure interval (min)	Maximum departure number/train	Optimal satisfaction	Average optimal satisfaction	Average algorithm converges algebra
20	72	753606.1	750200.7	415
15	96	759746.8	754210.2	427
10	144	765667.0	758934.0	819

TABLE 5: Optimal starting timetable for passenger convenient travel.

Number	Turnback station	Optimal departure time		
		10 min interval	15 min interval	20 min interval
1	Guiyang (K)	1082 (18:02)	1187 (19:47)	1082 (18:02)
2	Beijing (Z)	700 (11:40)	619 (10:19)	680 (11:20)
3	Beijing (T)	671 (11:11)	389 (06:29)	588 (09:48)
4	Beijing (K)	745 (12:25)	520 (08:40)	633 (10:33)
5	Wuhan (Z)	410 (06:50)	1069 (17:49)	316 (05:16)
6	Wuhan (T)	798 (13:18)	966 (16:06)	815 (13:35)
7	Wuhan (K)	645 (10:45)	740 (12:20)	702 (11:42)
8	Xi'an (T)	423 (07:03)	1362 (22:42)	146 (02:26)
9	Xi'an (K)	1277 (21:17)	1325 (22:05)	1271 (21:11)
10	Zhengzhou (Z)	1100 (18:20)	1052 (17:32)	1114 (18:34)
11	Zhengzhou (K)	772 (12:52)	723 (12:03)	1001 (16:41)
12	Lanzhou (K)	458 (07:38)	1208 (20:08)	254 (04:14)
13	Kunming (K)	849 (14:09)	812 (13:32)	783 (13:03)
14	Guangzhou (Z)	613 (10:13)	651 (10:51)	1058 (17:38)
15	Guangzhou (K)	1141 (19:01)	1267 (21:07)	1251 (20:51)
16	Nanchang (T)	688 (11:28)	765 (12:45)	657 (10:57)
17	Nanchang (K)	627 (10:27)	783 (13:03)	457 (07:37)
18	Nanjing (K)	658 (10:58)	1289 (21:29)	745 (12:25)
19	Shanghai (K)	336 (05:36)	277 (04:37)	392 (06:32)
20	Changsha (Z)	1187 (19:47)	1141 (19:01)	1134 (18:54)
21	Changsha (K)	810 (13:30)	837 (13:57)	965 (16:05)
22	Hangzhou (K)	762 (12:42)	1034 (17:14)	891 (14:51)
23	Shenyang (K)	913 (15:13)	1085 (18:05)	856 (14:16)

optimization space makes the optimization effect more obvious; but at the same time, the average convergence algebra and execution time of the algorithm also increase. Under different departure intervals, the optimal dispatched departure time for each train at Chengdu Railway Station is shown in Table 5.

## 6. Conclusion

Considering the characteristics of Chinese common-speed railway network, such as long east-west line and large north-south span, this study uses the passenger satisfaction of arrival/departure time of the train as a key indicator when



optimizing the departure time of all trains. In order to obtain the passenger satisfaction, many solution strategies have been used, such as clustering analysis of railway stations, estimation of train travel time based on existing train working diagram, and fitting of passengers getting on and off each station, which ensured that the overall passenger satisfaction of train pairs can be calculated without the compilation of actual train working diagram. The optimization model for optimizing the departure time of all trains is founded based on the passenger satisfaction of train pairs and a simulated annealing algorithm is designed to solve this model, which provides a new perspective for the study of the optimization of the reasonable departure time domains of passenger trains.

Finally, 23 pairs of passenger trains with different grades from Chengdu Station are taken as examples to verify the feasibility and effectiveness of the model and algorithm. It is revealed that the optimization results of the reasonable departure domain of different passenger trains are closely related to factors such as train travel time, number of passengers getting on and off along the route, passenger satisfaction, and station departure interval. The research result shows that taking passengers satisfaction as a consideration index when coordinating the departure time of passenger trains is of great significance, which is helpful to optimize the passenger train working diagram and improve the service quality of passenger trains.

### Data Availability

All data included in this study are available upon request to the corresponding author.

### Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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