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Train Schedule Adjustment Strategies for Train Dispatch

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Abstract

Train schedule adjustment is the identity of key components of Train Dispatch System. Manually arranging the time table is a time-consuming and error-prone process. In this work, we mainly discuss three strategies of train schedule adjustment in train dispatch. First, we propose a new algorithm to calculate the maximum traffic capacity of freight-train in Beijing-Shanghai railway. We use a VMM (Vacancy Maximum Matching) grid to find the vacancy time table of freight-train base on the passenger train schedule, and solve the possible time sequence of freight-train by searching the bottleneck of freight-train traffic capacity. Second, we study the special circumstances in China when the spring transport or the Golden Week comes. It is necessary to put on extra passenger trains and in order to arrange the extra passenger trains, we set up a double objective model, and the experiment shows that all the extra passenger trains arrive at the terminus within 20 hours. Finally, for the speed raising adjustment or train reschedule, we propose the SIA (Schedule inherited adjustment) algorithm to reschedule the freight-train time table. We compare the results of the SIA algorithm with that of the regular method, and find that the SIA leads to better results.

Keywords: VMM algorithm, SIA algorithm, extra passenger train arrangement, train dispatch

1. Introduction

Train Dispatch System (TDS) have been actively developed in the recent years for controlling the train's movement over a line, plan the meeting and passing of trains in the single-track sections, align switches to control each train's movement and perform information gathering and communication with train crew and station (or yard) workers [1]-[3]. Currently, computers are increasingly used to support these critical tasks. Computerized dispatching systems are being evolved from a basic computer aided dispatch, through automated dispatch, to an integrated system for dispatch operation and control of each train [4], [5].

In this paper, we describe a computer-aided approach for train dispatch planning. The solution uses VMM vacancy time table primarily to analyze freight-train movements and to aid control center operators (CCO) to make the most appropriate decisions by using SIA algorithm when the train schedule changes. Next, a case study conducted at Beijing-Shanghai Railway (Located between the north and south of China) is reported. The paper concludes by discussing the main results and the steps to be pursued next.

The TDS is composed of a set of modules for planning feasible train movements, which consider some constraints including: multiple trains should not run in a single track section at the same time; sufficient time interval must be reserved between two trains for safety consideration; the passenger trains have higher priority than the freight-trains, etc [6]-[11].

To demonstrate the train dispatch planning solution, we list below all the symbols that will be used in the following sections.

c_i: No. i passenger train;
g_k: No. k freight-train;
p_r: No. r temporary train;
S_j: No. j station;
T_s: The safety interval time between two trains;
$tc_{(i, j)}$: The time at which No. i passenger train arrives at the No. j station;

$to_{(i, j)}$: The time at which No. i passenger train leaves the No. j station;

$tc_{(k, j)}$: The time at which No. k freight-train arrives at the No. j station;

$to_{(k, j)}$: The time at which No. k freight-train leaves the No. j station;

$tc_{(r, j)}$: The time at which No. i temporary train arrives at the No. j station;

$to_{(r, j)}$: The time at which No. i temporary train leaves the No. j station;

v_{gmax}: The maximum velocity of the freight-train (80 *km/h*);

$d_{(j, j+1)}$: The distance between station i and station $i+1$;

$\Delta t_{vacancy}$: The vacancy time zone;

$\Delta t^*_{vacancy}$: Estimated time of arrival based on the $\Delta t_{vacancy}$;

There are three primary influencing factors in train dispatch [12]-[17]:

1) Freight-train vacancy time table: The tables indicate all the available time besides those occupied by the passenger trains. Freight-train dispatch should be based on this table because passenger trains have higher priority.

2) Freight-train current state: Freight-train dispatch should not conflict with the trains that have already been arranged, which means the dispatching should consider both freight-train and passenger train.

3) Freight task: Whether we arrange the freight-train depends on the freight task. If there is no freight task, we don't dispatch.

All these factors influence the freight-train dispatch, but the vacancy time table is the dominant one. To calculate the maximum traffic capacity of freight-train, we neglect the other two factors.

2. Freight-Train Arrangement Strategy
2.1. Vacancy Time Table

There will be two passenger trains c_j and c_{j+1} passing two adjacent stations S_j and S_{j+1}. We will try to arrange one freight-train g_k (or several freight-trains) and ensure safety time intervals between all the trains. To achieve that goal the following conditions should be satisfied:

g_k's departure time from S_j is later than that of c_j by at least T_s: $t_{o(k, j)} - T_s \geq t_{o(i, j)}$;

g_k's departure time from S_j is earlier than that of c_{j+1} by at least T_s: $t_{o(k, j)} + T_s \leq t_{o(i+1, j)}$;

g_k's arrival time at S_{j+1} is later than that of c_j by at least T_s: $t_{c(k, j+1)} \geq t_{c(i, j+1)} + T_s$;

g_k's arrival time at S_{j+1} is earlier than that of c_{j+1} by at least T_s: $t_{c(k, j+1)} \leq t_{c(i+1, j+1)} - T_s$;

g_k's travel time between S_j and S_{j+1} should be longer than that of a freight-train at its highest speed: $t_{c(k, j+1)} - t_{o(k, j)} \geq d_{(j, j+1)}/v_{gmax}$;

We can calculate the vacancy time table of S_j when the above conditions are satisfied, and all the estimated time of arrival can be calculated based on the $\Delta t_{vacancy}$.

$\Delta t_{vacancy} = max(t_{o(k, j)}) - min(t_{o(k, j)})$

Actually, there are a number of passenger trains passing through a station, so every station has a number of vacancy time periods. Based on the entire table we can work out the maximum traffic capacity of freight-trains: N_{gmax} by the formula (1).

$$N_{g\max} = \min_{j \in [1,44]} \left(\sum_{l=1}^{wj} \frac{\Delta t_{vacancy(j,l)}}{T_s} + 1 \right) \tag{1}$$

Where w_j is the count of j station's vacancy time periods, and $\Delta t_{vacancy(j, l)}$ is the No. l vacancy time period of j station. In our study, we use the *Jinan-XuZhou* railway as the example, which has 8 stations.

2.2. VMM Algorithm

In 2.1 we have obtained the vacancy time table of each station and the maximum traffic capacity of freight-trains. Based on those results we can set up a VMM Grid as shown in table 1, and we accomplish the VMM algorithm following the steps below:

Table1. VMM grid example

	Station 0		…		Station M	
Freight-train 1	Departure time from station 0	Arrival time at Station 1	…	…	Departure time from station M	Arrival time at Station $M+1$
…	…	…	…	…	…	…
Freight-train N	Departure time from station 0	Arrival time at Station 1	…	…	Departure time from station M	Arrival time at Station $M+1$

Step 1: Create an empty VMM grid, and its number of rows (*VMMGrid.Lines.Count*) equals to the number of stations (8 in our case), its number of columns (*VMMGrid.Columns.Count*) equals to the theoretical maximum traffic capacity of freight-trains. Put the station variable S_j ($j=0,…,6$) into the first row: *VMMGrid.Lines[0]* and start with the second column, we only put 7 stations because the arrival time of the last station depends on the penultimate station. Put the freight-train variable g_k ($k=1,…, N_{gmax}$) into the first column *VMMGrid.Columns[0]* and start with the second line;

Step 2: List all the vacancy time periods $\Delta t_{vacancy}$ and the arrival time $\Delta t^*_{vacancy}$ of each station in descending order;

Step 3: Choose the station S_j which has the N_{gmax} as S_{j0};

Step 4: Calculate the vacancy time tables for S_{j0} and the stations after S_{j0};

Step 4.1: Calculate all the vacancy time periods between S_{j0} and S_{j0+1};

Step 4.2: If all the vacancy time periods are processed then go to step 4.5, otherwise, process the next vacancy time period, and set the first vacancy time period as t_0;

Step 4.3: Calculate the arrival time t^*_0 at station S_{j0+1} for the freight-train which departs at t_0 according to the speed and the distance between S_{j0} and S_{j0+1}. Put t_0 into the first empty cell in *VMMGrid.Columns [2j_0+1]* and put t^*_0 into the next cell;

Step 4.4: If t_0+T_s is still covered by the current vacancy time period, then set $t_0=t_0+T_s$, and go to step 4.3, otherwise go to step 4.2;

Step 4.5: if *VMMGrid.Columns [2(j_0+1)+1]* has been filled in, then set *VMMGrid. Columns [2(j_0+1)+1]* as key and refill in it in ascending order, then go to step 4.10. If the vacancy time period of S_{j0+1} has been processed then go to step 4.9, otherwise take the next vacancy time period of S_{j0} and set it as t'_0;

Step 4.6: Calculate the arrival time t^*_0 at station S_{j0+2} for the freight-train which departs at t'_0 according to the speed and the distance between S_{j0+1} and S_{j0+2};

Step 4.7: Take the cell t^*_0 in *VMMGrid. Columns [2j_0+1]* which has never been compared, if $t'_0 \geq t^*_0$, then the result is true, and put t'_0 mod (24 hour) into the first empty cell in *VMMGrid. Columns [2(j_0+1)+1]*, and put the t^*_0 to the next of t'_0;

Step 4.8: If $t'_0 + T_s$ is still covered by current vacancy time period, then set $t'_0=t'_0 + T_s$, and go to step 4.6, otherwise go to step 4.5;

Step 4.9: Add 24 hours to the time table of S_{j0+1} which has been processed unless the time is already in the VMM Grid;

Step 4.10: If S_6 has been processed, then go to step 4.11, otherwise set $S_{j0}=S_{j0+1}$, $S_{j0+1}=S_{j0+2}$, and go to step 4.1;

Step 4.11: If all the stations between S_{j0} and the stations after S_{j0} have been processed then quit step 4;

Step 5: Calculate VMM grid of all the stations before the S_{j0}. Since this procedure is similar to the previous steps, the details are omitted.

2.3. The Experiment Result of VMM Algorithm

According to the VMM algorithm in the previous section, we use *60 km/h* as the average speed of freight-trains, and we get the result of a big VMM grid, so the details of the VMM grid is shown in Table 2.

Table2. VMM grid of Jinan-Taishan

| Stations | Jinan-Taishan | |
Sequence	Vacancy time	Estimate arrival time
1	0:22-1:02	1:33-2:13
2	2:24-2:30	3:35-3:41
3	3:53-4:19	5:04-5:30
4	4:51-4:52	6:02-6:03
5	6:29-6:31	7:40-7:42
6	7:03-7:05	8:14-8:16
7	8:57-11:14	10:08-12:25
8	11:46-12:30	12:57-13:41
9	14:25-14:58	15:36-16:09
10	16:04-16:18	17:15-17:29
11	16:50-17:02	18:01-18:13
12	17:34-18:04	18:45-18:55
13	18:56-19:03	20:07-20:14

From the VMM grid, we can calculate the freight-train schedule (shown in Figure 1). It shows that there is no crossed line in the schedule, which indicates the result is qualified for practical use. Dispatching operator can choose the lines according to the freight task.
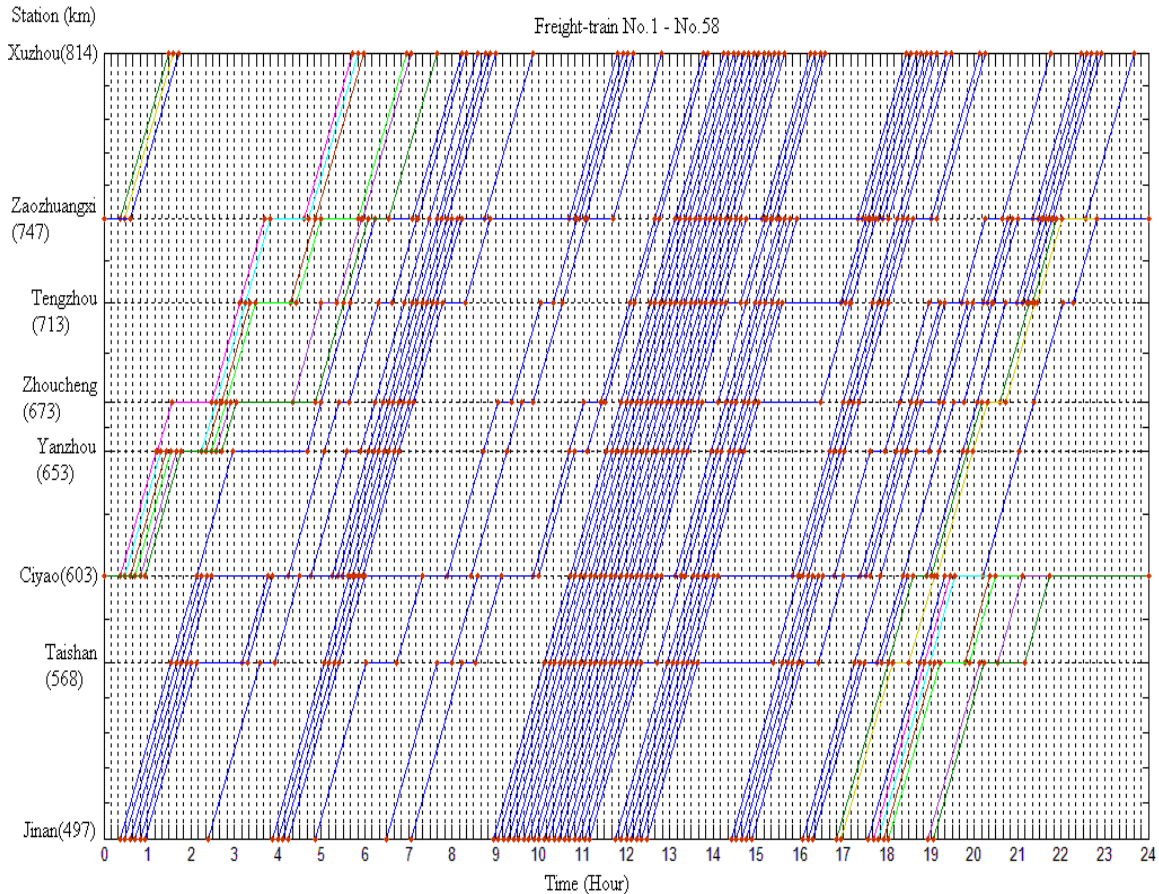

Figure 1. Freight-Train Running Graph (Xuzhou - Jinan)

If we use different average speed of freight-trains, we will get different traffic capacity of freight-train (Figure 2). It shows that the maximum traffic capacity of freight-trains is actually in proportion to their average speed.
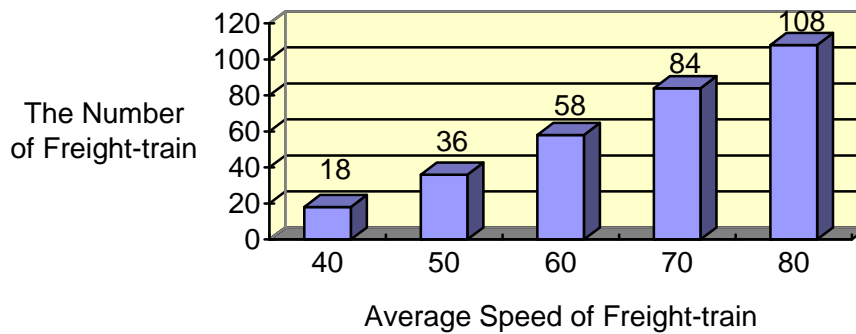
Figure 2. Maximum traffic capacity of freight-train (Xuzhou - Jinan)

3. Extra Passenger Train Arrangement Strategy

In China, during the spring transport or the Golden Week, it is necessary to put on extra passenger trains. In this section we will discuss how to create the extra passenger train's time table which minimizes the adverse effects to the original time table.

3.1. Double Objective Model of Extra Passenger Train Arrangement

In order to arrange the extra passenger train's time table reasonably, the extra passenger train must satisfy two conditions: one is the running time of the train needs to be as short as possible, and the other is the extra passenger train's time table needs to be created based on the vacancy time table which is different with the vacancy time table of the passenger train. We assume that five extra passenger trains will be needed as follows:

1) Beijing <---> Shanghai.
2) Beijing <---> Nanjing.
3) Tianjin <---> Shanghai.
4) Beijing <---> Jinan.
5) Beijing <---> Bengbu.

The key to solve this problem is to find out the most suitable solution for the target and satisfy the constraints of the extra passenger train. We search the vacancy time table which is available for the four extra passenger trains in order, and when the result is rendered, we put it into the existing vacancy time table and start searching for the next extra passenger train. We mark those five extra passenger trains as 1 to 5, and take No.1 extra passenger train as the example.

Since the railway is completely electrified and double-tracked, the up train and down train are relatively independent. We only need to look into the down train and the up train can be handled using the similar methods.

According to the above analysis, we set up a double objective model for the down train of the No. 1 extra passenger train (from Beijing to Shanghai). The objective function and constraints can be described by two sets of equations.

$$\begin{cases} \min\left(t_{c(1,Shanghai)} - t_{o(1,Beijing)}\right) \\ \min\left(\sum_{j=1}^{44} m\left(\left[t_{o(1,j)}, t_{c(1,j+1)}\right] \cap I_j\right)\right) \end{cases} \qquad (3)$$

$$\begin{cases} t_{c(1,Shanghai)} - t_{o(1,Beijng)} \le \lambda; \\ m\left(\left[t_{o(1,j)}, t_{c(1,j+1)}\right] \cap I_j\right) \le \delta_j, j = 1,...,44; \\ t_{o(1,j)}, t_{c(1,j)} \in A_j; \end{cases} \qquad (4)$$

In (3) I_j indicates the collection of all the vacancy time periods which are available for the freight-train of station j; m indicates the Lebesgue measure of the zone's length. In (4) λ is an input parameter which means the time limitation of the extra passenger train running from the originating station to the terminus; δ_j is an influencing factor indicating how strong the extra passenger train will affect the freight-train.

3.2. The Experiment Result of Extra Passenger Train Arrangement

Before we start the search process, we need to initiate the input parameter λ and δ_j. We choose the parameter from actual circumstances. The recommended values of λ is 20, and $\delta_j = \dfrac{1}{10} m(I_j)$. We choose several different periods to process the searching for the typical result and we get the extra passenger train's time table shown in Figure 3.
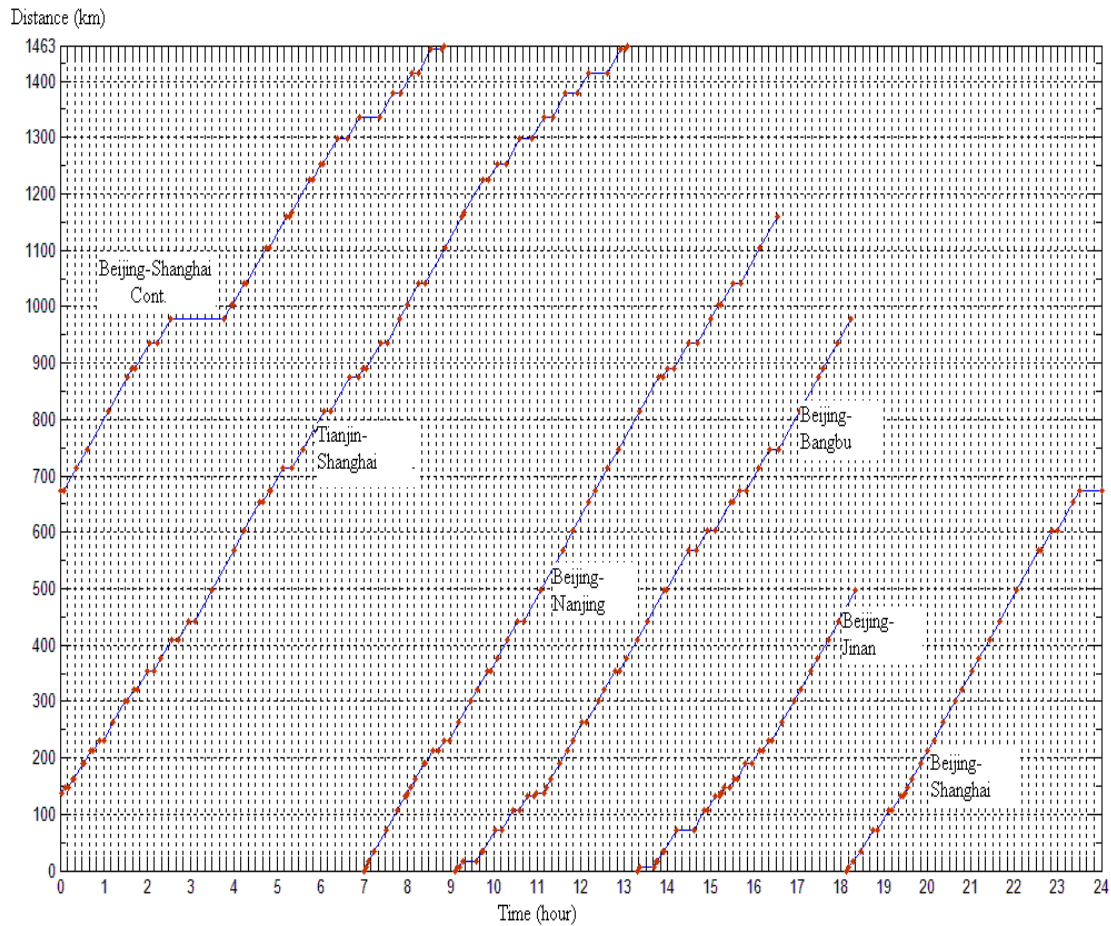

Figure 3. Extra passenger train running graph

The time table shows that the five extra passenger trains arrive at the terminus within 20 hours; during the travel all the trains have certain stop time. Those results are reasonable and in accordance with the actual case.

4. Speed Adjustment Strategy
4.1. SIA algorithm

We have developed a new strategy for controlling train traffic with which operators are able to reschedule the freight-train time table. Usually, there are two methods to adjust the time table, one is creating a whole new time table, and the other is adjusting the time table based on the old one. In this paper, we choose the later method by using the VMM algorithm. We still use the Jinan-Xuzhou railway as the example.

The main purpose of SIA algorithm (Figure 4) is to accelerate all the passenger train and keep the time interval of their arrival and departure not changed. For convenience, we divide the algorithm into two parts. The first part is to deal with those trains whose routes are completely covered by the Beijing-Shanghai railway, then find out the fastest passenger train in previous time table and accelerate it, and based on the shortened travel time we can adjust the other passenger trains so as to assure the maximum speed will not be exceeded; the second part is to deal with those trains passing through the railway, and we use the VMM algorithm to calculate the vacancy time table of the first part, and add the trains into the second part, then the new time table is generated.
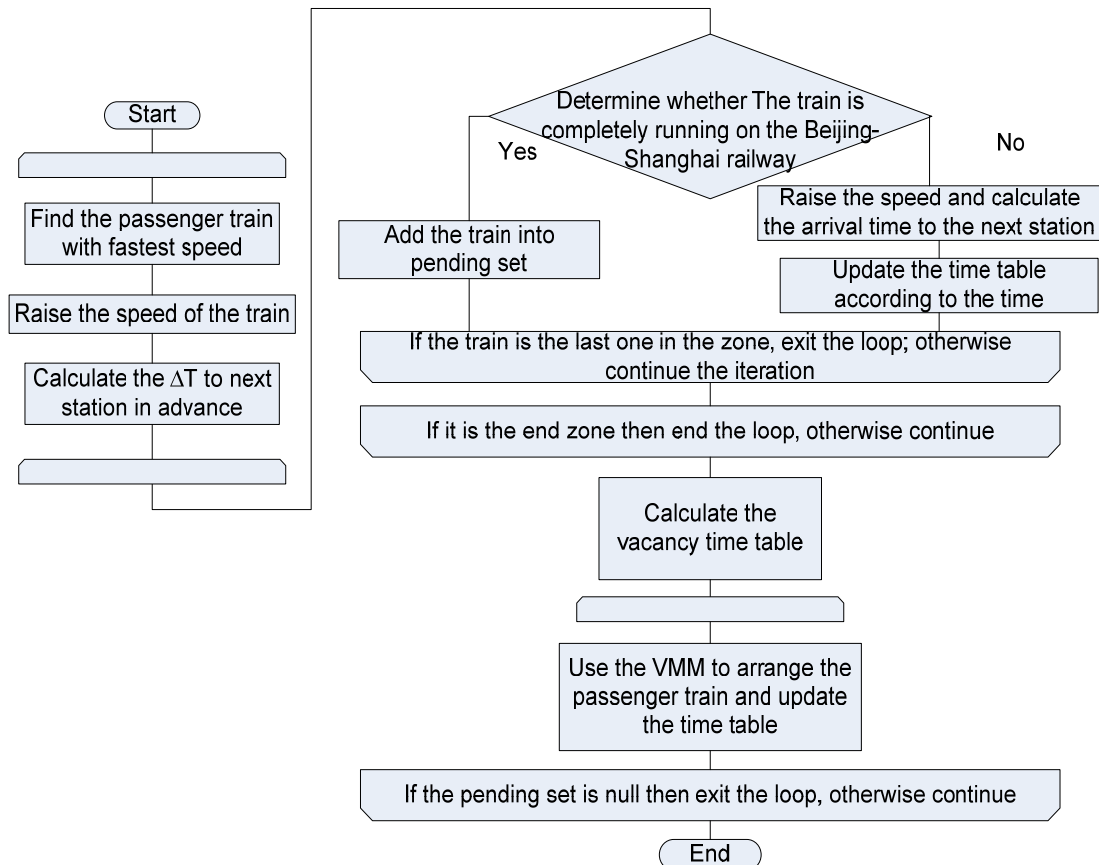
Figure 4. SIA Algorithm process

4.2. The Experiment Result of SIA Algorithm

We use the lines to denote the passenger train's time table, and the Figure 5 shows that there is a lot of vacancy time after the acceleration.
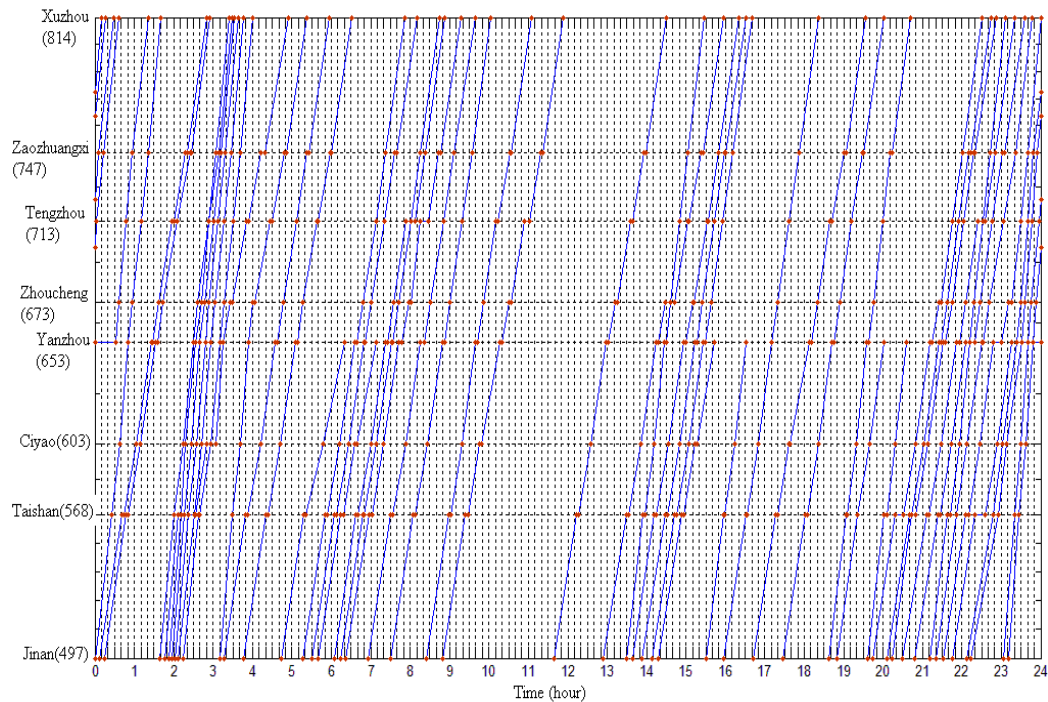
Figure 5. Passenger train running graph after acceleration (Jinan-Xuzhou)

5. Conclusion

Three train schedule adjustment strategies introduced in this paper have provided an effective mechanism to develop satisfactory solutions in real time train schedule planning. In this paper, we use the average speed of train to calculate the arrival time, which is a simplified and practical process. It would be more accurate if the average speed is replaced with the real-time speed. In extra passenger train arrangement, we use the double objective model which has the global optimal solution and high time complexity, and we set the initial search in specified time period to get the local optimal solution which has low time complexity. Future work will focus on overdue schedule adjustment strategy which is the most common issue in TDS. The late-running train is needed to avoid the collision with the other trains and to prevent the vicious circle.

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