Research on Optimizing Method of High Speed Railway Passing Capacity Utilization

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Abstract. The mode of transportation organization adopted by China's high-speed railways is the "transportation organization for trains running at different speeds". The advantage of this model is that it facilitates the travel of travelers, reduces the time and energy wastage caused by the transfer, and improves the travel experience of passengers. However, this mode has many disadvantages and may not necessarily meet the passenger travel demand. Therefore, this paper focuses on how to use the idea of compressed operation diagrams to create an optimized model under the mode of “transport organizations with different speed-class trains collinearly operating”. Stop plan provides a reference.

1. Introduction
High-speed railway (passenger dedicated line) refers to the transformation of existing lines to make the operating speed of more than two hundred kilometers per hour, or a new line with an operating speed of more than two hundred and fifty kilometers. The main transportation organization mode adopted by my country's high-speed railways is “mixed travel”: high-speed trains are used as the main line running trains, while trains which run from one line to another are operated at the same time, and medium-speed trains exist. But this is the mode adopted in the early stage of network formation. It is worth considering that when trains of different speeds are mixed, the capacity of the line is reduced. Therefore, study what factors will limit the passing capacity, and how to quantitatively and qualitatively analyze it, and how to match different trains under speed difference, and how to design a stop plan and an overtaking plan to achieve the ultimate goal of strengthening the passing capacity is of great importance. This article is discussed under this background.

2. Calculation model of passing capacity based on operation diagram compression method
2.1. Problem description
Through the improved operation diagram compression method, when the number of medium-speed and high-speed trains in a certain passenger flow section, and the proportion of them and the proportion of stops at different stations are known, a paving plan is found to minimize the total time that the trains occupy the operation diagram. Specifically, under the constraints of section operation hours, minimum tracking train interval time, start and end time and other conditions, calculate the compressed schedule and capacity utilization rate without any buffer time under this scheme, and use the number of running lines on the current operation chart to divide the calculated capacity utilization rate, that is, the passing capacity under the current operating graph structure.
2.2. Symbol definition

| Symbol | Symbol description |
|--------|--------------------|
| $TTr$  | set of the train, $i, j \in TTr$ |
| $S$    | set of the station, $s \in S$ |
| $o(i)$ | starting point of the train $i, i \in Trr$ |
| $d(i)$ | ending point of the train $i, i \in Trr$ |
| $\delta_i$ | extra time to start the train $i, i \in Trr, 2\text{mins}$ |
| $\varphi_i$ | extra time to stop the train $i, i \in Trr, 3\text{mins}$ |
| $i_i^s,i_i^{s+1}$ | pure running time of the train $i$ in the section of $[s, s+1], i \in Trr, s \in S$ |
| $\tau_i^s$ | minimum stop time of the train $i$ at the station $s, i \in Trr, s \in S, 2\text{mins}$ |
| $\tau_i^v$ | maximum stop time of the train $i$ at the station $s, i \in Trr, s \in S, 20\text{mins}$ |
| $D$    | earliest departure time of the train $i, 6:00\text{a.m.}$ |
| $A$    | latest arrival time of the train $i, 24:00\text{p.m.}$ |
| $I_{wd}$ | tracking train interval time of passing and arriving, $6\text{mins}$ |
| $I_{ff}$ | tracking train interval time of starting and starting, $5\text{mins}$ |
| $I_{dd}$ | tracking train interval time of arriving and arriving, $4\text{mins}$ |
| $I_{dt}$ | tracking train interval time of arriving and passing, $3\text{mins}$ |
| $I_{ft}$ | tracking train interval time of starting and passing, $6\text{mins}$ |
| $I_{gt}$ | tracking train interval time of passing and starting, $2\text{mins}$ |
| $I_{tt}$ | tracking train interval time of passing and passing, $4\text{mins}$ |

| Symbol | Symbol description |
|--------|--------------------|
| $r_{ij}^{s-1,s}$ | is a variable on behalf of $0$ or $1$, when it’s $1$, it means $j$ is $i$’s train behind in the section of $[s-1, s], i \in Trr, s \in S$; if not |
| $x_i^s$ | is a variable on behalf of $0$ or $1$, when it’s $1$, it means $i$ stops at the station $s$, $i \in Trr, s \in S$; if not |
| $a_i^s$ | the arriving time of train $i$ at the station $s, i \in Trr, s \in S$ |
| $d_i^s$ | the starting time of train $i$ at the station $s, i \in Trr, s \in S$ |
| $\omega_i$ | $\omega_i$ is a variable on behalf of $0$ or $1$, when it’s $1$, it means $i$ is a high-speed train, when it’s $0$, it means $i$ is a medium-speed train $i \in Trr$; if not |

2.3. Objective function

Set up the objective function of the integer linear programming model with the goal of "minimum total train travel time".
2.4. Restrictions

2.4.1. Time constraint of starting and ending

\[ d^i_l - D \geq 0 \quad i \in T_r_r, s \in S \] \hspace{1cm} (2)

\[ a^i_l - A \leq 0 \quad i \in T_r_r, s \in S \] \hspace{1cm} (3)

The Figure 1 describes this relationship.

2.4.2. Time constraint of running in the section

\[ a^{i+1}_l - d^{i+1}_l - x^i_l \delta^i_l - x^{i+1}_l \varphi^i_l = \xi^{i+1}_l \quad i \in T_r_r, s \in S \] \hspace{1cm} (4)

The Figure 2 describes this relationship.

2.4.3. Tracking interval time constraint

\[ d^i_l - d^j_l - L_r + M \left( 2 - x^i_l - \xi^{i+1}_r \right) \geq 0 \quad \forall i, j \in T_r_r, s \in S \] \hspace{1cm} (5)

In the equation (5), M is to convert nonlinear constraints into linear constraints and ensure the establishment of the constraints. \( M \left( 2 - x^i_l - \xi^{i+1}_r \right) \) is correct when train \( i \) stops at the station \( s \) and running with \( j \) back and forth. In this case, \( d^i_l - d^j_l - L_r \geq 0 \). Or \( M \left( 2 - x^i_l - \xi^{i+1}_r \right) \) tends to infinity to ensure the establishment of the equation. The Figure 3 shows this relationship.

\[ d^i_l - d^j_l - L_s + M \left( 2 - x^i_l - \xi^{i+1}_s \right) \geq 0 \quad \forall i, j \in T_r_r, s \in S \] \hspace{1cm} (6)

The Figure 4 describes this relationship.

Figure 1. The time of starting and ending

Figure 2. The running time in the section

Figure 3. Tracking interval time of passing and starting

Figure 4. Tracking interval time of starting and passing

Figure 5. Tracking interval time of passing and arriving

Figure 6. Tracking interval time of arriving and passing
The Figure 5 describes this relationship.

\[
\alpha_i - d_i^j - I_{ix} + M \left( 2 - x_i^j - r_i^{j+1} \right) \geq 0 \quad \forall i, j \in T_{rr}, s \in S
\]  

(7)

The Figure 6 describes this relationship.

\[
d_i^j - a_i^j - I_{ix} + M \left( 2 - x_i^j - r_i^{j+1} \right) \geq 0 \quad \forall i, j \in T_{rr}, s \in S
\]  

(8)

The Figure 7 describes this relationship.

\[
d_i^j - d_i^j - I_{ix} \left( 1 + x_i^j + x_i^j - r_i^{j+1} \right) \geq 0 \quad \forall i, j \in T_{rr}, s \in S
\]  

(9)

The Figure 8 describes this relationship.

\[
a_i^j - d_i^j - I_{ix} + M \left( 3 - x_i^j - x_i^j - r_i^{j+1} \right) \geq 0 \quad \forall i, j \in T_{rr}, s \in S
\]  

(10)

The Figure 9 describes this relationship.

\[
d_i^j - d_i^j - I_{ix} + M \left( 3 - x_i^j - x_i^j - r_i^{j+1} \right) \geq 0 \quad \forall i, j \in T_{rr}, s \in S
\]  

(11)

2.4.4. The stopping time constraint at the station

\[
x_i^j \leq d_i^j - a_i^j \leq x_i^j \quad i \in T_{rr}, s \in S
\]  

(12)

The Figure 10 describes this relationship.

2.5. Computing capacity

\[
T_{\text{efficient}} = (A - 3.6S/\sqrt{V} - T_{\text{starting}} - T_{\text{stopping}}) - D
\]  

(13)

In the equation, \( T_{\text{starting}} \) means additional time when the train starts. \( T_{\text{stopping}} \) means additional time when the train stops. \( T_{\text{efficient}} \) means effective time period of train’s running. These unit of measurement is second. Then using the value of \( Z \) and \( T_{\text{efficient}} \) obtained by the model, we can obtain the utilization coefficient \( k \) of passing capacity.
\[ k = \frac{Z}{T_{\text{efficient}}} \]  

(14)

Then calculate train’s passing capacity with the following equation.

\[ N = \frac{m}{k} \]  

(15)

In the equation, \( m \) means the number of run lines after compression. \( N \) means passing capacity, its unit of measurement is second.

2.6. Steps to solve the model
It can be solved using LINGO software. LINGO is mainly used to solve linear programming, nonlinear programming, quadratic programming and integer programming. It can also solve nonlinear and linear equations, as well as algebraic equations for roots. The built-in modeling language can easily express problems and is a simple tool for efficient solving.

3. Analyze an example
3.1. Overview of calculation examples
Suppose a high-speed line has 4 stations, A station, B station, C station, and D station. There is a passenger flow section between each two adjacent stations. Two types of trains run between each section, namely high-speed trains and medium-speed trains, hereinafter referred to as category A trains and category B trains respectively. In this example, the ratio of high and medium speed trains is set to 7:3. There are 30 trains in total, namely 21 high-speed trains and 9 medium-speed trains. For category A trains in the section of \([A, B]\), it’s pure running time is 25mins. In the section of \([B, C]\), it’s pure running time is 52mins. In the section of \([C, D]\), it’s pure running time is 33mins. For category B trains in the section of \([A, B]\), it’s pure running time is 45mins. In the section of \([B, C]\), it’s pure running time is 84mins. In the section of \([C, D]\), it’s pure running time is 56mins. And the frequency of all the trains stop at station B is 10 times, at station C is 17 times. Given the conditions above, the optimization model established in Chapter 2 is used to solve the specific operation of 30 trains. The conditions include the arrival and departure time of each station, stop or overrun conditions, etc. Finally, we can get the compressed operation diagram, compared with the operation diagram before compression, proving the availability and superiority of the model, and get maximum passing capacity with no buffer time theoretically.

3.2. Result analysis

![Figure 11. The window of LINGO](image1)

![Figure 12. Train operation diagram after optimization](image2)

![Figure 13. Train operation diagram without optimization](image3)
Put the known information into LINGO, and write code as shown in Figure 11 above, after being functioned, and use "Run Line Laying" program of C#, we can get the train operation diagram as Figure 12. In addition, the train operation diagram without optimization is Figure 13.

From the two figures above, we can find that the diagram after optimization can pave more train lines per unit time which improves the passing capacity of the section, which intuitively proves the usability and superiority of the model.

3.3. Passing capacity calculation and analysis
Using the above method steps, the passing capacity under the original timetable before optimization is calculated as 40 rows/day; the passing capacity after optimization is 90 rows/day. Comparing the two cases, it is found that the value of passing ability has been significantly improved after the calculation of the model.

4. Conclusion
this paper focuses on how to use the idea of compressed operation diagrams to create an optimized model under the mode of “transport organizations with different speed-class trains collinearly operating”. Stop plan provides a reference.

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