Integration Optimization of Timetable and EMU Schedule for High Speed Railway

Shu-shan WANG¹⁺, Lei-shan ZHOU¹ and Han-xiao ZHOU¹

¹School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China

*Corresponding author

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Abstract. Based on the analysis of the existing optimization model of train diagram and EMU schedule, combined with the theory and method of integration optimization, the integrated optimization model of high-speed train diagram and EMU schedule was constructed in this thesis, of which the objective function is to build the largest number of running lines between its zones. An EMU schedule plan which better satisfied the given traction plan was obtained in this thesis, using GAMS to solve the model. To test the effectiveness of the model as well as the method, the train diagram and EMU schedule scheme of Beijing-Tianjin Intercity Train was optimized and solved. The optimization results showed that for the EMU schedule of the Beijing-Tianjin line, the number of EMU trains could satisfy the actual operation of high-speed railways, while 6 more trains could be operated at the same time. This solution could provide support of high-speed railway train diagram and EMU schedule scheme for the Beijing-Tianjin line.

Introduction

Train operation diagram and EMU schedule are two basic plans of high speed railway transportation organization. The train operation diagram stipulates the specific arrival time of each train at each station in its operating section. The EMU routing plan is one of the important components of the EMU schedule. It stipulates the relationship between the train bottom turnover and the first level maintenance arrangement.

In view of the related problems of these two plans, there are large number of research results. For the compilation or optimization of train diagram, it is difficult to solve complex problems. Thus, the operation diagram is regarded as a known input condition.

Shi et al. (2011) and others considered the time interval and mileage interval of daily maintenance and first order maintenance, established an integrated optimization model of EMU application plan and maintenance plan, and designed the solution method of simulated annealing algorithm [1]. They combined the EMU connection with the station arrival and departure line operation, which designed the EMU schedule with the minimum waiting time of EMUs as the objective function [2]. In order to better describe the problems of EMU Operation Planning and maintenance planning, Wang et al. (2015) have added the main constraints to use the routing and maintenance procedures of the EMU, and they use the simulated annealing algorithm to solve the problems of EMU schedule and maintenance planning [3]. Li et al. put forward a model to solve the least target function of EMU schedule, which divide the model into two stages. Each stage is optimized only for one target, thus reducing the difficulty of solving the problem [4]. Taking the single line as the research goal, Arianna Alfieri (2006) set up a model of EMU turnover plan [5].

Statement of the Problem

From the existing optimization methods at home and abroad, the train operation diagram and the development of the motor train are two sets of relatively independent systems for optimization and development. This situation will cause railway operators to master and maintain 2 systems when they are in use. Under the condition of unfixed use of the EMU, the train diagram of the high-speed railway is a tightly connected whole. The optimization method in this paper is to consider the
optimization of train diagram and the optimization of EMU operation. The application track of the EMU vehicle bottom in the EMU utilization plan is used as the compiling plan of the train diagram.

This article should solve the problem of how to arrange as many trains as possible in the train diagram under the condition of a certain number of EMU. First, we need to make decisions on the train diagram. In the case of the determination of the number of use of the EMU, the train diagram can make the overall optimal decision in the possible range by reference to the routing plan of the EMU and the performance effect of the train. The framework for its overall decision making is shown in Fig. 1.

Figure 1. Framework map of integrated optimization.

**Integrated Optimization Model of High-speed Railway Train Diagram and EMUs Operation**

**Symbolic Description**

The assumptions and naming of variables, parameters, objective functions and constraints in a mathematical model are based on symbols and sets, so the hypothesis of symbols and sets is crucial. The following symbols and sets should be involved in the construction of integrated train operation diagram and train operation optimization model.
Integrated Optimization Model of High-speed Railway Train Diagram and EMUs Operation

The first task of motor vehicle operation is to complete a given traction task. Under the premise of satisfying the condition, the more the number of interval running lines, the better the integration of high-speed railway train diagram and train operation. Therefore, in the integrated optimization model, the maximum number of interval lines is usually the target. We calculate the total interval lines $Z$ in the following way:

$$\max Z = \sum_{n=0}^{N} x_{i,j}(n) \cdot j(n) \cdot j(n)$$

subject to:

$$\sum_{n=0}^{N} x_{i,j}(n) \cdot j(n) \cdot j(n) \leq B_{j}, \text{ where } i \neq j, \text{ and } i, j \in A$$

$$\sum_{j \in A} x_{i,j}(n) \cdot j(n) \cdot j(n) \leq B, \text{ where } i \neq j, \text{ and } i, j \in A$$

Where

$x_{i,j}(n) \cdot j(n) \cdot j(n)$——No. n EMU whether starts from i station at $t_{i}(n)$ and arrives at j station at $t_{j}(n)$.

The following method can be taken for value:

$$x_{i,j}(n) \cdot j(n) \cdot j(n) = \begin{cases} 1, & \text{when the construction EMU set off from i station} \\ 0, & \text{otherwise} \end{cases}$$

Subject to:

$$\sum_{n=0}^{N} x_{i,j}(n) \cdot j(n) \cdot j(n) \leq B_{j}, \text{ where } i \neq j, \text{ and } i, j \in A$$

$$\sum_{j \in A} x_{i,j}(n) \cdot j(n) \cdot j(n) \leq B, \text{ where } i \neq j, \text{ and } i, j \in A$$
\[
\begin{array}{l}
[y_j \cdot (t_j(n) - t_j'(n))] \times y_j \leq E, \quad \text{when } j \in C \\
[y_j \cdot (t_j(n) - t_j'(n))] \times y_j \leq D, \quad \text{otherwise}
\end{array}
\] (4)

Where

\[y_j\] — Whether or not the bullet train stops at the j station.

The following method can be taken for value:

\[y_j = \begin{cases} 
1 & \text{when the train stops at } j \text{ station} \\
0 & \text{otherwise}
\end{cases}
\]

\[
\begin{align*}
& t_i(n) - t_i(n-1) \geq I_0 \\
& t_i(n+1) - t_i(n) \geq I_0
\end{align*}
\] (5)

\[
\sum_{i,j} T_{R}(n) = \sum_{i,j} [t_j(n) - t_j'(n)] \times x_{i,j}^{(n),j,n} \\
\text{where } n \in N, i \neq j, \text{ and } i, j \in A
\] (6)

\[
\sum_{j} I_{RE}(n) = \sum_{j} [t_j(n) - t_j'(n)] \times x_{i,j}^{(n),j,n} \times y_j \\
\text{where } e \in N
\] (7)

\[
\sum_{i,j} T_{R}(n) + \sum_{i,j} I_{AD}(n) \leq 48\times 60 \\
\text{where } e \in N
\] (8)

\[
\sum_{i,j} m_{i,j}(n) \times x_{i,j}^{(n),i,n} \leq 4000 \\
\text{where } n \in N, i \neq j, \text{ and } i, j \in A
\] (9)

\[
\begin{align*}
& \text{Earliest departure time } \geq 6:00 \\
& \text{Arrival time at the latest } \leq 24:00
\end{align*}
\] (10)

The constraint condition (2) indicates that the total number of stops at all stations is not greater than the parameters \(B_j\). The parameters \(B_j\) vary with the j station. Constraint condition (3) indicates that the total number of stops of all trains at all stations is not greater than that of parameters B. The parameter B varies with the station set. The constraint condition (4) indicates the stopping time of the train at the j station, including four cases, that is, whether the train is reentrant at the terminal (the reentrant time standard is E) and whether the train stops at the middle station (the stop time standard is D), and the E is changed as the station is different. The constraint condition (5) indicates that the station interval time of avoiding train is less than the minimum interval time, that is, when the time and space path of the train passes through a point, the adjacent points which are not satisfied with the interval time of the point can’t be arranged by the other train space-time path. The constraint condition (6) indicates the sum of the pure running time of No. n EMU between stations. The constraint condition (7) indicates the sum of the stopping time of No. n EMU. The constraint condition (8) indicates that the total running time of No. n EMU can’t exceed 48 hours, that is, 2880min. The constraint condition (9) indicates that the total number of kilometers of No. n EMU is no more than 4000km. The constraint condition (10) indicates that the EMU’s online journey time is 6:00-24:00.

**Application and Analysis of Examples**

**Solution Tool**

The research model of this paper is a single objective model, which includes several stations and has a certain scale. So, the following models are solved by using GAMS software.
**Basic Data**

Beijing-Tianjin intercity rail has a total length of 120 km with 5 stations, which is including Beijingnan station, Yizhuang station (not yet opened), Yongle station (not yet opened), Wuqing station and Tianjin station. Beijingnan Station has Beijing EMU section, Tianjin Railway Station has the Tianjin Cao Zhuang motor vehicle operating station.

We can simplify Beijing-Tianjin intercity rail. The simplified line is shown in Fig. 2.

![Simplified Line Diagram](image_url)

- **Common station**: Beijingnan, Wuqing, Tianjin
- **Station of EMU section**: 84km, 36km

**Example Illustration**

There is a total of 152 trains running on this line. They stopped at the middle station for 45 times, Beijingnan Railway Station stops 77 times, Tianjin Railway Station stops 75 times. The stopping time of EMU at Wuqing Railway Station (intermediate station) is 1 min, and the shortest departure time of EMU is 5 min.

Therefore, considering the above conditions, we can simplify the solution of the model by assuming that the train departure time is chosen to be 12min. According to the actual situation, the paper designs the stop time standard of the EMU in the intermediate station is 1min, and the stopping time standard of the EMU at the terminal is 15min. The pure running time $T_R$ between trains. Because of the night skylight time of the train, the trains have to stop at the Beijing section of the Beijingnan Station and the Tianjin Cao Zhuang train near Tianjin Station as well as the train stations and Tianjin Station so that the train can start at the same time in the south of Beijing and at the same time. After considering the actual departure condition of the train, we assume Beijingnan station is station 1, Wuqing Station is station 2, and Tianjin station is station 3. The first train emits from Beijingnan Station at 6:01. Thus, we set $t_1(1)=6:01$. The first train from Tianjin Station starts at 6:18. Thus, we set $t_3(1)=6:18$. Considering the daily skylight, therefore, taking 6:00-24:00 time section as an example, the train timetable of Beijing-Tianjin intercity rail is solved by GAMS.

**The Result and Analysis of the Solution**

We write GAMS program code, and run it in GAMS software, then you can find the result. By summarizing the above data, we can see that when the number of EMU is 9 groups, there are 80,48,78 trains sent in Beijingnan, Wuqing and Tianjin. When the number of EMU is reduced to 8 groups, there are 76,45,78 trains sent in Beijingnan, Wuqing and Tianjin. The plan can’t satisfy the actual situation of the 77 trains sent by Tianjin.

Thus, we can output the data for the set of EMUs is 9. And we get the train schedule of Beijing-Tianjin Intercity rail when the number of EMU is 9. When we draw the Beijing Tianjin Intercity EMU turnover plan (Fig. 3) to the running map, we can get the EMU road map (Fig. 4) when the EMU is used in 9 groups.

![Running Map](image_url)

The running track of the EMU can constitute the train diagram of the high-speed railway.
Conclusion

This paper constructs an integrated optimization model of train diagram and motor vehicle operation. In this paper, the integrated optimization model of high-speed railway train diagram and EMU operation is transformed into a single objective model which can be solved by GAMS software. This is convenient for the next instance to verify the feasibility of the model further.

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References


