Research on Shipping Scheme of Express by High-speed Railway Passenger Train

Jiayi Yang1*, Qilan Zhao2
1,2 School of Economics and Management, Beijing Jiaotong University, Beijing, 100044, China
*Corresponding author’s e-mail: jiayijiehen2@163.com

Abstract. High-speed rail express mainly uses the remaining space of passenger trains for transportation from the originating station to the terminal station. The number of shipments at the intermediate station of the train is small, but the transportation demand at them is also considerable. If the high-speed rail express shipping plan considers the express delivery demand of the intermediate station, it can help the high-speed rail express operation enterprise to increase profits by coordinating the demand of the stations along the global optimal angle. This paper considers the short-term stop time of the high-speed rail, limited train loading space, different timeliness requirements of high-speed rail express products, etc., and establishes the mathematical model of the high-speed rail express shipping scheme. This paper predicts the demand for various products of Beijing-Shanghai high-speed rail express in 2025 and calculate the transportation capacity of B-S HSR. The shipping plan obtained verifies the effectiveness of model.

1. Introduction
High-speed rail express is a express delivery service that uses high speed passenger trains to complete trunk transportation. Hu Y T studied the economic and social benefits that high-speed rail express can bring[1]. Huang Y L discussed the transportation plan and feasibility of the Guangzhou-Changsha high-speed rail line for high-speed rail express business[2]. Song F studied the application of high-speed rail express in China[3]. Ma Si established a comprehensive optimization model for the operation chart of high-speed railway fast freight trains with the highest efficiency and minimum transportation time consumption, and designed a genetic algorithm to solve the model[4]. Liang X H obtained the importance of high-speed railway package and mail route selection for the use of high-speed railway economies of scale[5]. Jiang C analyzes the high-speed rail express organization model of Beijing-Shanghai high-speed rail line[6]. Li C Z discussed the organization mode of high-speed rail express on the basis of analyzing the demand of high-speed rail express[7].

Scholars only conducted a qualitative analysis of the feasibility and importance of high-speed rail express. At present, no scholars have quantitatively analyzed the high-speed rail express transportation plan. Therefore, this paper establishes the mathematical model of the high-speed rail express shipping program, considering the short-term stop time of the high-speed rail, the limited loading space of the train, and the different timeliness requirements of the high-speed rail express products.
2. Problem Description
The shipping scheme, the loading and shipping scheme for express shipments, allocates limited transportation resources to meet transportation needs within the required time period. The main contents include the development of transportation routes and the distribution of shipments on various carriers. The shipping plan studied in this paper does not involve the specific operation of the loading and unloading truck, and the layout of the express in the compartment.

3. Model Establishment
3.1. Basic assumption
The assumptions are as following. The high-speed train transportation capacity is insufficient to meet the express transportation needs of all stations. Therefore, it is necessary to consider the impact of overdue expenses on profits, and to formulate a shipping plan that can maximize transportation profits under capacity constraints. High-speed trains have space for loading express, and the capacity is affected by the model and passenger load factor.

3.2. Symbolic representation
$G$ is collection of high speed trains. $m_{od}^l$ indicates the amount of express delivery of the level that needs to be sent to the destination station. $J$ is collection of high-speed rail express transport routes, consisting of a series of stations and trains, designated to send stations, to station and ship high-speed trains. The decision variable $x_{odlj}^m$ indicates the weight (kg) of the shipment of the level $l$ express that needs to be sent from original station to destination station.

3.3. Objective function
This paper takes the maximum profit of high-speed rail express delivery enterprises as the target, considering factors such as overdue fees, escorting costs, transit costs, transportation costs, and freight income of different transportation service products.

$$\max Z = \sum_{m \in M} \sum_{j \in J} \rho_j \sum_{x \in X} x_{odlj}^m - \sum_{j \in J} \sum_{x \in X} x_{odlj}^m - \sum_{x \in X} \left[ \min \left\{ n_x \left[ a_{odlj} \right] / 24, \right. \right.$$

$$\left. \left. b_{odlj} \right] \right\} \right] - \sum_{x \in X} \delta x_{odlj}^m - \sum_{j \in J} \sum_{x \in X} \left[ \left( \delta_{odlj} \right) x_{odlj}^m \right]$$

3.3.1. Freight income
$l$ indicates the grade of the express product. $l = 1, 2, 3, 4$. $p_l$ is the shipping price of the corresponding grade express product. Formula (1) represents the freight charges for all express products.

$$\sum_{m \in M} \rho_j \sum_{x \in X} x_{odlj}^m$$

3.3.2. Transportation costs
Different mileage intervals have different rates, $e_{fj}$. After the express delivery is completed, the high-speed rail express operation enterprise needs to pay the railway bureau transportation cost as formula (2) represents.

$$\sum_{j \in J} e_{fj} \sum_{x \in X} x_{odlj}^m$$

3.3.3. Transit cost
The transfer cost is charged according to the number of transfers $n_j$ and the number of boxes $\sum_{x \in X} x_{odlj}^m / \delta$ as formula (3) represents.
3.3.4. Loading and unloading cost
Cost incurred during loading and unloading operations that formula (4) shows charge by number of boxes.
\[
\text{if} \sum_{m,d,j} x_{m,d,j}^{\text{load/unload}} / \delta
\]

(4)

3.3.5. Overdue cost
If the shipment cannot be completed, it will be paid to the consumer according to a certain percentage of the freight rate and the number of overdue days. When the shipment \(m\) is not shipped within the time limit, the company shall pay the overdue cost according to ratio \(\delta_m\) for each day overdue. \(\delta_m\) has a maximum value of \(\text{up} / \text{od} \times 24\). Formula (5) shows overdue cost.
\[
\sum_{m,d,j} \left( \max \left\{ \min \left( \delta_m \left[ (T_{m,j} - L_{m,j}) / 24 \right], \text{up} \delta_m \right), 0 \right\} \right) / \sum_{j,d} x_{m,d,j}^{\text{over}}
\]

(5)

3.3.6. Guarding cost
In order to prevent passengers from causing damage to the express mail, the company needs to arrange personnel to take care of the express mail with the car, thereby generating the cost of escort. As formula (6) shows, it is affected by the running distance and the quantity of the shipment.
\[
\sum_{j,d} \left[ \left( \sum_{m,d,j} x_{m,d,j}^{\text{guard}} \right) / \left( ge_{d,j} - \lambda_{d,j} \right) \right]
\]

(6)

3.4. Restrictions
The constraints are as follow.

3.4.1. High-speed train loading capacity constraint
As inequality (7) shows, the loading of high-speed trains at each stop cannot be greater than the maximum load of the train.
\[
\sum_{m,d,j} x_{m,d,j}^{\text{load}} / \delta_{m,j} \leq \text{ge}_{d,j}
\]

(7)

3.4.2. Total express transportation constraint
As inequality (8) shows, transport capacity is insufficient to meet all transportation needs.
\[
\sum_{j,d} x_{m,d,j}^{\text{over}} \leq \sum_{m,d} \sum_{i} m_{i,d}^{\text{over}}
\]

(8)

3.4.3. Uniqueness constraint
As inequality (9) shows, each shipment can be transported by only one vehicle.
\[
\sum_{j,d} x_{m,d,j}^{\text{over}} \leq 1
\]

(9)

3.4.4. Station loading and unloading time constraint
As inequality (10) shows, loading and unloading time at each station should be within the train stop time.
\[
\sum_{m \in M} \sum_{j \in \mathcal{J}} \left( x_{j}^{m} \eta_{j,i} \phi_{j, i} \right) \leq w_{i}
\]

When \( \phi_{j, i} = \begin{cases} 1, & s = \text{startGJS}_{j,i} + \text{endGJS}_{j,i} \\ 0, & s = \text{GS}_{j} - \text{startGJS}_{j,i} - \text{endGJS}_{j,i} \end{cases} \) is 1, the express needs to be loaded or unloaded.

### 3.4.5 Station maximum workload constraint

As inequality (11) shows, the station has a limited number of loading and unloading operations.

\[
\sum_{m \in M} \sum_{j \in \mathcal{J}} \left( x_{j}^{m} \eta_{j,i} \right) \leq q_{i}
\]

\( \eta_{j,i} = \begin{cases} 1, & s = \text{startJS}_{j,i} + \text{endJS}_{j} \\ 2, & s = \text{transJS}_{j} \\ 0, & s = \text{JS}_{j} - \text{startJS}_{j,i} - \text{endJS}_{j,i} - \text{transJS}_{j} \end{cases} \) counts the number of loading and unloading operations at the station.

#### 3.4.6 Decision variable constraint

The weight of the shipment \( m \) that selects the path \( j \) for transportation \( x_{j}^{m} \) is greater than or equal to 0. \( y_{j}^{m} \) can only be 0 or 1.

### 4 Case Analysis

This paper uses the data of 66 high-speed train running on the Beijing-Shanghai high-speed railway line, and predicts 2025 high-speed rail express demand of 11 stations. The model is solved by genetic algorithm using Matlab software, and the shipment is obtained through 200 iterations in a short time. Due to the large amount of data on the complete Beijing-Shanghai high-speed rail express truck program, the case select the shipments from Tianjin to Texas as example.

It is predicted that the demand for express mail transportation from Tianjin to Jinan in 2025 will be 118.1 kg, including 9.5 kg for the express delivery on the day, 7.09 kg for the next morning, and 89.76 kg for the next day, and 11.81 kg for the express delivery every other day.

Table 1 shows time schedule and model of 5 trains from Tianjin to Texas. Based on Table 1, the loading and unloading plan of the 5 trains at 11 stations are shown in Table 2 and Table 3. It can be seen that the loading amount of the train is equal to the unloading amount, indicating that the shipping plan is reasonable.

| Train No. | 12 | 16 | 17 | 23 | 24 |
|-----------|----|----|----|----|----|
| Train code| G113 | G115 | G211 | G121 | G213 |
| Model     | CRH380BL | CRH380AL | CRH380CL | CRH380AL | CRH380AL |
| Beijing   | 8:53 | 9:22 | –   | 10:28 | –   |
| Langfang  | –   | –   | 9:31 | 11:09 | 10:44 |
| Tianjin   | 9:27 | 9:56 | 10:01 | 11:16 |
| Zhangzhou | –   | –   | 11:27 | –   | –   |
| Texas     | 10:18 | 10:42 | –   | 11:55 | 11:44 |
| Jinan     | 10:44 | 11:08 | 10:49 | 12:21 | 12:10 |
| Taian     | –   | 11:27 | –   | –   | –   |
| Xuzhou    | 11:51 | 12:20 | –   | 13:41 | 13:21 |
| Bengbu    | –   | –   | –   | –   | –   |
| Nanjing   | 13:08 | 13:36 | 13:11 | 14:57 | 14:39 |
| Shanghai  | 14:30 | 15:07 | 14:40 | 16:28 | 16:16 |
In order to analyze the benefit of the shipping plan that consider the demand of the intermediate station on the profit, this paper conduct an comparison with shipping plan from the originating station to the final station.

**Table 2.** Loading plan of the 5 trains at 11 stations (kg)

| Train No. | 12     | 16     | 17     | 23     | 24     |
|-----------|--------|--------|--------|--------|--------|
| Train code| G113   | G115   | G211   | G121   | G213   |
| Beijing   | 618.65 | 460.78 | —      | 235    | —      |
| Langfang  | —      | —      | —      | 265.8  | —      |
| Tianjin   | 499.21 | 170.04 | 880.23 | 111.47 | 592    |
| Zhangzhou | —      | —      | 152.33 | —      | 208    |
| Texas     | 40.94  | 125    | —      | 50     | 75     |
| Jinan     | 177.09 | 325.06 | 75     | 125    | 157.41 |
| Taian     | —      | —      | —      | —      | —      |
| Xuzhou    | 25     | 25     | —      | —      | 0.59   |
| Bengbu    | —      | —      | —      | —      | —      |
| Nanjing   | —      | —      | —      | —      | —      |
| Shanghai  | —      | —      | —      | —      | —      |
| Total     | 1361   | 1106   | 1108   | 787    | 1033   |

**Table 3.** Unloading plan of the 5 trains at 11 stations

| Train No. | 12     | 16     | 17     | 23     | 24     |
|-----------|--------|--------|--------|--------|--------|
| Train code| G113   | G115   | G211   | G121   | G213   |
| Beijing   | —      | —      | —      | —      | —      |
| Langfang  | —      | —      | —      | —      | —      |
| Tianjin   | 270.78 | 156.06 | —      | 112.53 | —      |
| Zhangzhou | —      | —      | 145.22 | —      | 75     |
| Texas     | 205.84 | 91.53  | —      | 181.33 | 158    |
| Jinan     | 242.24 | —      | 319.53 | —      | —      |
| Taian     | —      | 541.39 | —      | —      | —      |
| Xuzhou    | 185.61 | 149.98 | —      | 225    | 300    |
| Bengbu    | —      | —      | —      | —      | —      |
| Nanjing   | 182.48 | 166.92 | 233.48 | 97.35  | 92.59  |
| Shanghai  | 273.93 | —      | 409.34 | 77.65  | 407.41 |
| Total     | 1361   | 1105   | 1108   | 787    | 1033   |

Figure 1 is a comparison of the revenue, cost, cost and profit of the shipping scheme of this paper with the original scheme without considering the intermediate station.
5. Conclusion

Using the optimization theory and mixed integer nonlinear programming, this paper aims at the maximum profit of high-speed rail express operation enterprises, and formulates the model of high-speed rail express delivery scheme under the restriction of high-speed train transportation capacity and high-speed rail station loading and unloading capacity. Through the calculation of the model, the number of shipments, shipments, and loading and unloading sites of different time-efficient express products including each site can be obtained. This paper designs the shipping scheme of Beijing-Shanghai high-speed rail express, and proves the validity of the model and algorithm.

However, this section only considers the mainline transportation link of the high-speed rail express, and does not consider the fluctuation of the train attendance rate during this period, and the new transportation demand generated during the period. Therefore, subsequent studies can consider dynamic multi-stage programming and end-to-end multimodal transportation schemes when modeling.

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