Selection of cargo transit nodes based on node split

Xiuquan Chen\textsuperscript{1, a}, Zhimei Wang\textsuperscript{2, b*}

\textsuperscript{1}School of Traffic and Transportation, Beijing Jiaotong University, Beijing, China
\textsuperscript{2}School of Traffic and Transportation, Beijing Jiaotong University, Beijing, China
\textsuperscript{a}20125706@bjtu.edu.cn
\textsuperscript{b*}Corresponding author: zmwang@bjtu.edu.cn

Abstract—This paper studies the express train transportation organization to ensure that the cargo can be delivered in the shortest time. Based on this, this paper makes the following research: By comparing the characteristics of express cargo and the characteristics of its transportation, the time value of express cargo is studied. This paper analyzes the transportation organization of the express train, introduces the organization of the express train, and divides it into direct trains and transit trains to analyze the transportation organization process. Then, the model of the express train transfer node selection model is established. The model is based on the minimum cost of the train and the sum of the unit mileage cost and the time cost. The conditions for the delivery of various cargo, transportation capacity and traffic flow are constrained. The model and the solution ideas are proposed. The above model is verified by constructing a virtual network and formulating reasonable data. Finally, the stop nodes of each express train are obtained, and the correctness of the model is verified.

1. INTRODUCTION
At present, with the rapid development of China's economy, the better transportation mode and the gradual improvement of people's living standards, the demand for freight transportation between different places is expanding, and the types and transportation requirements of cargo are also increasing. Among them, the demand for fast transport cargo such as electronic products, daily necessities and food is expanding day by day. Better service needs to be provided by transportation companies. With the increasing demand of this kind of small batch and various types of express cargo, road and air transportation modes first occupy the market of this part of cargo, while railways mainly transport bulk cargo. With the increasing demand of small-scale express cargo and the decrease of bulk cargo transportation, railways must provide better express products to enter this part of the market. Therefore, the railway should improve its own competitiveness, overcome the shortcomings of tedious operation, and provide suitable express products for shippers. Based on the above reasons, China's railway has launched the express train. Because the railway transportation is relatively stable, it is not affected by the weather and environment and can operate normally in most of the time. Compared with the disadvantages of highway transportation and air transportation which are seriously affected by roads and weather, railway transportation has obvious advantages.

With the rapid development of economy, great changes have taken place in the category of cargo and transportation requirements. Therefore, how to reasonably arrange the operation of express trains according to the characteristics of high requirements of express cargo, and set up appropriate intermediate
transfer nodes for express trains according to freight demand, so as to reduce the time caused by cargo transfer on the way and ensure the fast delivery of cargo, this becomes the key of this paper.

Establishing freight transportation network is the basis for solving network optimization problems. Many scholars at home and abroad have studied the construction of transportation networks. In the field of railway transportation, most of the researches are on the operation plan of through trains and the rational organization and optimization of train flow. Some scholars analyzed the current situation of China’s railway transportation, made clear the influencing factors of railway product quality, proposed methods to improve the existing freight organization model and a new transportation system, studied the number of trains and the running route, and obtained a reasonable operation scheme with the minimum transportation cost as the goal by constructing the model [1-4].

Usually we divide express direct trains into direct trains and combined direct trains to optimize the dynamic service network [5-8]. Wang established a two-layer spatio-temporal network model based on marshalling plan and freight demand organization to clearly express the organization process of express trains in the hub, and established an optimization model based on the organization of train flow [9]. Many scholars have designed a multi-modal express network for the transportation of express cargo [10-14]. Seung-Ju established a corresponding mathematical model based on the impact of transportation costs and transit time on transportation benefits, and performed solution analysis [15].

On the basis of previous research, this article analyzes the time value of express freight, establishes an express train transportation service network based on node splitting, clarifies the meaning of each node and arc in the network, and uses the network to clearly describe the train operation, provide a theoretical basis for the following model building. Then, an express train transit node selection model with the goal of minimizing the sum of train operation cost, mileage cost and time cost is established, which restricts the delivery deadline, transport capacity and traffic continuity of various cargo. Finally, the above model was verified by constructing a virtual network and drawing up reasonable route data, and finally got the stop plan of each express train, which verified the correctness of the model.

2. METHOD

2.1 Time value of express cargo

2.1.1 Time value of different categories of cargo

For express cargo, the railway can deliver the cargo to the destination in a shorter time, and the cargo will enter the market faster and create greater revenue for customers. A reference point is introduced to describe the time value (Figure 1). The advance delivery of cargo can release the funds occupied by the cargo and prevent the loss of devaluation due to the slow delivery of cargo beyond the delivery deadline.

For customers, although the use of faster transportation products may cost more, due to the reduction of transportation time, it may bring greater benefits to the owner. If the cargo owner chooses a slower transportation product, although the cost of transportation is less, the time value of the cargo decreases because it takes longer in the transportation process. Overall, the cargo owner’s profit may decrease. Moreover, the time value of the cargo is related to the value of the cargo themselves. The higher the value of the cargo themselves, the higher the time value brought by saving transportation time. Therefore, cargo owners need to choose different transportation plans according to different cargo, and express cargo generally have high added value, and require shorter transportation time than ordinary cargo.

![Figure 1. Time value of cargo](image-url)
2.1.2 Cargo time value coefficient
The time value of cargo reflects the impact of the time consumed during the transportation of cargo on their own profits. The faster the cargo are transported, the greater the owner’s profit. Usually the formula is used to calculate the time value of cargo:

\[ \beta = \frac{C \times IR}{HY} \]  

In the formula: \( \beta \) represents the time value coefficient; \( C \) represents the average price of cargo; the average price of express cargo can be calculated based on the price and weight of various types of cargo transactions on Taobao; \( IR \) stands for the cost of cargo delay, generally 1%; \( HY \) means 24 hours.

It can be seen that the value of cargo has an important influence on their time value. For express cargo with high added value, the importance of transportation time is much greater than that of ordinary cargo.

2.2 Express train service network based on node splitting
In order to make the transportation process of the traffic flow in the service network more clearly expressed, this paper splits each node into two nodes: departure and arrival. Here, we split the nodes in the train transportation service network to obtain the new train transportation service network shown (Figure 2). In this network, the transfer arc between the arrival node and the departure node of the same station represents the transfer operation or the train group drop-and-pump operation performed by the traffic flow at this station, and the train connection between the departure node and the arrival node between different stations. The arc represents the train connection between two stations, which may be the entire train or a certain section of the train.

![Figure 2. The railway express trains the transportation service network after the node is split](image)

Applying the node splitting network to the model of train transfer node selection has the following advantages: Through the node splitting network, the various routes of the train can be expressed, as well as the time spent by train for different operations at each station, and the train is clearly running. It can also consider whether the traffic flow is feasible in the transfer and renewal time, and the resulting plan is more accurate.

In summary, the problem of selecting transit nodes for railway freight trains in this article can be regarded as adding arcs to the split network, and then turning it into a special network design problem. All traffic flows are assigned to this transportation network, so we can think of it as a traditional traffic distribution problem.

2.3 Selection Model of Transit Nodes for Railway Express Train
In order to maximize the benefits of railway transportation and deliver the cargo in time to ensure that customers are satisfied with railway express, this paper establishes a selection model of transfer node for express train, the purpose is to deliver the cargo to the destination.
2.3.1 Model assumptions
Due to the difference in freight volume, different trains operate in different sections. As the direct train does not need to stop in the middle, the transit time is saved, while the transit train generates a lot of transit time due to the difference in the stop location and the number of stops. Therefore, for different cargo flows, how to choose the transit node of the train has become the key. This article optimizes the choice of transit nodes for two organizational methods to minimize the total transportation cost. This article makes the following assumptions:

(i) Assume that each station in the network can handle train transfer operations and train group drop-and-hook operations.

(ii) The flow of cargo in the model cannot be split. That is, cargo between the same OD can only be transported by the same train.

(iii) As express trains are of high grade and relatively small volume, the limitation of section passing capacity is not considered.

(iv) The limitation of station capacity is not considered.

(v) The cargoes are divided into two categories: bulk cargo and express cargo. Considering the requirements of different types of goods, the shortest path is taken as far as possible, and a certain penalty coefficient is set for the cost of other routes.

(vi) Since this article is mainly studying the choice of stopping schemes, whether trains are transferred at stations is the key to this article. The speed of trains in the interval has little effect on the results, so it is assumed that direct trains and transfer trains are transported by fast freight trains with a running speed of 120km/h.

2.3.2 Symbol Description
To facilitate model construction, first define the set, parameters and variables that will be used, as shown in Table 1.

| Symbol | Definition |
|--------|------------|
| S      | The train set, \( s \in S \), the difference between different trains is mainly in the different operating intervals and whether the train group drop and pull operation is performed at the passing station. |
| V      | Node collection. \( V = V_1 \cup V_2 \), \( V_1 \) represents the set of departure nodes at each station, and \( V_2 \) represents the set of arrival nodes at each station. |
| A      | Collection of arcs. \( a \in A \), \( A = A_1 \cup A_2 \), \( A_1 \) represents the set of running arcs, and the time corresponding to the running arc is related to the length of the interval corresponding to the arc and the running speed of the train. \( A_2 \) represents the set of transit arcs, and the time corresponding to the transit arc is related to the operating capacity of each station. |
| D      | Collection of freight demand, \( d \in D \). |
| \( R_d \) | The collection of transportation paths of traffic flow \( d \) is a path composed of a series of arcs connected end to end. \( r \in R_d \). |
| \( \psi_d \) | The fixed cost of the trains is related to the use of rolling stock, fuel use, and the direct cost of the station and section capacity of the train. |
| \( c_a \) | The unit vehicle operating cost of traffic flow on arc \( a \). If \( a \in A_1 \), \( c_a \) is the running cost of the unit vehicle on the operating arc \( a \). If \( a \in A_2 \), \( c_a \) represents the running cost of a unit vehicle on the transit arc \( a \). |
| \( u_q \) | The size of traffic flow \( q \). |
| \( m_d \) | The category of freight demand \( d \) can be divided into bulk cargo and express cargo. |
δ_{m_d} The cost amplification coefficient of different routes for different types of goods. For a certain d, if m_d is bulk cargo, then for any r_d, the value of δ_{m_d} is 1; if m_d is express cargo: δ_{m_d} = 1, δ_{m_d}^2 = 3, δ_{m_d}^3 = 5.

\( t_a \) The time it takes for traffic to pass through arc a. When a ∈ A1, \( t_a \) represents the running time of the traffic flow in the interval represented by arc a, which is related to the length of the interval and the running speed of the train. When a ∈ A2, \( t_a \) represents the time it takes for the flow of cargo to transit at the station, which is related to the station’s operating capacity.

\( T_d \) Delivery time required by freight demand d.

\( m_s \) Maximum number of trains.

\( f_s \) Frequency of train s.

\( \beta \) The time value coefficient represents the impact of the time spent in the transportation of cargo on sales.

\( \gamma \) Cost factor related to cargo running time

\( W \) W is a constant, \( w = 100000 \).

\( N \) Collection of natural numbers.

\( k_{ra} \) 0-1 variable, indicating whether the path r contains arc a.

\( g_{ra} \) 0-1 variable, indicating whether the travel path of train s contains arc a.

\( x_a \) 0-1 decision variable, indicating whether the train s is open.

\( y_{rd} \) 0-1 decision variable, indicating whether the traffic flow d chooses the path r.

\( f_s \) Integer decision variable, indicating the operating frequency of train s.

2.3.3 Objective function and constraints

(1) Objective function

The objective function in the model consists of three parts, which is the fixed cost of train operation, the cost of transportation mileage and the time cost of cargo transportation. The cost of freight mileage is related to the distance travelled by the cargo flow. The time consumed by the cargo in the transportation process includes the time spent in the interval and the stop time caused by the transit operation. In addition, transportation mileage cost and time cost are affected by the type of the cargo. The model takes the minimum of the sum of fixed cost, mileage cost and time cost as the goal. The objective function is:

\[
min z = \sum_{s \in S} f_s x_s + \sum_{a \in A} \sum_{r \in R_d} \sum_{d \in D} \delta_{m_d}^r u_d y_{rd} k_{ra} c_a + \gamma \sum_{s \in A} \sum_{r \in R_d} \sum_{d \in D} \delta_{m_d}^r u_d y_{rd} k_{ra} t_a
\]  

(2) Constraints

(i) Represent the principle of inseparable traffic flow. When railway transportation organizes the cargo flow, the vehicles choose different lanes for assembly according to whereabouts. For the cargo flow of the same OD, although different cargo belong to different cargo owners, the operations performed during the railway transportation are the same. They are treated the same in the assembly process and are transported as a whole. Only one of the alternative routes can be selected for transport and cannot be disassembled for transport.

\[
\sum_{r \in R_d} y_{rd} = 1 \quad \forall \; q \in Q
\]  

(ii) Represent the constraint on the frequency of train operation. For any arc a, if the traffic flow of all traffic on arc a is 0, it means that no traffic flow chooses arc a for transportation. Because there is no traffic flow on this arc, no trains will be operated. This constraint avoids the unreasonable situation of no-flow driving.
\[ \sum_{s \in S} f_s x_s g_s^a \leq W \sum_{r \in R_d} \sum_{d \in D} u_d y_d^r k_r^a \quad \forall a \in A \]  \(4\)

(iii) Restrict the delivery time of each share of cargo flow. In the process of transportation, railway enterprises must not only ensure that the total transportation cost is the lowest and the total time is minimized, but also that each share of cargo flow must be delivered within the time promised to the owner of the cargo. The further screening of alternative paths for the flow of cargo per share can ensure timely delivery of cargo and improve customer satisfaction.

\[ \sum_{a \in A} \sum_{r \in R_d} t_a y_d^r k_r^a \leq T_d \quad \forall d \in D \]  \(5\)

(iv) Represent the transportation capacity constraint, which means that the transportation capacity corresponding to the arc should be greater than its transportation demand. The transportation capacity corresponding to the arc is related to the number of trains running on arc \(a\) and the number of vehicles in each train. The railway bureau must operate enough trains to meet transportation needs.

\[ \sum_{r \in R_d} \sum_{d \in D} u_d y_d^r k_r^a \leq \sum_{s \in S} m+ f_s x_s g_s^a \quad \forall a \in A \]  \(6\)

(v) Constraints on variable value range:

\[ x_s \in \{0, 1\} \quad \forall s \in S \]  \(7\)

\[ y_d^r \in \{0, 1\} \quad \forall d \in D, \quad r \in R_d \]  \(8\)

\[ f_s \in N \quad \forall s \in S \]  \(9\)

3. CASE STUDY

This chapter will test the model established above. In order to verify the correctness of the model, the following paragraphs will establish a virtual network based on the experience of railway planning, and set the parameters of the network reasonably. After that, according to the model made above, the appropriate scheme is designed for the transfer train.

3.1 Road network structure and cargo flow between stations

3.1.1 Road network structure and parameter setting

We describe the topology of the virtual network to be studied in this chapter (Figure 3). Only to verify the correctness of the model, so the number of nodes and sections in this article is relatively small. The road network in the figure has 9 stations, and all have the capacity of train arrival and departure and transit operations, and 10 sections are set up.

Figure 3. Physical structure of road network

Table 2 describes the distance between the various railway networks:
### TABLE 2 DISTANCE BETWEEN THE VARIOUS RAILWAY NETWORKS

| Serial number | Section | Mileage (km) |
|---------------|---------|--------------|
| 1             | 1-2     | 230          |
| 2             | 1-6     | 300          |
| 3             | 2-3     | 270          |
| 4             | 2-6     | 200          |
| 5             | 3-4     | 200          |
| 6             | 3-8     | 250          |
| 7             | 5-6     | 260          |
| 8             | 6-7     | 250          |
| 9             | 6-8     | 350          |
| 10            | 8-9     | 200          |

3.1.2 Freight demand between stations

As the railway transportation system is extremely complex, and in the actual road network, there is not a demand for express transportation between stations. For the above reasons, some representative freight requirements have been drawn up for calculation verification. And it is fully considered that in the actual transportation of express cargo, the requirements of the shipper for the time of each type of freight demand are not the same, so this article not only considers the total cost of transportation and the shortest time, but also makes the delivery period for each type of cargo flow. Restrict accordingly to make the model closer to reality. Since the cargo connection time is relatively fixed at both ends, this article only gives the time for the cargo to be transported online.

### TABLE 3 OD DEMAND PARAMETERS OF CARGO FLOW

| Serial number | OD     | Traffic volume | Maximum allowable delivery time (h) | Category of the cargo |
|---------------|--------|----------------|--------------------------------------|-----------------------|
| 1             | 1-4    | 18             | 31                                   | bulk cargo            |
| 2             | 1-6    | 21             | 24                                   | bulk cargo            |
| 3             | 1-7    | 16             | 38                                   | express cargo         |
| 4             | 2-5    | 12             | 24                                   | express cargo         |
| 5             | 2-6    | 10             | 21                                   | express cargo         |
| 6             | 2-8    | 15             | 30                                   | bulk cargo            |
| 7             | 3-4    | 16             | 26                                   | bulk cargo            |
| 8             | 3-5    | 17             | 37                                   | bulk cargo            |
| 9             | 3-9    | 10             | 30                                   | express cargo         |
| 10            | 4-2    | 11             | 21                                   | express cargo         |
| 11            | 4-6    | 13             | 39                                   | express cargo         |
| 12            | 4-8    | 16             | 26                                   | bulk cargo            |
| 13            | 5-6    | 13             | 30                                   | express cargo         |
| 14            | 5-8    | 18             | 26                                   | bulk cargo            |
| 15            | 6-3    | 20             | 30                                   | bulk cargo            |
| 16            | 6-9    | 14             | 20                                   | express cargo         |
| 17            | 8-4    | 16             | 28                                   | bulk cargo            |
| 18            | 8-9    | 12             | 15                                   | express cargo         |
3.2 Optimization Results

In this paper, LINGO is used to solve the calculation example, and the global optimal solution is 3193150 yuan after running for 10 seconds. It is calculated that a total of 13 trains are operated, of which 10 trains are direct trains, and the other 3 are transfer trains. The stop plan and composition of the train are shown (Figure 4).

Figure 4. Train stop plan and marshalling composition.

According to the calculation, the plan is selected, which not only ensures that each cargo flow can be delivered at a faster speed within the fixed time, but also can run the trains reasonably to improve the efficiency of the railway transportation company.

4. CONCLUSION

With the rapid development of modern logistics today, in order to improve the competitiveness of railway transportation in express transportation, it is necessary to deliver cargo to the destination at a faster speed. The choice of the stop node of the train has a great influence on the delivery time of the train. Therefore, this paper studies the stop node of the train to ensure that the railway will deliver the cargo as soon as possible at a lower cost. This article analyzes the time value of express cargo based on the characteristics of express cargo and railway express. According to the railway network, this paper establishes an express train service network based on node splitting, and analyzes the meaning of each node and arc, and provides a theoretical basis for the following construction model. Considering the influence of cargo category and train route, we establish a model for selecting transit nodes for express trains, aiming to minimize fixed costs, mileage costs, and time costs, and limit the delivery time and transportation capacity of each cargo flow, and verify the correctness of the model through a small example.

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