Study on Optimization of International Intermodal Container Route Selection - A Case of Zhengzhou Railway Bureau

Shiyao Teng¹, Jinjin Tang¹*

¹ School of Traffic and Transportation, Beijing Jiaotong University, No. 3 Shangyuan Village, Haidian District, Beijing, 100044, China
*Corresponding author’s e-mail: jjtang@bjtu.edu.cn

Abstract. In view of the fact that international container intermodal transportation has become an indispensable mode of transportation for the exchange of China and surrounding countries, the paper studies the transportation network formed by Zhengzhou Railway Bureau and surrounding container node cities with the transportation costs and transportation time as the research direction, and constructs a multi-objective optimization model for the optimization of the mode and route of international container transportation between Zhengzhou Railway Bureau and Europe. And the genetic algorithm is used to solve the optimal solution under different weights. The case shows that the model is effective and feasible in practice, and can provide a more effective guiding optimization plan for the selection of international intermodal container routes of Zhengzhou Railway Bureau.

1. Introduction
Container transport[1][2] is a kind of modern trade means to transport scattered goods into standardized containers, which is easy to carry, load and unload, and it can make full use of a series of advantages such as carrying tool’s load and volume to better guarantee the efficiency and quality of freight transportation. And its standardized, containerized transportation can also better realize multimodal transportation, has become a major way of international cargo joint transportation.

At present, Zhengzhou Railway Bureau[3] has two main modes for international container intermodal transportation in Europe: China-Europe Railway Express[4][5] and sea-rail combined transportation[6][7][8][9]. These two modes have their own advantages and disadvantages: the overall speed of land transportation is relatively fast, and the time consumption is also relatively fixed, but the price is slightly more expensive, and its transportation capacity is much larger than the mode of the sea transportation; For the sea transportation, the transportation capacity is relatively high and the price is cheap, but its transportation time is long and it is greatly affected by weather and other reasons. Therefore, with the rapid growth of international container intermodal transportation business of Zhengzhou Railway Bureau, how to choose the appropriate transportation mode and route according to the characteristics of goods for the full use of power resources and improvement of the efficiency of container intermodal transportation has become an urgent problem.

2. Analysis on the international intermodal container status in Zhengzhou Railway Bureau

2.1. The current status of the Zhengzhou China-Europe Railway Express
The Zhengzhou China-Europe Railway Express was first launched on July 18, 2013. At present, there are two main routes: one is from Putian Freight Center Station of Zhengzhou Railway Bureau, passing
through Erlianhaote in Inner Mongolia to Hamburg, Germany; the second is from Zhengzhou Railway Bureau Putian Freight Center, passing through the Alashankou in Xinjiang also arrived in Hamburg, Germany.

For China-Europe Railway Express of Zhengzhou Railway Bureau, the transportation time mainly includes the transit time, the storage time and the time of the rail change loading and unloading in the country. The corresponding costs also include transportation costs on the way, storage costs and border costs. These will be the key factors to consider in the subsequent optimization process.

2.2. The current status of sea-railway combined transportation in Zhengzhou Railway Bureau

The meaning of international container sea-railway combined transport means that inland container cargo is transported by rail line to the container terminal, and then transported by sea to foreign countries, or materials transported by sea from abroad, and then transported by rail to the inland city.

Zhengzhou Railway Bureau international container sea-railway combined transportation is mainly from Putian freight station, transportation containers to the adjacent ports, and then exchange goods with Europe, Japan and South Korea. There are four main lines in the domestic section of the Zhengzhou Railway Bureau sea-rail container transportation:

(1) Zhengzhou—Qingdao
(2) Zhengzhou—Lianyungang
(3) Zhengzhou—Port of Tianjin
(4) Zhengzhou—Port of Shanghai

For the container sea-railway combined transport of Zhengzhou Railway Bureau, the time is mainly spent on: the time of transportation between the nodes, the transit time of different modes of transportation, the loading and unloading time and the storage time. These are the data that need to be considered and calculated in the subsequent optimization process.

3. Optimization model and algorithm of international container transportation route

3.1. Model building

As an important mode of international cargo transportation, international container intermodal transportation needs to use a variety of transportation modes, passing through several nodes, and finally complete the entire transportation process. In this process, the organizer needs to select a better transportation route and mode according to the actual situation through reasonable arrangement and coordination, so as to pursue the maximization of profit and benefit of container transportation and highlight that different transportation modes have their own advantages. Among various modes of transportation, railway, road and sea transportation are the most common.

In the above process, a batch of goods is transported from the starting point (A) through the container to several destination cities (B). These container node cities constitute a container transportation network. There are several modes of transportation between different cities, and different transportation modes have different transportation time, transportation costs, transit times and transit costs.

In order to facilitate the construction and solution of the international container intermodal transportation model, the research in this paper makes the following assumptions:

(1) Only one transportation mode can be selected between any two container node cities, and the connection and transfer of different transportation modes can only occur in container node cities.
(2) Since this paper does not consider the problem of container transport capacity, this paper takes a 20ft container as the unit for transportation, that is 1TEU.

In this paper, some symbols are defined as follows for the convenience of expression:

- $M$ indicates the collection of goods;
- $K$ indicates the collection of modes of transportation;
- $A$ indicates the collection of city nodes;
- $C_{m,k}$ indicates the transportation cost of a single container of goods $m$ using transportation mode $k$ at a unit distance;
- $l_{i,j}$ indicates the transportation distance
using transportation mode $k$ between city $i$ and city $j$; $Q_m$ indicates the number of containers of goods $m$; $C_{mk,i}^j$ indicates the transit costs required for a container of goods $m$ from the mode of transportation $k$ to the mode of transportation $l$ in city $i$; $D_i^{mk}m$ indicates the storage costs required for a container of goods $m$ using the mode of transportation $k$ in city $i$; $\mu_{ij}^k$ is equal to 1 if the transportation mode $k$ is selected between city $i$ and city $j$, otherwise 0; $\Theta_{ij}^{kl}$ is equal to 1 if there is a change in the transportation mode $k$ to transportation mode $l$ in city $i$, otherwise 0; $t_{ij}^{mk}$ indicates the transportation time of goods $m$ using transportation mode $k$ between city $i$ and city $j$; $X_{ij}^{mk}$ indicates the storage time required for a container of goods $m$ using the mode of transportation $k$ in city $i$; $o_v$ indicates the origin of route; $d_v$ indicates the destination of route.

According to the process and characteristics of international container intermodal transportation, this paper mainly includes two optimization objectives of international container intermodal transportation route:

(1) Minimization of transportation costs.

$$\min C = \sum_{i \in A} \sum_{j \in A} \sum_{m \in M} \sum_{k \in K} [(C_{mk,i}^j + D_i^{mk}) \mu_{ij}^k Q_m] + \sum_{i \in A} \sum_{m \in M} \sum_{k \in K} \sum_{l \in K} (C_{mj,i}^j \Theta_{ij}^{kl} Q_m)$$ (1)

(2) Minimization of transportation time.

$$\min T = \sum_{i \in A} \sum_{j \in A} \sum_{m \in M} \sum_{k \in K} [(t_{ij}^{mk} + X_{ij}^{mk}) \mu_{ij}^k] + \sum_{i \in A} \sum_{m \in M} \sum_{k \in K} \sum_{l \in K} (Z_{ij}^{mk} \Theta_{ij}^{kl})$$ (2)

The model contains the following constraints:

$$\sum_{k \in K} \mu_{ij}^k = 1 \quad \forall i \in A, \forall j \in A$$ (3)

$$\sum_{j \in A} \sum_{k \in K} \mu_{ij}^k = 1 \quad i = o_v$$ (4)

$$\sum_{i \in A} \sum_{k \in K} \mu_{ij}^k = 1 \quad j = d_v$$ (5)

$$\sum_{j \in A} \sum_{k \in K} \mu_{ij}^k - \sum_{n \in A} \sum_{k \in K} \mu_{nj}^k \quad i \notin \{o_v, d_v\}$$ (6)

Constraint (3) ensures that only one mode of transportation can be selected between the two places. Constraint (4), (5) and (6) ensure that the route can smoothly reach the ending point from the starting point.

This paper uses a two-objective planning model with transportation time and transportation cost being optimization goals. As a whole, in order to optimize the system, two goals need to be transformed into a single goal optimization:

$$\min Z = \min (f_tC + f_zT)$$ (7)

Among them, $f_t$ is used to represent the weight, and different solutions are obtained by giving each group different weights. In the follow-up study, this paper will simulate different kinds of weights and obtain the optimal route selection optimization results under different conditions.
3.2. Route optimization solution based on genetic algorithm

The solution of the genetic algorithm is mainly composed of six operational steps, namely the coding of individual chromosomes, the composition of the initial population, fitness function, crossover, mutation, and inheritance.

(1) Chromosome coding. The process of coding is actually the essence of genetic algorithm, and the excellence or otherwise of coding directly affects the operation ability of genetic algorithm and the excellent population. According to the characteristics of the problem described in this paper, the chromosomes of this paper are divided into two parts:

The first part indicates whether to pass through the city, if passing through, it is 1, and if not, it is 0. The chromosome structure is as follows:

1 0 1 1 0 0 1

Figure 1. Schematic diagram of the chromosome of the first part.

The different positions represent the different cities, and the corresponding gene value represents whether the city is selected. In this example, there are seven midway node cities, namely Erlianhaote, Alashankou, Shanghai, Qingdao, Lianyungang, Tianjin and Hamburg.

The second part shows the mode of transportation between any two nodes. 1 represents road transportation. 2 represents railway transportation. 3 means sea transportation. Taking the route from Zhengzhou to Qingdao by railway and then from Qingdao to Rotterdam by sea as an example. The scheme code is as follows:

0 0 0 2 0 0 3

Figure 2. Schematic diagram of the chromosome of the second part.

(2) Fitness function. The value of fitness function is to measure the individual's ability to adapt to the natural environment. The higher the fitness function value, the more adaptive it is to this natural world. According to the principle of survival of the fittest value, it is easier to be retained. Since the fitness function value also represents the probability of being selected, the value must be non-negative.

In this paper, the formulas with different weights of the objective function are used as the fitness function. The formula of the fitness function is as follows:

\[ F(x) = \alpha C + \beta T \]

Among them, \( \alpha \) indicates the weight of transportation costs; \( \beta \) indicates the Weight of transportation time; \( C \) indicates the transportation costs; \( T \) indicates the transportation time.

(3) Selection. The selection idea of this paper is as follows: firstly, the chromosome population in this paper is divided into two parts according to the objective function, which are equally divided, and then the solution is carried out in each part according to the objective function of this part, the specific process is shown in the figure below:

Figure 3. Selection diagram of genetic algorithm.
(4) Crossover. In this paper, the two-point intersection is used to randomly select two from the parent chromosomes, and then select any two gene positions on each chromosome, and they cross each other to iterate, thus generating a new chromosome. However, new chromosomes may not be able to satisfy the constraints due to gene transformation. If they are not satisfied, they will continue to cross each other until a new chromosome that satisfies the constraint is obtained.

(5) Mutation. The difference between crossover and mutation is that crossover can only select chromosomes within the existing population to carry out part of gene crossover call, while mutation can expand beyond the existing model of the population to conduct random search in the neighbourhood of the population, which can effectively expand the population and enhance the search ability of the genetic algorithm. Moreover, with the crossover and selection operation, poor choices are continuously excluded, so the diversity of the population is declining all the time. However, variation can expand the diversity of the population in a disguised way, and the necessity of variation is that it can avoid local optimization.

In this paper, the basic position variation is used. The basic position variation means that the genes of each chromosome are mutated with a certain probability, and after the mutation, an arbitrary number is generated. If the arbitrary number exceeds the mutation probability, the gene is not required to change. The opposite is needed. Assuming that the gene string of a chromosome is $S_1 = a_1a_2......a_L \in (0,1)$, the specific operation method is as follows:

1) Given the variation frequency $P$.
2) Each gene on each chromosome produces a random number $r_i \in (0,1), i = 1,2,3.....L$.
3) Generate the new individual $S_2 = a_1a_2....a_L \in (0,1)$.

If more than $L*P$ genes have changed, there is no need to change the genes on the new chromosome, otherwise it will be needed.

4. Case analysis
This paper selects Zhengzhou as the starting point and Rotterdam as the ending point and transports a 20-foot container. The important node cities of Zhengzhou Railway Bureau's international container transportation include: Erlianhaote, Alashankou, Tianjin, Lianyungang, Qingdao, Shanghai and Hamburg. Due to the small volume of air transportation mode, it is rarely used in actual container transportation, so this paper does not consider this. This paper mainly studies three modes of transportation: road transportation, railway transportation and sea transportation. This paper constructs a container transportation network from Zhengzhou to Rotterdam:

Figure 4. The container transportation network from Zhengzhou to Rotterdam.
Railway transportation costs and sea transportation costs can be obtained through research and investigation. The calculation method of road transportation costs is as follows: A 20-foot standard container can carry a maximum weight of 24 tons, while a container truck carrying 20 tons of cargo consumes about 33L/(100km) of fuel, and the latest diesel costs are about 6.5 yuan/L. The current toll for a 20-foot container is about 3 yuan/km. This paper assumes that there are 10 round trips per month and the average cost is charged to each vehicle.

Table 1. The calculation method of transportation costs.

| Project name              | Numerical value and calculation (yuan)                          |
|---------------------------|-----------------------------------------------------------------|
| Fixed costs               |                                                                 |
| Vehicle reimbursement     | 5                                                                |
| Vehicle depreciation      | Vehicle price * (1 - salvage cost) / (depreciation life *12*20) |
|                          | =8.8                                                             |
| Driver's salary           | 267                                                              |
| Transportation management fee | 13                                                             |
| Variable costs            |                                                                 |
| Fuel surcharge            | Fuel consumption standard * distance * fuel price                |
| Tolls                     | Distance * toll rate                                             |
| Maintenance costs         | 134                                                              |

The value of transportation costs and transportation time is as follows by consulting data and calculating the average value.

Table 2. The transit costs and transit time.

| Transit costs  (yuan/TEU) | Road-railway | Railway-sea | Road-sea | Railway-road | Sea-railway | Sea-road |
|---------------------------|--------------|-------------|----------|--------------|-------------|----------|
| Transit time (h/TEU)      | 2            | 4           | 3.5      | 2            | 4           | 3.5      |

Railway transportation time and sea transportation time can be obtained by consulting literature and investigation. This paper assumes that the road transportation time is only related to the transport distance and the speed of the vehicle. The data can be obtained from any two cities. The average speed of container road transportation can be obtained through research. Therefore, the total transportation time and total transportation costs (including the storage time and storage costs) of the three transportation modes in the Zhengzhou-Rotterdam international intermodal container network can be calculated:
Table 3. The total transportation time and total transportation costs (including the storage time and storage costs) of the three modes of transportation in the Zhengzhou-Rotterdam international intermodal container network.

| Route | The total transportation costs (yuan) | The total transportation time (h) |
|-------|--------------------------------------|----------------------------------|
|       | Road       | Railway | Sea | Road       | Railway | Sea |
| Zhengzhou-Alashankou | 20299 | 7079 | \ | 71.4 | 96 | \ |
| Zhengzhou-Qingdao | 4636 | 2271 | \ | 15.1 | 24 | \ |
| Zhengzhou-Lianyungang | 3577 | 1775 | \ | 11.3 | 12 | \ |
| Zhengzhou-Tianjin | 4475 | 2622 | \ | 14.5 | 36 | \ |
| Zhengzhou-Erlianhaote | 6944 | 3252 | \ | 23.4 | 48 | \ |
| Zhengzhou-Shanghai | 5991 | 3062 | \ | 20 | 48 | \ |
| Erlianhaote-Shanghai | 10851 | 5980 | \ | 37.4 | 72 | \ |
| Erlianhaote-Alashankou | 18655 | 9132 | \ | 65.4 | 96 | \ |
| Erlianhaote-Tianjin | 4831 | 2588 | \ | 15.8 | 36 | \ |
| Erlianhaote-Qingdao | 7618 | 3470 | \ | 25.8 | 36 | \ |
| Erlianhaote-Lianyungang | 8287 | 4530 | \ | 28.2 | 48 | \ |
| Erlianhaote-Hamburg | \ | 21677 | \ | \ | 240 | \ |
| Alashankou-Shanghai | 24981 | 14215 | \ | 88.1 | 144 | \ |
| Alashankou-Qingdao | 22752 | 13334 | \ | 80.1 | 132 | \ |
| Alashankou-Tianjin | 19407 | 11998 | \ | 68.1 | 108 | \ |

This paper uses MATLAB to solve the problem. According to the actual situation of different types of goods and owners’ requirements for time and costs, this paper takes the proportion of costs and time to 0.1-0.9 respectively to simulate routes under different conditions to select the optimization results. In order to avoid the impact of the magnitude of the costs and time values, the following improvements were made to the model.
\[ \min Z = f_1 \cdot C \cdot (C_{\text{min}})^{-1} + f_2 \cdot T \cdot (T_{\text{min}})^{-1} \]  

Among them: \( C_{\text{min}} \) and \( T_{\text{min}} \) are the optimized values of the model considering only costs and time, \( C_{\text{min}} = 7165 \) and \( T_{\text{min}} = 269.4 \). And the route optimization results are as follows:

**Table 4. The route optimization results.**

| Serial number | \( f_1 \) | \( Z \) | Costs (yuan) | Time (h) | ROUTE | Path 1 | Path 2 | Path 3 |
|---------------|-----------|---------|-------------|---------|-------|--------|--------|--------|
| 1             | 0.1       | 1.350196| 30581       | 276.4   | O-Erliahaote-Hamburg-D | 1      | 2      | 2      |
| 2             | 0.2       | 1.756161| 26890       | 301     | O-Erliahaote-Hamburg-D | 2      | 2      | 2      |
| 3             | 0.3       | 1.887910| 26162       | 305     | O-Erliahaote-Hamburg-D | 2      | 2      | 3      |
| 4             | 0.4       | 2.139832| 26162       | 305     | O-Erliahaote-Hamburg-D | 2      | 2      | 3      |
| 5             | 0.5       | 2.032878| 8067        | 792     | O-Shanghai-D          | 2      | 3      |        |
| 6             | 0.6       | 1.793764| 7165        | 804     | O-Lianyungang-D       | 2      | 3      |        |
| 7             | 0.7       | 1.595323| 7165        | 804     | O-Lianyungang-D       | 2      | 3      |        |
| 8             | 0.8       | 1.396882| 7165        | 804     | O-Lianyungang-D       | 2      | 3      |        |
| 9             | 0.9       | 1.198441| 7165        | 804     | O-Lianyungang-D       | 2      | 3      |        |

The Numbers in the path column represent different modes of transportation, with 1 representing road transportation, 2 representing railway transportation and 3 representing sea transportation. For example, when \( f_1 = 0.5 \), the optimal route is: from Zhengzhou to Shanghai by railway, and then to Rotterdam by sea.

According to the optimization results, when the weight ratio of transportation time is relatively large, they tend to choose to transport containers from the land, while the weight ratio of transportation cost is relatively large, they prefer to transport containers to the port first and then to Rotterdam through sea transportation, which indicates that the model is generally consistent with the actual situation.

5. Conclusion

This paper studies the optimization of the international container transportation route selection of Zhengzhou Railway Bureau. The main research work is as follows:

(1) This paper tackles the international container transportation work of Zhengzhou Railway Bureau. The status quo, characteristics, business process and related costs and time of the international container transportation of Zhengzhou Railway Bureau are studied, which lays a foundation for the subsequent model research.

(2) This paper takes the transportation time and transportation mode as the dual objective, and the optimization model of international container transportation route selection is constructed.

(3) The applicability of the genetic algorithm for this problem is studied and the model is solved by genetic algorithm. And the correctness of the model is verified by the case of the Zhengzhou-Rotterdam transportation network.

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