Optimization of Train Operation Scheme for Container Sea-Rail Multimodal Transport

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Abstract. In the past, the external costs, such as transportation costs and transit costs, are usually considered in the model of container sea-rail multimodal transport, without considering the time value cost of goods and the social costs such as traffic accident cost and environmental pollution cost caused by the transportation process. Goods transportation is a kind of social and economic activity. The whole transportation process of goods from the place of departure to the destination needs time. When time is connected with specific social and economic activities, it has value, that is time value. [1] The time value cost of goods will become a large part of the cost in the process of transportation. Improving the efficiency of goods transportation is a major goal of goods transportation. However, while improving the efficiency of goods transportation, we should also take into account the social costs brought about by the transportation of goods. In this paper, the time value of goods and social cost are considered to optimize the operation scheme of container sea-rail multimodal transport trains.

Keywords: Sea-rail multimodal transport, optimization scheme, genetic algorithm.

1. Introduction

Container goods are transported from multiple places of departure to the single destination. In the process of transportation, container goods arrive at the coastal port through sea transportation from multiple places of departure. Then transported by railway to the final destination. In the whole process of transportation, the transportation path and mode are relatively fixed, and it is necessary to ensure the time limit of the goods. The transportation route of the goods is shown in Figure 1.

The time value cost of goods is mainly reflected by the devalued currency value of the goods, while the social cost is mainly reflected by the impact of the transportation process on the society. Social cost is the negative impact of transportation production or consumption activities on other individuals or groups, such as traffic accidents, environmental pollution, and economic losses to human life and health.[2] For high value time sensitive goods, the earlier the delivery, the higher the time value.[3] Consider the cost of the entire transportation process from multiple perspectives, the problems to be solved in this paper are as follows: Under the condition of ensuring the value of goods and taking into account the social costs, this paper explores the optimal scheme for the operation of container sea rail multimodal transport trains, so as to realize the minimum comprehensive cost of a single container (40 feet container) from the place of origin to the destination.
2. Model Assumptions
The optimization model of container sea rail multimodal transport train operation scheme has the following assumptions.

(1) In the process of intermodal transportation, containers only transit twice at the port and the terminal railway station, but not in the intermediate railway station.

(2) The transportation route of the whole combined transportation process is determined, and the mode of transportation in each transportation link is also determined.

(3) The container type is 40 feet.

(4) Highway transportation in the process of combined transportation is short distance transportation in the process of transshipment.

3. Establishment of Model

3.1. Parameter description

$m$: means the mode of transportation, $m \in M$, $M=\{1,2,3\}$, 1 represents marine transportation, 2 represents railway transportation, 3 represents highway transportation.

$t_m$: represents the time consumed by the m-th mode of transportation.

$t_r$: transit time of containers at terminal railway station.

$n$: the number of containers transported by each container train.

$n_{\text{max}}$: the maximum number of containers transported by each container train, $n_{\text{max}}=50$.

$a, b$: node label in transportation path, $a \in A, A=\{1,2,3,4,5,6,7\}, b \in B, B=\{6,7,8\}$, and $a < b$.

$k$: monthly depreciation rate of goods.

$t$: the number of days the goods have experienced from the time of departure from the place of origin to the time of delivery.

$P_{\text{max}}$: the maximum initial value of a full container at the start of shipment.

$C_{a,b}^{\text{m}}$: unit transportation cost of m-th mode of transportation from node a to node b.

$L_{a,b}^{\text{m}}$: pricing transportation mileage of m-th mode of transportation from node a to node b.

$C_{a,b}^{\text{mp}}$: fixed transportation cost of m-th mode of transportation from node a to node b.

$e_{a,b}^{\text{m}}$: unit social cost of m-th mode of transportation from node a to node b.

$C_a^{\text{z}}$: other costs of container goods in transit at node a.

$j$: the j-th container ship arriving at the port within a specified time.
$t_j$: the time of arrival of containers on the j-th container ship from the time of arrival at the port to the departure of the container train.

$T'_j$: departure time of containers on the j-th container ship to be transported by container train.

$T_j$: arrival time of containers on the j-th container ship.

$n_j$: the number of containers on the j-th container ship loaded on the container train.

Decision variables:

- $x_{a,b}^m = 1$ when the m-th mode of transportation is selected from node a to node b
- $x_{a,b}^m = 0$ when the m-th mode of transportation is not selected from node a to node b
- $x_a = 1$ when transfer occurs at node a
- $x_a = 0$ when no transfer occurs at node a
- $y_j = 1$ when the containers on the j-th container ship are transported by the container train
- $y_j = 0$ when the containers on the j-th container ship are not transported by the container train

3.2. Objective function

The model adopts the form of multi-objective function. On the one hand, it requires that the average transportation cost of single container is the lowest, on the other hand, the average connection time of container in port is the shortest.

Objective function:

$$\min C = \left[ \sum_{a \in A, b \in B, m \in M, j \in N} n_j C_{a,b}^m L_{a,b}^m x_{a,b}^m + \sum_{a \in A, b \in B, m \in M, j \in N} n_j C_{a,b}^m x_{a,b}^m + \sum_{a \in A, j \in N, m \in M} n_j C_{a}^m x_a^m + \sum_{a \in A, b \in B, m \in M, j \in N} n_j C_{a,b}^m L_{a,b}^m x_{a,b}^m + \sum_{a \in A, j \in N} n_j P_{max} \frac{kt}{30} \right] / n$$

(1)

$$\min T = \sum_{j \in N} t_j y_j n_j / \sum_{j \in N} n_j$$

(2)

Constraint condition:

(1) There is only one mode of transportation between the two nodes.

$$\sum_{m \in M} x_{a,b}^m = 1$$

(3)

(2) At node a, there is at most one transfer.

$$x_a \leq 1$$

(4)

(3) The number of containers transported by the train not exceed the maximum number of containers transported by the train and not be less than 20.

$$20 \leq n \leq n_{max}$$

(5)

(4) The container on the j-th container ship was transported by the train later than its arrival time.

$$T_j < T'_j$$

(6)
(5) The number of containers transferred from all container ships to the container train is equal to the number of containers transported by the whole train.

\[ \sum_{j \in N} n_j = n \] (7)

(6) The number of days that container goods experiences from the time of departure to the time of delivery.

\[ t = t_j + t_r + \sum_{m \in M} t_m \] (8)

(7) The number of containers loaded on the j-th container ship on the container train.

\[ 0 < n_j \leq 25 \] (9)

4. Algorithm Design

In order to ensure the efficiency and accuracy of the operation, this paper uses genetic algorithm to solve the model, and seeks the optimal solution from the global. The main design steps are as follows.

(1) Coding

There are five variables in this model, that is the number of containers transported to the container train on five container ships. The five variables are coded in the form of binary coding and set as five gene coding.

(2) Generating initial population

When the initial population is generated, according to the constraints of the model in this chapter, the number of containers transported to the container train of each container ship is assigned, and the initial feasible solution satisfying the conditions is obtained. Repeat the operation of the initial feasible solution to obtain a certain number of initial population.

(3) Determination of fitness function

The model is a multi-objective function, and the dimensions of the two objective functions are different. The values of the two objective functions are normalized dimensionless, and then the corresponding weights are given, which are used as fitness functions to judge the fitness of feasible solutions. The fitness function is as follows.

\[ F = \frac{1}{\theta_1 C' + \theta_2 T'} \] (10)

\( \theta_1 \): Weight of average transportation cost of per container in fitness function.
\( \theta_2 \): Weight of average waiting time of per container in fitness function.
\( C' \): The value of average transportation cost of per container after dimensionless normalization.
\( T' \): The value of average waiting time of per container after dimensionless normalization.

(4) Selection operation

According to the fitness function, the fitness value of each individual is obtained, and Roulette is selected for each individual, there is a positive correlation between the probability of each individual being selected and its fitness. [4]

(5) Cross operation

Crossover operation is a process of genetic algorithm in which some chromosomes between two individuals are exchanged with a certain probability and new individuals are generated. First, two chromosomes were randomly selected for random pairing, and after gene coding was exchanged, new feasible solution individuals were generated.
(6) Mutation operation
Mutation operation in genetic algorithm is to change a gene value of an individual according to a small probability, so as to generate a new individual. In this paper, the chromosome of genetic algorithm has five segments of gene coding. One of them is selected to mutate, and then new individuals are generated.

(7) Termination discrimination
In this paper, the final termination condition of genetic algorithm is set as the maximum number of iterations. When the maximum number of iterations is reached, the algorithm will terminate and output the optimal solution in the global iteration process.

5. Example Solving
In this paper, high-value time sensitive goods are the target goods of container trains. When high value time sensitive goods are fully loaded, the average initial cargo value of a single container (40 feet container) is 3 million yuan, and the monthly value depreciation rate is 10%.

5.1. Cost data

5.1.1. The cost of shipping. The shipping cost of container mainly includes the basic freight rate of ocean transportation, miscellaneous charges at the port, storage yard fee and customs declaration fee. The shipping cost of 40 feet container is calculated according to Table 1.

| Name of fee               | Unit of calculation       | Unit Price (yuan) |
|---------------------------|---------------------------|-------------------|
| basic freight rate        | yuan/container·km         | 0.65              |
| miscellaneous charges     | yuan/container            | 500               |
| customs declaration fee   | yuan/container            | 250               |
| storage yard fee          | yuan/container·d          | 150               |

5.1.2. The cost of Railway. The transportation cost of railway includes basic freight and other expenses. The freight price is shown in Table 2.

| Container size | Base price 1 | Base price 2 |
|----------------|--------------|--------------|
|                | Unit of calculation | Unit Price (yuan) | Unit of calculation | Unit Price (yuan) |
| 40 feet        | yuan/container | 459.00        | yuan/container·km | 1.9040          |

Single container freight rate of containerized goods = Base price 1 + Base price 2 × Freight kilometers.

Other costs of inland railway terminal station mainly include handling charges, transfer charges and miscellaneous charges. The cost prices are shown in Table 3.

| Name of fee         | Unit of calculation | Unit Price (yuan) |
|---------------------|---------------------|-------------------|
| handling charges    | yuan/container      | 290               |
| transfer charges    | yuan/container      | 225               |
| miscellaneous charges| yuan/container    | 100               |

5.1.3. The cost of highway. After the container arrives at the terminal station of inland railway, the container realizes the final short barge link through road transportation, and transports the goods to the
delivery place. The cost of container road short distance transportation usually includes two parts, one is the cost of per container, the other is based on the transportation mileage. The cost of 40 feet container for domestic road transportation is 25 yuan/container, and the cost of mileage part is 9 yuan/container-km.

5.1.4. The cost of environmental. The five main pollutants emitted by transportation industry are HC, NOx, SO2, CO, PM. [5] The social environmental cost of transportation industry can be obtained by calculating the emission price of the five pollutants. The cost of waterway transportation is $1.64 \times 10^{-3}$ yuan/ton-km, the cost of railway transportation is $5.43 \times 10^{-3}$ yuan/ton-km, the cost of highway transportation is $1.61 \times 10^{-2}$ yuan/ton-km.

5.1.5. The cost of accident. The unit accident cost of highway transportation is $4.85 \times 10^{-3}$ yuan/ton-km, the unit accident cost of railway transportation is $3.0 \times 10^{-3}$ yuan/ton-km, the unit accident cost of waterway transportation is $0.9 \times 10^{-3}$ yuan/ton-km.

5.2. Time data

5.2.1. Travel time. Five marine routes are selected as the research object in this paper. The mileage and duration of the routes are shown in Table 4.

| Number | Port of departure | Port of arrive | Mileage (km) | Sailing days (d) |
|--------|-------------------|----------------|--------------|------------------|
| 1      | Haiphong port     | Nansha port    | 2000         | 3                |
| 2      | Tokyo port        | Nansha port    | 3300         | 5                |
| 3      | Osaka port        | Nansha port    | 3000         | 4                |
| 4      | Singapore port    | Nansha port    | 3000         | 4                |
| 5      | Long Beach port   | Nansha port    | 12000        | 17               |

The railway transportation line selected in this paper, the railway transportation mileage from Nansha port to Chengdu is 2600 km, the train speed is 100 km/h, and the operation time is 26 hours. In this paper, we assume that the average distance of inland highway distribution is 60 km, and the average time of truck distribution is 1.5 hours.

5.2.2. Node operation time. After the container ship arrives at the port, the operation time of unloading, inspection and short barge in the port is calculated as 0.5 days. The operation time of container transfer from port to railway station, loading and train assembling is calculated as 1 day. The stacking time of containers in the port yard is calculated according to the container in port time minus the operation time, and the whole number of days are taken. The connection time between inland railway station and highway truck is calculated as 0.5 days.

5.2.3. Berthing time. This paper selects the berthing schedule of some ships in Nansha port in the first ten days of April 2020. The specific berthing time of ships is shown in Table 5.

| Ship serial number | Port of departure | Date of berth | Time of berth |
|--------------------|-------------------|---------------|---------------|
| 1                  | Haiphong port     | 2020.04.03    | 17:00         |
| 2                  | Tokyo port        | 2020.04.04    | 09:00         |
| 3                  | Osaka port        | 2020.04.06    | 06:00         |
| 4                  | Singapore port    | 2020.04.07    | 16:00         |
| 5                  | Long Beach port   | 2020.04.08    | 08:00         |
5.3. Parameter setting
The setting of parameters in genetic algorithm is shown in Table 6.

| Table 6. Parameters setting in genetic algorithm. |
|-------------------------------------------------|
| Population size | Number of iterations | Mutation probability | Crossover probability |
| 100              | 300                  | 0.02                 | 0.75                 |

5.4. Solution result
Table 7 shows the cost of a single box and the connection time in port of high value time sensitive goods.

| Table 7. Single box cost and connection time in port of high value time sensitive goods. |
|---------------------------------------------------------------|
| Ship serial number | Single box cost (Thousand yuan) | Connection time in port (h) |
| 1                 | 117.94                      | 147                |
| 2                 | 132.03                      | 131                |
| 3                 | 102.81                      | 86                 |
| 4                 | 88.46                       | 52                 |
| 5                 | 218.25                      | 36                 |

High value time sensitive goods are more sensitive to time and more tolerant to transportation costs. The weight of cost and time is set to 0.25 and 0.75 respectively to solve the problem. The results are shown in Table 8.

| Table 8. Solution results of high value time sensitive goods. |
|-------------------------------------------------------------|
| Content          | Solution result  |
| \( n_1 \)       | 3 box            |
| \( n_2 \)       | 4 box            |
| \( n_3 \)       | 3 box            |
| \( n_4 \)       | 24 box           |
| \( n_5 \)       | 9 box            |
| Average cost per box | 122740 yuan  |
| Average connection time | 65 h          |

From the above results, when the weight of time is relatively large, the container with late arrival time will be preferred for railway transportation.

6. Conclusions
Based on the research of this paper, a multi-objective function based optimization model of container sea-rail intermodal transportation is established, and the genetic algorithm is used to solve the model. The operation scheme of container sea-rail multi-modal train is obtained when considering the time value of goods and social cost, which reduces the container integration transportation costs in the process of sea-rail intermodal transportation to the greatest extent. It provides a certain reference for the operation scheme of container sea-rail intermodal trains.

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