Study on the Optimization of the Multimodal Transport Scheme of Railway Containers

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Abstract. Based on the VRP model, we establish a model for path optimization. Through the node splitting method, different transport paths and modes are combined into the multimodal network, and a model of the multimodal path optimization problem targeting transport cost and transport time minimum by the introduced weights is constructed and solved with EXCLE. Finally, the examples are calculated to verify the feasibility and effectiveness of the path optimization models.

1. Introduction
In the face of increasing international economic and trade exchanges, transportation, as an important intermediate bridge and multimodal transport as an important support for the comprehensive transportation system, has received strong support at the national strategic level. The transport efficiency of container multimodal transport depends on the choice of transport route and mode of transport, which are both constrained and promoting. By studying the choice of transportation methods and routes, managers can make more scientific management decisions, reduce transportation costs and improve the overall efficiency of transportation. Therefore, it is particularly important to discuss the transport route and mode of transport.

Many scholars at home and abroad have made extensive and profound research in multimodal transport. Yang Xue[1] developed a 0-1 integer planning model with a change-over time and cost, and solved it using Matlab software. Yang Xiaoqiang[2] uses the hybrid algorithm of Dijkstra-genetic algorithm to directly add freight and transportation into the target function and use Matlab simulation software. With the goal of maximizing the time value of goods and minimizing the total transportation cost, Cui Mingyang[3] established an optimization model of the multi-objective function, solved by the ant colony algorithm, and analyzed the Suzhou-German example to verify the feasibility of the model.

2. Optimizing the container multimodal transport path model based on the VRP model

2.1 Definition and Basic Form of the VRP Model
The VRP, is a vehicle path problem. Solution of distribution problems commonly used in transport networks. Usually, there are several delivery points in the urban transportation network. Under certain constraint conditions, such as vehicle transportation capacity limit and mileage limit, they should scientifically arrange vehicle transportation tasks and design reasonable transportation routes to achieve the minimum cost, the shortest time and the shortest distance. The general form of the VRP model is the
minimum transportation cost or the shortest driving path, because the transportation cost is proportional to the vehicle driving path.

To better simplify the problem and model, the VRP model usually follows the following assumptions, as shown in Table 1 below.

| Order Number | Concrete Content |
|--------------|------------------|
| Suppose I    | During the whole transportation process, the transportation tasks cannot be divided, and the transportation volume remains unchanged, excluding the cargo loss, etc. |
| Suppose II   | In the transport network, if there is a transport path at two points, the appropriate mode of transport needs to be selected according to the actual situation, and the transport can only occur at the node, i.e. that is, there is no intermediate transport. |
| Suppose III  | Various modes of transport can be seamlessly connected, when the transfer is only considering the transit time. |
| Suppose IV   | There is no ring between any nodes (itself to its own arc). |
| Suppose V    | The mean speed of the mode of transport is fixed, where the mean velocity is the same. |

The VRP basic model minimizes the total transport cost as the optimization objective of this objective function, see formula (1). The total transportation costs include transportation costs, transit costs, and punishment costs.

\[
\min Z = \sum_{i \in n} \sum_{k \in s} Q \cdot c_{ij}^k \cdot d_{ij} + \sum_{i \in n} \sum_{k \in s} \sum_{l \in s} Q \cdot y_{ij}^k \cdot c_{il}^k + \sum_{i \in n} \sum_{k \in s} Q \cdot x_{ij}^k \cdot t_{ij}^k \cdot p_{\text{max}} \cdot M
\] (1)

The constraints are as (2) - (7):

1. Ensure that the adjacent nodes can choose only one mode of transportation
   \[
   \sum_{k \in s} x_{ij}^k = 1
   \] (2)

2. Ensure that when transit at node i, the transport can only be converted from one to another.
   \[
   \sum_{k \in s} y_{ij}^k = 1
   \] (3)

3. Ensure the continuity of multimodal transport.
   \[
   x_{i-1,i}^k + x_{i,i+1}^k \geq 2
   \] (4)

4. Ensure that the total transportation time of the plan cannot exceed the time period.
   \[
   T = \sum_{i \in n} \sum_{k \in s} x_{i,i+1}^k \cdot t_{i,i+1}^k + \sum_{i \in n} \sum_{k \in s} \sum_{l \in s} y_{ij}^k \cdot t_{ij}^l \leq T_n
   \] (5)

5. Ensure that the traffic volume of the goods cannot exceed its transport capacity.
   \[
   Q \leq f_{ij}^k
   \] (6)

6. Ensure that the decision variable can only value 0 or 1
   \[
   x_{i-1,i}^k \cdot y_{ij}^k \in \{0, 1\}
   \] (7)

Parameters and meanings are shown in Table 2.

| Parameter | Meaning |
|-----------|---------|
| Z         | Target function for the total cost |
| n         | A collection of all the transport nodes |
| s         | Collection of all modes of transport |
| Q         | The traffic volume of the goods |
| i         | Represents a node in the transport network, \(i \in n\) |
| k, l      | The various modes of transport, \(k, l \in s\) |
| \(X_{ij}^k\) | Select transport mode from node i to node k |
| \(t_{ij}^k\) | Time required to transport from node i to node i + 1 via transport mode k |
| \(C_{ij}^k\) | Unit freight volume and unit transportation distance, k transportation from node i to node i + 1 via k |
| \(y_{ij}^{kl}\) | At node i, transport mode k to transport mode l |
| \(t_{ij}^{kl}\) | At node i, the transit time converted from transport mode k to transport mode l |
| \(c_{ij}^{kl}\) | Unit freight volume is at node i from transport mode k to l |
| \(d_{ij}\) | Transport distance from node i to node i + 1 |
Transport capacity required from node $i$ to node $i + 1$ via transport $k$  
$M$ Sufficient and large penalty factor  
$T$ Total transport time from origin to destination  
$T_u$ Permissible time period from place of origin to destination  
$P_{\text{max}}$ The value of the unit container at the start of transportation  
$\text{Sgn}(x)$ Symbol function that makes $x=T-T_u$, when $x>0$, $\text{Sgn}(x)=1$; when $x<0$, $\text{Sgn}(x)=0$

2.2 Problem Description

An existing shipper wants to transport a batch of container goods from $O$ nodes to $D$, each with different alternative modes of transportation, but with different transportation and freight. Each node can also be transferred, and the resulting transit time and transit cost and total time. In addition, the total transportation time must not exceed the prescribed transportation time limit, otherwise there will be a huge time punishment cost. Therefore, the goal of the research is to scientifically design and reasonably arrange the transportation path of container goods and their combination of transportation methods within the prescribed transportation period to minimize the total transportation cost.

2.3 Model Building

According on the problem description the relevant parameters of the model can be determined. The model still follows the five assumptions mentioned in 2.1, and this model does not consider the limitation of transport capacity, the capacity weight of the arc. Because in fact, the cargo volume is usually very large, the transport capacity can basically meet the specific requirements.

In this paper, the VRP model will be improved, emphasizing the transportation cost and transportation time according to the needs of the cargo owner for different transportation tasks. Generally speaking, the transportation time is short, the transportation cost and other costs are high, so the transportation cost and time will be considered in specific applications.

The objective function of this optimization model is the total transportation cost, which is the transportation cost and time cost. The solution of the multi-objective model function is more complex, increasing the weight of transportation cost and transportation time to simplify the solution, simplifying the model to a single objective function, which specifically reflects the shipper's importance to transportation cost and transportation time in path selection. The specific meaning of the model formula is shown in Table 3 below.

| Order Number | Meaning                          | Constituent Part                                         |
|--------------|----------------------------------|---------------------------------------------------------|
| Formula (8)  | Total transportation costs       | Transportation cost and time cost                        |
| Formula (9)  | Transportation cost              | Pure en-route transportation costs and transfer costs    |
| Formula (10) | Time cost                        | Pure en-route transportation time and transfer time      |
Continued Table 3

| Formula | Description | When node i to node j is transported by transport mode k |
|---------|-------------|--------------------------------------------------------|
| Formula (11) | Pure en-route transportation costs | | |
| Formula (12) | Pure en-route transportation time | | |

However, due to the large difference between the attribute, unit and order of magnitude of transportation costs and transportation time, it cannot be directly added directly. In order to eliminate the impact of the above reasons as far as possible, we need to outline the transportation cost and transportation time. Select the extreme value processing method for the corresponding conversion, specifically the following formula (13)

\[ c'_{ij} = \frac{c_{ij} - \min(c_{ij})}{\max(c_{ij}) - \min(c_{ij})} \]

Similarly, tij, and get new C' and T'. After dimensional unification, the model is converted into formula (14)

\[ \min Z = \alpha \cdot C' + \beta \cdot T' \]

The following formula (15) is the constraint, where the second, third and fourth lines guarantee that the solution of the model gets the transportation route from the starting point to the end line, the fifth line guarantee that the direction of the transportation path must be from the starting point, and the sixth line means that the decision variable can only be taken 0 or 1.

\[
\begin{align*}
\sum_{j \in n} x_{ij} &= 1, \quad i = n_0 \\
\sum_{j \in n} x_{ji} &= 1, \quad i = n_0 \\
\sum_{j \in n} x_{ij} - \sum_{j' \in n} x_{ij'} &= 0, \quad i \in n - n_0 - n_0 \\
\sum_{j \in n} x_{ij} &\leq 1, \quad \forall i = n \\
x_{ij} &\in \{0,1\}
\end{align*}
\]

The parameters and meanings in the above are shown in Table 4

| Table 4 Parameters and meanings |
|---------------------------------|
| Parameter | Meaning |
| Z, C, T | The target function representing the total cost, transportation cost, and time cost, respectively |
| α, β | Weight of the transportation costs and time costs, respectively |
| N, no, nd | Collection, initial, end to end nodes of all transport nodes |
| s | The collection of all modes of transport, namely highway, railway, sea transport, aviation, and is expressed in numbers 1, 2, 3, 4, respectively |
| i, j | Represents a node in the transport network, i,j∈n |
| k, l | Represents one of the various modes of transport, the type k, l mode, k,l∈s |
| \(x^k_{ij}\) | Select transport mode k from node i to node j |
| \(t^k_{ij}\) | Time required to transport from node i to node j by transport mode k |
| \(c^k_{ij}\) | Transportation from node i to node j via transport k |
| \(y^k_{ij}\) | At node j, transport mode k to transport mode l |

Continued Table 4

| Parameter | Meaning |
|-----------|---------|
| \(t^{\text{ld}}_{ij}\) | At node j, the transit time converted from transport mode k to transport mode l |
| \(c^{kl}_{ij}\) | Transfer costs converted from mode of transport k to l |
| \(d_{ij}\) | Transport distance from node i to node j |
| \(f_k\) | Unit freight for the k mode |
| \(V_k\) | Transportation speed of the k transportation mode |
The above is on the basis of in-depth analysis of the actual problems, considering the characteristics of each transportation node and the characteristics of different transport, to get rid of the arbitrariness of the previous research for the transit process. Using this method, the scheme optimization problem is successfully transformed into a mathematical problem that minimizes the sum of the total transportation cost and time cost theory.

3. Case Analysis

3.1 Problem Description
Suppose a 20ft container is transported from Zhengzhou to Busan, South Korea, with two transfer stations: Jinan and Xuzhou, and two ports: Qingdao and Lianyungang. The transportation network and transportation modes between the cities are shown in Figure 1 below. The node splitting method is used to transform the transportation network between the nodes in Figure 2 below, where the numbers and their representative meanings are shown in Table 5 below.

![Fig. 1 Transport networks between cities](image1)

![Fig. 2 Transport network among nodes after changes](image2)

| Node | Meaning |
|------|---------|
| 0    | Virtual initial node |
| 1    | Select the road transportation in Zhengzhou |
| 2    | Select the railway transportation in Zhengzhou |
| 3    | Select the road transportation in Jinan |
| 4    | Select the railway transportation in Jinan |
| 5    | Choose the highway transportation in Xuzhou |
| 6    | Select the railway transportation in Xuzhou |
| 7    | Select the road transportation in Qingdao |
| 8    | Select the railway transportation in Qingdao |
| 9    | Select the road transportation in Lianyungang |
| 10   | Select the railway transportation in Lianyungang |
| 11   | Choose the waterway transportation in Qingdao |
| 12   | Choose the waterway transportation in Lianyungang |
| 13   | It ends in Busan, South Korea |
3.2 Computing method and results

Get transportation cost and time of transportation between cities. Among them, the freight and freight time between the two nodes of the non-existent transportation path are both large enough, and 99999 is adopted in this paper. According to the model established above, the transportation cost and transportation time of each node are unified. If the customer valued the transportation cost and transportation time as 7:3, the total transportation cost between the nodes is obtained by the previous model. Table 6 below.

Using EXCLE, according on the results, When $\alpha =0.7$, $\beta =0.3$, the total cost minimum path passes through nodes 0,2,6,10,10,12,13 and transforms into the corresponding transport path and transport mode of Zhengzhou- (railway) -Xuzhou- (railway) -Lianyungang- (waterway) -Busan, Korea. The transportation cost is RMB 3,209.6, and the transportation time is 39.3 hours.

If the parameters are numerically determined, the optimal solution exists for the model. In reality, the demand and demand for transportation cost and time between enterprises and goods vary, and the value of $\alpha$, $\beta$ changes and finally gets a different optimal solution. However, paths with shorter transport times usually have higher transport costs; vice versa, low. Enterprises need to analyze specific situations, adjust the parameters according to different needs, weigh the transportation cost and transportation time, and finally choose the optimal and most suitable transportation path.

| Z       | 0     | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13    |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Origin  |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 0       | 997.83 | 0.00 | 0.00 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 |
| 1       | 997.83 | 997.83 | 997.83 | 0.60 | 997.83 | 0.54 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 |
| 2       | 997.83 | 997.83 | 997.83 | 997.83 | 0.73 | 997.83 | 0.37 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 |
| 3       | 997.83 | 997.83 | 997.83 | 997.83 | 0.00 | 997.83 | 997.83 | 0.51 | 997.83 | 0.53 | 997.83 | 997.83 | 997.83 | 997.83 |
| 4       | 997.83 | 997.83 | 997.83 | 997.83 | 0.00 | 997.83 | 997.83 | 997.83 | 997.83 | 0.41 | 997.83 | 997.83 | 997.83 | 997.83 |
| 5       | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 |
| 6       | 997.83 | 997.83 | 997.83 | 997.83 | 0.32 | 0.00 | 997.83 | 997.83 | 997.83 | 997.83 | 0.16 | 997.83 | 997.83 | 997.83 |
| 7       | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 0.02 | 997.83 | 997.83 | 997.83 |
| 8       | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 0.02 | 997.83 | 997.83 | 997.83 |
| 9       | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 0.05 | 997.83 | 997.83 | 997.83 |
| 10      | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 0.02 | 997.83 | 997.83 | 997.83 |
| 11      | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 0.05 | 997.83 | 997.83 | 997.83 |
| 12      | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 0.98 | 997.83 | 997.83 | 997.83 |
| 13      | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 997.83 | 1.00 | 997.83 | 997.83 | 997.83 |

4. Conclusion

For the rapid development of railway container multimodal transport, this paper considers transit cost, VRP model and basic model, establishes the subjective objective expectation and cargo characteristics, and transforms the multi-objective function into single objective function. The node splitting method is used to transform the transportation network, and finally the EXCLE is used to solve the model planning, so as to reasonably allocate all kinds of transportation resources.

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