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Research on the Economy of Multimodal Transport Considering Low Carbon and Time Cost

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ABSTRACT: In order to verify the high efficiency and low carbon nature of multimodal transport, this paper, according to the main components and network characteristics of multimodal transport, takes container multimodal transport as the research object, and comprehensively considers the carbon emission and transportation time in the transportation process. To minimize the comprehensive cost of container multimodal transport, the comprehensive cost model of multimodal transport including time, transportation and replacement cost is established. At the same time, combined with the actual calculation of examples, the design and analysis of the multimodal transport scheme. As for the transportation time, this paper introduces the monthly depreciation rate of goods and transforms the transportation time into the time cost. It can be concluded that with the increase of the monthly depreciation rate of goods, the multimodal transport mode is more economical and efficient than the single transportation mode. For the problem of carbon emission, this paper will quantify the carbon emission, it can be found that in the multimodal transportation, the reasonable connection of transportation mode can greatly reduce the carbon emission in the transportation process, so as to achieve low carbon transportation.

KEYWORDS: Multimodal Transport;Carbon Emissions;Time Cost; Container; Monthly Depreciation Rate

Ⅰ. INTRODUCTION

With the rapid development of China 's economy, people 's requirements for the transportation of goods are getting higher and higher. The most significant point is the time of cargo transportation. Therefore, it is urgent to explore efficient transportation methods [1].

With the increasingly prominent problem of global environmental pollution, the development of low-carbon economy has become a new trend of the times. As an energy-intensive activity, transportation has a very high proportion of carbon emissions. According to statistics, the carbon dioxide emissions of China 's transportation industry are as high as about 22% [2]. In order to effectively reduce carbon emissions, carbon trading mechanisms have developed rapidly in various countries. In 2011, the National Development and Reform Commission issued a pilot work on the carbon emission trading mechanism for carbon emission issues, which was tested in Beijing, Tianjin, Shanghai and other places. Many scholars have also made a lot of research on the carbon trading mechanism. Fang Lan, Tang Heyan [3] studied the impact of the carbon emission trading mechanism on the carbon emission reduction of enterprises, and concluded that the carbon emission mechanism can promote economic growth ; zhang Xiufan and Fu Ningning [4] studied the carbon emission trading mechanism under the " double carbon " strategic goal, focused on the analysis of the four emission reduction mechanisms of carbon emissions, and summarized the measures affecting emission reduction ; Zhang Xiufan and Fan Decheng [5] collected the data of China 's carbon trading market in the past ten years. Through analysis, it is concluded that the carbon trading market plays a positive role in carbon emission reduction efficiency.

As a modern new mode of transportation, multimodal transport realizes the integration of resources in the process of transportation by combining the traditional single mode of transportation and relying on the efficient comprehensive transportation system [6], that is, the effective connection of various modes of transportation, which is conducive to achieving the purpose of reducing costs and increasing efficiency in economies of scale.

In this paper, the multimodal transport of containers is taken as the research object. Considering the transportation cost, time cost and carbon emissions, a comprehensive cost model of multimodal transport with the goal of minimizing the total cost is constructed to study the economy of container multimodal transport.

Ⅱ. PROBLEM DESCRIPTION AND MODEL CONSTRUCTION

2.1 BASIC ASSUMPTIONS

Container multimodal transport network refers to a system in which multiple modes of transportation cooperate to complete the task of transportation. Transportation cost, time cost and carbon emission cost are important indicators to measure the performance of the system, and they are also the core factors to be considered when optimizing the multimodal transport network.

In order to facilitate the research, some assumptions are made on the research questions : the container type is 20-foot standard container, the weight is 10 tons / TEU ; the goods are only reloaded on the nodes, and each node is reloaded at most once.

2.2 CARBON EMISSIONS

For the carbon emissions in container multimodal transport, this paper only considers the carbon emissions generated during the transportation of the three modes of transportation of waterways, railways and highways and the carbon emissions generated when the nodes are replaced.

2.2.1CARBON EMISSIONS FROM TRANSPORT

It is assumed that the vehicles of road, railway and waterway transportation are diesel trucks, diesel freight trains and diesel ships respectively. The energy consumption coefficients of the three modes of transport [7], as shown in Table 1.

Table 1 Energy consumption coefficient (kg/(TEU*km))

Transportation mode	highway	railway	waterway
Energy consumption coefficient	0.783	0.024	0.028

According to the IPCC, 3.17 kg CO2 will be generated for every 1 kg of diesel consumed. Using this conversion coefficient, the energy consumption coefficient of the transportation mode in Table 1 is converted into a carbon dioxide emission coefficient, as shown in Table 2.

Table 2 Carbon dioxide emission coefficientr(kg/(TEU*km))

Transportation mode	highway	railway	waterway
Carbon emission factor	2.48211	0.07608	0.08876

2.2.2 CARBON EMISSIONS GENERATED BY RELOADING

The carbon dioxide emission coefficient generated by the replacement of various modes of transportation in the multimodal transport network is shown in Table 3.

Table 3 Carbon dioxide emission coefficient(kg/TEU)

Replacement method	carbon emission coefficient
h—w	5.31
h—r	5.06
w—r	5.81

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2.2.3 CARBON EMISSION CALCULATION OF MULTIMODAL TRANSPORT

Variables are defined as follows:

K={1,2,3}:denotes the set of transportation modes:1 denotes road transportation, 2 denotes railway transportation, 3 denotes waterway transportation, $k \in K$, $l \in K$;

M={1, 2, 3... m}:denotes the set of nodes, $i \in M$, $j \in M$.

d_{ij}^{k}:denotes the distance from node i to node j to choose the k th mode of transportation.

c_{ij}^{k}:represents the carbon emission coefficient of the kth mode of transportation from node i to node j ;

n_{ij}:denotes the freight volume (TEU) from node i to node j ;

ε^{kl}:represents the carbon emission coefficient when the kth mode of transport is replaced by the lth mode of transport ;

z_{ij}^{k}={1,0}:transport from node i to node j in the kth way, then take 1 ;

y_{j}^{kl}={1,0}:at node j, it is changed from transport mode k to transport mode l, and then it is taken as 1 ;

the calculation of carbon emissions is as follows：

$$Q_e = \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} z_{ij}^{k} d_{ij}^{k} c_{ij}^{k} n_{ij} + \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} y_{j}^{kl}\, \varepsilon^{kl} n_{ij} \quad (1)$$

2.3 TIME COST

In the time cost of container multimodal transport, this paper only considers the transit time in the process of cargo transportation and the reloading time of goods at the node, and converts the transportation time into time cost.

Table 4 Time of changeover(h/TEU)

Replacement method	Unit replacement time
h—w	0.34
h—r	0.2
w—r	0.45

Variables are defined as follows:

T_{ij}^{k}:indicates the transit time of selecting the k th mode of transportation from node i to node j ;

t_{j}^{kl}:the replacement time of the node j from the kth mode of transportation to the lth mode of transportation.

The transportation time T is calculated as Eq. 2 :

$$T = \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} z_{ij}^{k} T_{ij}^{k} + \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} y_{j}^{kl} t_{j}^{kl} \quad (2)$$

In order to conform to reality, the cost of transportation time is calculated based on the monthly depreciation rate of the goods [8].

Assuming that there is only one kind of goods in the transportation process, the monthly calculation is based on 30 days, and the monthly depreciation rate of the goods is constant, the time cost of goods transportation C_1 is calculated as follows 3 :

$$C_1 = P \times \beta \times \frac{T}{30 \times 24} \quad (3)$$

The variable is defined as follows:P represents the value of the goods, β represents the monthly depreciation rate of the goods.

2.4 TRANSPORTATION COSTS

Variables are defined as follows :

a_{ij}^{k}:denotes the unit transportation cost (yuan/TEU*km) of selecting the k th mode of transportation from node i to node j ;

d_{ij}^{k}:denotes the distance from node i to node j to choose the k th mode of transportation ;

n_{ij}:represents the freight volume from node i to node j.

$$C_2 = \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} a_{ij}^{k} d_{ij}^{k} n_{ij} \quad (4)$$

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Table 5 Unit transportation cost of different modes

Mode	unit cost(Yuan/TEU*km)
highway	4.5
railway	3.2
waterway	2.5

2.5 REPLACEMENT COST

Variables are defined as follows :

Q_j^{kl} :represents the replacement cost (yuan / TEU) of the node j from the kth mode of transportation to the lth mode of transportation.

$$C_3 = \sum_{k=1}^{K} \sum_{i=1}^{M} \sum_{j=1}^{M} y_j^{kl} Q_j^{kl} \quad (5)$$

Table 6 Replacement costs between different modes

method	Replacement cost per unit (yuan / TEU)
h—w	7
h—r	5
w—r	10

2.6 MODEL ESTABLISHMENT

This paper will study the economy of container multimodal transport under the mandatory carbon emission policy. According to the relevant policies, the maximum value of carbon emission D (kg) in the process of multimodal transport is set up(QeD), and the comprehensive cost model of container multimodal transport is constructed as follows :

$$\mathrm{Min}C = C_1 + C_2 + C_3 \quad (6)$$

$$Q_e \leq D \quad (7)$$

$$\sum_{k=1}^{K} z_{ij}^k = 1 \quad (8)$$

$$\sum_{i=1}^{M} \sum_{j=1}^{M} z_{ij}^k \leq 1 \quad (9)$$

$$z_{ij}^k z_{jr}^l = y_j^{kl} \quad (10)$$

$$n_{ij} \leq N_{ij}^k \quad (11)$$

Among them, Nijk represent the maximum freight volume of the kth mode of transportation selected from node i to node j is expressed ; equation (8) indicates that only one mode of transportation is selected from node i to node j ; equation (9) indicates that only one reloading or no reloading is performed from node i to node j ; eq. (10) represents the continuity of the node replacement ; equation (11) indicates that the freight volume from node i to node j cannot be greater than that of the kth mode of transportation during transportation.

Ⅲ. EXAMPLE SHOWS

Suppose there is a batch of goods with a value of 5 million yuan and a total quantity of 50 boxes, starting from the starting point O, through three nodes 1,2 and 3, and finally transported to the end point D, where the three nodes can be changed between the three modes of transportation. In order to better describe the example, the transportation speed of the three modes of transportation is given, see table 7 ; at the same time, the transportation distances between adjacent nodes under the three transportation modes are different, and the detailed distances are shown in Table 8.

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Table 7 Transport speed of different modes

mode	highway	railway	waterway
Speed（km/h）	100	80	24

Table 8 Transportation distance under different modes

Distance (km)	highway	railway	waterway
O- 1	250	400	450
1-2	338	450	550
2-3	550	518	600
3-D	322	500	347

According to the model constructed above, the monthly depreciation rate β of the product is taken as 0,0.1 and 0.3, and the costs of using a single mode of transportation from the starting point O to the end point D are calculated respectively. The results are shown in table 9.

Table 9 Cost comparison table of single mode of transportation

β	Mode	Total cost	Carbon emissions (kg)	Time cost	Transportation cost	Transportation time (h)
0	highway	328500	181194.03	0	328500	14.60
	railway	298880	7105.87	0	298880	23.35
	waterway	243375	8640.79	0	243375	81.13
0.1	highway	328500	181194.03	10138.8	328500	14.60
	railway	315095.3	7105.87	16215.2	298880	23.35
	waterway	299715.2	8640.79	56340.3	243375	81.13
0.3	highway	358916.6	181194.03	30416.6	328500	14.60
	railway	347525.8	7105.87	48645.9	298880	23.35
	waterway	412395.7	8640.79	169021	243375	81.13

According to Table 9, it can be seen that:1 the carbon emissions generated by waterway transportation are the least, and the road is the most, which is in line with the actual situation; secondly, with the increase of the monthly depreciation rate β of the product, the timeliness of the product is stronger, and the corresponding time cost will be higher.

Ⅳ. ECONOMIC ANALYSIS OF MULTIMODAL TRANSPORT

4.1 SELECTION OF CONTAINER MULTIMODAL TRANSPORT SCHEMES CONSIDERING TIME COST

It can be seen from the costs of a single mode of transportation:

When the monthly depreciation rate β of the goods is 0, the goods will not depreciate over time, so the time cost can be ignored in the cost calculation at this time. Finally, it is concluded that the single mode of transportation with the lowest comprehensive cost is waterway transportation, which is obviously an ideal state.

In order to make the cost calculation more in line with the actual transportation, the monthly depreciation rate of goods β is taken as 0.1 and 0.3, and the time cost will be generated in the transportation of goods. And the greater the β value, the higher the time cost.

From the perspective of reducing the transportation time of goods, when β is 0.1, the road-water intermodal transportation mode is selected, that is, the O-2 node adopts road transportation and the 2-D node adopts waterway transportation. By reducing the mileage of waterway transportation and replacing it with road transportation, it can accelerate the transportation speed, shorten the transportation time, and thus reduce the time cost ; when the monthly depreciation rate of goods β is 0.3, the road-rail combined transportation mode is selected to further reduce the transportation time and complete the transportation of goods quickly. Substituting the relevant data into the multimodal transport comprehensive cost model, the costs of the multimodal transport scheme are obtained, as shown in table 10.

Table 10 Cost analysis of multimodal transport scheme

β	Route	Total cost	Carbon emissions（kg）	Time cost	Transportation cost	Replacement cost	Transportation time (h)
0	O-w-D	243375	8640.79	0	243375	0	81.13
0.1	O-h-2-w-D	287358.33	77442.32	43083.33	243925	350	62.04
0.3	O-h-2-r-3-h -D	362255	115412.48	74125	287630	500	35.58

From the results of the solution, it can be found that compared with a single mode of transportation, multimodal transport can complete the transportation of goods more efficiently, but the transportation time is reduced, and the carbon emissions are increasing. In order to meet the low-carbon requirements, this paper will further explore the multimodal transport scheme considering carbon emissions.

4.2 SELECTION OF CONTAINER MULTIMODAL TRANSPORT SCHEMES CONSIDERING CARBON EMISSIONS

In order to reduce carbon emissions, this paper further optimizes the multimodal transport scheme based on the time cost.

When β = 0.1, the road-rail-water intermodal transportation mode is adopted, and the railway transportation is selected to replace part of the road transportation, thereby reducing the road transportation distance and reducing carbon emissions ; when β = 0.3, we choose to increase the proportion of railway transportation and reduce the proportion of road transportation, so as to reduce the carbon emissions in the transportation process, so as to achieve the purpose of green and low-carbon transportation. Substituting the relevant data into the comprehensive cost model of multimodal transport, the costs of the multimodal transport scheme are obtained, as shown in Table 11.

Table 11 Cost analysis of multimodal transport scheme

β	Route	Total cost	rate of change	Carbon emissions	rate of change	Transportation cost	Time cost	Replacement cost	Transportation time (h)
0	O-w-D	243375	0.00%	8640.79	0.00%	243375	0	0	81.13
0.1	O-h-1-r-3-w-D	298005	3.71%	36792.13	-52.50%	254505	42750	750	61.56
0.3	O-r-3-h-D	354746.7	-2.07%	45418.84	-60.65%	291330	63167	250	30.32

From table 11, it can be seen that the carbon emissions of the selected schemes after considering carbon emissions are significantly reduced. When β = 0.1, carbon emissions are reduced by 52.5 %, and the comprehensive cost is only increased by 3.71 %. When β = 0.3, the carbon emission is reduced by 60.65 %, and the comprehensive cost is reduced by 2.07 %, which meets the optimization goal.

Ⅴ. CONCLUSION

Aiming at the problem of container multimodal transport, this paper constructs a comprehensive cost model of multimodal transport considering time cost, transportation cost and reloading cost, and considers carbon emissions, and studies the economy of container multimodal transport. Combined with the actual example, the multimodal transport scheme is designed. The results show that : 1 With the increase of the time correlation of goods, that is, the increase of the monthly depreciation rate of goods, the higher the efficiency requirement of goods transportation. Compared with a single mode of transportation, choosing the appropriate mode of transportation for multimodal transport in different sections can efficiently transport goods and reduce time costs ; secondly, reasonable arrangement of transportation mode connection in multimodal transport can greatly reduce carbon emissions and achieve the purpose of green transportation. However, this paper does not consider the cost of carbon emissions when constructing a comprehensive cost model, which can be further studied in the future.

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