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Study on optimization of multimodal transportation of marine container considering carbon emission

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ABSTRACT

In order to make the mode selection of container sea land multimodal transport more in line with the requirements of energy conservation and emission reduction, this paper analyzes the influencing factors of carbon emission, establishes the calculation model of carbon emission and the calculation model of transportation cost, and establishes a multi-objective decision-making model based on carbon emission, transportation cost, and transportation time, through the decision-making model, this paper compares and selects the combined transportation modes. Taking the container sea land multimodal transport from Harbin to Tai'an City as an example, the paper uses the above multi-objective decision-making model to obtain the "rail sea rail combined transport" mode as the optimal scheme.

Keywords: Container; Land sea multimodal transport; Carbon emission; Multi-objective decision-making

1. Introduction

Nowadays, the carbon emission reduction of multimodal transport industry is becoming more and more important because of the significant carbon emission reduction effect of multimodal transport, e past, and scholars only consider the two factors that affect the economic efficiency of multimodal transport. 4 Scholars only consider the two factors that affect the economic efficiency of multimodal transport, even if some scholars study the carbon emissions of multimodal transport, most of them are qualitative analysis, but few quantitative studies. In the context of global advocacy of low-carbon transportation, carbon emissions will become a factor that must be considered in the selection of sea land multimodal transport mode. A multi-objective decision-making model based on carbon emission, transportation cost, and transportation time is established by adding carbon emission into the mode selection [1–3].

2. Literature review

Yu and Jie [4] analyzed the multimodal transport model without considering carbon emissions and considering carbon emissions. On this basis, a multi-objective 0–1 programming model for minimizing the total transportation cost and total transportation carbon emissions was proposed. The concept of weight was applied to the solution of the ideal point method, and the multi-objective planning was transformed into a single objective function. This paper compares and analyzes the solution results of different weights and different solutions [4]. Container multimodal transport embodies the combination advantages and comprehensive efficiency of various transport modes and serves the national "The Belt and Road Initiative" development strategy. Junxia and Gang [8] discussed the practical problems in the development of multimodal transport in Wuhan according to the development status

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and structure system of container multimodal transport in Wuhan, Wuhan should seize the development opportunity, promote the construction of national demonstration project of container multimodal transport, and realize the transformation and upgrading of logistics industry [5]. The congestion of container deep-sea port is increasing and the transportation capacity is insufficient, As a result, inland transport systems worldwide are increasingly dependent on inland terminals and rely on high-capacity transport modes to generate economies of scale and reduce the negative effects of freight transport. In this case, the maturity date and soft time window, which are called demurrage and detention (D & D), must also be considered in the planning of marine container transportation between deep sea ports and final inland destinations. First of all, the paper evaluates the effects of different modes of transport planning on the efficiency of inland transport system, trucks were forced to be used as buffers, followed by containers pushed to unnecessary seaport locations [6].

3. Analysis on the current situation of 1 waterway transportation channel

At present, the main cargo types of waterway transportation are dry bulk cargo (coal mine, iron ore, mining construction materials, and non-metallic ore), liquid bulk cargo, container, commodity automobile, and so on. With the rapid development of Yangtze River shipping and the rapid growth of dam crossing demand, the problem of insufficient capacity of Three Gorges ship lock is becoming increasingly prominent, which has become the bottleneck restricting the development of shipping in the upper reaches of the Yangtze River. The cargo throughput of the Three Gorges project exceeded its designed navigable capacity 19 y in advance. In 2017, the throughput of the Three Gorges shiplock reached 138 million tons, 38% of the designed capacity. The average daily number of vessels waiting for lock in the dam area was 614, and the average waiting time was 106 h. The freight transport capacity of coastal railway along the Yangtze River was weak, mainly reflected in the saturation of transportation capacity of Xiangyang Chongqing railway and Chongqing Huaihua line, and the lack of freight transportation through Shanghai Hanrong channel in the central part. Most of the railways in the coastal ports along the Yangtze River have not been coordinated by the railway. The coastal highways along the Yangtze River mainly include Shanghai Chengdu expressway, Shanghai Chongqing Expressway, and other coastal high-speed highways along the river, including some first-class national roads and a large number of local roads along the river. Multimodal transport is a convenient, economic, safe, reliable, intensive and efficient, green, and low-carbon transportation organization mode. It can provide strong support for the green and ecological development of the current water transport economic belt [7,8].

4. Container multimodal transport mode

4.1. High seas intermodal mode

High seas intermodal transport means that goods are transported to coastal ports and wharves by road, and then transported to destination ports by ships, or goods are transported to coastal ports and wharves by ships. Because of its high efficiency and low efficiency, it cannot be completed once more. At present, it is still the main mode of container sea land multimodal transport. In the whole transportation process of high seas intermodal transport, only two modes of transportation are involved [9,10].

4.2. Rail sea intermodal transport mode

Rail sea intermodal transportation is a mode of transportation in which goods are transported to coastal ports and wharves by rail, then transported to the destination port by ship, or goods are transported to coastal ports and wharves by ship, and then transported to the final destination by rail. It only needs "one declaration, one inspection, and one release" to complete the whole transportation process. Although rail sea intermodal transport is inferior in terms of cargo collection time, it has become a priority mode of transportation in various countries due to its huge transport capacity, high operation efficiency, less exhaust emission, and lower cost. In the whole transportation process of rail sea intermodal transportation, in addition to railway and sea transport modes, the rail sea intermodal transport mode has become a priority mode of transportation in various countries. There are also road transportation from the place of departure to the railway container yard and from the railway container station to the final destination.

5. Carbon emission decision-making based on time cost

5.1. Calculation of carbon emissions from land sea multimodal transport

The carbon emission calculation formula of land sea multimodal transport is:

$$W_{\text{union}} = \alpha_{\text{sea}} \times w_{\text{sea}} + \alpha_{\text{land}} \times w_{\text{land}} \tag{1}$$

In Eq. (1): W is the carbon emission per kilometer of land sea multimodal transport, kg; α is the proportion of sea and land transportation mileage in the total mileage of multimodal transport; W_{sea} is the carbon emission per kilometer of sea transportation section, kg; and W_{land} is the carbon emission per kilometer of land transportation section, kg. Because of the same sea transportation section between high sea and rail sea transportation, it is only necessary to compare the carbon emission of land section under the two modes. In the high seas intermodal mode, the calculation formula of carbon emission per unit mileage of highway transportation is as follows:

$$\text{WGM} = \beta_{\text{steam}} \times g_{\text{steam}} \times f_{\text{steam}} + \beta_{\text{diesel}} \times g_{\text{diesel}} \times f_{\text{diesel}} \tag{2}$$

where W is the carbon emission per kilometer of road transportation, kg; β is the proportion of gasoline consumption in the total fuel consumption; g is the gasoline consumption per standard container per kilometer; according to relevant research, g takes 0.689ll (TEU · km); f is the carbon dioxide produced per liter of gasoline, according to the information of the Intergovernmental Panel on climate change (IPCC), *f* is 2.27 kg gL; el fuel is the proportion of diesel oil consumption in total fuel consumption in highway transportation; *g* diesel fuel is diesel oil consumption per standard container per kilometer, taking 0.606ll (TEU · km); f_{diesel} is carbon dioxide produced per liter of diesel oil, which is taken as 2.74 kg gL (M28) according to IPCC data [11].

In the rail sea intermodal mode, most of the railway locomotives in operation in China are electric locomotives. Although electric locomotives do not produce carbon emissions during operation, the power generation enterprises that supply power for them produce carbon emissions. Therefore, in the rail sea intermodal mode, the calculation formula of carbon dioxide emission per unit mileage of railway section is as follows [12–14].

$$W_{\text{Fe}} = g_{\text{electricity}} \times f_{\text{electricity}} \tag{3}$$

where *W* railway is the carbon dioxide emission per kilometer transportation of railway section, kg; *g* power is the electricity consumption per kilometer of standard container transportation, according to the data of China Transportation Yearbook, *g* power is 0.1106kw · HH (TEU · km); *f* power is the carbon dioxide emission per kilowatt-hour produced by upstream power generation enterprises, *f* power = 0.717 kg g (kW·h).

5.2. Calculation of transportation cost of land sea multimodal transport

The transportation cost of land sea intermodal transportation refers to the total expenses in the whole process of transportation, including the distribution of goods, the site rent, insurance, and labor costs incurred in the operation of each transfer center. This paper only compares and analyzes the different modes of multimodal transport at the same destination. Because of the same sea transportation section, the transportation cost of land sea multimodal transport is the total cost of transportation. In the cost calculation, only the highway transportation section and the railway transportation section are compared.

5.2.1. Calculation formula of highway transportation cost

The calculation formula of transportation cost of each standard box in highway transportation section is as follows:

$$C_{\text{gong}} = C_1 \times L_1 + y + 2A_1 + a_2 \tag{4}$$

where *C* is the transportation cost of each standard container in the highway transportation section, yuan; C_1 is the transportation cost of each standard container per kilometer in highway transportation, yuan; *y* is the bridge and road toll of container truck, yuan; L_1 is the truck transportation mileage of container, km; a_1 is the loading and unloading fee at the container yard, yuan; a_2 is the provincial cost of container truck, yuan.

5.2.2. Calculation formula of railway transportation cost

The calculation formula of transportation cost of each standard box in railway transportation section is:

$$C_{\text{Fe}} = B_1 + \left(C_2 + e_1 + e_2\right) \times L_2 + B_2 + B_3 + B_4 + B_5 + m \tag{5}$$

where *C* railway is the transportation cost of each standard container in the railway transportation section, yuan; C_2 is the transportation cost per standard container per kilometer in railway transportation, yuan; L_2 is railway transportation mileage, km; E_1 is railway construction fund rate; E_2 is railway transportation related average freight, yuan; B_1 is the base price of each standard container of railway transportation, yuan; B_2 is the container use fee, yuan; and; B_4 is the loading and unloading fee of railway station, yuan; B_5 is the sealing material fee and organization service fee, yuan; *m* is the highway transportation cost associated with railway transportation, yuan.

5.3. Multi objective decision making model based on carbon emission, cost, and time

The multi-objective decision-making model is established as follows:

5.3.1. Determine decision matrix

Suppose that a multi-objective decision-making problem has *n* alternatives, and the set of optimal decision-making schemes is:

$$R = \left\{x_1, x_2, \dots, x_n\right\} \tag{6}$$

If there are *p* kinds of objectives for each scheme, then the objective set of multi-objective optimal decision is:

$$F(x) = \left[f_1(x), f_2(x), \dots, f_p(x)\right]^T \tag{7}$$

Among them, the first *k* goals are the smaller, the better ones are:

$$f_1(x) = \left[f_1(x), f_2(x), \dots, f_k(x)\right]^T \tag{8}$$

The larger the latter *P*–*K*, the better:

$$f_2(x) = \left[f_{k+1}(x), \dots, f_p(x)\right]^T \tag{9}$$

The decision matrix of the problem is obtained:

$$A = \begin{bmatrix} f_1(x_1) & f_1(x_n) \\ f_p(x_1) & f_p(x_n) \end{bmatrix} \tag{10}$$

Order:

$$U_j = \min\left\{f_j(x_1), f_j(x_2), \dots, f_j(x_n)\right\} \ \left(j = 1, 2, \dots, k\right) \tag{11}$$

$$U'_j = \max\left\{f_j(x_1), f_j(x_2), \dots, f_j(x_n)\right\} \ \left(j = k+1, \dots, p\right) \tag{12}$$

$$V_j = \min\left\{f_j(x_1), f_j(x_2), \dots, f_j(x_n)\right\} \ \left(j = k+1, \dots, p\right) \tag{13}$$

$$V_j' = \max\left\{f_j(x_1), f_j(x_2), \ldots, f_j(x_n)\right\} \quad (j = 1,2,\ldots,k) \tag{14}$$

5.3.2. Definite ideal solution and negative ideal solution

In the multi-objective optimal decision-making problem, it is assumed that there are ideal solutions and negative ideal solutions. Each objective value in the ideal solution is the optimal value in all schemes, and each objective value in the negative ideal solution is the worst value in all schemes:

$$X^* = \left(U_1, U_2, \ldots, U_k, U_{k+1}', \ldots, U_p'\right)^T \tag{15}$$

The negative ideal solution is:

$$X' = \left(V_1', V_2', \ldots, V_k', V_k, \ldots, V_p\right)^T \tag{16}$$

5.3.3. Calculate proximity

The formula for calculating the proximity of each scheme to the ideal solution is:

$$R_i = \frac{1}{p}\left[\sum_{j=1}^{k} \frac{U_j}{f_i(x_i)} + \sum_{j=k+1}^{p} \frac{f_i(x_i)}{U_j'}\right] \quad (i = 1,2,\ldots,n; j = 1,2,\ldots,p) \tag{17}$$

The formula for calculating the proximity of each scheme to the negative ideal solution is:

$$r_i = \frac{1}{p}\left[\sum_{j=1}^{k} \frac{f_i(x_i)}{V_j'} + \sum_{j=k+1}^{p} \frac{V_j}{f_j(x_i)}\right] \quad (i = 1,2,\ldots,n; j = 1,2,\ldots,p) \tag{18}$$

5.3.4. Calculate relative proximity

In this paper, the advantages and disadvantages of each scheme are evaluated by calculating the relative closeness of each scheme to the ideal solution:

$$\mu_i = \frac{R}{r_i + R_i}, \quad 0 \le \mu_i \le 1,2,\ldots,n \tag{19}$$

5.3.5. Optimal scheme

All schemes are arranged from large to small according to the calculated *I* value.

6. Empirical analysis

Different modes of land sea multimodal transport between Harbin and Tai'an are selected. The following is set: 80 TEU is transported by one railway train, and the weight of each TEU is 10 t. Other basic data are shown in Table 1 and carbon emission, transportation cost, and transportation time of different modes are shown in Table 2.

- Four modes of sea land intermodal transportation, including rail sea rail, rail sea highway, highway sea rail, and highway sea highway, are selected. The values of relevant quantities in Eqs. (1)–(5) are as follows: steam = 20%; C_1 = 6.5 yuan km; Harbin Dalian y = 360 yuan; Yantai Tai'an y = 200 yuan; A_1 = 60 yuan km; A_2 = 15 yuan km; C_2 = 0.7128 yuan km; B_1 = 161 yuan TEU; B_2 = 100 yuan TEU; B_3 = 4 yuan TEU; B_4 = 386.1 yuan TEU; B_5 = 65 yuan TEU; E_1 = 0.528 yuan/km; E_2 = 0.0176 yuan/km; m = 900 yuan.

According to the multi-objective decision-making model, the calculation results of three objectives in four schemes are obtained, as shown in Table 3.

- The ideal solution and negative ideal solution are calculated

$$X^* = \left(U_1, U_2, \ldots, U_k, U_{k+1}', \ldots, U_p'\right)^T = \left(121.90, 5753.39, 72\right)^T \tag{20}$$

Table 1
Basic data of land sea multimodal transport from Harbin to Tai'an

Line section	Seaway transportation		Railway transportation		Road transport	
	Distance n (min)	Time length (h)	Distance from (km)	Time length (h)	Distance from (km)	Time length (h)
Harbin Dalian	/	/	946	12	932	11
Dalian Yantai	89	7	/	/	/	/
Yantai Taian	/	/	597	7.5	520	5.5

Table 2
Carbon emission, transportation cost, and transportation time of different modes

Pattern	Carbon emissions from land transport (kg g TEU)	Land transportation cost (yuan TEU)	Transportation time (h)	Loading and unloading, waiting, and collecting time (d)
Iron sea iron	121.90	5,753.39	24	5
Iron sea public	928.05	7,022.05	23	4
Public sea iron	1,576.58	8,920.36	25	3
Public sea public	2,382.73	10,768.50	24	2

Table 3
Calculation results of different transport modes

Program	Carbon emissions from land transport *f*1*XX* (kg g TEU)	Land transportation cost *f*2*XX* (yuan TEU)	Transportation time *f*3*XX* h
X_1	121.90	5,753.39	144
X_2	928.05	7,022.05	119
X_3	1,576.58	8,920.36	110
X_4	2,382.73	10,768.50	72

The negative ideal solution is:

$$X' = \left(V_1', V_2', \ldots, V_k', V_{k+1}, \ldots, V_p\right)^T = \left(2382.73, 10768.50, 144\right)^T \quad (21)$$

- Calculate the proximity of each scheme

The approximation degree of each scheme to the ideal solution is $R_1 = 0.832$, $R_2 = 0.518$, $R_3 = 0.458$, and $R_4 = 0.368$. The approximation degree of each scheme to the negative ideal solution is $R_1 = 0.528$, $R_2 = 0.622$, $R_3 = 0.750$, and $R_4 = 0.832$.

- Relative closeness of each scheme to the ideal solution is calculated, and the results are as follows: 0.612, 0.454, 0.379, and 0.484, respectively
- Optimal scheme

Therefore, from the large-scale mode to the small-scale mode (1.4), the result is ranked as 1 > 4.

7. Result analysis

According to the transportation cost calculation model established in this paper, the economic transportation distance of each standard box is 320 km, that is, when the transportation distance is less than 320 km, the highway transportation cost is lower than the railway transportation. According to the carbon emission calculation model, the carbon emission of highway transportation section is 1.641 KGg (TEU · km), and the carbon emission of railway transportation section is only 0.079 KGg (TEU · km). Compared with highway, railway has a strong advantage. According to the multi-objective decision-making model based on carbon emission, cost, and time, the mode selection of container multimodal transport can be carried out under different conditions by comprehensively considering the influence factors of carbon emission, transportation cost, and transportation time.

8. Conclusion

Container sea land multimodal transport has the advantages of low transportation cost, high efficiency, and low emission. Therefore, China should vigorously develop container sea land multimodal transport at this stage. From the empirical analysis results, we can see that the carbon emission, transportation cost, and transportation time of container sea land multimodal transport are different under different modes. Under the global trend of advocating low-carbon economy, container sea land multimodal transport has its own advantages. When choosing the mode, we should not only consider the cost and time, but also consider the influence factor of carbon emission. This paper analyzes the different modes of container sea land multimodal transport, and adds the factor of carbon emission on the basis of considering the cost and time, so that the analysis results can better reflect the social requirements of energy conservation and emission reduction. It is more in line with the concept of sustainable development in modern society. In this paper, taking the sea land multimodal transport line from Harbin to Tai'an as an example, the model is applied to carry out empirical analysis. The results show that the model is practical and feasible, and corresponding decisions can be made according to the specific situation. In addition to considering carbon emission, transportation cost, and transportation time, the mode selection of sea land multimodal transport also involves many factors, such as the cost of air pollution control and the requirements of cargo owners. Therefore, it is the future research direction to add more influencing factors to the mode selection of container sea land multimodal transport based on the existing model.

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