

# Research on Container Intermodal Transport Route Optimization under the Carbon Emission Trading

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**Abstract**— The reasonable selection of container intermodal path is of great significance to the reduction of the transportation cost. With the implementation of carbon trading market, analysis the impact of carbon emission trading on the selection of the intermodal path and the total cost is conducive to provide constructive advice. A path optimization model aiming at minimizing the total cost was established under the current initial quota mechanism of carbon trading market. Then, the CPLEX software was used to solve the model. Finally, a preliminary discussion was presented. The results show that discriminative path exist in different scenarios; the total cost and carbon emissions of path optimization model with the carbon cost are far less than that of path optimization model without carbon cost. Arranging the production rationally, selling out the extra carbon quota and converting the carbon cost into the additional profit, to some extent, the total cost can be decreased under the different carbon quota and prices.

**Keywords**—Integrated Transportation; Carbon Trading Market; Intermodal Transport; Route Optimization; Low-Carbon

## I. INTRODUCTION

According to the data from the national development and reform commission, the total national social logistics have grown to 17.73 billion yuan, total social logistics cost ratio of GDP 18% in 2012. With the development of market economy, logistics industry has grown as a leading industry to guide production and promote consumption. However, the logistics industry is also a high energy consumption and high pollution industry, which has been a more and more serious negative impact on the ecological environment, such as exhaust gas pollution, noise pollution and carbon emissions, etc. The stern report shows logistics transportation accounts for 14% of global greenhouse gas emissions. And China's logistics industry fuel consumption accounts for about 34% of the total consumption, carbon dioxide emissions 18.9%, and energy costs accounted for 40% of logistics enterprises and even the 80% [1]. Therefore development of convenient and efficient, green low carbon transport has become the inevitable trend of logistics industry; And intermodal transport, with its huge capacity, lower transport costs and relatively less pollution emissions and other unique advantages, has become a prior

transportation mode of all countries in the world, which is one of the 12 key projects among the medium and long-term development of logistics industry planning (2014-2020) (hereinafter referred to as the "plan") issued by the State Council on September 12, 2014

The existing research on path optimization of intermodal transport is mostly based on the traveling salesman model (TSP) and the vehicle routing problem (VRP) model. Most early research concentrated on the linear programming model established by minimizing the total cost of the target [2-5]. For example, Chun-Hsiung Liao et al. (2009) [6] calculated the carbon dioxide emissions of the trucks and compare it with that of the truck-rail. The result shows that it will effectively reduce carbon dioxide emissions when highway-railway intermodal transport replace the long-haul truck. M. Soysaln et al. (2014) [7] took minimization carbon emissions as one of the objective functions but transformed the objective function into constraints to solve it. Gloria R. Gerilla et al. (2005) [8] Analyzed and compared intermodal transport emission issue from the manufacturer to the middlemen on the basis of the theory of life cycle analysis; and results show that the greenhouse gas emission of the highway transportation is most serious among other transportation modes. Based on multi-objective optimization model, Nam Seok Kim et al. (2009) [9] analyzed the relationship between logistics cost and carbon emissions and found that there is a negative correlation between logistics cost and carbon dioxide emissions, it is suggested to moderately balance the relationship between them.

Though the above literatures consider the environmental factors, it is of less actual significance to only take carbon emissions as the objective function or constraint. As the proposition of gradually establishing a carbon emissions trading market by the "twelfth five-year" plan and the beginning of the pilot work on carbon emissions trading in seven provinces and cities such as Beijing, Tianjin, the research on routes optimization with carbon trading will be more realistic and important; however, most of the existing articles about carbon trading focus on the traditional VRP problems [10]-[12]. Few literatures combined with carbon emission trading study the intermodal transport route optimization.

Above all, this paper aims at studying problem of intermodal transport route choice from the low-carbon prospective. Different from the past will only carbon emissions as the target or constraint and innovation points of this paper is to consider the carbon cost, combined with the background introduction of carbon trading market price, converts carbon emissions to the carbon costs. This paper is divided into four parts: the first part is introduction, introduces relevant background and literature review; The second part of the carbon emission trading intermodal transport path optimization model is set up; The third part introduces the algorithm; The fourth part USES case to verify this solution model; The fifth part is the full text of the summary and outlook.

## II. MODEL FORMULATION

### A. Problem Description and Assumptions

Assume a batch of goods starts from the originating node O to the destination D passing several cities with three modes of transportation. Thus this paper aims to (1) analysis the impact of the changes of the carbon trading price and carbon quota on the total cost of the intermodal transport under different scenarios; (2) choose the appropriate route and transport mode, make the goods transport to the destination with the lowest total cost. In this article, we make the following assumptions: (1) The buying or selling carbon quotas is a one-time activity; and (2) the carbon trading buying and selling prices are assumed to be a constant to facilitate the later concrete analysis, because carbon price fluctuates dramatically affected by the relation between supply and demand of the carbon market.

### B. Indices and Parameters

$c_{ij}^m$ : Unit cost from node  $i$  to node  $j$  with the mode of the transportation  $m$

$c_i^{mn}$ : Unit transship cost in node  $i$  from the mode of the transportation  $m$  to  $n$

$t_{ij}^m$ : Transit time from node  $i$  to node  $j$  with the mode of the transportation  $m$

$t_i^{mn}$ : Transshipping time in node  $i$  from the mode of the transportation  $m$  to  $n$

$e_{ij}^m$ : Unit distance carbon dioxide emissions from node to node  $j$  with the mode of transportation  $m$

$e_i^{mn}$ : Unitized cargo carbon dioxide emissions at node  $i$  from mode of transportation  $m$  to mode of transportation  $n$

$d_{ij}^m$ : Distance from node  $i$  to  $j$  with the mode of transportation  $m$

$cap_{ij}^m$ : Transportation capacity limitation from node  $i$  to node with the mode of transportation  $m$

$q$ : Freight volume

$T$ : The freight total time agreed in the contract

$P$ : Carbon price

$\alpha$ : Auction ratio (the proportion of auctioned carbon quota in the total quota)

$L$ : Initial carbon quotas

$W$ : Total carbon dioxide emission

$N$ : Delivery times

$$x_{ij}^m = \begin{cases} 1, & \text{existing route from } i \text{ to } j \text{ with } m \\ 0, & \text{otherwise} \end{cases}$$

$$y_i^{mn} = \begin{cases} 1, & \text{converting mode from } m \text{ to } n \text{ at } i \\ 0, & \text{otherwise} \end{cases}$$

### C. Objective function and constraints

According to the distribution of carbon quotas of the carbon emission trading, we introduce the auction ratio into the objective function (1):  $\alpha \cdot P_1 \cdot L + P_2 \cdot (N \cdot W - L)$  means carbon emission cost; formula (2) is the total carbon emissions in the process of transportation (transport carbon emission and the transship carbon emission). formula (3) and (4) are special situations, respectively: when  $\alpha = 0$  and  $N \cdot W = L$ , formula (1) converts to formula (3) with the economic cost minimization objective function (The initial carbon quotas of the enterprise are free distribution, and carbon quotas rightly equally to the actual carbon emissions); when  $\alpha = 0$  and  $N \cdot W \neq L$ , The objective function is formula (4):

$$\min C = N \cdot \left[ \sum_{i,j \in V} \sum_{m,n \in M} (c_{ij}^m x_{ij}^m q d_{ij}^m + y_i^{mn} c_i^{mn} q) \right] + \alpha \cdot L \cdot P_1 + P_2 \cdot (N \cdot W - L) \quad (1)$$

$$W = \sum_{i,j \in V} \sum_{m,n \in M} e_{ij}^m x_{ij}^m q d_{ij}^m + \sum_{i,j \in V} \sum_{m,n \in M} e_i^{mn} y_i^{mn} q \quad (2)$$

$$\min C_0 = N \cdot \left[ \sum_{i,j \in V} \sum_{m,n \in M} (c_{ij}^m x_{ij}^m q d_{ij}^m + y_i^{mn} c_i^{mn} q) \right] \quad (3)$$

$$\min C^s = N \cdot \left[ \sum_{i,j \in V} \sum_{m,n \in M} (c_{ij}^m x_{ij}^m q d_{ij}^m + y_i^{mn} c_i^{mn} q) \right] + P_2 \cdot (N \cdot W - L) \quad (4)$$

s.t.

$$\sum_{m \in M} x_{ij}^m - \sum_{m \in M} x_{ji}^m = \begin{cases} 1, & \forall i \in S \\ -1, & \forall i \in D \\ 0, & \forall i \in V \end{cases} \quad (5)$$

$$\sum_{m \in M} x_{ij}^m \leq 1 \quad \forall i, j \in V \quad (6)$$

$$\sum_{m \in M} \sum_{n \in M} y_i^{mn} \leq 1 \quad \forall i \in V \quad (7)$$

$$\sum_{i,j \in V} \sum_{m \in M} x_{ij}^m t_{ij}^m + \sum_{i \in V} \sum_{m,n \in M} y_i^{mn} t_i^{mn} \leq T \quad (8)$$

$$q x_{ij}^m \leq cap_{ij}^m x_{ij}^m \quad \forall i \in V, \forall m, n \in M \quad (9)$$

$$x_{k,i}^m + x_{i,j}^n \geq 2y_i^{mn} \quad \forall k,i,j \in V, \forall m,n \in M \quad (10)$$

$$x_{k,i}^m + x_{i,j}^n - 1 \leq 2y_i^{mn} \quad \forall k,i,j \in V, \forall m,n \in M \quad (11)$$

$$x_{ij}^m, y_i^{mn} \in \{1,0\} \quad \forall i \in V, \forall m,n \in M \quad (12)$$

Constraint (5) means the integrity of the transportation channels (the uniqueness of the in and out channel of each node); (6) if it is allowed to exist transport path between two nodes, then only one path with one mode of transportation; (7) if one node has to transform its mode of transportation, then only from one mode of transportation to another one mode of transportation; (8) the total transportation time must be within the stipulated time; (9) is the limitation of the capacity from node  $i$  to node  $j$  with the mode of the transportation  $m$ ; (10) and (11) ensure the continuity during the transportation; (12) means the  $x_{ij}^m$  and  $y_i^{mn}$  are binary variable.

### III. NUMERIC ANALYSIS

As shown in Figure 1: We assume that a batch of goods starting from node S to the destination D through 4 nodes. There are 3 kind of mode of transportation: highway, railway and waterway. The relevant simulated data in the transportation network are given by the Tab.1 (distance of the 6 nodes, unit transportation costs, unit transportation time, et al.). Table 2 is relevant simulated transship data (switching cost, time per unit and CO<sub>2</sub> emissions from different transport modes) [13]. The carbon trading price  $P$  (¥/t): 20, 31 and 53, which are the minimum, average and maximum of the 5 pilots (Beijing, Tianjin, Shanghai, Guangzhou, Chongqing) of carbon trading market in China, respectively. Here,  $N=24$ , assuming that there is 24 transportation activities within a year. The software CPLEX is used to solve the model.

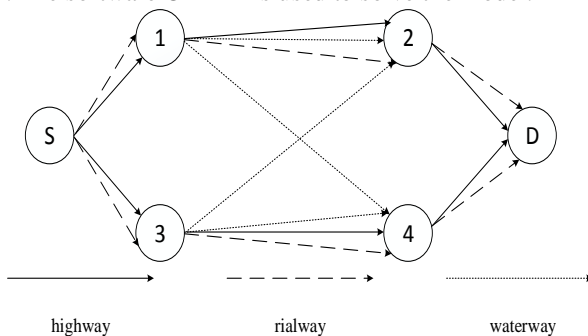


Figure.1 Intermodal Transportation Case Diagram

TABLE I. DATA FOR CONTAINER INTERMODAL TRANSPORT NETWORK CASE

Node	Distance(km)			Unit of Distance Transportation Cost (¥/tkm)		
	Road	rail	water	Road	rail	water
S→1	300	500	—	3	2	—
S→3	290	340	—	3	2	—
1→2	250	370	180	3	2	1
1→4	—	—	190	—	—	1

2→D	180	260	—	3	2	—
3→2	—	—	200	—	—	1
3→4	140	220	130	3	2	1
4→D	190	240	—	3	2	—

TABLE II. SWITCHING COST/TIME PER UNIT AND CO<sub>2</sub> EMISSIONS FACTORS OF DIFFERENT TRANSPORT MODES

	Road	rail	water
Road	0/0	3/2	2/1
Rail	3/2	0/0	2/2
water	2/1	2/2	0/0
Carbon emission	0.04795	0.00841	0.01733

### IV. DISCUSSION

#### A. The Impact of the Carbon Emission Trading on the Route Selection

The two best routes are shown in table 3. Scenario1: When enterprises only consider economic cost (there isn't carbon dioxide emission constraint), the optimal transport routes is S road 3 water 2 rail D; total carbon dioxide emission and cost are 571 488, 41900 000, respectively. Scenario 2: under the carbon trading market (with free initial carbon quota  $L=30\ 000$ ; 40 000 and  $P=31$ ), the optimal transport routes is S rail 1 water 2 rail D. because of the constraint of the carbon emission trading, the carbon dioxide emission dramatic declines to 318 312.

When  $L=30\ 000 \leq N \cdot W (N=24)$ , actual carbon quotas exceeds initial carbon quotas, enterprises need to purchase carbon credits. carbon dioxide emission cost as punishment cost added to the total cost. Thus the total cost under Scenario 2 is significantly higher than that of Scenario 1. when  $L=40\ 000 \geq N \cdot W (N=24)$ , the enterprise actual carbon quotas is less than initial carbon quotas. After the enterprise sells surplus carbon quotas, carbon cost is converted into additional profits, the total costs is down to 38840 000.

TABLE III. INTERMODAL TRANSPORTATION PLANS AND TOTAL COST UNDER DIFFERENT SCENARIOS

scenario	Best route	Carbon dioxide emission	Total cost (L=30 000 L=40 000)
1	S <u>road</u> 3 <u>water</u> 2 <u>rail</u> D	571 488	41900 000
2	S <u>rail</u> 1 <u>water</u> 2 <u>rail</u> D	318 312	43508 000 38840 000

#### B. The Impact of the Carbon Emission Trading on the Cost

a)  $\alpha = 0$  and  $N \cdot W = L$ , formula (1) is converted into(3). the total cost is composed of transportation costs and switching costs without the effect of the Transportation costs and switching costs. Here we mainly focus on formula (4)) ( $N \cdot W \neq L$ ):

$N \cdot W - L > 0$ , actual carbon quotas exceed initial carbon quotas, enterprises need to purchase carbon credits

in carbon trading market. Carbon dioxide emission cost as punishment cost added to the total cost. The fewer the carbon quotas, the higher the total cost will be. And under the same carbon quotas, the higher the price of carbon trading is, the more the enterprise spends to buy carbon quotas. When  $N \cdot W - L < 0$ , the enterprise actual carbon quotas is less than initial carbon quotas. The carbon cost is negative, which, as a part of profit, plays a more and more important role offsetting total cost. Therefore, the more carbon quotas, the less the total cost would become; And under the same carbon quotas, the higher the carbon price becomes, the more income of selling carbon and the less total cost will be.

b)  $\alpha \neq 0$ , enterprise needs to purchase  $\alpha$  percent of the initial carbon quotas with the price. The remainder ( $L - \alpha \cdot L$ ) is free distribution.

When  $NW < L$ , if auction ratio  $\alpha < \frac{P_2(L - N \cdot W)}{P_1 \cdot L}$ , thus

$P_2 \cdot (N \cdot W - L) > \alpha P_1 L$ . When the auction  $\alpha$  and auction prices  $P_1$  remain unchanged, with the increasing of the  $P_2$  (carbon price for buying) and  $N \cdot W - L$  (carbon quota balance), the offset of the carbon cost becomes greater, and total cost will reduce; When  $P_2$  and remain unchanged, total cost raises with the increase of the  $\alpha > \frac{P_2(L - N \cdot W)}{P_1 \cdot L}$ , the total cost raises as  $\alpha$ ,  $P_2$  and  $L$  rise.

TABLE IV. THE CHANGES OF THE TOTAL COST AND PURCHASE QUANTITY OF CARBON QUOTA UNDER DIFFERENT CARBON TRADING PRICE AND QUANTITY OF CARBON QUOTA

L	P2=20	P2=31	P2=53	Carbon quota buying/selling
100 000	47307 000	49708 000	54511 000	218 312 <sup>+</sup>
200 000	45307 000	46608 000	49211 000	118 312 <sup>+</sup>
300 000	43307 000	43508 000	43911 000	18 312 <sup>+</sup>
318 312	41940 000	41940 000	41940 000	0
400 000	41307 000	40408 000	38611 000	81 688 <sup>-</sup>
500 000	39307 000	37308 000	33311 000	181 688 <sup>-</sup>
600 000	37307 000	34208 000	28011 000	281 688 <sup>-</sup>
700 000	35307 000	31108 000	22711 000	381 688 <sup>-</sup>
800 000	33307 000	2 8008 000	17411 000	481 688 <sup>-</sup>
900 000	31307 000	24908 000	12110 000	581 688 <sup>-</sup>

## V. CONCLUSIONS

This paper makes a study of intermodal transport route optimization problems combined with the carbon emission trading, compares two different models with objective function of the traditional economic cost minimization and carbon emission cost, and analyzes the

impact of the  $\alpha$  (auction ratio),  $P$  (carbon price) and  $L$  (carbon quota). And it is found that as long as enterprises make reasonable arrangement of the production, and do a good job in energy conservation, emissions reduction and decrease carbon dioxide emission, the sold remainder carbon quotas can convert carbon cost into the parts of the enterprise profits to reduce the total cost. In the future, more researches can focus on factors of the carbon price, or consider other carbon policies, such as carbon tax, carbon offset et al.

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