Research on the optimization of express delivery route of logistics base under the constraint of carbon quota

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Abstract. This paper considers the route selection of express delivery under the constraint of carbon emission. Two kinds of path optimization models, not considering carbon emissions and under the constraint of carbon quota, are constructed respectively to optimize the distribution route of express delivery stations, and this paper further analyses the impact mechanism of carbon quota on the optimization decision-making of distribution route. Finally, carbon emission policy recommendations are obtained.

1. Introduction

There are three main sources of carbon emissions. The transportation industry's carbon emissions are second only to the manufacturing industry, while the automobile's carbon emissions have accounted for 25% of the total carbon emissions. Foreign research shows that in recent 10 years, in addition to the carbon emissions of transportation industry is still increasing year by year, the carbon emissions of other industries and fields have been effectively curbed, and transportation industry has become the most important factor causing the world climate change. Since the reform and opening up, China's economy has been developing rapidly, and the corresponding carbon emissions in China are also increasing. In 2005, the carbon emissions generated by road transportation in China have reached 21%. In 2015, China issued the first 10-year action program of manufacturing power strategy "made in China 2025", which requires that the added value of unit carbon emissions in 2025 should be reduced by 40% on the basis of 2015.

At present, most of the optimization of logistics distribution path only considers the factor of the lowest total cost, but to develop the logistics industry healthily and efficiently, it is not enough to optimize the distribution path network only from the economic point of view. It is also necessary to add the factor of carbon emission into the optimization of logistics distribution path network, so that the total cost and carbon emission in the distribution process can be minimized or balanced. This is also the requirement of energy conservation and emission reduction and the development of green logistics in China. As a big energy consumer, the development of low-carbon logistics is not only the requirement of energy conservation and emission reduction, but also the requirement of sustainable development.
Therefore, it is of great significance to study the optimization of logistics distribution path under carbon emission constraints. In recent years, some foreign scholars have added the influence of carbon emissions to the research of vehicle distribution path optimization. Cairns [1] studies the impact on the environment when the grocery store delivers goods to the door, transforms the objective function from the distribution distance to the carbon emission and optimizes it, but does not consider the impact of speed changes and other factors. Andrew Palmer [2] calculated the impact of speed on vehicle fuel consumption with the help of driving conditions, indirectly confirmed the impact of vehicle flow and speed on carbon emissions, and constructed e-vrp model to optimize vehicle distribution path. Figliozzi [3,4] added the constraints of time window, took the sum of vehicle, distance, time and carbon emission cost as the objective function, banjaafar[5] incorporated the carbon emission constraints into the logistics distribution system, established the strict carbon quota constraint model, carbon trading constraint model, and elaborated the carbon quota and carbon trading constraint.

China's research on the optimization of distribution path under low-carbon constraints started late. Gao Minji [6] established the optimization model of low-carbon logistics distribution network based on cloud computing. The model uses multi-modal transport, cloud logistics platform, and re plans the path, making the distribution path change to the direction of low-carbon emissions, completely changing the traditional distribution network, and realizing green logistics. Lin Diansheng et al [7] established a low-carbon logistics distribution centre location model based on the uncertainty of demand. The model fully considered the carbon emissions of each link related to the distribution centre location decision in the distribution network to avoid the result error. Li Shuangyan et al. [8] established a path optimization model for split transportation of low carbon vehicles to minimize the total carbon emissions in the transportation process. In this paper, through the establishment of the path optimization model of carbon limit constraints, the comparison and analysis of the path selection and cost changes, starting from the reality, it is of theoretical and practical significance to really guide enterprises to choose the low-carbon distribution path and achieve the best overall and environmental benefits of the distribution path.

2. Optimization model of distribution path without considering carbon emission

2.1. Model hypothesis
When choosing the distribution route, we usually consider the necessary principles and some influencing factors. From the economic point of view, this paper constructs a distribution route optimization model with the objective function of minimizing the total transportation cost. Finally, in order to facilitate the establishment of model analysis, and make the following assumptions:

1. Model 1 is mainly constructed to compare with the later carbon constraints, so storage cost and other costs are not considered in the total cost of this paper;
2. The loading capacity of each vehicle is equal;
3. All distribution vehicles move at a constant speed;
4. Each express station has and only has one vehicle for delivery.

2.2. Model parameter description
V refers to the collection of all express delivery sites (nodes), including logistics base. i and j are any two nodes, and S represents the starting point (Logistics base), D represents the destination (Express Station), and the logistics base number is 0. N is the number of express delivery stations, and M, number of distribution vehicles. c_i, transportation cost of unit goods in node i, and f is the fixed cost per kilometre of each vehicle. Q is freight capacity of each vehicle and q_i, the quantity of goods at express delivery point, where i= 1, 2,...,n. A: the number of stations distributed by each vehicle. d_{ij}: represents the distance between node i and node j.

Decision variables is
$x_{ij}^k = \begin{cases} 1 & \text{Goods are transported from node } i \text{ to node } j \text{ by vehicle } k, \\ 0 & \text{Otherwise} \end{cases}$

$y_{ij}^k = \begin{cases} 1 & \text{Vehicle } k \text{ completes the cargo transportation of node } i \\ 0 & \text{Otherwise} \end{cases}$

2.3. Mathematical model construction

The objective function is

$$MINZ = \sum_{k=1}^{M} \sum_{i=0}^{N} \sum_{j=0}^{N} f_{ij} x_{ij}^k d_{ij} + \sum_{i=1}^{N} c_i q_i,$$

(1)

$\sum_{k=1}^{M} \sum_{i=0}^{N} \sum_{j=0}^{N} f_{ij} x_{ij}^k d_{ij}$ represents the variable cost in transportation cost and $\sum_{j=1}^{N} c_i q_i$ is the fixed cost in transportation cost, subject to

$$\sum_{i=1}^{N} y_{ij}^k < Q \quad k = 1, 2, \ldots, M$$

(2)

$$\sum_{k=1}^{M} y_{ij}^k = 1 \quad i = 1, 2, \ldots, N$$

(3)

$$\sum_{x=1}^{X} x_{ij}^k = y_{ij}^k \quad j = 1, 2, \ldots, N, k = 1, 2, \ldots, M$$

(4)

$$\sum_{y=1}^{Y} y_{ij}^k = x_{ij}^k \quad i = 1, 2, \ldots, N, k = 1, 2, \ldots, M$$

(5)

$$\sum_{x=1}^{X} y_{ij}^k \leq A \quad k = 1, 2, \ldots, M$$

(6)

$$x_{ij}^k, y_{ij}^k \in \{1, 0\} \quad \forall i, \forall j \in V, \forall k \in M$$

(7)

Model 1 does not have the limitation of carbon constraint, but chooses the corresponding path with the minimum cost as the objective function. Equation (1) is the objective function, constraint (2) is the load limit of each vehicle, constraint (3) indicates that each node has a vehicle distribution, constraint (4) and (5) ensure that each node can only enter and exit once, and constraint (6) indicates the limit of the number of stations for each vehicle distribution, constraints (7) are all 0-1 variables. In fact, this model is equivalent to the model of finding the shortest distribution path.

3. Optimization model of distribution path under carbon limit

3.1. Model hypothesis

In model 2, based on Model 1, carbon limit constraints are added. Carbon limitation is a kind of emission reduction tool regulated by the government. It mainly relies on administrative means to limit the carbon emission ceiling of enterprises to force enterprises to reduce carbon emissions. This kind of carbon emission reduction restriction is relatively easy for the government to implement, the management cost is very low and the operation is very simple. The government only needs to regulate the relevant laws and regulations, and formulate a reasonable carbon emission ceiling, so it is easy to promote. However, for enterprises, this means mainly relies on administrative means, which cannot help enterprises to save energy and reduce emissions in the long run. Enterprises often reduce emissions at the expense of their own interests. Administrative means can only achieve the effect of energy conservation and emission reduction in the short term, and cannot improve the enthusiasm of enterprises in energy conservation and emission reduction, so the acceptability of enterprises will be low.
3.2. Model concept
First of all, the government stipulates the upper limit of carbon emission for an enterprise. Under the administrative means, in order to achieve the emission reduction goal, the enterprise will be forced to choose the distribution route with low carbon emission to achieve the government's emission reduction goal. According to the effect of emission reduction in a certain period of time, the government can choose to readjust the carbon emission ceiling, or give some enterprises some preferential policies to help them better achieve the emission reduction goals.

3.3. Model parameter description
Model 1 has given some specific model parameters, which are not repeated here, only the parameters of the newly added model are given.

\( e \) represents the carbon emission factor, indicating carbon dioxide emission per unit distance of goods, and \( L \), upper limit of carbon dioxide emission, actual carbon dioxide emissions of enterprises and \( T \), the total weight of the distribution vehicle when carrying the goods.

3.4. Mathematical model construction
The carbon emission of enterprises shall be lower than the carbon emission limit stipulated by the government:

\[
\sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=1}^{M} e_{ij}^k t_{ij} \leq L \quad (8)
\]

The actual carbon emission \( E \) of the enterprise is

\[
E = \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=1}^{M} e_{ij}^k t_{ij} \quad (9)
\]

Model 2 adds a carbon emission constraint (8) on the basis of model 1, so the distribution path optimization model under the carbon quota constraint is as follows: the objective function is (1), and the constraint conditions are (2) to (8). The objective function is still the lowest total cost, and the constraints (2) to (7) are the same as model 1.

4. Example
Take the logistics distribution data of Nanning Suning logistics base and 22 express delivery stations as an example. Due to the limited space, the distance data is not listed, only according to the model 1, according to the size of the total cost, eight distribution routes are listed, which are low cost distribution schemes in Nanning Suning logistics base. Based on this, the carbon quota model is analysed.

The upper limit of carbon emissions is not constant. Policy makers can adjust the upper limit of carbon emissions appropriately according to the size, complexity, overall emission objectives and operation of enterprises. When the upper limit of carbon emission \( l \) becomes smaller, the enterprise's optional distribution path will become less. When \( l \) increases, the enterprise's optional distribution path will become more. If we want to implement a carbon limit policy, decision-makers can only adjust the size of \( L \) to determine the degree of easing of the policy.

This paper discusses the impact of different circumstances on the selection of distribution routes and the change of cost from two aspects, i.e. the initial carbon quota \( L \) is free \((\alpha = 0)\) and the need for auction \((0 < \alpha < 0.3)\).

1) In the case of free issuance of initial carbon quota, the impact of initial carbon quota \( L \) and transaction price \( P_2 \) on line selection and cost.

In this paper, we use the data of 8 kinds of distribution schemes calculated by the model (1) to analyse these route distribution schemes under the constraint of carbon trading again, and compare the cost differences before and after, so as to provide reference for enterprises. Take \( P_2 = 40 \), \( L = 50 \) as an example to analyse the cost changes of these eight distribution schemes. The results are shown in Figure
1. The total cost 1 is the simple transportation cost calculated by the model 1, and the total cost 2 is the total cost after adding the carbon transaction cost under the carbon transaction constraint. It can be seen from this that in scheme 6 and later distribution schemes, only the distribution cost of carbon trading constraints exceeds the total cost before. Therefore, the distribution routes of enterprises will also produce corresponding changes, and the distribution schemes have changed from 8 to 5.

![Figure 1. Total cost change of distribution scheme under carbon constraint](image1)

Under the constraint of carbon trading, both the initial carbon quota L and the trading price P2 can be regulated, while different L and P2 have different effects on the selection of distribution scheme. Here, the discussion range of the initial carbon quota L is 25-50, and the trading price P2 is 10, 20, 30, 40, 50 and 60 respectively to compare the distribution scheme 1, and draw a figure 2. Because the carbon emission of this distribution scheme is 42.29903, the six curves in Figure 2 intersect at the place where the initial carbon quota is 42.29903, with 42.29903 as the critical value, and the two sides of the intersection are:

(1) E-L > 0 is the left part of the critical value. When the actual carbon emission in the distribution process of Nanning Suning logistics base is greater than the initial carbon emission L, then the carbon cost P2 (E-L) > 0 becomes the penalty cost, and with the reduction of the initial carbon quota and the increase of carbon trading price, the total cost will be higher.

(2)E-L < 0 is the right part of the critical value. When the actual carbon emission in the distribution process of Nanning Suning logistics base is less than the initial carbon emission L, the remaining carbon quota can be sold to other enterprises. At this time, the carbon cost P2 (E-L) < 0 can offset the transportation cost. And the larger the initial carbon quota and transaction price, the greater the offset transportation cost.

![Figure 2. Total cost changes under different initial carbon quotas and transaction prices](image2)
5. Conclusion

5.1. Path optimization without considering carbon constraints
Because in the modelling, the total cost is selected as the solution goal, the model is the optimal distribution path without considering the carbon constraints, but the optimal distribution path strength is optimized in the perfect situation. In reality, enterprises can not only choose one distribution path scheme. This model is mainly compared with other models.

5.2. Path optimization under carbon limitation
From the perspective of policy makers, this paper gives a reference method to determine the carbon emission ceiling. By adjusting the carbon emission ceiling, the policy makers can implement more strict or loose emission reduction policies. From the perspective of the enterprise, the distribution scheme that the enterprise can choose changes with the change of the carbon emission upper limit. When the carbon emission upper limit is reduced, the distribution scheme that the enterprise can choose will be reduced. On the contrary, when the carbon emission upper limit is increased, the distribution schemes that the enterprise can choose will also be increased correspondingly.

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