Study on Location Selection of Low-Carbon Fresh Fruit Distribution Center Considering Customer Satisfaction-Route Optimization

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Abstract: With the development of society and the needs of consumers, the concept of low-carbon and the improvement of customer satisfaction have become the focus of enterprises. Cold chain logistics is a product with high energy consumption and perishable characteristics, this paper will consider improving customer satisfaction on the basis of low carbon, and establish a cold chain distribution center location-routing optimization model with the minimum total cost as the optimization objective. The mathematical model is constructed and solved by using bi level programming theory and genetic algorithm, and neighborhood search is added to the lower model to optimize the route structure. Finally, the simulation results show that the final cost of considering carbon emissions and customer satisfaction is less than the cost of only considering the shortest route.

1. Introduction
In the current rapid development of the economic environment, cold chain fresh food has become the new consumption object of the majority of consumers, the demand for fresh fruits and vegetables is growing, so that many enterprises and investors have opened up the fresh food market, and constantly promote the development of cold chain logistics. Fresh food has the characteristics of high energy consumption and corrosive. The quality, delivery time and cost of cold chain food have become the concerns of scholars. Low carbon emission reduction and improving satisfaction of customers are also the common needs of today's environmental market and enterprises. How to ensure satisfaction of customer under the premise of low carbon.

In terms of cold chain center location and path optimization, many scholars have conducted researches. Wang Meng calculated the emissions of greenhouse gases and other air pollutants respectively in terms of emissions, and introduced the freshness function to describe the decay degree of fresh products in terms of freshness [1]. Zhou Xiang established a self pick-up point gradual coverage location model with customer satisfaction and maximum coverage as dual objectives to realize self
pick-up point location [2]; Gaoyuan Qin et al. introduced carbon trading mechanism to calculate carbon emission cost [3]; Shi Wenjia added constraints such as soft time window and vehicle load [4]; Qi Chengming et al. established the emergency cold chain logistics scheduling model based on the idea of network optimization and Baidu map API combined with the traffic conditions of actual distribution routes[5]; Zhang Yunchuan considered the refrigeration energy consumption of vehicles in transit and loading and unloading state [6]; Luan considered the vehicle no-load penalty cost when building the cold chain location path optimization model[7]. In recent years, the number of scholars’ research on distribution center location and path optimization algorithm is decreasing while the research on customer satisfaction, carbon emissions, real-time road conditions and other issues has gradually become a research hotspot. Cold chain logistics accounts for 13.2% and 15.1% of the literature on center location and path optimization in the past five years, respectively. The literature on carbon emissions and customer satisfaction accounts for 8.7% of the literature on cold chain. However, there is little research on cold chain location path optimization. In the past five years, the total literature only accounts for about 7% of the literature on location path optimization. It can be seen that the problem also has research value.

2. Materials and Methods

2.1. Problem Description and Hypothesis

2.1.1. Problem Description

Considering the joint optimization of cold chain distribution center location and path optimization, and considering the customer satisfaction under the condition of low carbon, this paper sets the carbon emission reference carbon tax price as carbon emission cost[8], and sets the customer satisfaction as penalty cost function, constructs the bi-level programming model, and sets the upper and lower objective functions as the lowest cost.

Suppose that the geographical location of distribution center and retailer is known; the demand of retailer is known, and the demand will not fluctuate in a period of time; there are many kinds of fresh food and different time and temperature requirements, so for the convenience of the research, this paper will choose a lifetime fresh fruit as the research object; a retailer is only distributed by one vehicle, and the vehicle models are the same, and the vehicle capacity can meet the demand of each retailer; the transportation speed of vehicle distribution is known and fixed; each vehicle can only be called by one distribution center, and it will return to the distribution center when the distribution is completed.

2.1.2. Symbols and Decision Variables

\( P \) : represents the supplier
\( J = \{ j | j = 1, 2, 3, ..., j \} \): represents that there are j alternative distribution centers
\( N = \{ i | i = 1, 2, 3, ..., n \} \): represents that there are n retailers
\( S = J \cup N \): represents a collection of distribution centers and retailers
\( Z_{j} \): whether to establish a distribution center at j, \( Z_{j} = \begin{cases} 1, & \text{establish a distribution center at } j \\ 0, & \text{not} \end{cases} \)
\( F_{j} \): represents the cost of establishing a distribution center at j
\( G_{i} \): represents the operating cost after the establishment of the distribution center at j
\( D_{ij} \): represents the distance from retailer i to retailer j
\( C_{ij} \): represents the unit transportation cost from retailer i to retailer j
\( R = \{ r | r = 1, 2, 3, ..., r \} \): represents there are r distribution vehicles and r distribution lines
\( C_{r} \): represents the fixed use cost of vehicle r
\( X_r \): represents whether vehicle \( r \) is used, \( X_r = \begin{cases} \text{1. Vehicle } r \text{ is used} , & r \in R \\ \text{0. not} & \end{cases} \)

\( X_r' \): represents the \( r \)-th vehicle is delivered from retailer \( j \) to retailer \( i \),

\( \begin{cases} \text{1, the \( r \)-th car is delivered from } j \text{ to } i \\ \text{0, not} & \end{cases} \), \( r \in H, i \in N, j \in S \)

\( C_{c2} \): represents the price of carbon tax

2.2. Model Building

2.2.1. Calculation of Carbon Emission

In the cold chain logistics, carbon emissions are not only generated in the process of vehicle driving, but also because of technical problems. At present, the cold chain still relies on automobile engine for refrigeration, and gasoline is the main raw material of refrigeration equipment, which leads to carbon emissions from refrigeration. Therefore, this paper will consider the carbon emission in the process of vehicle driving and the carbon emission in the process of refrigeration.

1) Carbon emissions from vehicle driving:

First of all, in the process of vehicle driving, the amount of carbon emissions is also closely related to the vehicle load, and the fuel consumption and load of vehicle driving distance can be approximated as a linear function:

\[ \rho(u) = a(U_0 + u) + b \]  \hspace{1cm} (1)

\( U_0 \) is the weight of the vehicle and \( u \) is the load of the vehicle.

When the vehicle is empty: \( \rho_0 = aU_0 + b \)  \hspace{1cm} (2)

When the vehicle is fully loaded: \( \rho_1 = a(U_0 + U_1) + b \)  \hspace{1cm} (3)

Then it can be concluded that when the load is \( u \), the fuel consumption per unit distance can be calculated:

\[ \rho(u) = \rho_0 + u(\rho_1 - \rho_0) / U_1 \] \hspace{1cm} (4)

The results show that the carbon emission of vehicles in the process of driving is:

\[ L_1 = l_1 \rho(U_0)D_0 \] \hspace{1cm} (5)

Among them \( l_1 \) is the fuel carbon emission index during vehicle driving.

2) Carbon emissions from vehicle refrigeration process:

The carbon emission of vehicle refrigeration is also related to driving distance and vehicle load, the carbon emission is:

\[ L_2 = l_2 D_0 U_0 \] \hspace{1cm} (6)

Among them \( l_2 \) is the carbon emission index for vehicle refrigeration.

3) the cost of carbon emission:

\[ C_{c2} = c_{c2} \sum_{r \in H} \sum_{i \in N} \sum_{j \in S} X_r' D_0 \left( l_1 \rho(U_0) + l_2 U_0 \right) \] \hspace{1cm} (7)

2.2.2. Penalty cost of customer satisfaction

How to calculate customer satisfaction, this paper refers to the literature of other scholars, and finally selects the mixed time window to formulate the penalty cost. Compared with hard time window and soft time window, hybrid time window is more practical and has more reference and research value[10].
Within the customer specified time period \([ET, ti]\), customer satisfaction is the highest, and penalty cost is 0; in the time period \([E, ET]\), when fresh fruits and vegetables are delivered in advance, vehicles need to wait for customers to increase the waiting cost. The longer the waiting time is, the greater the waiting cost is, \(\gamma_1\) is the penalty cost coefficient of early delivery; When the time period is \([IT, I]\), the penalty cost increases gradually with time, and \(\gamma_2\) is the penalty cost coefficient for late delivery; when \([0, E]\) and \([I, +\infty] \) are beyond the customer tolerance range, the penalty cost will be a maximum real number \(M\), and the objective model will have no solution. The penalty cost expression is as follows:

\[
P_E(t_i) = \gamma_1 \sum_{i \in N} \max[(ET - t_i), 0] + \gamma_2 \sum_{i \in N} \max[(t_i - IT), 0]
\]

(9)

2.2.3. Model Building

1) The upper model takes the lowest operation cost and construction cost as the goal to establish the objective function:

\[
\min C_u = \sum_{j \in J} F_j Z_j + \sum_{j \in J} G_j Z_j
\]

(10)

\[
\sum_{j \in J} Z_j \geq 1
\]

(11)

\[
\sum_{j \in J} Q_{ij} Z_j \geq \sum_{i \in N} K_i
\]

(12)

S.T

\[
\sum_{j \in J} F_j Z_j \leq C,
\]

(13)

\[
Z_j = \begin{cases} 1, & \text{establish distribution center at } j, \\ 0, & \text{not }, \ j \in J \\
\end{cases}
\]

(14)

Among them, (11) represents to establish at least one distribution center, (12) represents that the capacity of the distribution center meets the needs of retailers, (13) represents that the construction cost does not exceed the company budget.

2) The lower model takes the lowest transportation cost, vehicle use cost, carbon emission cost and penalty cost as the objective to establish the objective function:

\[
\min C_v = \sum_{i \in N} C_i X_i + \sum_{i \in N} \sum_{j \in J} C_{ij} \hat{X}_{ij} + C_{co} \sum_{i \in N} \sum_{j \in J} \sum_{\nu \in \nu} X_{ij} \hat{D}_{ij} (l_i \rho (U_{ij}) + I_i U_{ij})
\]

\[
+ \gamma_1 \sum_{i \in N} \max[(ET - t_i), 0] + \gamma_2 \sum_{i \in N} \max[(t_i - IT), 0]
\]

(15)
\[
\sum_{i, j \in S} X_{ij}^e = 1, \quad i \in N
\]
(16)

\[
\sum_{i, j \in S} X_{ij}^r \leq 1, \quad r \in R
\]
(17)

S.T

\[
\sum_{i, j \in S} K_{ij} X_{ij}^r \leq Q_r, \quad r \in R
\]
(18)

\[
\sum_{p, k \in S} X_{p, k}^e - \sum_{a, b \in S} X_{a, b}^e = 1, \quad r \in R, \quad j \in N
\]
(19)

\[
P_r(t_i) = \begin{cases} 
M, & 0 < t_i < E \\
\gamma_1 (ET - t_i), & E < t_i < ET \\
\gamma_2 (t_i - IT), & IT < t_i < I \\
0, & t_i > I 
\end{cases}
\]
(20)

Among them, (16) represents that each retailer is only distributed by one vehicle, (17) represents that each distribution vehicle starts and ends at the same distribution center, (18) represents that the retailer's demand is less than the distribution vehicle capacity, (19) represents that I is continuous from the distribution center J to the retailer, and (20) represents the time window limit.

2.3. Genetic Algorithm Solution

The above bi level programming model has been established, the upper and lower levels are to minimize the cost as the goal. At present, heuristic algorithm is widely used in location and route optimization model [11]-[16], while genetic algorithm has excellent self-adaptive ability and global probability search ability for intelligent logistics distribution center location -route optimization problem[17].

Therefore, this paper selects the genetic algorithm to solve the upper and lower layers respectively, and adds the neighborhood search to optimize the lower genetic algorithm.
In coding, generating population, setting fitness function, selection operator and crossover mutation operator, the upper and lower genetic algorithms use the same method.

1. Chromosome coding. Selecting natural number encoding can effectively reduce the generation of invalid solutions. For example, 0 represents the distribution center, 1, 2, ..., 6 represents the retailer, chromosome 024013560 represents that the first car starts from the distribution center 0 to reach the retailers 2 and 4 and then returns to the distribution center ①, and the second car starts from the distribution center to reach the retailers 1, 3, 5 and 6 and then returns to the distribution center ②.

2. The initial population. Because the natural number code is selected in this paper, popsize with a population number of 20-200 is selected as the population size on the initial population, and the initial population is generated in a random manner.

3. Fitness function. In the genetic algorithm, the basis for evaluating the pros and cons of individuals to determine whether to perform genetic operations is the size of the fitness function value. The larger the fitness value, the better the individual. The fitness function in this paper is set as: 
   \[ f = CMAX - \eta \]
   CMAX is a large positive In order to ensure that the fitness function value is non-negative, \( \eta \) is the objective function value of the model to achieve the goal that the smaller the objective function, the larger the fitness value.

4. Select the operator. Using roulette to randomly select operators, the greater the proportion of individuals with larger fitness function values on the roulette, the greater the probability of being randomly selected.

5. Crossover operator. Select partial matching crossover. For example, the parent X chromosome is 1423|587|6, the parent Y chromosome is 6453|821|7, and the crossover can get new individual A: 7453|821|6 and individual B: 6413|587|2.

6. Mutation operator. Choose the way of inversion mutation, such as individual 12|365|4 get 12|563|4 after inversion mutation.

7. Termination conditions. This paper chooses to terminate the operation after reaching a certain iterative condition.

3. Results & Discussion
Taking a fresh fruit and vegetable manufacturer in Qingdao as an example, this paper constructs a
distribution center location-routing optimization model for its 27 retailers, and selects four distribution centers as alternative points. The load of the distribution vehicle is 5 tons, and the vehicle speed is 30 km / h. The construction cost and operation cost of the distribution center are known. The retailer's demand is in the interval [0.5,3], and the retailer's satisfaction is determined according to the retailer's scale. In the interval [25,150], the retailer with larger demand has shorter maximum satisfaction waiting time, and the penalty coefficient for early arrival is 0.6, and the penalty coefficient for late arrival is 0.8. The price of carbon tax is 100 yuan / ton, the CO2 emission coefficient during driving is 3.63kg/km, and the CO2 emission coefficient during refrigeration is 0.01g/kg · km. In this paper, the genetic algorithm population size is set at 100, the crossover probability is 0.6, the mutation probability is 0.2, the number of iterations is 200, the lower neighborhood search number is 15, and the search number is 20. The running results are shown in Figure 5.

Figure 5. Location distribution-routes results

| Table 1 Comparison of total distance and total cost of different objectives |
|---------------------------------------------------------------|
| Total distance | Total cost |
|-----------------|------------|
| the shortest distance | 106074m | 45768 |
| considering carbon emission and customer satisfaction | 112785m | 32642 |

It can be seen from table 1 that the total distance of the model considering the lowest cost of carbon emissions and customer satisfaction is 112785m, while the total distance of the model not considering carbon emissions and customer satisfaction is 106074m, which is increased by 6.3% after optimization. The model aiming at the shortest distance is not significantly better than the one considering carbon emissions and customer satisfaction. The total cost of the model considering the lowest cost of carbon emissions and customer satisfaction is 32642, while the total cost of the model without considering carbon emissions and customer satisfaction is 35768, which is 28.7% lower than that without optimization. After optimization, although the distance increased, the total cost decreased significantly.

4. Conclusions
Based on the two factors of carbon emission and customer satisfaction in fresh fruit distribution, this paper establishes a bi level programming model of customer satisfaction location-path optimization
based on low carbon, in order to be closer to the actual needs of enterprises and retailers. Genetic algorithm is used to solve the model, and compared with the shortest total cost of distribution route. The numerical analysis results show that the proposed LRP model considering customer satisfaction based on low carbon is feasible and effective, and considering customer satisfaction in the case of low carbon can reduce the cost of enterprises. Considering low-carbon environmental protection and improving customer satisfaction is the demand of the market and society, which can create a better reputation and greater market competitiveness for fresh fruit enterprises.

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