Research on Optimization of Joint Distribution of Cold Chain Logistics Adopts Carbon Emission

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Abstract. Aiming at high energy consumption, high carbon emission and high cost of cold chain logistics distribution. In this paper, an optimization model of cold chain joint distribution terminal distribution path with carbon emission is established, and the model takes fixed cost, carbon emission cost, transportation cost, damage cost and penalty cost with time window into consideration, and optimizes the total distribution cost. In this paper, genetic algorithm is used as the optimization algorithm to solve the model, and combined with concrete examples to demonstrate.

1. Introduction
At present, the research on joint distribution of cold chain logistics mainly focuses on the three directions of joint distribution of multi-distribution centers, multi-temperature co-distribution and urban cold chain logistics joint distribution. Xiang F[1] started from analyzing the factors affecting the cold-chain logistics distribution of agricultural products, and then put forward a set of distribution path optimization strategies. Li H.H [2] proposed two multi-temperature co-matching modes, mechanical and cold storage, constructed models respectively, and then analyzed the results solved by genetic algorithm. Qian G.Y [3] deeply analyzed the characteristics of cold chain logistics distribution of agricultural products under the new form of "farm-Supermarket link", comprehensively considered the fixed cost, carbon emission cost, transportation cost and other factors, constructed the model and designed the algorithm, and then carried out simulation to obtain the corresponding optimal distribution scheme. Cao B.Y [4] puts forward the concept of cold chain green logistics against the background of new retail, and constructs the joint distribution model of multi-supplier, third-party logistics and different customers. From the perspective of new retail, Li Y[5] constructed the corresponding model and algorithm, conducted optimization research on the common distribution path of urban cold chain logistics, and also made an example analysis. On the basis of these studies, this paper constructs a joint distribution mathematical model, which takes fixed cost, transportation cost, refrigeration cost, carbon emission cost, cargo damage cost and time penalty cost into consideration, takes the total distribution cost as the optimization goal, and uses genetic algorithm to solve this model to get the optimal distribution path scheme.
2. **Construction of joint distribution mode**

At present, there are mainly B2B mode and B2C mode in urban cold chain logistics. B2B mode is a way for sellers to cooperate with each other, and the service is mainly provided by some supermarket and retail markets, catering industry and so on. B2B mode has the characteristics of reducing cost and improving service efficiency. The B2C model is mainly faced with terminal customers are residential consumers. It has the characteristics of small demand for cold chain food and relatively scattered receiving locations. The idea of co-distribution for 2B customers and 2C consumers is proposed. The B2B and B2C distribution modes and co-distribution modes are shown in the figure below [5].

![B2B distribution model](image1)

![B2C distribution model](image2)

![Joint distribution model](image3)

3. **Construction of mathematical model**

3.1. **Model A description**

For the convenience of study, this paper takes the form of one to many distribution is performed by a cold-chain logistics distribution center distribution work orders for customers and consumers, and the location of the distribution center and distribution receiving site coordinates are known and determine the same, all participating distribution operated vehicles to return distribution center after finish the homework. The vehicle in charge of distribution needs to complete the task within the time window for the arrival of fresh food required by customers and consumers. Otherwise, certain economic losses will be brought to the distribution center, which will be taken as the penalty cost of the time window of the distribution center. In order to minimize the total distribution cost, an optimization model of the common distribution path of urban cold chain logistics was established by comprehensively considering all the factors affecting the distribution of urban cold chain logistics.

3.2. **Model constraint**

(1) Each distribution refrigerator truck shall not load more than its own maximum capacity;
(2) To carry out the distribution task within the specified time window;
(3) Each customer has only one delivery and only one vehicle to complete the delivery;
(4) Each distribution vehicle must return to the distribution center after completing the relevant
distribution tasks;

3.3. Model parameters and meaning description
R: The total cost incurred in a single distribution task is the total cost; \( w_{ijk} \): Unit mileage charge for the
kth refrigerator car between distribution station i and distribution station j;
m: There are a total of M refrigerated vehicles in the distribution center, and the distribution task
needs to be completed;
n: The number of distribution sites with required services;
f: The fixed cost of each refrigerated vehicle when used;
nk: Value 0 or 1. \( r_k \) of the kth vehicle participating in the distribution activity is 1; otherwise, it is 0;
lj: Distance between the geographical location of distribution site i and distribution site j;
dijk: Value 0 or 1. When the K vehicle does not pass through the path (i,j), \( d_{ijk} = 0 \); otherwise, it is 1;
M: The quantity of goods loaded by the distribution vehicle;
Q_0: Net weight of refrigerated vehicle;
Q: The weight of the goods loaded when the car is fully loaded;
Vk: The volume of the body of the k refrigerator car;
t_{ikb}: The time of the k refrigerated vehicle waiting for unloading at distribution station i;

3.4. The construction of mathematical model
The fixed cost of each vehicle in the distribution process is:
\[
W_1 = f \sum_{k=1}^{m} r_k
\]  
(1)
\( r_k \) is a variable with the value of 0 or 1. When \( r_k = 0 \), it means that the k car does not participate in
the distribution task. On the contrary, \( r_k = 1 \).
Total transportation cost \( W_2 \) required for refrigerated trucks to complete the distribution task:
\[
W_2 = \sum_{k=1}^{m} \sum_{i=0}^{n} W_{ijk} l_{ij} d_{ijk}
\]  
(2)
\( W_{ijk} \) represents the cost of the K refrigerated vehicle per unit journey from I to distribution station j;
\( d_{ijk} \) value 0 or 1, \( d_{ijk} = 0 \) means that the k vehicle has no distribution task between the section of station i
and station j, and does not pass between them; \( l_{ij} \) represents the length of the path between site i and site
j.

In this paper, the carbon emission in the process of urban cold chain logistics distribution is mainly
from the fuel consumption of vehicles, and the carbon emission cost is calculated by carbon tax. "\( \partial \)" is
used to represent the carbon tax, the carbon emission cost in the whole distribution task can be expressed
as follows:
\[
W_3 = \partial \sum_{k=1}^{m} \sum_{i=0}^{n} \sum_{j=0}^{n} d_{ijk} l_{ij} \rho (Q_{ij})
\]  
(3)
The refrigeration cost is related to the surface area, thermal conductivity, internal and external
temperature and other factors. The total refrigeration cost \( W_4 \) generated when the distribution task is
completed is:
\[
W_4 = \sum_{k=1}^{m} \chi_l (1+\varepsilon) \theta S^* S^* \Delta T \Delta t
\]  
(4)
\( \varepsilon \) is the box depreciation rate; \( \theta \) is Heat transfer coefficient; \( S \) is Sunlit compartment area, and
\( S = \sqrt{S_0 S_i} \), \( S_0 \) is the exterior area of the car body, \( S_i \) is the inside surface area of the car, and they’re
all in units of \( m^2 \); \( \Delta T \) is the temperature difference between the body and the outside; \( \chi_l \) is the cost per
unit refrigerant; \( \Delta t \) is the difference between the time it took to ship the last stop for the KTH refrigerated
vehicle and the time it took to leave the distribution center.

The damage of goods mainly occurs in the process of transportation and waiting for unloading. This
part of cold chain food is in the closed environment of refrigerated trucks, and the corruption degree of
goods is only positively correlated with the time. Total cost of goods damage in distribution operation $W_5$:

$$W_5 = \sum_{k=0}^{m} \sum_{i=0}^{n} \sum_{j=0}^{n} \xi_i \eta X_j \left( t_{ij}^k + t_{kb}^j \right)$$

(5)

$\eta$ is the rate of deterioration of goods; $X_j$ is the value of the goods transported by the refrigerated truck at the distribution station $j$; $t_{ij}^k$ is the time for the K vehicle to wait for unloading at station $j$.

this paper to consider the penalty cost of soft time window. A penalty cost distribution site $Z_i$ is:

$$Z_i = \begin{cases} 
\alpha X_i \left( t_i^{ET} - t_i^k \right), & t_i^k < t_i^{ET} \\
0, & t_i^{ET} \leq t_i^k \leq t_i^{LT} \\
\zeta X_i \left( t_i^{LT} - t_i^k \right), & t_i^{LT} < t_i^k 
\end{cases}$$

(6)

(14)

where $t_i^k$ is the moment when the k car arrives at station $i$; $[t_i^{ET}, t_i^{LT}]$ is the best time frame for delivery; $\alpha$ and $\zeta$ punishment coefficient for different situations.

The total penalty cost $W_6$ is:

$$W_6 = \sum_{i=1}^{n} Z_i$$

(7)

Based on the above cost analysis, the total cost of cold chain logistics joint distribution considering carbon emissions is as follows:

$$R = W_1 + W_2 + W_3 + W_4 + W_5 + W_6$$

(8)

The optimization objective of this paper is to optimize the total cost, as follows:

$$\min(R)$$

s.t.

$$\sum_{i=1}^{m} \xi_i = \begin{cases} 
1, & i=1,2,..,n \\
m, & i=0 
\end{cases}$$

(9)

$$\sum_{j=0}^{n} w_{ij}^k \leq 1, i=0, k=1,2..m$$

(10)

$$\sum_{i=0}^{n} \sum_{j=0}^{n} \xi_i \leq n, i=1,2..,n, k \in m$$

(11)

$$\sum_{i=0}^{n} \sum_{j=0}^{n} Y_{i,j} \leq Q, k=1,2..m$$

(12)

$$t_j = t_i + t_{ij}^k + t_{kb}^j$$

(13)

$$Z_i = \begin{cases} 
\alpha X_i \left( t_i^{ET} - t_i^k \right), & t_i^k < t_i^{ET} \\
0, & t_i^{ET} \leq t_i^k \leq t_i^{LT} \\
\zeta X_i \left( t_i^{LT} - t_i^k \right), & t_i^{LT} < t_i^k 
\end{cases}$$

(14)

3-8- total distribution cost; 3-9- There are a total of m refrigerated vehicles participating in the distribution task and one distribution point is served once; 3-10- The vehicle that completes the distribution task needs to return to the starting point distribution center; 3-11-the number of stations delivered by the k vehicle is less than or equal to the total number of distribution stations; 3-12- Load capacity shall not be greater than the maximum load capacity of the vehicle; 3-13- The operation time of the distribution vehicle under the optimal condition, ignoring the time spent in other situations; 3-14-Penalty cost of site $i$.

4. Algorithm design

In this paper, genetic algorithm is proposed to solve this problem for the common distribution path of urban cold chain logistics.

(1) Coding

Considering the characteristics of the problem studied in this paper, natural number coding is chosen in this paper.

The variables to be coded in this study include distribution centers, delivery stations receiving services and vehicles participating in delivery. The distribution center is numbered 0, and the service site is numbered 1,2,.. N. For different vehicle routing information participating in the distribution, insert it into the site. Such as a distribution center need to deliver the goods to eight sites, the study
identified a 09574018360 distribution scheme, which suggests that need two refrigerated trucks to participate in the distribution, to produce two distribution path, 9, 5, 7 and 4 sites in turn by the no. 1 car distribution, the 1, 8, 3 and 6 sites in turn by the no. 2 car distribution, all vehicles after complete the task to go back to the original starting point.

(2) Produce the initial population
In this paper, based on whether the maximum carrying capacity of the refrigerator vehicle is reached, each individual generated is screened until the population quantity reaches the set scale. Generally, the initial population quantity is within [20,200].

(3) Fitness function
In this paper, the objective function is to minimize. The fitness function generally takes the reciprocal of the objective function and converts it into a maximization problem.

(4) Choose. Selection is a mechanism of elimination, the so-called superior survival of the fittest. In this paper, the selection method of roulette is used to screen individuals.

(5) Cross. In this paper, the crossover is set according to the single point crossover rule.

(6) Variation. In this paper, mutation is carried out by means of exchange. The mutation pattern is shown in the figure below.

(7) Termination of the algorithm. In order to prevent the genetic algorithm from going on indefinitely, it is necessary to set the termination condition for the algorithm. In this paper, the number of iterations is set as 1000.

5. Example verification

5.1. The example to introduce
Suppose a company B in Zhengzhou specializing in cold chain logistics and distribution is responsible for providing distribution services to large supermarkets, catering industries and individuals in demand in Zhengzhou. Company B distributes cold chain goods for 20 stations in Zhengzhou, among which 15 are large supermarkets and 5 are distribution stations that are responsible for serving individual consumers.

The vehicle starts from the distribution center and travels at a constant speed of 55km/h. The transportation cost per unit kilometer is 5 yuan /km, and the fixed distribution cost per refrigerated vehicle is 220 yuan. The external meteorological temperature of the vehicle was "12℃", and the internal temperature was "5℃". The refrigerator car type was Dayun CGC5040XLCHDD33E refrigerator car.

Assume that the geographic location information, demand, delivery time and other information of each site served by Company B are known and will not change. Seeing Figure 1 and Table 1.

![Figure 4 Location coordinates of distribution stations](image-url)
Table 1 Demand information of each distribution station

| Number of each site | The order quantity (t) | Value of goods corresponding to order Quantity (yuan) | \([\xi^T, \omega^T]\) | Waiting time \(\omega^T\) (h) |
|---------------------|------------------------|------------------------------------------------------|-----------------|---------------------|
| 0                   | 0                      | -                                                   | [5:30-18:00]    | 0                   |
| 1                   | 0.37                   | 3500                                                | [7:00-8:00]     | 0.15                |
| 2                   | 0.41                   | 3800                                                | [6:00-7:30]     | 0.08                |
| 3                   | 0.43                   | 2700                                                | [6:00-8:00]     | 0.13                |
| 4                   | 0.31                   | 2800                                                | [6:30-7:40]     | 0.06                |
| 5                   | 0.39                   | 2000                                                | [6:20-8:10]     | 0.11                |
| 6                   | 0.45                   | 2400                                                | [7:30-8:30]     | 0.24                |
| 7                   | 0.37                   | 2900                                                | [5:40-7:00]     | 0.17                |
| 8                   | 0.32                   | 2300                                                | [6:40-7:20]     | 0.10                |
| 9                   | 0.35                   | 1900                                                | [7:40-9:00]     | 0.25                |
| 10                  | 0.38                   | 3600                                                | [6:40-7:40]     | 0.02                |
| 11                  | 0.41                   | 2500                                                | [6:20-7:30]     | 0.09                |
| 12                  | 0.32                   | 3700                                                | [7:00-8:00]     | 0.14                |
| 13                  | 0.27                   | 2100                                                | [6:30-7:30]     | 0.12                |
| 14                  | 0.38                   | 3900                                                | [6:30-8:00]     | 0.08                |
| 15                  | 0.34                   | 3300                                                | [6:30-8:00]     | 0.13                |
| 16                  | 0.08                   | 1200                                                |                 |                     |
| 17                  | 0.11                   | 1900                                                |                 |                     |
| 18                  | 0.10                   | 1700                                                |                 |                     |
| 19                  | 0.14                   | 2100                                                |                 |                     |
| 20                  | 0.06                   | 1000                                                |                 |                     |

In addition to knowing the basic information about the customer, you also need to assign values to some of the parameters in the model. According to the experimental needs, relevant parameters are assigned as shown in Table 2 below.

Table 2 Values of relevant parameters

| Model parameters                        | Corresponding values |
|-----------------------------------------|----------------------|
| M (Service station points)              | 10                   |
| Q0 (The net weight of the car)          | 4375 kg              |
| Q (The maximum carrying capacity of the car) | 1120 kg             |
| f (A fixed fee per car)                 | 220 yuan             |
| \(\rho\) (Full load fuel consumption)   | 0.362 L/km           |
| \(\rho_0\) (No-load fuel consumption)   | 0.127 L/km           |
| \(\tau\) (Carbon emission factor)      | 2.53 kg/L            |
| \(\delta\) (A carbon tax)              | 870 yuan/t           |
| \(\alpha\) (Dilapidated condition of the carriage) | 0.05                |
| \(\theta\) (Thermal conductivity)      | 2.51 KCal/(h*m2*°C)  |
| \(\chi\) (Unit refrigerant cost)       | 1.6 yuan/kCal        |
| \(V_k\) (The volume of the body)       | 15.795 m3            |
| \(\eta\) (Corruption rate)             | 0.003                |
| \(\alpha\) (Penalty cost parameter)    | 0.01                 |
| \(\zeta\) (Penalty cost parameter)     | 0.03                 |

5.2. Result analysis
In the costing process, the carbon tax is assumed to be 0.87 yuan/kg. The distribution scheme adopted
by Company B and the genetic algorithm were used to solve the objective function set in this paper. The paths generated after 1000 iterations were shown in Table 3.

Table 3 Vehicle distribution scheme

| Delivery vehicle serial number | Path arrangement before optimization | Optimized path arrangement |
|-------------------------------|-------------------------------------|---------------------------|
| 1                             | 0-20-13-10-4-0                      | 0-15-8-5-19-0             |
| 2                             | 0-6-19-18-12-0                      | 0-1-2-3-0                 |
| 3                             | 0-2-16-8-17-0                       | 0-20-16-18-12-10-13-0     |
| 4                             | 0-15-5-1-0                          | 0-7-14-11-0               |
| 5                             | 0-3-7-11-0                          | 0-17-6-9-4-0              |
| 6                             | 0-9-14-0                            |                           |

The distribution costs generated by B company before and after optimization are compared and analyzed, and the results are shown in Table 4.

Table 4 Comparison of results

| Distribution plan before optimization | Optimized distribution scheme |
|--------------------------------------|------------------------------|
| Total distribution cost              | 8360.4 yuan                 |
| Fixed costs                          | 1320 yuan                   |
| Transportation cost                  | 5357 yuan                   |
| Carbon cost                          | 250.3 yuan                  |
| Cooling costs                         | 6203.3 yuan                 |
| The cost of damage                   | 32.8 yuan                   |
| Punishment cost                       | 1.3 yuan                    |
| Total after optimization             | 7051.4 yuan                 |
| Fixed costs after optimization       | 1100 yuan                   |
| Transportation cost after optimization | 388.8 yuan       |
| Carbon cost after optimization       | 184.8 yuan                  |
| Cooling costs after optimization     | 5350 yuan                   |
| The cost of damage after optimization | 26.6 yuan                   |
| Punishment cost after optimization   | 1.2 yuan                    |

As can be seen from the above results, considering carbon emission as a part of the operating cost of enterprises, the distribution path under this circumstance is better than that without considering carbon emission factor, which not only saves the distribution cost but also reduces the carbon dioxide emission.

6. Conclusion

Through the analysis of the cost factors in the distribution process, the model of total distribution cost minimization is established, and the corresponding solution algorithm is given. Finally, in order to prove the utility of the model and algorithm, the simulation analysis is carried out for the two cases of considering the cost of carbon emission and not considering the cost of carbon emission. The simulation analysis process is realized by matlab. The results show that the driving path planned with consideration of carbon emission factors can not only reduce carbon emission, but also reduce some economic costs for enterprises.

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