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Research on ant colony optimization algorithm for cold chain low-carbon logistics routing optimization[1]

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Abstract. Green low-carbon development has become the development direction of cold chain logistics industry. On the basis of analyzing the various costs of the cold chain logistics, considering the low-carbon environmental factors, taking the vehicle capacity and time windows as constraints, the paper constructs the optimization model of the cold chain low-carbon logistics routing with the minimum total cost and solves optimization model of cold chain low-carbon logistics routing by ant colony optimization algorithm. The results show that the total cost of the cold chain logistics routing optimization model considering carbon emission is smaller and the optimization effect is better. The rationality and feasibility of cold chain low-carbon logistics routing optimization model are verified.

Key words. Cold chain logistics, low-carbon, routing optimization, ant colony optimization algorithm.

1. Introduction

Cold chain logistics refers to the system engineering to ensure the quality of goods under which refrigerated and frozen goods in production, transportation, storage, processing and sales of the whole process is always under the low temperature [1]. It is a low temperature logistics process based on refrigeration technology and refrigeration technology. The complete cold chain logistics is composed of four parts: low temperature processing, low temperature storage, low temperature transportation and distribution, cold storage and refrigeration sales [2]. At the same time, with the

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development of economy and society, people's awareness of environmental protection is gradually increasing. Cold chain logistics as a high energy consumption and high carbon emissions business in the logistics industry, green low-carbon is the only way for the sustainable development of cold chain logistics, but also a new direction of development of cold chain logistics industry. Some scholars at home and abroad have carried out studies on cold chain low-carbon logistics [3]–[5].

2. Cold chain low-carbon logistics routing optimization model

In this paper, we study the routing optimization problem of a single distribution center to multiple customers. Each customer can be served and delivery service can only be completed by a refrigerated truck, refrigerated transport vehicles have limited carrying capacity. Customer's product demand, geographic location and delivery time requirements are known. Road conditions are not considered, the vehicle is uniform and will return to the distribution center after distribution. Under the background of low-carbon economy, in order to better reflect the actual situation of cold chain logistics, this paper considers the comprehensive cost includes the fixed cost, transportation cost, damage cost, refrigeration cost and carbon emission cost in the process of cold chain distribution [6].

In summary, the cold chain logistics path optimization problem of a cold chain logistics distribution center with m refrigerated vehicles for n customers is studied. Based on overall consideration of various factors, the cold chain low-carbon logistics routing optimization model is [6], [7]

$$\min Z = \sum_{k=1}^{m} f_k + \sum_{k=1}^{m}\sum_{i,j=0}^{n} c_{ij}^k d_{ij} x_{ij}^k + \sum_{k=1}^{m}\sum_{j=0}^{n} p_1 Q_j y_j^k (1 - \mathrm{e}^{-a_1 t_j^k}) +$$

$$+ \sum_{k=1}^{m}\sum_{j=0}^{n} p_1 Q_j y_j^k (1 - \mathrm{e}^{-a_2 T_j}) + \sum_{k=1}^{m}\sum_{i,j=0}^{n} p_{21} x_{ij}^k t_{ij}^k + \sum_{k=1}^{m}\sum_{j=0}^{n} p_{22} T_j +$$

$$+ p_c \sum_{k=1}^{m}\sum_{i,j=0}^{n} e E_1 d_{ij} x_{ij}^k + p_c \sum_{k=1}^{m}\sum_{i,j=0}^{n} e E_2 q_{ij} t_{ij}^k x_{ij}^k \,, \tag{1}$$

s.t

$$\sum_{j=1}^{n} x_{ij}^k = \sum_{j=1}^{n} x_{ji}^k \le 1,\ i = 0,\ k = 1, 2, ..., m \,, \tag{2}$$

$$\sum_{k=1}^{m} y_j^k = \begin{cases} m, j = 0 \\ 1, j = 1, 2, ..., n \end{cases} \,, \tag{3}$$

$$\sum_{j=0}^{n} y_j^k Q_j \le Q_M \,, \tag{4}$$

$$EET_j \le t_j^k \le LLT_j \,. \tag{5}$$

The fixed cost of the kth vehicle is f_k. c_{ij}^k refers to the cost of vehicle driving per kilometer of the kth vehicle from customer i to customer j, d_{ij} means the distance between two customers, $x_{ij}^k = 1$ means the kth vehicle drives from customer i to customer j, $x_{ij}^k = 0$ means the kth vehicle does not drive from customer i to customer j. Further, p_1 is the price of unit product, Q_j is goods demand of customer j, deteriorating rate in transit is a_1, deteriorating rate is increased to a_2 in unloading t_j^k is travelling time of vehicle k from the distribution center to customer j, T_j is unloading time of vehicle at kth customer. Symbol p_{21} is the refrigeration cost of unit time in the process of the cold chain transportation, p_{22} is the refrigeration cost of unit time in the process of unloading, t_{ij}^k is travelling time of vehicle k from customer i to customer j, E_1 is fuel consumption of refrigerated transport vehicle in unit distance, e is emission factor of CO_2, E_2 is energy consumption of refrigeration equipment unit weight goods per unit time, q_{ij} is volume of goods transported of vehicle from customer i to customer j, and p_c is unit carbon tax price.

Formula (1) as the objective function, in order to minimize the total cost, consists of five parts including fixed cost, transportation cost, damage cost, refrigeration cost and carbon emission cost. Formula (2) indicates that the refrigeration vehicle will start from the distribution center and return to the distribution center when the services are provided. Formula (3) represents that the distribution center has m vehicles and each customer can only be distributed by one vehicle. Formula (4) shows the load limit of refrigeration vehicle. Symbol Q_{M} denotes the maximum load of refrigeration vehicle. Formula (5) indicates that the service time of each vehicle satisfies the customer time window constraint. Finally, $[EET_j, LLT_j]$ is the acceptable time window for customer j.

3. Solving process of cold chain low-carbon logistics routing optimization model

Step 1. Initialize the parameters of ant colony optimization and calculate the distance matrix between customers.

Step 2. Construct the solution space. In total m ants are placed in the distribution center, on the basis of meeting the vehicle load limit, each ant chooses to visit the customer according to the transfer probability calculated by formula (4), which is added to path record table Tabu_k. Repeat the process until each ant traverses all the customers and returns to the distribution center, Selecting mechanism is [8].

$$P_{ij}^k = \begin{cases} \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}(t)]^\beta}{\sum_{s \in \mathrm{allow}_k} [\tau_{is}(t)]^\alpha [\eta_{is}(t)]^\beta}, & s \in \mathrm{allow}_k \\ 0, & \text{otherwise} \end{cases}, \tag{6}$$

where, α is an importance degree factor of pheromone, β is an importance degree factor of the heuristic function, $\tau_{ij}(t)$ is pheromone concentration between customer i and customer j at the time t. Symbol $\eta_{ij}(t)$ denotes a heuristic function, representing the expectation of ant transferring from customer i to customer j, $\eta_{ij}(t) = 1/d_{ij}$,

d_{ij} indicating the distance between two customers. Finally, allow_k is the customer set to be visited by ant k.

Step 3. Calculate the path length L_k and integrated cost ZC_k of each ant, and record the current optimal L_k and ZC_k.

Step 4. After all the ants have completed a cycle, the pheromone on the path needs to be updated according to the formulae (7)–(9) in order to prevent the residue content of the pheromone on the path too high, empty Tabu_k and turn to Step 2, Updating mechanism is as follows.

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij}\,, \tag{7}$$

$$\Delta\tau_{ij} = \sum_{k=1}^{n} \Delta\tau_{ij}^{k}\,, \tag{8}$$

$$\Delta\tau_{ij}^{k} = \begin{cases} Q/L_k, \text{ if ant on the path}(i,j) \\ 0, \text{ otherwise} \end{cases}\,, \tag{9}$$

where ρ indicates the degree of volatilization, $\rho \in (0,1)$. Symbol $\Delta\tau_{ij}$ is the sum of pheromone concentration of all ants between customer i and customer j, $\Delta\tau_{ij}^{k}$ indicates the pheromone concentration released by the kth ant on the path between customer i and customer j, Q denotes total pheromone released by the ant in a cycle, and L_k is the length of path walked by the kth ant.

Step 5. When the algorithm reaches the maximum number of iterations, the iteration is terminated and the optimal routing and the minimum comprehensive cost are output.

4. Example solution and analysis

A cold chain distribution company for example has 1 distribution center providing distribution services to 20 customers. The location coordinates of the distribution center are (41, 49). The vehicle departs from distribution center at 5:00 and the Q_{M} is 9 t. Customer location, demand, time window and service time are shown in Table 1. Ant colony optimization algorithm parameters are set as follows: Ant colony number is 60, the maximum number of iterations $NC_{\max} = 300$, and the parameters are selected according to literature [9]. Pheromone importance degree factor $\alpha = 1$, heuristic function importance degree factor $\beta = 5$, global pheromone volatilization factor $\rho = 0.5$, and total pheromone release $Q = 100$.

Taking the cold chain distribution company above as an example, the cold chain low-carbon logistics routing optimization model and cold chain logistics routing optimization model without considering carbon emission cost were solved 20 times by ant colony optimization.

The results of cold chain low-carbon logistics routing optimization model is that the comprehensive cost is 3441.27 and distribution center requires 4 refrigerated vehicles. Vehicle 1 provides services to customers 2, 11, 3, 20, 1, 12 and 5. Vehicle 2 provides services to customers 17, 4, 16, 15, 13 and 14. Vehicle 3 provides services to customers 6, 7, 18, 10 and 9. Vehicle 4 provides services to customers 19 and 8. Vehicles return to distribution center after distribution. The results of model without considering carbon emission is that comprehensive cost is 3014.09 and the actual cost of carbon emissions in the distribution process is 521.36. The total cost of the cold chain logistics routing optimization model is 3535.45. Distribution center requires 4 refrigerated vehicles. Vehicle 1 provides services to customers 9, 10, 18, 6 and 17. Vehicle 2 provides services to customers 7, 16, 4, 15, 13, 14 and 1. Vehicle 3 provides services to customers 5, 12, 20, 3, 11 and 2. Vehicle 4 provides services to customers 19 and 8. Vehicles return to distribution center after distribution. Comparing the results of the above two models show that the solution effect of cold chain logistics routing optimization model considering carbon emissions is better.

Table 1. Experiment data

N	Coord.	D	Time windows	ST	N	Coord.	D	Time windows	ST
1	(35, 17)	1.5	6: 30-9: 20	20	11	(50, 35)	1	6: 00-10: 30	15
2	(55, 45)	0.5	5: 40-9: 30	10	12	(30, 25)	0.5	6: 00-10: 00	10
3	(55, 20)	1.5	6: 45-9: 40	20	13	(15, 10)	0.5	7: 00-10: 30	10
4	(15, 30)	1.5	7: 15-9: 30	20	14	(30, 5)	1.5	5: 30-10: 00	20
5	(25, 30)	2	5: 30-10: 00	25	15	(15, 10)	2	6: 00-9: 45	25
6	(20, 50)	2	6: 30-10: 30	25	16	(30, 5)	1.5	6: 15-9: 40	20
7	(10, 43)	1.5	6: 20-9: 30	20	17	(10, 20)	1.5	6: 45-9: 30	20
8	(55, 60)	1	6: 30-9: 30	15	18	(15, 60)	0.5	6: 30-10: 00	10
9	(30, 60)	1	6: 30-10: 00	15	19	(45, 65)	2.5	7: 00-9: 40	30
10	(20, 65)	1	7: 00-9: 40	15	20	(45, 20)	1	6: 00-10: 15	15

Notes: N = Number, D = Demand, ST = Service Time

Figure 1 and Figure 2 are the convergence process of the ant colony optimization for solving the two models. It can be seen from the graphs that ant colony optimization for solving the cold chain low-carbon logistics routing optimization model have higher convergence efficiency and verifies the feasibility and effectiveness of ant colony optimization algorithm for solving the model.

5. Conclusion

In this paper, overall consideration is given to the vehicle fixed cost, transport cost, damage cost and cooling cost in the process of cold chain logistics distribution and carbon emission cost considering low-carbon is introduced to construct a cold chain low-carbon logistics routing optimization model with the minimum comprehensive total cost taking vehicle load and time windows as constraints, and ant colony optimization is used to solve the model. The results show that, compared

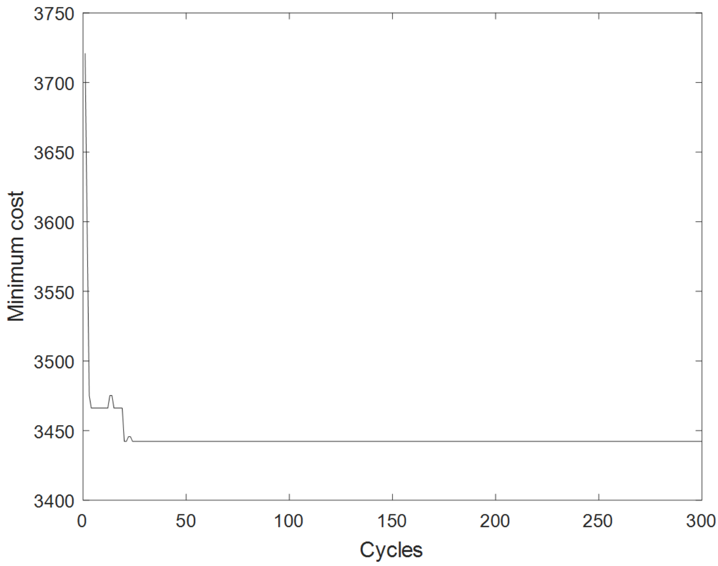

Fig. 1. Convergence procedure chart of solving cold chain low-carbon logistics model

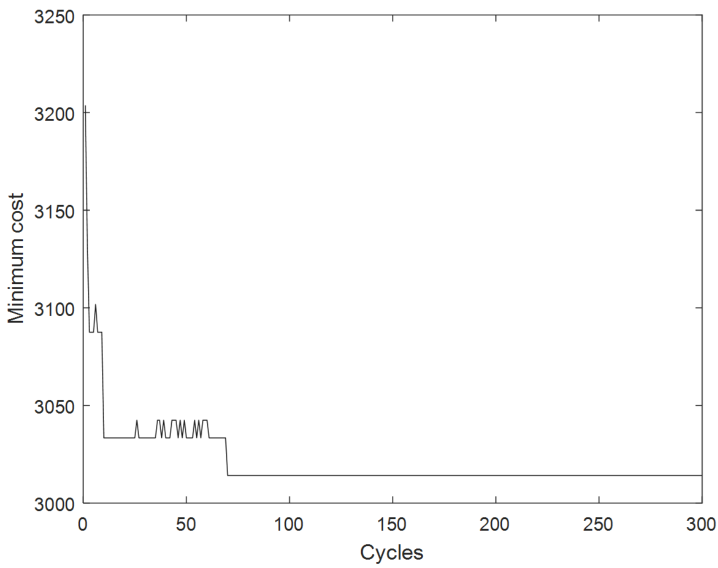

Fig. 2. Convergence procedure chart of solving cold chain logistics model

with the cold chain logistics routing optimization model with no consideration of carbon emissions, the optimization model of cold chain low-carbon logistics routing optimization is better. The rationality and feasibility of the cold chain low-carbon logistics routing optimization model are verified. However, since there are many factors that affect the cost of cold chain logistics, not all factors are considered by constructing the cold chain low-carbon logistics routing optimization model in this paper, the model will be further improved in the future studies.

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