Research article

Research on the optimized route of cold chain logistics transportation of fresh products in context of energy-saving and emission reduction

Zheng Liu[1], Hangxin Guo[1], Yuanjun Zhao[2], Bin Hu[1],*, Lihua Shi[1], Lingling Lang[1] and Bangtong Huang[1]

[1] School of Management, Shanghai University of Engineering Science, Shanghai 201620, China
[2] School of Business Administration, Shanghai Lixin University of Accounting and Finance, Shanghai 201209, China

* **Correspondence:** Email: 03070004@sues.edu.cn.

Abstract: With the level of science and technology, the logistics industry is paying more and more attention to sustainable development. However, the current cold chain logistics industry generally has problems such as backward refrigeration technology, irrational distribution management, and outdated equipment, which make its energy consumption serious and cause severe carbon emission effects on the environment. Optimizing the carbon emission structure of the cold chain logistics industry is the top priority for ensuring the sustainable development of the logistics industry. The circulation of fresh products is mainly through cold chain logistics. However, there are some problems of excessively high cost of the cold chain and easy disconnection during the cold transportation process in Chinese cold chain logistics, which severely restricts the development of Chinese cold chain logistics. Because of the perishability and strong timeliness of distribution of fresh products, inventory costs, penalties, and damage costs need to be considered. Because fresh products should utilize refrigerated transportation, it is also necessary to consider refrigerated costs during transportation and cold storage cost in distribution centers. Based on the goal of the lowest total cost, this paper constructs an integer programming model and analyzes cases. By comparing the simulation results of the genetic algorithm and the hybrid algorithm, it is concluded that the hybrid algorithm is more effective.

Keywords: cold chain logistics; logistics transportation; fresh products; path optimization; energy-saving and emission reduction

1. Introduction

As one of the important factors affecting the global climate, carbon emission has always been a green indicator concerned by countries all over the world [1]. Cold chain logistics is very difficult to control the quality of products due to the particularity of its products and the harsh requirements of transportation conditions. To ensure the final quality and yield of products, the quality of each link and interface must be guaranteed. As a supply chain system with high investment, high energy consumption and severe pollution, optimizing the cold chain logistics distribution path can effectively reduce the carbon emissions of the entire supply chain system, thereby meeting the requirements of sustainable development. The distribution of cold chain product is the last link of cold chain logistics and the optimization of distribution route is a key link in distribution optimization. In the process of distribution, whether the distribution route is reasonable or not has a great impact on the cost and benefit of distribution. Designing a reasonable and efficient distribution route scheme can not only reduce the distribution time, reduce the operating costs, improve the efficiency of enterprises, but also better serve customers. Therefore, in view of the strong timeliness of cold chain logistics, providing a reasonable and effective distribution solution is a problem that cold chain logistics enterprises need to solve urgently.

Fresh products refer to the primary products that can be sold without cooking and deep processing, only with necessary simple treatment and preservation. Mainly including fruits and vegetables, aquatic products, meat, etc. The transportation mode of fresh food mainly is cold chain transportation. In recent years, scholars have done a lot of research on the optimization of cold chain logistics distribution path. Zhang et al. [2] studied the assembly path optimization of different cold chain products in the same vehicle, established the minimum delivery cost model, and solved it with genetic algorithm. Finally, taking a cold chain logistics company in Beijing as an example, the feasibility of the model was proved. Beheshti et al. [3] classified customers according to the priority of time window, optimized the path for different types of customers respectively, and designed a coevolutionary multi-objective quantum genetic algorithm to solve it. Koc et al. [4] took the minimum transportation distance as the objective function, designed a hybrid heuristic algorithm to study the vehicle path optimization problem. Singh et al. [5] proposed a hybrid model for how to choose a suitable third-party logistics in a fuzzy environment. This model combines fuzzy analytic hierarchy process and fuzzy TOPSIS method. Mejjaouli et al. [6] recommended using cloud computing and RFID technology to implement transportation route decisions and real-time monitoring of temperature in cold chain logistics. According to the uncertainty of customer demand, X G Ma et al. [7] established the optimization model of cold chain logistics vehicle path with random demand, and designed the improved genetic algorithm to solve it. Finally, according to the actual case, the optimized transportation route can save the cold chain transportation cost. Lu et al. [8] put forward the concept of spatiotemporal similarity measure, comprehensively consider the geographical location and distribution time window of customers, and use the improved k-means clustering algorithm to partition customers, and finally use the genetic algorithm to optimize the distribution path of the partition. Bao et al. [9] introduced the concept of green logistics, transformed the carbon emission in the transportation process into the cost into the objective function, studied the joint distribution path optimization problem to minimize the total cost, and solved it with the improved genetic algorithm. Fan et al. [10] comprehensively considered the transportation cost, fixed cost, goods damage cost, penalty cost and energy consumption cost in the cold chain transportation

process, established a path optimization model with the total cost as the objective function, and solved it with the improved ant colony algorithm. Li et al. [11] established a green vehicle route optimization model for cold chain logistics, considering the factors of green logistics and low-carbon logistics, by utilizing the modified particle swarm optimization algorithm. Based on the research on the operation mode of cold chain logistics, Zhang et al. [12] proposed a nonlinear mixed integer programming model with the construction cost and operation cost of cold chain logistics outlets as the optimization objective, and solved the model by using the quantum particle swarm optimization algorithm. Bekir et al. [13] studied the path optimization of supply chain network, proposed a multi-level and multi segment iterative optimization algorithm that can embed qualitative or quantitative demand into the system to realize cost or benefit optimization, and optimized the transportation problem by taking the marine supply chain network as the research object. On the one hand, due to the perishability of fresh food and the high cost of cold chain infrastructure construction, the cold chain cost remains high. On the other hand, due to the timeliness of cold chain product distribution, the distribution efficiency becomes an important factor in cold chain distribution. Therefore, it has become a research hotspot to minimize the total cost and improve the efficiency of cold chain by reasonably selecting the pre cooling station, cold chain distribution center and planning the cold chain transportation path.

To sum up, scholars mainly focus on the research of cold chain logistics vehicle path optimization: set up the objective function according to the research object and design the corresponding algorithm to solve it. According to the literature review, the optimization objectives of the existing research mainly include: transportation cost, time penalty cost, carbon emission cost, goods loss cost, logistics service level, etc. The research problems include the single-level path optimization between distribution centers and between distribution centers and customers [14–16], and in the single-level path optimization problems, the single logistics center is the research object, and in the mathematical model, mainly the minimum cost in cold chain transportation is the objective function. The common solution methods include genetic algorithm, multi-objective particle swarm optimization algorithm and other intelligent algorithms. In the existing research, there are few research results on multi-level path optimization of "origin-distribution center-customer" and most of the existing research results are multi-level path optimization of a single distribution center [17,18]. The objective function of the study is similar to the single-level path optimization, mainly including the cost functions in the transportation process. This paper comprehensively considered the situation of fresh food in the actual production and transportation process, focused on the two-level path optimization problem of "origin-multiple distribution centers-multiple customers" by using genetic algorithm more in line with the actual transportation situation, with great practical significance.

2. Problem description and assumptions

2.1. Problem description

This paper takes fresh products as the research object, focusing on the path optimization of fresh products from "origin-distribution center-customer", which is shown in Figure 1. Considering the timeliness of fresh products distribution, the inventory cost of early arrival and the penalty cost of late arrival are considered; considering the perishable characteristics of fresh products, the cost of goods damage in the distribution process is considered; considering the characteristics of fresh

products that need cold storage transportation, the cold storage cost of the distribution center is considered; at the same time, the cost in the process of cold chain transportation is also considered. A nonlinear mixed integer programming model is established to minimize the total cost, which mainly solves the following problems:

(1) Through the minimum function of total cost to select the distribution center.

(2) Reduce the cost of cold chain transportation.
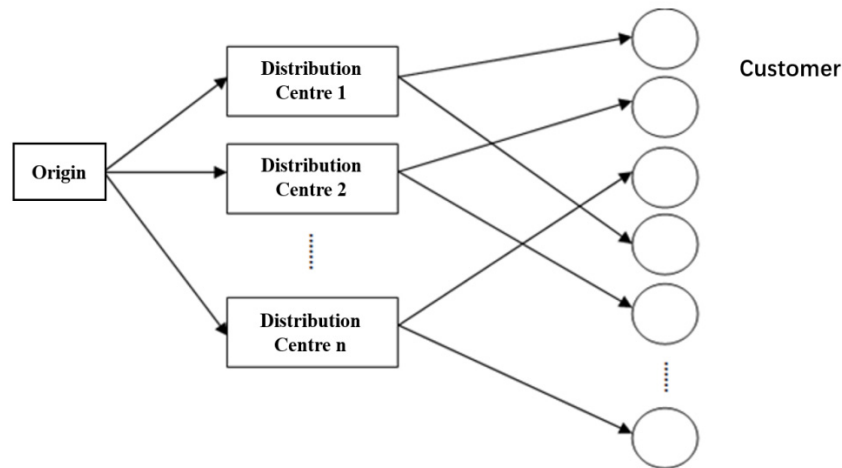
(3) Improve the efficiency of cold chain transportation.

Figure 1. Distribution of production distribution links.

2.2. Problem assumptions

(1) One place of origin, n distribution centers, m customers. One place of origin delivers goods to multiple distribution centers, and one distribution center only delivers goods to one customer.

(2) Origin, location of distribution center and customer, distribution center and customer demand are known.

(3) The output of the origin can meet the demand of the distribution center.

(4) Based on the economics of distribution costs, we assume that one customer only accepts one vehicle delivery service.

(5) There are service time window restrictions in the whole distribution process.

(6) There is no traffic jam during the delivery process.

(7) The vehicle starts from the distribution center and returns to the distribution center after the task is completed.

(8) The number of distribution vehicles is limited and the maximum vehicle load is known.

3. The optimal model of cold chain transportation path of fresh products

In this paper, the optimization of cold chain logistics transportation path of fresh products with time window is as follows: in a specific region, a fresh food origin distributes goods for several cold chain distribution centers, and several distribution centers provide cold chain products distribution services for several customers. On the basis of knowing the geographical location information of

origin, distribution center and customers, knowing the requirements of customers' demand and the soft and hard time window of distribution, the objective function of minimum total cost (including transportation cost, goods damage cost, penalty cost, inventory cost and refrigeration cost) is established. It is required to reasonably plan the transportation path of cold chain vehicles while meeting the constraints, and make the goods delivered within the time period acceptable to the customers as much as possible while minimizing the total transportation cost.

3.1. Cold chain logistics path optimization model

3.1.1. Symbol description

$a(A)$ indicates the types of product delivered, $a = \{1, 2, 3, ..., A\}$;

$b(B)$ indicates the number of distribution centers, $b = \{1, 2, 3, ..., B\}$;

$c(C)$ indicates the number of customers, $c = \{1, 2, 3, ..., C\}$;

e_{ab} indicates the unit freight of product a from the factory to the distribution center b;

f_{abc} indicates the unit freight of the product a from the distribution center b to the customer c;

n_{ac} indicates the customer c's demand for the product a;

s_b indicates the fixed refrigeration cost of goods from the place of origin by distribution center b;

k indicates the number of distribution centers;

t_{ab} indicates the actual delivery time of the product a from the place of origin to the distribution center b;

t'_{abc} indicates the actual delivery time of the product a from the distribution center b to the customer c;

$[l_{ac}, m_{ac}]$ indicates the customer's required delivery time for the product, which is the soft time window, and l_{ac} indicates the earliest delivery time specified by the customer for the distribution center. Similarly, m_{ac} indicates the earliest delivery time specified by the customer for the distribution center;

$[l'_{ac}, m'_{ac}]$ indicates the customer's required delivery time for the product, which is the hard time window, and l'_{ac} indicates the earliest delivery time that the customer can accept by the distribution center. Similarly, m'_{ac} indicates the latest delivery time that the customer can accept by the distribution center;

W indicates the cost of refrigeration during transportation, w indicates the refrigeration cost per unit time during transportation;

Z indicates the penalty cost for delay in delivery of products, Z_a indicates the unit time penalty cost for delay in delivery of products;

O indicates the storage cost of products delivered in advance, O_a indicates the unit time storage cost of product a delivered in advance;

p_a indicates the unit price of product a;

In addition, decision variables are specified:

q_{ab} indicates the transportation volume of product a from the origin to the distribution center b;

x_b is a 0–1 variable, indicating whether distribution center b is selected. If it is selected, the value is 1; otherwise, it is 0;

y_{abc} indicates whether to deliver goods from the distribution center to the customer. When delivering goods, the value is 1; otherwise, it is 0.

3.1.2. Modelling

$$\min z = \sum_{a=1}^{A}\sum_{b=1}^{B} e_{ab} \cdot q_{ab} + \sum_{a=1}^{A}\sum_{b=1}^{B}\sum_{c=1}^{C} f_{abc} \cdot n_{ac} \cdot y_{abc} + \sum_{b}^{B} s_b \cdot x_b + W + Z + O$$

$$+ \sum_{a=1}^{A}\sum_{b=1}^{B} P_a \cdot q_{ab}\left(1 - e^{-\lambda tab}\right) + \sum_{a=1}^{A}\sum_{b=1}^{B} P_a \cdot n_{ac} \cdot y_{abc}\left(1 - e^{-\lambda t_{ab}'}\right) \tag{1}$$

Restrictions,

$$\sum_{b=1}^{B} x_b \cdot n_{ac} = 1 \qquad \forall c \in C, a \in A \tag{2}$$

$$q_{ab} = \sum_{c=1}^{C} n_{ac} \cdot y_{abc} \qquad \forall a \in A, b \in B \tag{3}$$

$$\sum_{b=1}^{B} x_b = k \tag{4}$$

$$x_b, y_{abc} \in \{0,1\} \tag{5}$$

$$W = w \sum_{a=1}^{A}\sum_{b=1}^{B}\sum_{c=1}^{C} \left(t_{ab} + t_{abc}'\right) \cdot x_b \cdot y_{abc} \tag{6}$$

$$Z = \begin{cases} \displaystyle\sum_{a=1}^{A}\sum_{b=1}^{B}\sum_{c=1}^{C}\left(t_{ab} + t_{abc}' - m_{ac}\right)\cdot z_a \cdot x_b \cdot o_a \cdot y_{abc} &, & m_{ac} \le t_{ab} + t_{abc}' \le m_{ac}' \\ 0 &, & t_{ab} + t_{abc}' < m_{ac} \diamondsuit \\ M &, & t_{ab} + t_{abc}' > m_{ac}' \prec \end{cases} \tag{7}$$

$$O = \begin{cases} \displaystyle\sum_{a=1}^{A}\sum_{b=1}^{B}\sum_{c=1}^{C}\left[l_{ab} - \left(t_{ab} + t_{ab}'\right)\right]\cdot o_a \cdot x_b \cdot n_{abc} &, & l_{ac}' \le t_{ab} + t_{abc}' \le l_{ac} \\ 0 &, & t_{ab} + t_{abc}' > l_{ac} \bowtie \\ M &, & t_{ab} + t_{abc}' < l_{ac}' \prec \end{cases} \tag{8}$$

$$x_b \ge 0, \forall a \in A, b \in B \tag{9}$$

$$w, z, o_a \ge 0 \tag{10}$$

The formula (1) represents the transportation cost of products from the place of origin to the distribution center, the transportation cost of products from the distribution center to customers, the fixed refrigeration cost of the distribution center for products, the refrigeration cost of goods in transit, the penalty cost of products arriving late, the storage cost of products arriving in advance, the cost of products damage from the place of origin to the distribution center and the cost of products damage from the distribution center to customers.

The formula (2)–(10) is the constraint condition.

The formula (2) indicates that the products required by each customer can only come from one distribution center;

The formula (3) indicates a balance of supply and demand of products;

The formula (4) indicates that the number of distribution centers selected is equal to the number of distribution centers required;

The formula (5) indicates that x, y is 0–1 variable;

The formula (6) indicates the refrigeration cost during the transportation of products;

The formula (7) indicates the penalty cost incurred by the delayed delivery;

The formula (8) indicates the storage cost incurred by early delivery;

The formula (9) indicates 0–1 variable. When the value is 1, it means distribution center b is selected. Otherwise, it is not selected.

The formula (10) indicates that the refrigeration cost, penalty cost for delayed delivery and storage cost for early delivery are all greater than 0.

3.2. Model solving process

Genetic algorithm is the most widely used algorithm to solve the path optimization problem. At present, many scholars use genetic algorithm to solve this problem. Liang [19] and so on take the temperature as the decision variable, through adjusting the temperature in the cold chain transportation process to balance the refrigeration cost and the goods damage cost, so as to study the path optimization problem with the lowest total cost and solve it by genetic algorithm. In the process of designing the crossover and mutation of genetic algorithm, the method of double cut point crossover and reverse mutation are used to improve the local search ability of the algorithm and maintain the diversity of population. Finally, the feasibility of the model is verified by an example. Cao et al. [20] took the pelagic catches as the research object, established the multi-objective path optimization model of the shortest delivery time and the minimum cold chain cost. When designing the genetic algorithm to solve the problem, the inverse function of the objective function was selected as the fitness function to facilitate the calculation. The roulette selection method and the sequential crossover method were used to improve the accuracy of the solution. Finally, the feasibility of the model was verified by an example. Huang [21] used genetic algorithm to solve the cold chain distribution model with time window, sequential coding method is used to reduce the generation of invalid solutions for chromosomes, roulette selection method and partial matching crossover method are used, and the reciprocal method is used to calculate the fitness function to achieve the efficiency of the solution. Shao et al. [22] established a multi-objective path optimization model with minimum distribution cost and maximum customer satisfaction, used a heuristic function to express individual fitness, transformed multi-objective into single objective, and solved it with improved genetic algorithm. In terms of algorithm coding, selection and crossover design, they

adopted mixed coding strategy, and adopted proportional selection method and maximum reservation cross method. Genetic algorithm uses natural evolution mechanism to represent complex phenomena, which is suitable for solving NP-hard problems. But it is easy to fall into local optimum. Therefore, many scholars improve it, using ways such as design coding, selection and cross mode. Generally speaking, genetic algorithm is the most widely used algorithm to solve the path optimization problem.

According to the characteristics of the objective function, this paper combines the simulated annealing algorithm and genetic algorithm, uses MATLAB R2017b programming, designs a hybrid algorithm to solve it. The solution steps of the hybrid algorithm are as follows:

Step 1: Set the initial parameters of the algorithm. It includes population size, crossover probability, mutation probability and iteration times.

Step 2: Chromosome coding. Using integer coding method, according to the coordinate information of origin, distribution center and customer, the path is optimized level by level. First, the n-bit gene code is generated according to the number of distribution centers corresponding to the origin. Then, according to the number of customers corresponding to the distribution center (m), the m-bit gene code is generated. Among them, each level node is represented by 0 and listed in the code. The specific design method is shown in Figure 2.
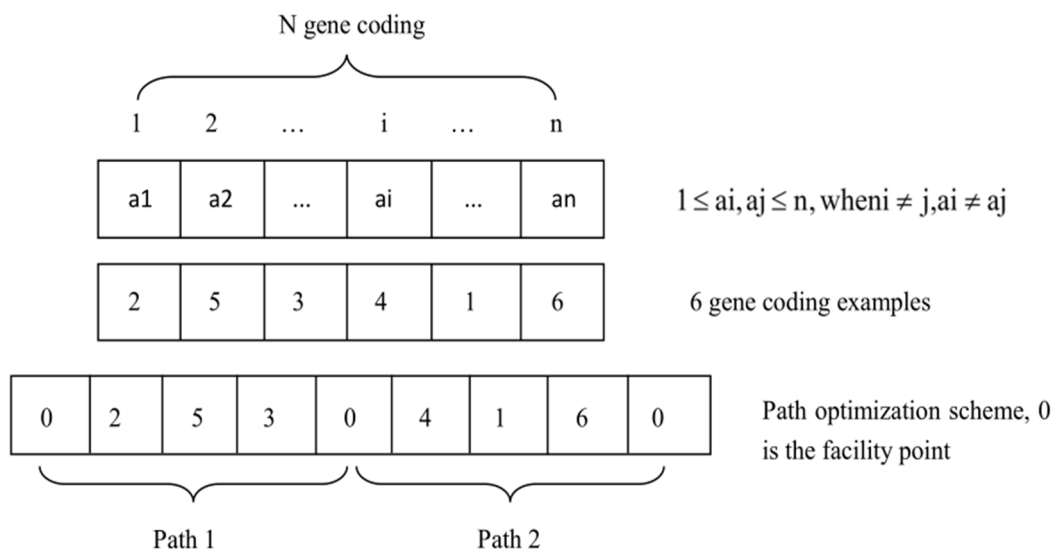

Figure 2. Coding design.

Step 3: Initialize the population.

Step 4: Calculation of fitness function. Combined with the design of fitness function in simulated annealing algorithm, the fitness function is stretched to avoid the premature phenomenon caused by the consistency of fitness in the later stage of genetic algorithm and the superiority of excellent individuals when they produce offspring is not obvious.

$$f_i = \frac{e^{f_i/T}}{\sum\limits_{i=1}^{M} e^{f_i/T}}$$

$$T = T_0(0.99^{g-1})$$

In the formula, f_i is the fitness of the second individual, M is the population size, T is the temperature, and T_0 is the initial temperature.

Step 5: Selection. The increment is calculated according to the fitness function of the previous generation, and the new generation is selected according to the Metropolis criterion in the simulated annealing algorithm.

Step 6: Genetic manipulation. Two-point crossover and Gaussian mutation are used to perform crossover operation and mutation operation respectively.

Step 7: Using the elite strategy selects the next generation of parents.

Step 8: Perform steps 4 to 7 until the evolution algebra reaches the maximum value and the algorithm ends.

The pseudo code of the hybrid algorithm is shown in Table 1.

Table 1. Pseudocode of hybrid algorithm.

1:    begin
2:        Initialize population size M , maximum iteration times Maxgen, crossover probability pc and mutation probability pm, initial temperature T_0 ;
3:        Randomly generate M chromosomes to form the initial population $P(0)$;
4:        for $g = 1$: Maxgen do
5:                for $i = 1$: M do
6:                    Evaluate fitness $f(i)$ by Eq 11;
7:                    Select child generation $P(g)$ by Metropolis criterion;
8:                    if $random(0,1) > pc$ then
9:                        Crossover operation to $P(g)$;
10:                    end if
11:                    if $random(0,1) > pm$ then
12:                        Mutation operation to $P(g)$;
13:                    end if
14:                    Select the best individual by elite strategy;
15:                end for
16:            Cooling annealing by Eq 12.
17:        end for
18:    end

4.   Example analyses

In order to verify the feasibility of the model, select the data of cold chain logistics enterprise A to calculate, and use MATLAB software to simulate.

4.1. Example parameter description

It is known that company A has one origin, five distribution centers and 26 customer points. For the convenience of calculation, coordinate the geographical location of origin, distribution center and customers. Among them, the origin coordinate is [41, 41] (unit: km), transportation cost

per unit of goods is 4 yuan/km/kg; attenuation coefficient of goods damage $\theta = 0.1$; unit price of goods is 20 yuan/kg; penalty cost per unit time is 6 yuan/hour/kg; refrigeration cost during transportation is 60 yuan/hour; driving speed during transportation is 35 km/hour; time window is [80, 100] minute; unloading time of goods is 20 minutes. In addition, it is known that the total transportation cost of company A before optimizing the route is 7000 yuan. Coordinates of distribution centers and customers, fixed cost of refrigeration, and customer demand in Tables 2 and 3 are as follows.

Table 2. Coordinates of distribution centers and fixed cost of refrigeration.

Distribution center	Coordinates	Refrigeration cost
A	[31,21]	310
B	[57,17]	340
C	[62,51]	410
D	[37,63]	440
E	[21,52]	285

Table 3. Coordinates of customers and demand.

Customer	Demand	Coordinates	Customer	Demand	Coordinates (km)
1	23.11	[52,43]	14	31.45	[45,58]
2	31.45	[38,66]	15	23.11	[65,25]
3	24.00	[12,11]	16	26.00	[18,30]
4	20.44	[66,45]	17	23.11	[52,66]
5	21.22	[45,19]	18	26.56	[26,57]
6	32.11	[12,20]	19	31.45	[35,47]
7	26.00	[73,42]	20	35.11	[53,32]
8	23.11	[49,10]	21	23.11	[33,56]
9	31.45	[70,12]	22	24.11	[30,70]
10	26.56	[30,3]	23	31.45	[60,66]
11	26.00	[12,60]	24	26.56	[13,69]
12	31.45	[62,10]	25	23.11	[9,45]
13	26.00	[30,36]	26	26.00	[65,60]

4.2. Model solution results

The standard genetic algorithm and hybrid algorithm are programmed with MATLAB. The same initial parameters are set. The population size $popsize = 60$ and $pc = 0.8$; the crossover probability is 0.18; the mutation probability is 0.1, and the number of iterations is 500. The initial temperature of simulated annealing is assumed to be 100. The results of the two algorithms are shown in the following Figures 3 and 4 and Tables 4–7.
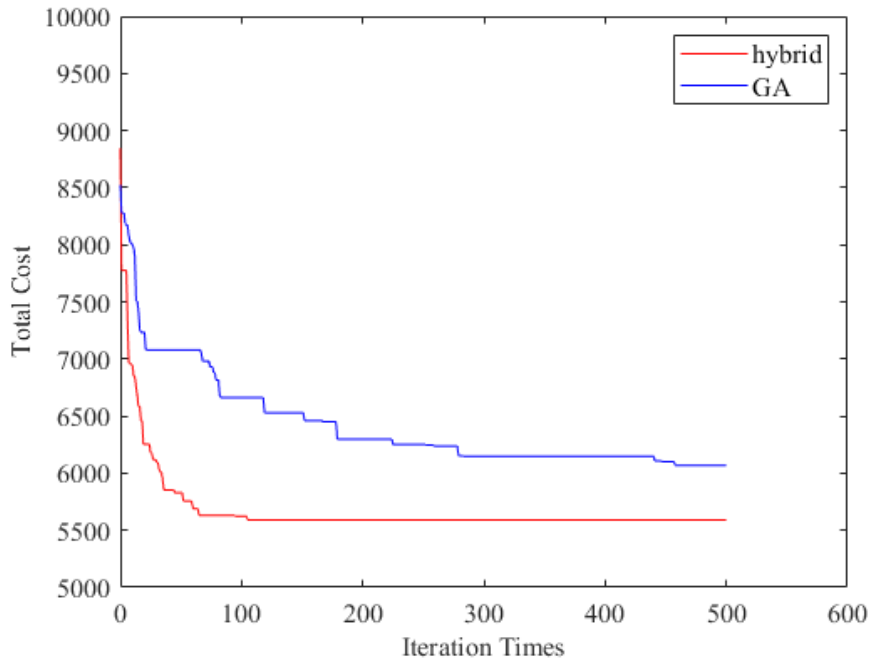
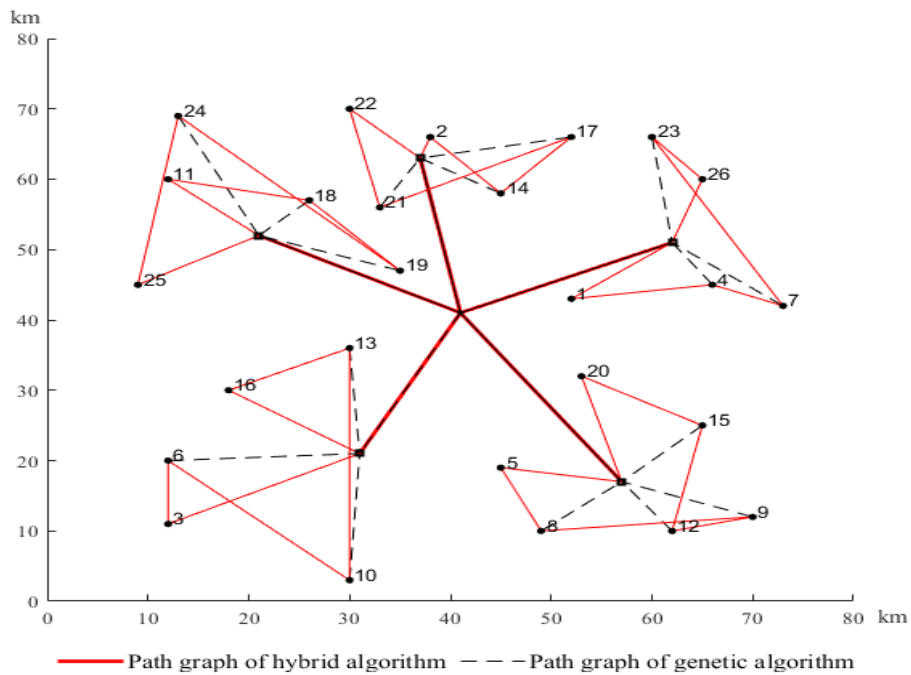**Figure 3.** GA and hybrid algorithm iteration diagram.

Figure 4. GA and hybrid algorithm distribution path optimization diagram.

Table 4. GA operation results.

Total cost (yuan)	6069.8987
Transportation cost from factory to refrigerator (yuan)	478.6024
Transportation cost from cold storage to demand point (yuan)	1608.3902
Fixed cost of cold storage (yuan)	1785
Refrigeration cost (yuan)	689.3101
Penalty cost (yuan)	0
Cost of goods damage from factory to refrigerator (yuan)	915.5919
Cost of goods damage from cold storage to demand point (yuan)	593.0042

Table 5. Operation results of hybrid algorithm.

Total cost (yuan)	5567.1193
Transportation cost from factory to refrigerator (yuan)	478.6024
Transportation cost from cold storage to demand point (yuan)	1318.9421
Fixed cost of cold storage (yuan)	1785
Refrigeration cost (yuan)	565.2613
Penalty cost (yuan)	0
Cost of goods damage from factory to refrigerator (yuan)	925.5919
Cost of goods damage from cold storage to demand point (yuan)	494.0067

Table 6. Distribution center corresponding to 1–26 customer points by GA algorithm.

Distribution center / Customer	A	B	C	D	E	Distribution center / Customer	A	B	C	D	E
1			C			14				D	
2				D		15		B			
3	A					16	A				
4			C			17			C		
5	A					18					E
6					E	19					E
7		B				20			C		
8		B				21				D	
9		B				22				D	
10	A					23				D	
11					E	24					E
12	A					25					E
13	A					26			C		

Table 7. Distribution centers corresponding to 1–26 customer points obtained by hybrid genetic algorithm.

Distribution center / Customer	A	B	C	D	E	Distribution center / Customer	A	B	C	D	E
1			C			14				D	
2				D		15		B			
3	A					16	A				
4			C			17				D	
5		B				18					E
6	A					19					E
7			C			20		B			
8		B				21				D	
9		B				22				D	
10	A					23			C		
11					E	24					E
12		B				25					E
13	A					26			C		

4.3. Result analysis

As can be seen from Figure 3, the calculation speed and accuracy of hybrid algorithm are better than that of genetic algorithm. After 300 iterations, the minimum total cost of the objective function of the two algorithms tends to be stable. In the result of hybrid algorithm, the minimum transportation cost is about 5567 yuan, which is about 500 yuan less than that of genetic algorithm. From Figure 4, we can see the optimization path of genetic algorithm and hybrid algorithm directly. Tables 5 and 6 show the Distribution Center for each customer. Through the case analysis of a company, the optimal transportation route is obtained while minimizing the transportation cost.

5. Conclusions

Compared with traditional logistics transportation, the requirements on product quality and timeliness of cold chain logistics is stricter, which resulting in increased costs. In addition, in the cold chain logistics distribution process, the carbon emissions not only come from the driving vehicle itself but also from various refrigeration equipment in the vehicle. Due to the implementation of the national carbon tax policy, the increase in carbon emissions not only pollutes the environment, but also increases the distribution costs of logistics companies. Therefore, ensuring the freshness of fresh products and realizing low-carbon transportation are the problems that need to be solved in cold chain logistics distribution.

With the rapid development of cold chain industry in China, the operation mode of cold chain logistics is also increasing, such as door-to-door e-commerce platform mode, fresh supermarket mode of distribution to stores, etc., which all affect the way of cold chain logistics path planning. The main direction of cold chain path optimization is how to optimize the operation mode of various cold

chain logistics, and then put forward the corresponding heuristic algorithm to solve it, so as to achieve the effect of high speed and precision of operation.

Based on the perishable characteristics of fresh products and the requirements of cold chain delivery time window, this paper combines cold chain logistics with path optimization to build a path optimization model of fresh products with time window, which includes the transportation cost, refrigeration cost, goods loss cost, storage cost and penalty cost related to time window. Through the establishment of the minimum total cost function, and the design of hybrid algorithm to solve, and finally combined with the actual transportation data of company A to get the path optimization results. The results show that the route optimization can save the transportation cost, and it has strong feasibility and practical value.

Several limitations need to be acknowledged. Firstly, for the convenience of the study, we assume that the fresh products come from a place of origin, which is not in line with the reality. Secondly, this paper verifies the effectiveness of the proposed algorithm to reduce the cost through simulation, but there is no comparison between the algorithms, and there is no research on whether there is a more effective optimization algorithm to reduce the cost. Therefore, in the future research, we will consider the case of fresh products from multiple origins, and propose an optimal algorithm to reduce the cost by comparing a variety of algorithms. In addition, the algorithm will be applied in real time by using GIS, or data will be extracted from Google maps.

Acknowledgments

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

1. Z. Liu, L. Lang, B. Hu, L. Shi, B. Huang, Y. Zhao, Emission reduction decision of agricultural supply chain considering carbon tax and investment cooperation, *J. Cleaner Prod.*, **294** (2021).
2. Y. Zhang, X. D. Chen, An optimization model for the vehicle routing problem in multi-product frozen food delivery, *J. Appl. Res. Technol.*, **12** (2014), 239–250.
3. A. K. Beheshti, S. R. Hejazi, M. Alinaghian, The vehicle routing problem with multiple prioritized time windows: a case study, *Comput. Ind. Eng.*, **90** (2015), 402–413.
4. C. Koc, T. Bektas, O. Jabali, G. Laporte, A hybrid evolutionary algorithm for heterogeneous fleet vehicle routing problems with time windows, *Comput. Oper. Res.*, **64** (2015), 11–27.
5. R. K. Singh, A. Gunasekaran, P. Kumar, Third party logistics (3PL) selection for cold chain management: a fuzzy AHP and fuzzy TOPSIS approach, *Ann. Oper. Res.*, **267** (2018), 531–553.
6. S. Mejjaouli, R. F. Babiceanu, Cold supply chain logistics: system optimization for real-time rerouting transportation solutions, *Comput. Ind.*, **98** (2018), 68–80.
7. X. Ma, T. Liu, P. Yang, R. Jiang, Vehicle routing optimization model of cold chain logistics based on stochastic demand, *J. Syst. Simul.*, **28** (2016), 1824–1832.
8. J. Lu, S. Zhang, Route optimization of partitioned distribution of cold chain logistics based on

spatiotemporal similarity measure, *J. Shanghai Mari. Univ.*, **39** (2018), 32–37.

9. C. Bao, S. Zhang, Route optimization of cold chain logistics in joint distribution: with consideration of carbon emission, *Ind. Eng. Manage.*, **23** (2018), 95–107.

10. S. Fan, D. Lou, Y. Sun, Optimization study on vehicle distribution routing of cold-chain logistics for fresh agricultural products, *Stor. Proc.*, **17** (2017), 106–111.

11. Y. Li, M. K. Lim, M. L. Tseng, A green vehicle routing model based on modified particle swarm optimization for cold chain logistics, *Ind. Manage. Data Syst.*, **119** (2019) 473–494.

12. W. Zhang, K. Liang, Optimization of cold-chain network nodes and delivery for fresh agricultural products, *Syst. Eng.*, **35** (2017), 119–123.

13. S. Bekir, S. Ahmet, Multi-Layer, Multi-segment iterative optimization for maritime supply chain operations in a dynamic fuzzy environment, *IEEE Access*, **8** (2020), 144993–145005.

14. Y. Zhou, Y. Ji, H. Yang, K. Yu, Optimization of vehicle routing problem with simultaneous delivery and pickup for cold-chain logistics, *Math. Pract. Theory*, **46** (2016), 18–26.

15. R. Zhang, Q. Liu, CO_2 Emission minimizing for the time-dependent VRP in urban area, *Ind. Eng. Manage.*, **20** (2015), 29–34.

16. Z. Wang, J. Lu, Optimizing the distribution path of low-carbon cold chain logistics vehicles, *Sci. Tech. Manage. Res.*, **17** (2017), 228–232.

17. X. Ge, H. Zhang, Study on the optimization of vehicle routing problem in urban real time traffic network, *Ind. Eng. Manage.*, **23** (2018), 140–156.

18. Z. Zeng, C. Zou, J. Wei, H. Lu, E. Lv, Q. Ruan, Optimization of distribution cost model of cold chain logistics for litchi based on ant colony algorithm, *Packag. Eng.*, **40** (2019), 58–65.

19. C. Liang, Q. Zou, Research on vehicle routing problem with temperature variable in cold chain logistics, *J. Guangxi. Univ.*, **42** (2017), 1802–1809.

20. S. Cao, Y. Chen, C. Chen, C. Hua, Ocean catches cold chain distribution based on multi-objective optimization, *J. Beijing Jiaotong Univ.*, **41** (2017), 34–38.

21. Z. Huang, Research on optimization of urban cold chain logistics distribution path based on genetic algorithm, *Manage. Adm.*, **8** (2018), 97–101.

22. J. Shao, Q. Cao, M. Chen, Y. Sun, Research on multi-objective optimization for fresh agricultural products VRP problem, *Ind. Eng. Manage.*, **20** (2015), 122–134.