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# Research on Cold Chain Logistics Route Optimization Based on Improved Genetic Algorithm

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**Abstract:** With the rapid growth in cold chain demand, cold chain logistics has become increasingly important in modern supply chain systems. However, in practical distribution processes, route optimization becomes more complex due to temperature control requirements, product perishability, and multiple operational constraints. This paper addresses the routing optimization problem in cold chain logistics distribution by developing a mathematical model with the objective of minimizing total distribution cost, comprehensively considering vehicle fixed costs, transportation costs, refrigeration costs, and cargo deterioration costs. On this basis, an improved genetic algorithm is designed to solve the model. The initial population is generated using a nearest-neighbor priority strategy, and a local search mechanism is incorporated to enhance the algorithm's search capability and convergence performance. A small-scale case is used for simulation analysis. The results show that the proposed method can obtain reasonable distribution routes under vehicle capacity constraints, and exhibits good convergence and stability, thereby verifying the effectiveness of the model and algorithm.

**Keywords:** Cold Chain Logistics; Vehicle Routing Problem; Improved Genetic Algorithm; Cost Minimization.

## 1. Introduction

With the upgrading of residents' consumption and the continuous growth of demand for cold chain preservation of fresh food, pharmaceutical products and other goods, cold chain logistics has become an important part of the modern logistics system. Compared with ordinary logistics, cold chain logistics not only needs to meet customers' distribution needs during transportation, but also maintain a suitable low-temperature environment to reduce the cargo spoilage rate and ensure quality. Therefore, its vehicle routing problem for distribution has high research value [1]. In recent years, the optimization of cold chain logistics distribution has gradually become an important research direction in the fields of logistics management and intelligent scheduling [2].

Existing research on the optimization of cold chain logistics routes mainly focuses on cost control, carbon emission constraints and the improvement of distribution efficiency, and has gradually applied intelligent optimization methods such as genetic algorithms, particle swarm optimization, sparrow search algorithm [3] and artificial bee colony algorithm [4] to route planning and solving. However, the traditional genetic algorithm still has shortcomings such as unstable initial solution quality and easy to fall into local optimum when solving the vehicle routing problem [5]. Therefore, it is necessary to make targeted improvements to it combined with the characteristics of cold chain distribution scenarios [6].

Based on this, this paper takes the cold chain logistics distribution process as the research object, constructs a path optimization model with the goal of minimizing the total distribution cost, and on the basis of comprehensively considering the vehicle fixed cost, transportation cost, refrigeration cost and cargo damage cost, proposes an improved genetic algorithm is proposed for solving it. Finally, simulation experiments are carried out based on examples to provide reference significance for enterprise operations.

## 2. Model Construction

### 2.1. Problem Description and Assumptions

The cold chain logistics distribution route optimization problem can be described as follows: under the condition of a single distribution center, vehicles depart from the distribution center, provide distribution services to multiple customer points, and return to the distribution center after completing the tasks. To facilitate the construction of the model, this paper combines the cold chain logistics distribution scenario and makes the following basic assumptions:

(1) The distribution center has sufficient inventory to meet the delivery demands of all customer points;

(2) Each customer point is served exactly once by one delivery vehicle.

(3) All delivery vehicles are of the same type and have the same capacity;

(4) The location, demand of each customer point and the distance between nodes are known;

(5) All vehicles depart from the distribution center and finally return to the distribution center;

(6) Random factors such as vehicle breakdowns and traffic congestion that affect the delivery process are not considered.

### 2.2. Objective Function and Constraints

This paper models the cold chain logistics distribution with the goal of minimizing the total distribution cost. Let the set of vehicles be $K=\{1,2,\cdots,k\}$, and the set of nodes be $N=\{0,1,2,\cdots,n\}$, where node 0 represents the distribution center and the remaining nodes represent customer points. The total cost is defined as follows:

(1) Fixed Cost

The fixed cost mainly includes expenses such as vehicle depreciation, driver salaries and vehicle dispatching, which is proportional to the actual number of vehicles used, and can be expressed as:

$$C_1 = c_0 \sum_{k\in K} \sum_{j\in N} x_{0jk} \quad (1)$$

In the formula, $c_0$ represents the fixed usage cost of a single distribution vehicle.

(2) Transportation Cost

The transportation cost is mainly composed of fuel consumption and vehicle wear and tear, and increases with the increase of driving distance, which can be expressed as:

$$C_2 = c_1 \sum_{k\in K} \sum_{i\in N} \sum_{j\in N} x_{ijk} d_{ij} \quad (2)$$

In the formula, $c_1$ is the transportation cost per unit distance, and $d_{ij}$ is the distance between node $i$ and node $j$.

(3) Refrigeration Cost

During cold-chain distribution, vehicles need to continuously maintain a low-temperature environment, so corresponding refrigeration costs are generated during the transportation stage, which can be expressed as:

$$C_3 = c_2 \sum_{k\in K} \sum_{i\in N} \sum_{j\in N} x_{ijk} t_{ij} \quad (3)$$

In the formula, $c_2$ is the cooling cost coefficient per unit time, and $t_{ij}$ is the transportation time for the vehicle to travel from node $i$ to node $j$.

(4) Damage Cost

During transportation, the quality of goods deteriorates with the extension of delivery time, resulting in goods damage costs, which can be expressed as:

$$C_4 = \beta \sum_{i=1}^{n} q_i t_i \quad (4)$$

In the formula, $\beta$ is the unit cost coefficient of cargo damage, and $t_i$is the cumulative delivery time of the vehicle when arriving at the customer point $i$.

In summary, the objective function is:

$$\min Z = C_1 + C_2 + C_3 + C_4 \quad (5)$$

The constraints are as follows:

(1) Vehicle Capacity Constraint:

$$\sum_{i\in N} y_{ik} q_i \le Q, \forall k \in K \quad (6)$$

(2) Unique Service Constraint:

$$\sum_{k\in K} \sum_{j\in N} x_{ijk} = 1, \forall i \in N, i \ne 0 \quad (7)$$

(3) Route Continuity Constraint:

$$\sum_{i\in N} x_{ijk} = \sum_{i\in N} x_{jik}, \forall j \in N, \forall k \in K \quad (8)$$

(4) Decision Variable Constraints:

$$x_{ijk} \in \{0,1\}, \forall i,j \in N, \forall k \in K \quad (9)$$

$$y_{ik} \in \{0,1\}, \forall i \in N, \forall k \in K \quad (10)$$

Define the decision variable $x_{ijk}$ as: $x_{ijk} = 1$ if vehicle $k$ travels from node $i$ to node $j$, otherwise $x_{ijk} = 0$; $y_{ik}$ indicates whether customer point $i$ is served by vehicle $k$, taking 1 if served and 0 otherwise. In addition, $q_i$ represents customer point $i$ 's demand quantity; the transportation time between nodes $t_{ij}$ can be determined by the distance $d_{ij}$ and the driving speed of the vehicle, and the node arrival time $t_i$ is the cumulative travel time of the vehicle from the distribution center to customer point $i$.

# 3. Design of the Improved Genetic Algorithm

The traditional genetic algorithm has problems such as low initial population quality and being prone to falling into local optima when solving the cold chain logistics distribution path optimization problem. To improve the solution quality of the algorithm, this paper improves on the basis of the traditional genetic algorithm and uses it to solve the cold chain logistics distribution path optimization model established in this paper.

## 3.1. Coding and Fitness Function

This paper uses natural number coding to represent the access order of customer points, and the chromosome is composed of the arrangement of customer point numbers. The chromosome is decoded according to the vehicle load capacity constraint to form the specific distribution route. The total cost objective function shown in Equation (5) is taken as the optimization objective, and the fitness function is defined as:

$$F = \frac{1}{Z} \quad (11)$$

In the formula, $Z$ represents the total cost of the distribution scheme corresponding to the individual.

## 3.2. Genetic Operations and Improvement Strategies

The selection operation adopts the roulette wheel method, the crossover operation adopts Partially Mapped Crossover (PMX), and the mutation operation adopts swap mutation to ensure the feasibility of path coding. To improve the algorithm's search capability, this paper introduces a proximity priority strategy in the initial population generation stage, and performs local search on dominant individuals during the iteration process to enhance population quality and reduce the risk of falling into local optima.

## 3.3. Algorithm Flow

Based on the above improvement strategies, the specific flow of the improved genetic algorithm constructed in this paper is as follows:

(1) Parameter initialization: Set parameters such as population size, maximum number of iterations, crossover probability and mutation probability;

(2) Initial population generation: The initial population is constructed by a combination of random generation and the neighbor priority strategy, and the chromosomes are decoded to form feasible delivery routes;

(3) Fitness calculation: Calculate the total cost of the individual according to Equation (5), and obtain the fitness value according to $F = 1/Z$;

(4) Selection operation: The roulette wheel selection method is adopted to select parent individuals based on fitness values.

(5) Crossover and Mutation: Perform Partially Mapped Crossover (PMX) and swap mutation operations on the selected individuals to generate a new generation of populations;

(6) Local search optimization: Perform neighborhood search on individuals with high fitness in the current generation, and further optimize the path structure through node swap or insertion operations;

(7) Update the population: Form a new generation population and record the current optimal individual;

(8) Termination judgment: If the maximum number of iterations is reached or the optimal solution no longer improves, output the optimal distribution route; otherwise, return to step (3) to continue iterating.

# 4. Instance Analysis

## 4.1. Analysis Objects and Parameters

To verify the effectiveness of the model and improved genetic algorithm proposed in this paper, simulation experiments were carried out on the MATLAB 2023b platform, with the computer hardware environment being an Intel i5 processor and 16GB of memory.

Referring to a cold chain logistics company in Suzhou, a small-scale cold chain logistics distribution example is constructed with one distribution center serving 15 customer points. The distances and demands between each customer point and the distribution center are shown in Table 1, and the distances between each customer point are shown in Table 2.

**Table 1.** Basic Information of Customer Nodes

| Customer Nodes | Distance from the distribution center /km | Demand /t |
|---|---|---|
| 1 | 6.5 | 1.2 |
| 2 | 8.3 | 0.8 |
| 3 | 12.7 | 1.5 |
| 4 | 15.2 | 2.0 |
| 5 | 9.8 | 1.1 |
| 6 | 18.4 | 2.3 |
| 7 | 22.1 | 1.7 |
| 8 | 5.9 | 0.6 |
| 9 | 14.6 | 1.9 |
| 10 | 11.3 | 1.4 |
| 11 | 19.8 | 2.5 |
| 12 | 25.6 | 2.8 |
| 13 | 7.4 | 0.9 |
| 14 | 16.7 | 1.6 |
| 15 | 13.5 | 1.3 |

**Table 2.** Distance Matrix of Each Customer Node

| Node | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 6.5 | 8.3 | 12.7 | 15.2 | 9.8 | 18.4 | 22.1 | 5.9 | 14.6 | 11.3 | 19.8 | 25.6 | 7.4 | 16.7 | 13.5 |
| 1 | 6.5 | 0 | 2.4 | 7.8 | 9.1 | 3.2 | 11.5 | 16.8 | 4.0 | 10.2 | 8.1 | 14.3 | 18.6 | 2.9 | 12.4 | 7.6 |
| 2 | 8.3 | 2.4 | 0 | 5.6 | 7.2 | 4.1 | 9.7 | 14.2 | 6.5 | 8.8 | 5.3 | 12.9 | 17.1 | 4.6 | 10.9 | 6.2 |
| 3 | 12.7 | 7.8 | 5.6 | 0 | 3.5 | 6.9 | 6.8 | 10.5 | 9.3 | 5.4 | 3.9 | 8.2 | 12.6 | 8.7 | 7.1 | 5.0 |
| 4 | 15.2 | 9.1 | 7.2 | 3.5 | 0 | 8.4 | 4.2 | 8.9 | 11.7 | 6.6 | 7.5 | 5.1 | 9.4 | 10.8 | 3.6 | 8.3 |
| 5 | 9.8 | 3.2 | 4.1 | 6.9 | 8.4 | 0 | 10.1 | 13.6 | 5.7 | 7.9 | 6.4 | 11.2 | 15.8 | 3.8 | 9.5 | 4.7 |
| 6 | 18.4 | 11.5 | 9.7 | 6.8 | 4.2 | 10.1 | 0 | 6.3 | 14.9 | 8.7 | 9.2 | 4.5 | 7.8 | 12.1 | 5.6 | 10.4 |
| 7 | 22.1 | 16.8 | 14.2 | 10.5 | 8.9 | 13.6 | 6.3 | 0 | 18.2 | 12.4 | 11.7 | 7.9 | 9.6 | 15.3 | 9.8 | 14.0 |
| 8 | 5.9 | 4.0 | 6.5 | 9.3 | 11.7 | 5.7 | 14.9 | 18.2 | 0 | 8.1 | 6.2 | 16.5 | 20.3 | 3.5 | 10.8 | 7.0 |
| 9 | 14.6 | 10.2 | 8.8 | 5.4 | 6.6 | 7.9 | 8.7 | 12.4 | 8.1 | 0 | 4.3 | 6.7 | 10.9 | 9.5 | 6.1 | 5.8 |
| 10 | 11.3 | 8.1 | 5.3 | 3.9 | 7.5 | 6.4 | 9.2 | 11.7 | 6.2 | 4.3 | 0 | 7.4 | 9.8 | 6.8 | 5.9 | 4.6 |
| 11 | 19.8 | 14.3 | 12.9 | 8.2 | 5.1 | 11.2 | 4.5 | 7.9 | 16.5 | 6.7 | 7.4 | 0 | 6.3 | 13.4 | 7.2 | 9.9 |
| 12 | 25.6 | 18.6 | 17.1 | 12.6 | 9.4 | 15.8 | 7.8 | 9.6 | 20.3 | 10.9 | 9.8 | 6.3 | 0 | 17.8 | 11.5 | 13.7 |
| 13 | 7.4 | 2.9 | 4.6 | 8.7 | 10.8 | 3.8 | 12.1 | 15.3 | 3.5 | 9.5 | 6.8 | 13.4 | 17.8 | 0 | 11.1 | 6.9 |
| 14 | 16.7 | 12.4 | 10.9 | 7.1 | 3.6 | 9.5 | 5.6 | 9.8 | 10.8 | 6.1 | 5.9 | 7.2 | 11.5 | 11.1 | 0 | 7.8 |
| 15 | 13.5 | 7.6 | 6.2 | 5.0 | 8.3 | 4.7 | 10.4 | 14.0 | 7.0 | 5.8 | 4.6 | 9.9 | 13.7 | 6.9 | 7.8 | 0 |

The parameters are set as follows: fixed vehicle usage cost $c_0 = 80$ yuan/vehicle, unit distance transportation cost $c_1 = 1$ yuan/km, unit time refrigeration cost coefficient$c_2 = 0.5$ yuan/h, and cargo damage cost coefficient $\beta = 0.2$.For the genetic algorithm, the parameters are set as: population size of 80, crossover probability $p_c = 0.6$, mutation probability $p_m = 0.01$, and maximum number of iterations of 300.The maximum load capacity of cold-chain distribution vehicles is set to $Q = 6$ t, and the average driving speed of vehicles is $v = 40$ km/h. Thus, the transportation time between nodes $t_{ij} = d_{ij}/v$.

## 4.2. Result Analysis

This section analyzes the results of the improved genetic algorithm for solving the cold chain logistics distribution path optimization model. As shown in Figure 1, it is the convergence curve of the algorithm. From the overall trend, the value of the objective function drops rapidly in the initial stage, indicating that the algorithm has a strong global search capability; the cost decreases significantly within the first about 50 generations, then the decline rate slows down, and it tends to be stable after about 80 generations, finally converging to approximately $1.22\times10^4$. This shows that the improved genetic algorithm can effectively avoid premature convergence and has good convergence stability.

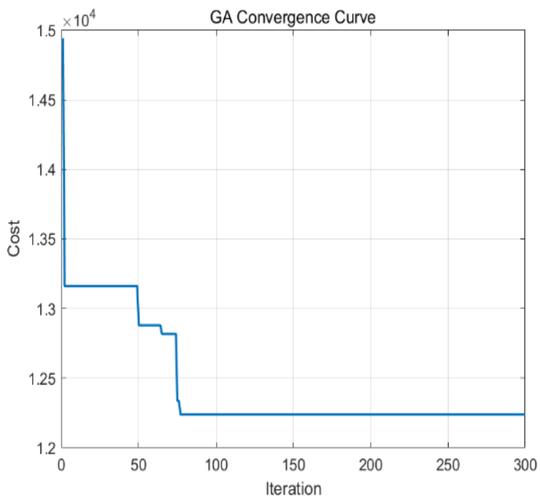


**Figure 1.** Iteration Curve of Total Cost

The distribution routes obtained based on the optimal solution are shown in Table 3. It can be seen that each vehicle departs from and finally returns to the distribution center, and meets the vehicle capacity constraint Q=6, realizing the complete coverage of 15 customer nodes.

The results show that the improved genetic algorithm can effectively solve the vehicle routing optimization problem in cold-chain logistics, and achieve a better distribution scheme and lower total cost on the premise of satisfying the constraints.

**Table 3.** Vehicle Distribution Routes

| Vehicle Number | Distribution Routes |
|---|---|
| Vehicle 1 | $0 \rightarrow 1 \rightarrow 2 \rightarrow 4 \rightarrow 3 \rightarrow 0$ |
| Vehicle 2 | $0 \rightarrow 11 \rightarrow 6 \rightarrow 5 \rightarrow 0$ |
| Vehicle 3 | $0 \rightarrow 13 \rightarrow 8 \rightarrow 14 \rightarrow 15 \rightarrow 0$ |
| Vehicle 4 | $0 \rightarrow 9 \rightarrow 10 \rightarrow 0$ |
| Vehicle 5 | $0 \rightarrow 12 \rightarrow 7 \rightarrow 0$ |

# 5. Conclusion

Aiming at the optimization problem of cold chain logistics distribution routes, this paper constructs a mathematical model with the goal of minimizing the total cost, and designs an improved genetic algorithm for solving it. Through the analysis of improved instance, the results show that the method can obtain a reasonable distribution route under the condition of satisfying the vehicle capacity constraint, and has good convergence and stability, which verifies the effectiveness of the model and algorithm and has reference significance for enterprises.

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