# Research on Low-carbon Fresh Food Logistics Path Optimization Based on Improved Ant Colony Algorithm

Xianhua Ke, Manhui He *

College of Business Administration, Liaoning Technical University, Huludao, Liaoning, 125105, China

(*2305147292@qq.com)

**Abstract.** For logistics companies facing the challenges of high distribution costs and high carbon emissions when delivering fresh produce, this text comprehensively analyzes comprehensive freight cost, time-window penalty, cargo loss, and refrigeration cost with respect to the characteristics of fresh logistics and carbon emission considerations. Based on this, a single-objective optimization model is constructed with the ultimate goal of reducing the cost of cargo transportation, and the issue is addressed using an improved ant colony algorithm. In this article a detailed experimental test of the model using the Solomon dataset. The final outcome show that the model designed in this article effectively reduces the total cost of fresh food distribution and carbon emissions, confirming the applicability and rationality of the research content of this article.

**Keywords:** Fresh produce logistics; path optimization; low carbon; Improved ACO Algorithm

## 1 INTRODUCTION

Around the development goal of achieving “peak carbon and carbon neutrality”, various industries are gradually transitioning to a green economy The logistics industry has become a key area of concern due to its huge consumption of resources and increasing carbon emissions year after year. In particular, the sum of the economic costs of product distribution and the carbon dioxide emissions resulting from a range of activities in the distribution process have remained high.Therefore, it is of great research value to realize the economization and greening of cold chain distribution.

Experts at home and abroad have conducted a lot of research on fresh food cold chain distribution: Wanchen Gao et al[1] taking cherry cold chain logistics as an example, a cost-minimizing optimization model is developed to reduce the total distribution costs of both buyers and sellers to the maximum extent possible.Jiantong Zhang[2] for this multi-distribution center situation, an optimization model for minimizing the integrated cost is developed and a two-stage algorithm is designed to solve this problem. Yanni Jiu et al[3]consider different fresh products have different freshness requirements, a freshness differentiated demand function is constructed, a single-objective optimization


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model to minimize the total cost of distribution is established, and it is solved using a hybrid particle swarm algorithm. Xiaofang Yang et al[4]analyzed tthe relationship between customer satisfaction and product freshness in the delivery of fresh products and established a corresponding optimization model. Kongyu Yang et al[5] analyzed the effect of road bumps on the distribution cost of fresh products and an immune genetic algorithm is designed to solve this problem effectively.

More and more researchers are focusing on the question of how to reduce CO2 emissions in cold chain logistics.Babagolzadeh et al[6]proposing a stochastic planning model to analyze the effects of carbon tax on cold chain material distribution.Kai Kang et al [7]a hybrid algorithm is designed to address the model with the goal of minimizing the overall cost of the vehicle distribution process. Min Cong et al [8]using an improved gray wolf algorithm to address the issue of high carbon emissions in fresh produce delivery process.Hongxing Deng et al [9]establishing and solving a multi-objective optimization model based on cargo damage cost and carbon emission cost in cold chain distribution process Jiancheng Zou et al[10] developing and solving a multi-objective planning model considering total cold chain distribution cost and customer satisfaction.

In summary, although scholars have analyzed various aspects of cold chain distribution of fresh products, they have rarely conducted detailed analysis on the cargo loss of fresh products, refrigeration costs generated by refrigeration equipment and the amount of carbon dioxide emitted by refrigeration equipment when refrigeration activities are carried out during product transportation. This article comprehensively analyzes the refrigeration cost generated by refrigeration equipment, the cost of lost goods and the carbon emission cost caused by fuel consumption during transportation and unloading in the transportation of fresh produce, and a single-objective optimization model with the objective of minimizing the integrated cost of transportation is developed. Simulation experiments verify the good applicability of the model and the improved ACO algorithm in reducing the total cost of transportation and the amount of carbon emissions.

## 2 MODELING

### 2.1 Problem Description and Assumptions

The issue examined by this article could be specifically described as follows: a product blending center comprehensively considering various economic cost factors, distribution route planning based on minimizing total product dispatch costs. Refrigerated trucks start from the product blending center, complete the material distribution requirements of specific customer groups, and finally return to the product blending center.

(1) In this article, we only consider a single distribution center with multiple customer locations;

(2) The location of each client is known and the needs of all clients can be met;

(3) All refrigerated trucks are equipped with sufficiently large refrigerated containers, and the speed of the transportation process is the same and maintained at a constant speed;

(4) Each refrigerated vehicle can provide fresh product distribution service to multiple customer points, and each customer point is provided with distribution service by one refrigerated vehicle and only once;

(5) Damage to the goods relates only to the length of time the goods have been in transit;

## 2.2 Symbol Description

According to the need of constructing the model in this article, the symbols and meanings of the problems in this article are defined as follows:

No. 0 denotes the distribution center; N denotes the customer point number N={1,2,3...n}; V denotes the vehicle number, V={0,1,2,3...m}; Qi denotes the mass of products left on the truck when the reefer trucks leave the customer i; g indicates the unit fixed cost of the vehicle; Ca denotes the unit transportation cost of the vehicle; dij denotes the distance between two customer points;p denotes the price per unit weight of the product; qi indicates the quantity demanded at demand point i;WR1S1 represents the cost of cooling due to heat transfer inside the vehicle;WR2S2 represents the cost of cooling due to heat transfer from the outside of the vehicle; a1 Indicates the rate of spoilage of fresh produce during transportation;a2 indicates the rate of product spoilage during loading and unloading; tiv denotes the specific moment when the reefer v arrives at the demand point i; tfv denotes the specific moment when the refrigerated truck v completes the distribution service at the last customer point;h denotes the amount of fuel consumed per unit of distance traveled by the refrigerated truck for the distribution service; tis indicates the time it takes for a reefer truck to complete loading, unloading, and handling services at demand point i;[ei,li] indicates the time range in which point i is allowed to receive services;p1 denotes the penalty factor if the product arrives at point i earlier than the earliest reachable time;p2 denotes the penalty factor if the product arrives at point i later than the latest available arrival time; T0 denotes the storage temperature of commodities in the reefer; Cc denotes the price per unit of carbon emission; u is a CO2 emission factor; o denotes the amount of carbon dioxide emitted per unit of distance of reefer refrigerating a unit of weight of fresh products during distribution; Qij denotes the amount of fresh produce transported from point i to point j; xijv indicates that the value of xijv is 1 if vehicle v carries out transportation activity from demand point i to point j; 0 otherwise; yiv denotes the value of 1 for yiv if vehicle v provides service at point i; 0 otherwise;;

Objective Function

(1) Fixed cost

Fixed costs are only related to the total number of vehicles and they are directly proportional.

$$C_1 = \sum_{v=1}^{m} g \tag{1}$$

(2) Transportation costs

In this article, the main consideration for transportation cost is the amount of fuel consumed, which increases with the distance the vehicle is transported, so in order to maximize cost savings, we need to choose the transportation option with the shortest distribution path.

$$C_2 = \sum_{v=1}^{m}\sum_{i,j=0}^{n} c_a d_{ij} x_{ijv} \tag{2}$$

(3) Cargo loss cost

In this article, taking into account the feasibility of the study, without considering other factors, the cargo loss is divided into two parts: one part is the cargo loss due to the accumulation of the delivery time; the other part is the cargo loss arising from the unloading of the cargo.

$$C_3 = \sum_{v=1}^{m}\sum_{j=1}^{n} y_{iv} p\left[q_i(1-e^{-a_1(t_{iv}-t_{0v})}) + Q_i(1-e^{-a_2 t_{is}})\right] \tag{3}$$

(4) Penalty costs

Fresh products because of their own characteristics, so the customer for fresh products will set a time window, the product can be delivered between this time period, but in the actual transportation process may be due to some reasons can not be delivered within this time period, you need to pay for the delivery of the product is too early or too late and the corresponding penalty cost.

$$C(p_i) = \begin{cases} p_1(e_i - t_{iv}), t_{iv} \le e_i \\ 0, t_{iv} \in (e_i, l_i), \\ p_2(t_{iv} - l_i), t_{iv} \ge l_i \end{cases} \tag{4}$$

Denote the total penalty cost by C4:

$$C_4 = \sum_{i=1}^{n} C(p_i) \tag{5}$$

(5) Refrigeration cost

Cooling costs considered in this article is mainly the cooling costs incurred by the refrigerated truck to keep the product at a constant temperature during traveli ng and the refrigeration cost incurred by the unloading to avoid spoilage of the r emaining fresh products due to the opening of the door of the truck.

$$C_5 = \sum_{v=1}^{m}\sum_{i,j=1}^{n} WR_1 S_1 (T - T_0)(t_{fv} - t_{0v}) x_{ijv} + \sum_{v=1}^{m}\sum_{i,j=1}^{n} WR_2 S_2 (T - T_0) t_i x_{ijv} \tag{6}$$

(6) Carbon emission cost

In this article, only carbon dioxide from fuel consumption and carbon dioxide from refrigeration activities of refrigeration equipment are considered for refrigera ted trucks while traveling.

$$C_6 = C_c \cdot \sum_{v=1}^{m}\sum_{i,j=0}^{n} x_{ijv} \cdot d_{ij} \cdot (ou(Q_{ij}) + hQ_{ij}). \tag{7}$$

### 2.3 Modeling

Objective function:

$$\min C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \tag{8}$$

Constraints:

$$\sum_{v=1}^{m}\sum_{j=1}^{n} x_{ijv} \le m, i = 0 \tag{9}$$

$$\sum_{v=1}^{m} y_{jv} = 1, j = 1,2,3,\cdots,n \tag{10}$$

$$\sum_{j=1}^{n} x_{ijv} = \sum_{j=1}^{n} x_{ijv} \le 1, i = 0, v = 1,2,\cdots,n \tag{11}$$

$$\sum_{j=1}^{n} q_j y_{jv} \le Q, v = 1,2,3,\cdots,m \tag{12}$$

Eq. (8) is the total cost incurred by minimizing the distribution service of fresh products;

Eq. (9) indicates that the total number of vehicles is able to meet transportation needs;

Eq.(10) indicates that the refrigerated truck will perform and only perform one delivery service to the point of demand;

Eq. (11)indicates that both the start and end positions of the refrigerated truck are at the distribution center;

Eq. (12) indicates that the goods to be transported do not exceed the maximum loading capacity of the refrigerated truck;

## 3 ALGORITHM DESIGN

The single-objective path optimization model for cold chain distribution developed in this article is compared with the traditional VRP problem. the considerations of customer hard time window constraints, carbon emission and product cargo damage are added to the model in this article, which will increase the complexity and difficulty of the problem to a large extent. The ant colony algorithm has the advantages of forward and reverse pheromone updating, distributed computing, global search capability and adaptability, which makes it an effective tool for solving path optimization problems. However, in the practical application of the ant colony algorithm, due to its small selection of initial pheromones, the ants lack sufficient information to guide them in choosing a path, which can make the initial iteration time longer, and may also allow the algorithm to fall into a locally optimal situation, so that the obtained solution has a large gap with the optimal solution.

Therefore, we devise an improved ant colony algorithm to solve the above problem. whose basic idea is:First, a genetic algorithm is used to obtain a better initial solution and then the pheromone transformed from the above initial solution is used for the pheromone searching for the optimal search of the ant colony algorithm. In the subsequent pheromone updating stage, in order to avoid the algorithm falling into the situation of local optimal solution, the candidate solution set generated from the above search for optimal solution will be selected probabilistically with the help of Metropolis criterion in the simulated annealing algorithm, so as to select the high-quality solution and update its pheromone concentration.

Step1: Natural number coding.

Step2: Generate the initial population. First of all, the existing n customer points are randomly sorted, and then both ends of the generated sequence are programmed with the serial number 0, which is meant to indicate that the starting point of the refrigerated truck and the final end point is the distribution center, so that we thus generate a chromosome. Repeating this process m times, we obtain a randomized initial population with a population size of m.

Step3: Determination of the fitness function.The inverse of the total cost in the model of this thesis was determined as the fitness function.

Step4: Selection operation. Sort the individuals of the initial population according to the size of the fitness value, leave the individuals with large fitness values, and discard the individuals with small fitness values.

Step5: Crossover operation. In each round of crossover activity will generate a random number K, his value size is between 0 and 1. Judge the size of the random number K and the crossover probability P. If the random number K is smaller than the crossover probability P, perform the two-point crossover operation.

Step6: Apply local reverse order to the results of Step5 for mutation processing.

Step7: Generate the initial pheromone distribution of the path. After iterating the genetic algorithm for a set number of evolutionary generations, the output value generated is used as the initial solution of the subsequent ACO algorithm, and the initial pheromone concentration on each path in the initial solution at this time is calculated.

Step8: ACO initialization. Initialize the relevant parameters and place m ants and randomly in different positions of n customer points.

Step9: Ant colony optimization. Calculate the transfer probability of each ant, select the next city a to be visited based on this probability, place the ants at point a and put the city a into the taboo table, calculate and record the total length of the road that each ant passes through until all the ants have visited all the cities.

Step10: Filter the quality solution set.Through the optimization operation in step 9, a candidate solution set containing m solutions is obtained and the solutions in the candidate solution set are filtered with the help of Metropolis criterion to generate a quality solution set.

Step11: Pheromone update. Introducing a volatilization factor to make the pheromone volatilize gradually after each iteration can prevent the pheromone from falling into the local optimal solution, and perform pheromone updating on it.

Step12: Repeat iteration. If the optimal solution no longer changes or the set number of iterations is reached, jump to Step9, otherwise terminate the loop and output the results.

Step13: Output the optimal route.

# 4 ALGORITHMIC ANALYSIS

In the selection of the arithmetic examples, the R101 data from the Solomon dataset is chosen in this article to demonstrate the superiority and applicability of the algorithm in this article. In the R101 dataset, a distribution center needs to serve 30 randomly distributed customers around it, which have specific demand and time window constraints.)

## 4.1 Algorithm Parameters

In this article, the improved ACO algorithm, the specific parameters are shown in Table 1:

**Table 1.** Parameter settings of the improved ACO algorithm

| parameter | population size | Number of iterations | Choice of operator (math.) | intersection operator (math.) | the calculus of variations (math.) | constant factor |
|---|---|---|---|---|---|---|
| numeric value | M=100 | G=5 | Ps=0.9 | Pc=0.7 | Pm=0.05 | Q=100 |
| parameter | Ant colony algorithm ant population | Number of iterations | pheromone volatilization factor | Percentage of pheromone concentration | Heuristic Impact Factor | Temperature attenuation coefficient |
| numeric value | m=50 | Ga=95 | ρ=0.5 | α=1 | β=2 | t=0.9 |

The specific parameters of the traditional ACO algorithm are shown in Table 2:

**Table 2.** Traditional ACO algorithm parameter settings

| parameter | population size | Number of iterations | Percentage of pheromone concentration |
|---|---|---|---|
| numeric value | M=100 | G=100 | α=1 |
| parameter | Heuristic Impact Factor | constant factor | pheromone volatilization factor |
| numeric value | β=2 | Q=100 | ρ=0.5 |

## 4.2 Model Parameters

The refrigerated truck has a load capacity of 5000 kg and performs distribution services at a speed of 50 km/h. The cost of transporting a kilometer by refrigerated truck is $1.5 and the cost of using each refrigerated truck is $500. The unit price of fresh products is RMB 30/kg, and the rate of product loss during transportation is 0.003, and loss rate during product handling is 0.005. and the refrigeration energy consumption per unit of time during transportation and loading/unloading of reefer trucks is RMB 12/h and RMB 15/h. The penalty cost of fresh products arriving at the customers' point earlier than the specified time window and arriving later than the time window is RMB 50/h and RMB 60/h respectively, and the carbon tax is RMB 0.1/kg.

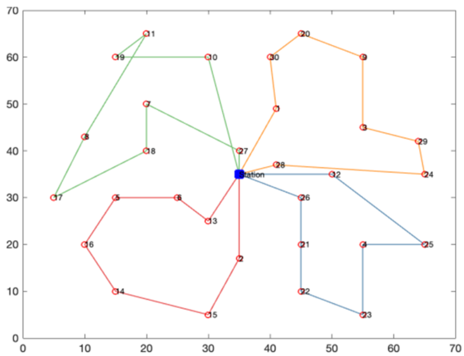

**Fig. 1.** Optimal roadmap

Taking the above parameters as the data base, the mathematical model of this article is solved by Matlab2022b using the traditional ACO algorithm and the improved ACO algorithm respectively. Figure 1 shows the optimal roadmap of the improved ACO algorithm, and Table 3 shows the comparison of the two algorithms.It can be clearly found that the optimization algorithm designed in this paper is better in terms of optimal solution quality, average solution quality and number of iterations. The specific data are the total cost of the model using the improved algorithm is reduced by $214. 7 compared with the traditional algorithm, the cost of carbon emission is reduced by $20.41, and the convergence speed of the algorithm is also obviously accelerated. Consequently the optimization algorithm designed in this article has good performance in reducing the total cost of cold chain distribution and the number of carbon emissions.

**Table 3.** Results of ant colony algorithm and improved ant colony algorithm are obtained

| Data set | Optimal solution | Mean solution | Mean frequency of convergence | Average carbon emission cost |
|---|---|---|---|---|
| Standard ant colony algorithm | 3529.8 | 3674.2 | 11.7 | 132.71 |
| Improved ant colony algorithm | 3315.1 | 3416.8 | 8.9 | 112.3 |

In this article, a single-objective path optimization model is established for realizing green and energy-saving fresh food cold chain logistics with the objective of minimizing the total cost of fresh food distribution by taking multiple factors into consideration. Meanwhile, an improved ant colony algorithm is designed by combining the advantages of ant colony algorithm and other algorithms, and the improved algorithm largely solves the deficiencies of the ordinary ant colony algorithm in the initial pheromone and the quality of the optimal solution. The improved algorithm has better applicability and reasonableness through the verification of experimental examples, and it reduces 214.7 dollars in the total cost and 20.41 dollars in the carbon emission cost. This is a strong theoretical support for fresh produce companies to green their product transportation and control the input of transportation cost.

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