Research on Cold Chain Logistics Distribution Path Based on Hybrid ant Colony Algorithm with Particle Swarms

Jiancheng Huang*, Jun Wan, Xue Wang

Liaoning Technical University, Liaoning Province, Huludao, 125105, China

*huangjiancheng0604@163.com
wanjunchina@vip.163.com
lgdwangxue@163.com

Abstract. In order to solve the problems of high distribution cost and relatively low distribution satisfaction in the fresh cold chain logistics industry, it is proposed to calculate the customer satisfaction according to the fuzzy time window function, analyze the cost factors, and construct the distribution path model with the goal of minimizing the total distribution cost. Aiming at the shortcomings of the ant colony algorithm, which has slow convergence speed and easily falls into local optimum, according to the characteristics of synergy among the particles of particle swarm algorithm, the tournament strategy can increase the characteristics of random perturbation, and combining with the characteristics of ant colony algorithm which utilizes pheromone-enhanced tracing, the particle swarm-based hybrid ant colony algorithm is constructed to improve the model's solving performance. Finally, taking the collected data as an example, the model is constructed for solving, and the solved optimal distribution program effectively reduces the distribution cost while obtaining high customer satisfaction, which is of some significance for improving the level of distribution operations.

Keywords: Cold chain logistics, Path optimization, Customer Satisfaction, Fuzzy time window, Ant colony algorithm.

1 INTRODUCTION

With the rapid development of China's economy and society, the material living standard of the people has been continuously improved, and people's demand for fresh cold chain products is increasing, and the quality requirements are getting higher and higher[1,2]. Fresh cold chain products have the characteristics of not easy to preserve, perishable, etc., and the distribution difficulty is higher than ordinary goods[3]. Cold chain logistics distribution path optimization is a typical NP-hard problem[4]. The centralized improvement ant colony algorithm becomes the trend to solve the VRP problem[5]. Ren Teng et al[6], Ma Guiping et al[7], Li Liying et al[8], Wu Yanfeng et al[9], proposed improved ACO algorithms and designed improved hybrid ACO algorithms

V. Vasilev et al. (eds.), *Proceedings of the 2024 5th International Conference on Management Science and Engineering Management (ICMSEM 2024)*, Advances in Economics, Business and Management Research 306,
https://doi.org/10.2991/978-94-6463-570-6_113

for solving. With the in-depth study of vehicle path problem, the introduction of time window becomes the hot spot of current research.Solomon[10], Songyi Wang et al[11] introduced the time factor and proposed the vehicle path problem with time window constraints.Diao X et al[12], Fan Houming et al[13], constructed a multi-objective distribution path optimization model based on fuzzy time window.

Ant colony algorithm is easy to fall into local optimization and has a long convergence time, and there are fewer literatures considering fuzzy time window with ant colony algorithm. Therefore, in this study, the customer satisfaction is calculated according to the fuzzy time window function, the basic ant colony algorithm is used as the basic solution algorithm, the tournament competition mechanism is introduced to avoid falling into the local optimum, and at the same time, the synergistic characteristics of the particle swarm algorithm among the particles are utilized to accelerate the convergence of the iterations, and the hybrid ant colony algorithm based on the particle swarm is constructed to improve the performance of the model solution.

2 FRESH FOOD COLD CHAIN DISTRIBUTION PATH MODELING

2.1 Problem Description and Modeling Assumptions

The customer distribution location information, customer cargo weight and delivery time requirements are known, and the refrigerated trucks depart from the distribution center without any midway assignment of tasks to deliver the fresh produce to each customer node on demand, in quantity and on time. It can be categorized as: single distribution center, single vehicle, closed, single distribution, fuzzy time window, single objective function optimization problem. The assumptions are as follows:

(1) The road congestion remains relatively stable, i.e., the road congestion remains unchanged from the time the distribution decision is made until the distribution vehicle passes through the roadway;

(2) The number of refrigerated distribution vehicles in the distribution center is fixed, each vehicle has a limited carrying capacity, and the total demand of each customer does not exceed the maximum loading capacity of a single vehicle;

(3) Each customer is guaranteed to receive delivery service, and the required fresh produce can only be delivered by one refrigerated truck;

(4) The total length on each distribution route is less than the range of the distribution vehicle;

(5) The distribution center has sufficient fresh produce and the customer's demand, geographic location, and time window constraints are known;

(6) Fresh products need to be delivered in a specified time window, and the time beyond is quantified using a fuzzy time window function;

(7) Only the effect of opening, closing and unloading the door on the refrigeration temperature is considered, and the effect of external temperature changes on the refrigeration temperature during traveling is not considered;

2.2 Objective Function Analysis

Parameter Description: M:Total number of vehicles participating in distribution;f_k :Fixed costs incurred for the kth vehicle;V:denotes the set of distribution nodes;d_{ij}:(i,j) Distance between distribution nodes;R:thermal conductivity;Q_0:Indicates refrigerant price;λ: Indicates the heat leakage coefficient of the refrigerator compartment body;k:kth vehicle in distribution;q:Cargo damage cost factor;H:Overall customer satisfaction;G:Authorized load for refrigerated trucks;S:External surface area of refrigerated compartments;S_d:Reefer body door surface area;T_i:T_i moment of the distribution vehicle's work;U_i:Distribution vehicle traveling time;i,j:distribution center and distribution node;t_{ij}:vehicle traveling time between distribution nodes i and j;g_i: the total weight of the distributed goods for the ith customer;h:is the average transportation cost per kilometer;M_e:the penalty factor to be paid for early arrival of the distribution;M_l:Penalty coefficient to be paid for late arrival of delivery;p:impairment of product value caused when goods are unloaded and handled;$S_i(t)$:satisfaction of the ith customer;L:Maximum distance traveled by the delivery vehicle;u:denotes the average unloading speed in general;[ET_i, LT_i]:upper and lower limits of the time window agreed by the customer;[MET_i, MLT_i]:upper and lower limits of the customer's tolerable time range;N:is the distribution node;

(1) Distribution fixed costs

$$C_1=\sum_{k=1}^{M} f_k \tag{1}$$

(2) Distribution and transportation costs

$$C_2=\sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} hx_{ij}^{k}d_{ij} \tag{2}$$

x_{ij}^k takes the value of 0 or 1, 1 when the kth delivery truck goes from delivery point i to j, otherwise its value takes 0.

(3) Vehicle refrigeration costs

$$C_3=Q_0\sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} t_{ij}x_{ij}^{k}G+Q_0\sum_{k=1}^{M}\sum_{i=0}^{N} ht_i^k\gamma S_d\Delta T \tag{3}$$

where t_{ij} is the traveling time between (i,j) nodes and G is the total heat load. $G=(1+\lambda)R\times S\times\Delta T$; ht_i^k is the unloading time of the kth quantity of reefer at node j, calculated according to the following equation:

$$ht_i^k=\frac{g_j}{u} \tag{4}$$

(4) Time window penalty costs

$$C_4=M_E\sum_{i=1}^{N}\sum_{k=1}^{M}\max\{ET_i-t_i^k,\ 0\}+M_L\sum_{i=1}^{N}\sum_{k=1}^{M}\max\{t_i^k-LT_i,\ 0\} \quad (5)$$

The fuzzy time window penalty cost is counted as a component term of total distribution cost, and for a single customer satisfaction function, the time sensitivity coefficient in this paper is set to 1 for the ith customer satisfaction function:

$$S(t_i^k)=\begin{cases}\dfrac{t_i^k-MET_i}{ET_i-MET_i} & t_i^k\in[MET_i,ET_i]\\ 1 & t_i^k\in[ET_i,LT_i]\\ \dfrac{MLT_i-t_i^k}{MLT_i-LT_i} & t_i^k\in[LT_i,MLT_i]\\ 0 & t_i^k\notin[MET_i,MLT_i]\end{cases} \quad (6)$$

$S(t_i^k)$ It only indicates the degree of satisfaction of individual customers with this delivery and cannot reflect the differences between customers. Therefore, the overall satisfaction of customers for this delivery service is calculated according to formula (7).

$$H=\frac{\sum_{i=1}^{N}g_iS(t_i^k)}{\sum_{i=1}^{N}g_i} \quad (7)$$

(5) Cost of lost goods

$$C_5=\sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N}x_{ij}^kqQ_{ij}^kt_{ij}+\sum_{k=1}^{M}\sum_{i=0}^{N}ht_i^kg_ip \quad (8)$$

2.3 VRP model construction

$$\begin{aligned}\min\{C\}=&\min\{C_1+C_2+C_3+C_4+C_5\}\\ =&\min\{\sum_{k=1}^{M}f_k+\sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N}hx_{ij}^kd_{ij}+\sum_{k=1}^{M}\sum_{i=0}^{N}ht_i^kg_ip\\ &+\sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N}x_{ij}^kqQ_{ij}^kt_{ij}+Q_0\sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N}t_{ij}x_{ij}^kG+\\ &+Q_0\sum_{k=1}^{M}\sum_{i=0}^{N}ht_i^k\gamma S_d\Delta T+M_E\sum_{i=1}^{N}\sum_{k=1}^{M}\max\{ET_i-t_i^k,\ 0\}\\ &+M_L\sum_{i=1}^{N}\sum_{k=1}^{M}\max\{t_i^k-LT_i,\ 0\}\end{aligned} \quad (9)$$

St.

$$\sum_{k=1}^{M}\sum_{j=0}^{N} x_{ij} \leq M\ ,\ (\ i=0\ ) \tag{10}$$

$$t_i \geq 0,\ ht_i^k \geq 0,\ \forall i, j\ \in\ V \tag{11}$$

$$MET_i \leq t_i^k \leq MLT_i,\ (\ i=1,2,3,...,N\ ) \tag{12}$$

$$\sum_{i=0}^{N} g_i \sum_{j=0}^{N} x_{ij}^k \leq G,\ (\ i=1,2,3,...,N,\ i \neq j\ ) \tag{13}$$

$$\sum_{k=1}^{M}\sum_{i=0}^{N} x_{ij}^k = \sum_{k=1}^{M}\sum_{j=0}^{N} x_{ji}^k = 1,\ \forall j \in v,\ k \in\ K \tag{14}$$

$$\sum_{i\in S}\sum_{i\in S} x_{ij}^k \leq |S| - 1,\ \forall S \in N,\ k \in K \tag{15}$$

Equation (10) is a constraint that the total number of distribution paths does not exceed the total number of vehicles in the distribution center, M; Equation (11) is a constraint for non-negative time variables; Equation (12) is a constraint that the arrival time of the distribution vehicle at the customer point must be within the maximum tolerated time window; Equation (13) is a constraint limiting the total amount of customer demand on each distribution path to no more than the maximum capacity of a single distribution vehicle; Equation (14) is a constraint on the continuity of the distribution, that is, the completion of the distribution from a node requires the departure from that node; and Equation (15) is the constraint used to eliminate the sub-loop.

3 MODEL SOLVING ALGORITHM DESIGN

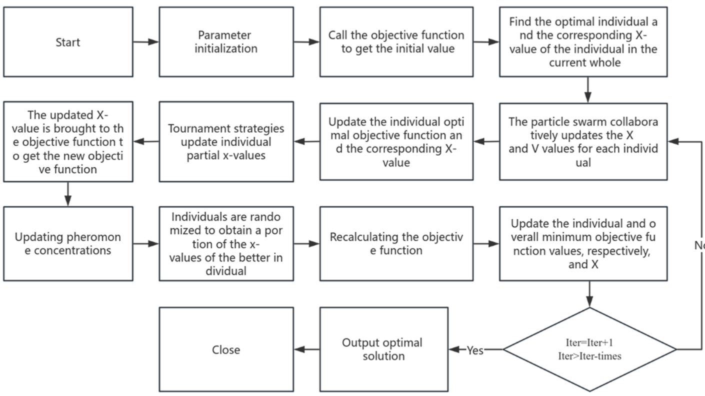

Fig. 1. Flow chart of hybrid ant colony algorithm based on particle swarm optimization

The algorithm flow diagram is shown in Figure 1.The core idea of ant colony algorithm is pheromone positive feedback; the core idea of particle swarm algorithm is collaborative evolution method, that is, the individual has the characteristic of approaching to the better individual; the core idea of tournament strategy is randomized extraction competition. The basic ant colony algorithm is used as the basic solution algorithm, and in the specific design of the solution algorithm, for the shortcomings of the basic ant colony algorithm, which converges slowly and easily falls into the local optimum, the tournament competition mechanism is introduced to avoid falling into the local optimum, and at the same time, the synergistic characteristics of particle swarm algorithm are used to accelerate the convergence of iterations among the particles. Based on this, this paper designs a hybrid ant colony algorithm based on particle swarm, the main idea of the algorithm is:(1) Generate a random path for all individuals (ants), which starts from the distribution center and returns to the distribution center, i.e., satisfying the path continuity constraint. Calculate the objective value (total distribution cost) corresponding to all paths, and record the global and individual optimal results.

(2) According to the particle swarm cooperative characteristic, use the global optimal individual and individual optimal results to update the speed attribute V of an individual and the location attribute X of an individual (distribution path).

(3) Using the tournament strategy, each individual has a seventy percent probability of being compared with a random individual, and if it is weaker than that random individual, its value of X takes the value of X of that random individual.

(4) Normalize the current target value, calculate the cumulative target value according to the pheromone concentration calculation method of ant colony algorithm, and if the cumulative target value of an individual is superior, the other individuals randomly take the value of a segment variable X of the superior individual.

4 EMPIRICAL RESULTS AND ANALYSIS

The specific location of the customer, the amount of demand and the request for delivery time is known, in order to facilitate the subsequent program processing, all the data related to the time in accordance with the 24-hour normalization process, for example: 8:00 a.m. after the normalization of the whole is about 0.33333, the processed data directly in accordance with the operation of the decimal number. Table 1 shows some of the organized node customer data, Table 2 shows the customer node distance.

Table 1. Cost distribution of optimized distribution scheme.

Number	Longitude and Latitude coordinates	Delivery volume	Earliest tolerable reception time	Earliest time to receive	Latest time for receipt	Tolerable minimum reception time
0	121.112782,40.983551	0	0	0	0	0
1	121.128787,41.138443	0.5	0.27083	0.27778	0.33333	0.34722
2	121.153447,41.115201	0.4	0.27083	0.29167	0.33333	0.34722
3	121.093664,41.100466	0.6	0.29167	0.3125	0.34028	0.35417
4	121.137229,41.096180	0.6	0.29861	0.31944	0.34028	0.35417

5	121.154751,41.113536	0.4	0.29167	0.3125	0.32639	0.35417
6	121.119252,41.107820	0.4	0.32639	0.34028	0.36111	0.375
7	121.119133,41.099319	0.5	0.27083	0.29167	0.31944	0.34028
8	121.179247,41.121538	0.4	0.28472	0.30556	0.33333	0.34722
9	121.108853,41.114696	0.5	0.29167	0.3125	0.34722	0.36111
10	121.116335,41.090011	0.8	0.28472	0.29861	0.32639	0.34028
11	121.127251,41.129371	0.5	0.29167	0.30556	0.33333	0.34722
12	121.157258,41.134319	0.3	0.28472	0.3125	0.35417	0.36806
13	121.137281,41.049473	0.4	0.27083	0.29167	0.33333	0.34722
14	121.131891,41.095140	0.6	0.30556	0.31944	0.35417	0.36806
15	121.169639,41.119779	0.5	0.29167	0.3125	0.34028	0.35417
16	121.163017,41.114621	0.4	0.3125	0.33333	0.35417	0.36806
17	121.161112,41.143486	0.6	0.29167	0.30556	0.32639	0.34028
18	121.159489,41.099500	0.6	0.32639	0.34028	0.36806	0.38194
19	121.086458,41.093987	0.4	0.29167	0.30556	0.34722	0.36111
20	121.159376,41.090748	0.5	0.29167	0.30556	0.34722	0.36111
21	121.103995,41.103141	0.6	0.3125	0.33333	0.36111	0.375
22	121.175777,41.112719	0.3	0.29167	0.30556	0.34028	0.35417
23	121.116083,41.144244	0.6	0.29167	0.30556	0.33333	0.34722
24	121.15344,41.1491790	0.4	0.29167	0.3125	0.35417	0.36806
25	121.184869,41.128127	0.5	0.29167	0.29861	0.32639	0.34028
26	121.202035,41.125362	0.6	0.29167	0.3125	0.36111	0.375
27	121.146533,41.121449	0.6	0.31944	0.33333	0.36806	0.38194

Table 2. Cost distribution of optimized distribution scheme

D_{ij}	0	1	2	3	4	5	6	...	21	22	23	24	25	26	27
0	0	20	17	17	15	17	16	...	15	19	22	22	22	23	27
1	20	0	5	6.2	6.6	5.2	5.5	...	5.4	6.6	1.7	3.3	5.3	8	18
2	17	5	0	7	4.1	2.6	5	...	6.2	2.9	6.9	4.8	3.7	4.7	3.1
3	17	6.2	7	0	4.5	5.4	4.2	...	1.3	8.8	7	9.3	9.5	11	2.2
4	15	6.6	4.1	4.5	0	3.2	4	...	3.9	5.7	7.4	8.3	7	10	6.3
5	17	5.2	2.6	5.4	3.2	0	3.4	...	3.6	4.1	6.6	5.5	3.4	6.2	4.4
6	16	5.5	5	4.2	4	3.4	0	...	2.2	6.1	5.6	7.7	7.9	7.1	2.7
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
21	15	5.4	6.2	1.3	3.9	3.6	2.2	...	0	8.4	6.2	9.4	8.3	9.9	5
22	19	6.6	2.9	8.8	5.7	4.1	6.1	...	8.4	0	8.4	6.1	2.2	3.5	5.7
23	22	1.7	6.9	7	7.4	6.6	5.6	...	6.2	8.4	0	5.3	7.1	9.3	3.5
24	22	3.3	4.8	9.3	8.3	5.5	7.7	...	9.4	6.1	5.3	0	4.1	6.8	4.3
25	22	5.3	3.7	9.5	7	3.4	7.9	...	8.3	2.2	7.1	4.1	0	2.3	3.6
26	23	8	4.7	11	10	6.2	7.1	...	9.9	3.5	9.3	6.8	2.3	0	5.2
27	18	3.1	2.2	6.3	4.4	2.7	5.4	...	5.7	3.5	5.2	4.3	3.6	5.2	0

Table 3. Cost distribution of optimized distribution scheme.

Program	Total c ost	Transportation cost	Cooling c osts	Cost of go ods	Penalty c osts	Customer Satis faction
Original	2700	584.8	629.2	220.3	165.7	72.70%
Optimal	2370	544.7	537.5	169.1	19.3	85.20%

Table 3 shows the Cost distribution of optimized distribution scheme. The comparison resulted in significant reductions in transportation costs, refrigeration costs, cargo damage costs, and time window penalty costs, an 88% reduction in penalty time window costs, and a 12.5% increase in customer satisfaction.

5 CAONCLUSION

Aiming at the problems of high distribution cost and low satisfaction in the fresh food cold chain logistics industry, we propose a set of comprehensive solutions. First, a fuzzy time window function is introduced to calculate customer satisfaction so as to evaluate the quality of distribution service more accurately. Then, the cost factors in the distribution process are analyzed in depth, and the distribution path model is constructed to minimize the total distribution cost. In the actual case, the model can effectively deal with the cold chain logistics distribution problem under the fuzzy time window, which provides theoretical guidance and practical reference for the optimization of the operation strategy of cold chain logistics enterprises.

REFERENCES

1. Yuan Y K,Chen J M,et al.Research on the Efficiency and Its Convergence of Cold-chain Logistics Considering Carbon Constriction:Taking Fresh Agricultural Products as an Example[J].Science and Technology Management Research,40(14):253-260.(2020).
2. Xiong Z Y,Shen C,et al.Research Hotspots and Frontiers in the Field of Fresh Cold Chain Logistics in China[J].Logistics Sci-Tech,47(07):137-141.(2024).
3. Miao G.Research on the Coordinated Development of Cold Chain Logistics of Rural Fresh Agricultural Products Based on the Background of Rural Revitalization[J].Logistics Sci-Tech,07:135-137.(2022).
4. Fu Z,Liu W,et al.A Tabu Search Algorithm for the Vehicle Routing Problem with Soft Time Windows and Split Deliveries by Order[J].Chinese Journal of Management Science,25(05):78-86.(2017).
5. Zeng S,Wang B,et al.Target logistics vehicle path optimization based on improved ant colony optimization algorithm[J].Modern Electronics Technique,47(07):181-186.(2024).
6. Ren T,Luo T Y, et al.Knowledge based ant colony algorithm for cold chain logistics distribution path optimization[J].Control and Decision,37(03):545-554.(2022).
7. Ma G P,Pan F..Logistics transportation route research based on improved ant colony algorithm[J].Computer Engineering & Science,42(03):523-528.(2020).
8. Li L Y,Luo J K,et al.Study on optimization of multi-center cold chain joint distribution route and profit allocation[J].Manufacturing Automation,45(10):203-210.(2023).

9. Wu Y F,Han P F,et al.Vehicle Routing Problem with Parallel Time Window Based on Improved Ant Colony Algorithm[J].Logistics Technology,41(06):28-32.(2022).
10. Solomom M. Algorithm for the Vehicle Routing and Scheduling Problems with Time Windows Constraints[J]. Operations Research, 35(2): 255-265.(1987).
11. Wang S Y,Tao F M,Shi Y H,et al.Optimization of Vehicle Routing Problem with Time Windows for Cold Chain Logistics Based on Carbon Tax[J].Sustainability,9(5):201-221.(2017) .
12. Diao X,Fan H, Ren X.et al.Multi-depot open vehicle routing problem with fuzzy time windows [J].Journal ofIntelligent & Fuzzy Systems: Application in Engineering and Technology,40(1):427-438.(2021).
13. Fan H M,Wu J X,et al.Hybrid Genetic Algorithm for Solving Fuzzy Demand and Time Windows Vehicle Routing Problem[J].Journal of Systems & Management,29(01):107-118.(2020).