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A Hybrid Ant Colony Algorithm for Fresh Delivery Route Optimization Considering Quality Loss

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Abstract. At present, the penetration rate of cold chain facilities and equipment in China is still relatively low. The purpose of this paper is to develop an optimal fresh food logistics distribution method on the premise that cold chain distribution cannot be meet. Considering the perishability and time dependence of fresh products, the optimization model of fresh distribution is established, which introduces the quality loss function and time penalty function on. And then, a hybrid ant colony algorithm by combining the 2-opt algorithm is designed, and the state transition rules and pheromone volatility coefficient are improved. Through the empirical study, the result shows that the proposed method has better performance than that of the ant colony optimization. Finally, the comparison with Simulation solution by Logware proves that this research provides an effective means to ensure fresh logistics distribution with low cost and high efficient.

1. Introduction

Since fresh agricultural products are perishable and time-dependent, transportation time and transportation environment are the key factors for their quality and safety. Therefore, reasonable control of logistics distribution of fresh agricultural products is particularly important. After long-term development, cold chain logistics get a lot of improvement in China at present, but the cold-chain infrastructure and equipment construction are also very insufficient [1], according to the report published by Cold chain logistics professional committee of CFLP, China has 134000 refrigerated trucks and 12 million cubic meters of cold storage at present, but the relative share is still not high. Therefore, on the premise that it is impossible to guarantee a good distribution environment, fresh delivery of distribution path planning has become urgent needs. How to choose the optimal distribution route of fresh products without considering cold chain distribution, thus shortening the transportation time of fresh products, reducing the loss of fresh product quality and reducing unnecessary logistics costs, has become an important content of fresh product distribution and the research direction of this paper[2].

The Vehicle Routing Problem was first proposed by Dantzig and Ramseur in 1959. After that, Solomon Marius M (1987) studied the design and analysis of algorithms for solving vehicle routing and scheduling problems with time window constraints[3]. And then, Vehicle Routing Problem with Simultaneous Pickup and Delivery (VRPSPD) began to be studied[4]. SaidSalhi and Grahamk. Rand (1989) started the study of LRP in the real sense[5]. In addition to the static VRP model, the dynamic vehicle path problem is also studied successively. Alinaghian M(2019) presents a new mathematical model for the location of temporary rescue center and the dynamic route of air rescue vehicles to distribute basic materials in rescue operation[6].

In addition to the model studies, the corresponding solution algorithm is also an important research direction with respect to VRP problem. Especially in recent years, intelligent optimization algorithm has been widely used in the field of vehicle path problem. Lahyani R et al.(2019) proposes a hybrid adaptive large neighborhood search algorithm to solve MDOVRP problem[7]. Yao et al.(2019) designed a hybrid ant colony algorithm combining ant colony algorithm and genetic algorithm to solve the problem of vehicle path optimization in fresh logistics[8]. Wang et al. (2016) adopted adaptive mutation particle swarm optimization algorithm to solve the vehicle path optimization[9].

In the research on the Vehicle Routing Problem of fresh agricultural products, Solomonw et al. (1988) applied the time window constraint condition to the vehicle routing[10]. J. b. riton et al.(2012) studied the fuzzy vehicle routing optimization problem of frozen food under uncertain time distribution[11].Pedro Amorim et al.(2014) studied the vehicle routing optimization problem of food distribution in Portugal, but the loss of the goods in transportation was not taken into account in the paper[12]. Kaveh Khalili et al. (2015) studied a new dual-objective mixed integer mathematical programming for the estimation and prediction of perishable products in distribution centers, which provides a method for predicting the quantity of fresh product[13]. K. Govindan et al.(2014) proposed a time window has two levels of location routing problem (2E-LRPTW)[14]. Bortolini M et al.(2016) adopted a fuzzy approach to deal with the uncertainty of time value in the distribution path of frozen products[15]. Hongtao Hu et al.(2017) established a time-dependent mixed integer programming model and an adaptive heuristic algorithm combining variable neighborhood search and particle swarm optimization is proposed. In order to improve the quality of the algorithm, a two-stage decomposition method is proposed[16]. Considering the mixed time window of time sensitive perishable product delay deterioration rate and delivery costs, Wang, X.P et al.(2018) proposed a mixed time window and perishability of the multi-objective optimization model for VRP and proposes a by variable neighborhood search and consider the space and time distance heuristic algorithm of genetic algorithm to solve the complicated multi-objective problem[17].

Considering the perishability and timeliness of fresh food logistics, this paper adds the quality loss function and penalty function as decision-making factors in the construction of fresh food distribution path model. Aiming at the timeliness of fresh delivery and the limitation of delivery time of each store, the state transition rules and pheromone volatility coefficient are improved on the basis of ant colony algorithm. A hybrid ant colony algorithm is designed to optimize the node state selection and path optimization mechanism of ants by combining with 2-opt local search mechanism.

2. Model

2.1. Problem Description

Fresh product distribution center has m special delivery vehicles to provide fresh products distribution service for n nodes. Each distribution vehicle starts from the distribution center and returns to the distribution center after passing through all nodes, and each node has a stipulated window limit for fresh products distribution. The route optimization problem of fresh product distribution is to seek a travel route of the delivery vehicle that meets the target requirements, such as the shortest distribution path, the lowest distribution cost and the best service quality. In view of the timeliness of fresh products, this paper proposes a new fresh distribution path model considering the product quality loss.

2.2. Mathematical Model

Considering that fresh products are perishable, the quality loss function is defined to describe the change of quality of fresh products with time in the process of delivery when modelling. Based on normal temperature distribution, temperature change is not considered, so the temperature of fresh products is set as a constant in the process of delivery. The expression of metamorphism function is:

$$Q(\mathrm{t}) = Q_0 \cdot K \cdot e^{-\beta t} \tag{1}$$

Where Q_0,the quality of fresh products is good, that is, quality before delivery ;t, delivery time; K ,the quality loss rate constant of fresh produce affected by temperature; β ,sensitivity of fresh produce to time, when fresh products are high sensitivity to time, β takes a smaller value, on the contrary, β takes a larger value.

The penalty function refers to the punishment that has not reached customer satisfaction, which is closely related to the time window problem. This paper adopts hard time window for punishment. $\left[a_i, b_i\right]$ is the time window required by each node for delivery arrival. When the delivery arrival time is within the time window, the satisfaction degree of each node is 100%, and no punishment is accepted. When the delivery arrival time is not within the time window, that is, earlier than a_i or later than b_i, the satisfaction degree of each node is 0, and it needs to be punished.

Considering the minimum logistics distribution cost under multiple constraints, the objective function of the distribution model is as follows:

$$\min Z = Q_1 + Q_2 + Q_3 + Q_4 \tag{2}$$

$$Q_1 = mf \tag{3}$$

$$Q_2 = \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{s} d_{ij} x_{ijk} c' \tag{4}$$

$$Q_3 = \mathrm{pg}_i K \left(1 - e^{-\beta t_{0i}}\right) \tag{5}$$

$$Q_4 = \theta_1 \left(t_i - M_i\right) \tag{6}$$

Where f, fixed cost of unit vehicle, including driver's salary, vehicle insurance and annual examination.

s.t.

$$\sum_{s \in m} y_{is} = \begin{cases} 1, i \in n \\ m, i = 0 \end{cases} \tag{7}$$

$$\sum_{s \in \mathrm{m}} \sum_{j \in n} x_{ijs} \le m, \forall i = 0 \tag{8}$$

$$\sum_{j \in n} x_{ijs} = \sum_{j \in n} x_{jis} \le 1, i = 0, k = 1, 2, , , m \tag{9}$$

$$\sum_{i, j \in n} d_{ij} x_{ijk} \le D, \forall s \in m \tag{10}$$

$$\sum_{i \in n} g_i y_{ki} \le Q_L, s = 1, 2, , , , m \tag{11}$$

In the above Eq.2-Eq.6, the objective function is the minimum total cost of fresh logistics distribution, Q_1 is the fixed cost, Q_2 is the transport cost, Q_3 is the cost of goods loss, and Q_4 is the penalty cost. Eq.7 means that each node has and only one vehicle for goods distribution, and all nodes use m vehicles for distribution. Eq.8 means that a vehicle can only have one distribution path, and the sum of all distribution paths is less than the total number of vehicles. Eq.9 means that the fresh logistics distribution center is the starting and ending place of the delivery vehicle. The delivery vehicle starts from the fresh logistics center and returns after completion, forming a closed distribution path. Eq.10 means that the total mileage of vehicles on each distribution path cannot exceed the maximum mileage of vehicles. Eq.11 means that the total demand on each distribution route cannot exceed the maximum capacity of each vehicle.

3. Algorithm

The VRP problem is an np problem. In this paper, ant colony algorithm is used to solve the problem. Due to its slow convergence speed and easy to fall into local optimal defects, so the ant colony algorithm is improved.

3.1. Solution Constructing

In the improved ant colony algorithm set forth herein, a successful solution is a series of distribution paths formed by a number of delivery vehicles starting from the logistics center and finally returning to the logistics center. These distribution routes must be able to provide service only once for all nodes, and must meet the time requirements, vehicle capacity and other constraints of each node. The logistics distribution center shall be set as 0 point, and the distribution route shall be coded in the order of vehicle driving path. As shown in fig. 1:

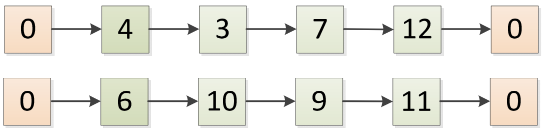

Figure 1. Example of distribution route coding

3.2. State Transition Rules

This paper improves the algorithm as required. When the ant selects the next node through the state transition rule, it is necessary to consider the following two aspects:

(1) the route length of the next node and the pheromone concentration of the path;

(2) the time window requirements of each node are mainly determined by the time window span of the next node and the time required to reach that node. The principle of selecting the next node is as follows: priority should be given to the node with smaller time window span and to the node with shorter time to travel to that node when the time window span is consistent.

When $t_j < E_j$,the delivery vehicle needs to wait until the time window of node j begins before the service; When $t_j > M_j$, the delivery vehicle fails to provide the delivery service for the node on time, which requires a certain degree of punishment and will cause cost burden. Therefore, this paper adds the time window factor of the node to the state transfer probability of the algorithm, which can improve the algorithm to a certain extent. When $E_j < t_j < M_j$, the time window of the node is satisfied, the punishment time $wait_j = 0$, when $t_j < E_j$, $wait_j = \begin{cases} E_j - t_j, & t_j < E_j \\ t_j - \mathrm{M}_j, & t_j > M_j \end{cases}$, and the shorter the penalty time, the greater the probability that the node is selected.

Let the time window span of node j meets: $width_j = M_j - E_j$.When the penalty time required for two nodes that have not been traversed is the same, comparing the time window span of two nodes, and delivery vehicles is priority to deliver the time window span of smaller nodes and the more urgent nodes,which can avoid potential penalty costs and provide more time service for later nodes, thus improving the efficiency of logistics delivery.

The selection of the next node is modified based on the time window. The rules that ants follow when choosing the next node are as Eq.12.

Where τ_{ij}, pheromone concentration; $\eta_{ij} = \frac{1}{d_{ij}}$, is visibility; α、β, the relative important degree of pheromones and heuristics; γ, the important degree that the time window span of the next node is to the path selection; δ, the important degree that the penalty time required for reaching the corresponding node is to the path selection.

$$j = \begin{cases} \max\limits_{j \in N_i^k} \left\{ [\tau_{ij}]^\alpha \, [\eta_{ij}]^\beta \left[\frac{1}{width_j}\right]^\gamma \left[\frac{1}{wait_j}\right]^\delta \right., & q < q_0 \\ P_{ij}^k = \dfrac{[\tau_{ij}]^\alpha \, [\eta_{ij}]^\beta \left[\frac{1}{width_j}\right]^\gamma \left[\frac{1}{wait_j}\right]^\delta}{\sum\limits_{l \in N_i^k} \left([\tau_{ij}]^\alpha \, [\eta_{ij}]^\beta \left[\frac{1}{width_j}\right]^\gamma \left[\frac{1}{wait_j}\right]^\delta \right)}, & q > q_0 \end{cases} \tag{12}$$

3.3. Pheromone Volatility

Based on the in-depth study and discussion of the pheromone volatility factor, this paper makes the following improvements to the original algorithm:

$$\rho = \begin{cases} 0.25, & 0 < N_c < 0.25N_{\max} \\ 0.5, & 0.25N_{\max} < N_c < 0.75N_{\max} \\ 0.75, & 0.75N_{\max} < N_c < N_{\max} \end{cases} \tag{13}$$

As shown in Eq.13， relatively small volatility coefficient is selected at the beginning of iteration to speed up the solution speed of the algorithm, so that the initial solution can be constructed quickly. In the mid-late iteration, the larger coefficient is selected to accelerate the volatilization of pheromone and avoid the algorithm falling into the local optimal solution.

3.4. Improvement Based on the Hybrid 2-Opt Algorithm

As shown in Fig.2, it is assumed that the above distribution path is the optimal solution, and node 4 and node 9 are the two nodes of the current optimal solution. Then thought 2-opt operation, the position of the two nodes in the path are exchanged and the direction of the path also is changed from 9 to 4, a new solution is obtained. Then we need calculate the distribution path cost of the new feasible solution. If Q (after switching) < Q (before switching), the new feasible solution is the current optimal solution.

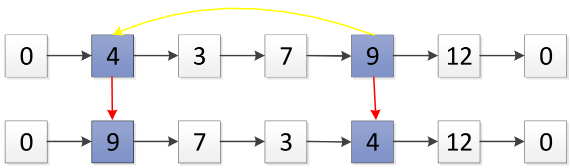

Figure 2. Example of 2- opt algorithm operation

4. Case Analysis

There are 41 stores in a chain-supermarket in Changchun. The delivery vehicles of the supermarket are all ordinary vans. The fresh product distribution mode of the supermarket adopts the traditional regional distribution mode, and the specific distribution routes of each region are arranged according to the distribution situation. This mode of distribution increases the distribution cost and extends the delivery distance. There are great potential risks for fresh products like fruits. Therefore, it is necessary to optimize the fresh delivery scheme of supermarket chains.

It is known that the speed of the delivery vehicle is 50 kilometers per hour, and the unit fuel consumption cost is 0.9465 yuan. The average unit price of fruit per kilo during the survey period is 9.2 yuan (Because of the variety of fresh products, we only use fruits as the research object). The sensitivity of fresh produce to time β =1/200. The type of delivery vehicle is a 5-ton van.

4.1. Algorithm Implementation

As a result of MATLAB software solution, the optimal distribution scheme is as Table 1.

Table 1. Results of hybrid ant colony algorithm solution

Algorithm	Hybrid ant colony algorithm				
Vehicle number	11	Route length/km	Vehicle load capacity utilization	Distribution costs (yuan/year)	
Total mileage	378.045 km				
Distribution path	0-3-1-40-17-0	36.9762	82%	Fixed cost	764500
	0-7-22-4-2-0	17.2768	50%		
	0-6-23-11-12-28-0	36.4094	84%	Transport cost	130603.99
	0-19-24-27-0	31.6421	70%		
	0-9-34-10-0	36.6359	72%	Penalty cost	113488.97
	0-38-30-14-0	43.5160	70%		
	0-29-41-25-20-0	72.3729	78		
	0-18-21-31-0	22.3619	80%	Loss cost	308363.24
	0-5-13-37-26-0	24.7662	76%		
	0-35-33-36-32-0	25.9597	81	The total cost	1259371.75
	0-15-39-16-8-0	30.1275	98%		

Eventually, 11 delivery vehicles are needed, and the total mileage of the delivery of 41 stores is 378.045 km, and the total cost is 1259371.75 yuan every year.

4.2. Distribution Solution Based on Logware Software

In this paper, the path optimization function of multiple vehicles and distribution points in Logware software was applied to optimize the frech delivery scheme of this chain-supermarket. The realization principle of this function chooses the shortest route of distribution route network.

The results show that 15 vehicles are needed for delivery and the detailed is shown in Table 2.

Table 2. Results of Logware runs

No.	Travel route	Quantity of store	Travel distance/ km	Travel time/h	Load/ kg	Load capacity utilization rate	Fuel costs
1	0-3-1-24-26-21-0	5	41.535	2.2474	5000	100%	39.31
2	0-5-4-7-39-0	4	31.364	2.1273	4100	82%	29.69
3	0-22-2-8-36-12-28-18-31-0	8	55.810	3.8662	4400	88%	52.82
4	0-9-29-25-0	3	60	2.5	4000	80%	57.22
5	0-15-14-41-37-0	4	52.799	2.3893	3250	65%	49.97
6	0-16-27-32-0	3	33	2.1	3400	68%	31.45
7	0-19-17-40-0	3	52	2.1	3900	78%	48.05
8	0-23-11-6-0	3	20	1.1	3500	70%	18.73
9	0-34-10-38-30-0	4	41	2.3	4800	96%	38.63
10	0-35-33-13-20-0	4	56	2.7	4400	88%	53.37
Total		41	443.508	23.4302	40750	81.5%	419.25

From Eq.2- Eq.6, we can obtain the annual total cost of the distribution scheme.

$$Q = Q_1 + Q_2 + Q_3 + Q_4 = 635000 + 153025.16 + 511262.07 + 61892.32$$
$$= 1361179.55 \text{ yuan}$$

4.3. Comparing Optimization Scheme between Software and Algorithm Implementation

The comparison between Table 1 and Table 2 shows that compared with hybrid ant colony algorithm, the solution obtained by Logware only needs 10 delivery vehicles. The quantity of vehicles has decreased by 9% and the average load capacity utilization rate for distribution vehicles has increased by 7.4 %. Therefore, it can reduce the waste of logistics resources to a certain extent and improve the utilization rate of vehicles. In addition, the Logware solution has a high punctuality rate, which greatly improves the logistics service quality of fresh logistics distribution and increases the satisfaction of each store in distribution. The Logware solution ignored the delivery mileage in the pursuit of fewer vehicles to meet the time window limit of each store to the maximum extent. As the distribution mileage of single delivery vehicle increases, the running time of the vehicle is extended, which makes the transportation cost and the cost of goods loss increase in the delivery process.

Although each store has higher satisfaction and fewer vehicles are delivered under the Logware optimized scheme, the distribution scheme obtained by the modified hybrid ant colony algorithm largely reduces the delivery mileage, shortens the running time of the delivery vehicle on the path, improves the efficiency of logistics distribution, and at the same time reduces the degree of inevitable loss of fresh goods in the transportation and distribution.

Table 3. Results of optimization

Algorithm	Hybrid ant colony algorithm				
Vehicle number	11	Route length/km	Vehicle load capacity utilization	Distribution costs (yuan/year)	
Total mileage	378.045 km				
Distribution path	0-3-1-24-26-21-0	41.535	100%	Fixed cost	635000
	0-5-4-7-39-0	31.364	82%		
	0-22-2-8-36-12-28-18-31-0	55.810	88%	Transport cost	153025.2
	0-9-29-25-0	60	80%		
	0-15-14-41-37-0	52.799	65%	Penalty cost	511262.07
	0-16-27-32-0	33	68%		
	0-19-17-40-0	52	78%		
	0-23-11-6-0	20	70%	Loss cost	61892.32
	0-34-10-38-30-0	41	96%		
	0-35-33-13-20-0	56	88%	The total cost	1259371.8
	0-15-39-16-8-0	30.1275	98%		

In conclusion, through the comparison of the two schemes, the modified hybrid ant colony algorithm can obtain a better distribution scheme. Table 3 shows the optimal distribution scheme of the supermarket chain.

5. Conclusions

Logistics distribution has always been a research hotspot in the field of logistics. With the rapid development of logistics in recent years, more enterprises begin to pay more attention to logistics distribution. A good distribution mechanism can bring considerable economic benefits to enterprises.

Considering the characteristics of fresh products, this paper introduces the quality loss function and penalty function, and the time-dependent of fresh products and the time limitation of stores can make the delivery optimization more accurate. On this basis, the logistics cost of the process design of fresh product distribution is analyzed, and the distribution scheme optimization model is established. Aiming for this problem, this paper designed a hybrid ant colony algorithm, and based on the case of fresh product delivery in changchun supermarket chain, this paper uses improved algorithm and Logware software to solve respectively, then compare and analyze it, which verified the feasibility of the algorithm. Although the improved algorithm can be verified, there are still some defects, such as not considering the possible traffic control and vehicle dynamics in real life. Furthermore, this paper only considers the time factor from the distribution center to each store, and does not consider the time of the origin to the distribution center. Therefore, we need to further study the fresh product delivery model and algorithm.

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