REAL-TIME TRAFFIC VEHICLE ROUTING PROBLEM FOR AGRICULTURAL PRODUCTS

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Abstract

High cost and long travel time are the major problems in the cold chain logistics distribution for fresh agricultural products. To solve this problem, the article proposes an urban distribution path optimization model based on real-time traffic conditions for agricultural products' cold chain logistic. It uses ant colony optimization algorithms to solve the model and using case study to validate. The results show that cold chain delivery of agricultural products, which is based on real-time traffic information, can effectively reduce the travel time of cold chain delivery and improve customer satisfaction.

Keywords: Vehicle routing problem, cold chain logistics, real-time traffic

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Introduction

With the adjustment of agricultural structure in various countries, the varieties and output of fresh agricultural products are on the rise year by year. Due to the increasing demand on the quality of fresh agricultural products and food safety, the output and cold-chain circulation of fresh agricultural products are also increasing. Distribution is an extremely important link in the cold chain circulation, as distribution takes over 80% of the time of the whole process from the production by agricultural enterprises or by farmers to becoming final dishes on the dining tables (Zhou, 2015). Therefore, it is of great importance to reduce the cost of cold chain logistics for the market competitiveness of fresh agricultural products by various means such as rationally arrangement of vehicle scheduling and routes, minimizing the delivery time of fresh agricultural products and reducing the loss in their circulation.

Research Objective

This paper discusses a vehicle routing problem (VRP) model that acquires information of urban traffic and applies to cold chain distribution of agricultural products. The optimized distribution program shortens the delivery time of fresh agricultural products and reduces the cost of cold chain logistics distribution. It can improve the market competitiveness of fresh agricultural products and promote farmers to increase their income.

Literature review

Dantzig & Ramser (1959) first proposed VRP in transportation. Afterwards, many scholars have paid attention and made a lot of research. In recent years, due to the diversification of customer needs, it is often necessary to send fresh produce to the demand point at a specified time or time frame. Thus, the VRP in the distribution has developed into a distribution vehicle path problem with time windows (VRPTW). Azi, Gendreau & Potvin (2007) established a VRPTW model for cold chain logistics distribution rigidly specifying delivery time of delivery vehicle, that is, the delivery time of perishable food. Then, it studied changes in total distribution cost if hard time window was relaxed to soft time window. Zhao (2009) studied the VRP model of food cold chain distribution with soft time windows, taking the minimum distribution cost as objective function, and considering the penalty cost of violating the time window. Subsequently, the cold chain distribution model established by Miao et al. (2011) considered the cost of cargo damage in the total cost of distribution in addition to the penalty cost. Cost of cargo damage includes heat loss generated during driving and opening of the compartment door. Shi & Fu (2013) systematically studied the optimization of food cold chain distribution. A function of customer satisfaction was designed based on soft time window to analyze the travel time in combination with the time-varying characteristics of the distribution network, thus establishing a simulation model under the time change conditions. On the basis of the study of traditional vehicle routing problem, Liu & Ru (2016) puts forward the vehicle routing problem considering the traffic jam and the workload balance. Results show that the traffic jam will significantly increase the total travel time by an average of 18.38%. Xiao et al. (2017) introduced travel restriction factors, such as urban subregions and vehicle models, into the vehicle routing problem. Aiming at the minimum total cost of transportation and other expenses, constructed a vehicle routing optimization model based on urban road travel restriction with multiple energy sources and multiple vehicle models. Worawattawechai, Intiyot & Jeenanunta (2016) proposed a vehicle routing problem with backhauls and time Windows (VRPBTW) involves two different subsets of customers known as linehauls and backhauls. And a cuckoo search (CS) algorithm is proposed to solve it.

Previous VRP studies for cold chain logistics distribution mainly focused on the VRP under static network. That means the components of distribution, such as vehicles, roads, and customer requirements, are assumed to be constant. However, in the actual management process of cold chain distribution, factors such as products' deteriorating speed & rate, traffic condition, and customer demand often change indefinitely. In particular, the increasingly poor urban traffic makes the urban distribution difficult in the "last mile" of cold chain logistics of agricultural products.

Description

Distributing fresh agricultural products from a cold chain logistics distribution center to various demand points (supermarkets, restaurants, canteens, convenience stores of residential communities, etc.) in urban area. The cold chain logistics distribution center has M special refrigerated vehicles to serve N demand points in the urban area. Each refrigerated vehicle leaves and returns to the center after passing designated demand points. The optimizing goal herein is to build a mathematical model based on existing resources and customer demand, obtain real-time road congestion information, and use a suitable algorithm to quickly find a distribution strategy. Refrigerated vehicles shall leave the cold chain logistics distribution center according to specified order, size of loading, departure time and driving route (line), thus minimizing total logistics costs of the whole process. The logistics costs include transportation and distribution cost, cargo damage cost, cooling energy cost, penalty cost, and fixed costs. It is as shown in Figure 1.

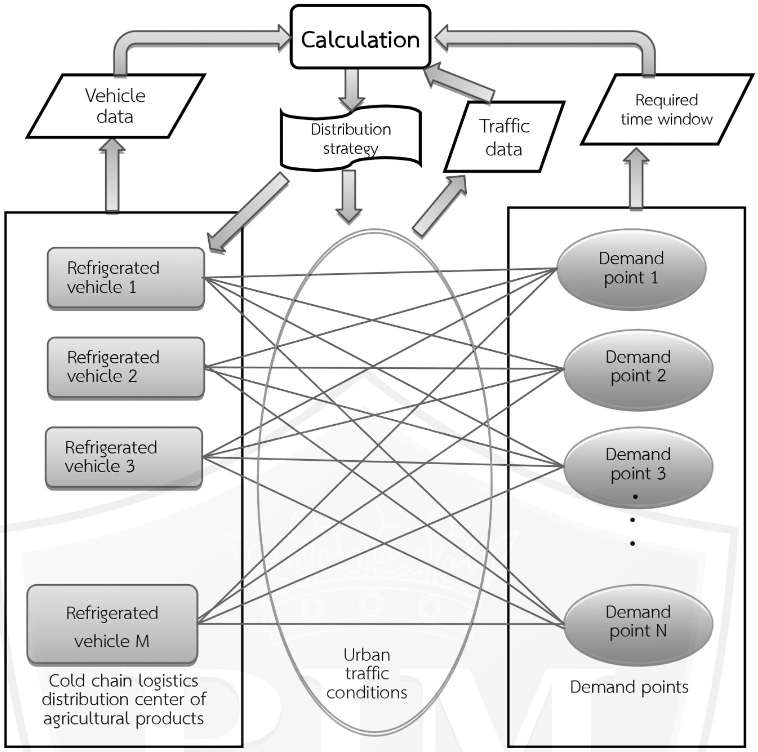

Figure 1 Cold chain logistics distribution based on real-time traffic conditions

Assumptions

(1) The road congestion situation remains relatively stable, that is, the road congestion condition remains unchanged from the time when the delivery decision is made until the delivery vehicle passes the road section.

(2) The number of refrigerated vehicles in the distribution center is fixed, the load capacity of each vehicle is limited, and the total demand of each customer does not exceed the maximum load of each single vehicle. (This assumption is for the convenience of solution of the model. In actual situations, if the total demand of a customer is greater than the maximum load of a vehicle, it can be handled by splitting the customer into two or more customers).

(3) Each customer is guaranteed to receive the service and the fresh agricultural products required can only be delivered by a refrigerated truck.

(4) The total distance of each delivery route is not greater than the endurance mileage of the delivery vehicle (i.e., no refueling in the midway of delivery).

(5) The distribution center has sufficient fresh agricultural products, and the customer's demand, geographical location and time window constraints are known.

(6) Fresh agricultural products shall be delivered at the specified time window, and overdue penalty shall be paid.

(7) After the loaded refrigerated vehicle leaves the distribution center, there is no temporarily assigned task during the delivery.

After the delivery is completed, the vehicle shall return to the distribution center.

Variables Analysis

1. Analysis on Time variables.

Number the distribution center and demand (customer) points, v_0 represents the distribution center, and v_i represents each customer point (I = 1, 2,...N). Real-time traffic congestion coefficient r_{ij} of each road segment (v_i, v_j) (i, j = 1, 2,...N) can be obtained through the free interface of urban real-time traffic conditions provided by Baidu map, Gaode map and other apps, wherein, $r_{ij} = r_{ji}$, $0 \le r_{ij} \le 1$, different levels of congestion are indicated from 0 (unblocked) to 1 (complete blockage).

The time of the delivery vehicle running on the (v_i, v_j) section is:

$$t_{ij} = \frac{L_{ij}}{V_0(1-r_{ij})} \qquad (1)$$

Wherein, L_{ij} represents the distance of (v_i, v_j), and V_0 represents the average speed of the normally running vehicle.

The unloading time for the v_i delivery vehicle is: $t_i = ug_i$, where g_i represents the demand of the i-th customer, and u represents the average unloading speed.

2. Analysis on Distribution Cost

(1) Fixed cost of delivery vehicles (C_1)

The fixed costs required for delivery services, such as drivers' salaries and vehicle depreciation costs, are only related to the number of refrigerated vehicles used at the distribution center. Therefore, the total fixed cost of the delivery vehicle is:

$$C_1 = f\sum_{i=1}^{M} sign(Car_i) \qquad (2)$$

Wherein, f is the fixed fee generated for using a delivery vehicle each time, and $sign$ (Car_i) is the identification function for using the i-th delivery vehicle, 1 for using and 0 for not using. That is:

$$sign(Car_i) = \begin{cases} 1, & Car_1 = 1,2,3,\cdots,\mathrm{M} \\ 0, & Car_i = 0 \end{cases} \qquad (3)$$

(2) Variable transportation cost of delivery vehicle (C_2)

The transportation cost of a refrigerated vehicle includes fuel cost, maintenance cost of the vehicle, and it is positively related to the mileage of the vehicle:

$$C_2 = \sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} hx_{kij}L_{ij} \qquad (4)$$

Wherein h is the transportation cost per kilometer of the delivery vehicle, x_{kij} is represented by 0 or 1, and $x_{kij} = 1$ indicates that the k-th vehicle passed the road segment (v_i, v_j), otherwise $x_{kij} = 0$.

(3) Cooling energy cost of refrigerated vehicles (C_3)

The cooling energy cost of refrigerated vehicles is mainly the cost of refrigerant consumption. Refrigerant consumption is related to cooling time, compartment size, temperature difference between inside and outside the vehicle, how much cargo is loaded in the vehicle, times of opening doors and time of opening the compartment (unloading time). The external environment is relatively stable due to the fixed specifications of the delivery vehicles and the requirement for the compartment's temperature in delivery of fresh agricultural products. The refrigeration cost for a refrigerated distribution vehicle can be approximately considered to be positively related to vehicle running time, times of opening doors and time of opening the compartment (unloading time, that is, the time spent at the customer's point). Moreover, it is required to open the compartment door only once when unloading the goods at each customer point in the entire distribution process, so the total unloading time at each point and the total customer demand are determined. This allows constant *a* to be used to represent the cooling cost for door opening and unloading during the entire distribution. Therefore, the cooling cost of refrigerated distribution vehicles can be expressed as:

$$C_3 = \sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} bx_{kij}t_{ij} + a = \sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} bx_{kij}\frac{L_{ij}}{V_0(1-r_{ij})} + a \qquad (5)$$

Wherein, *b* is the cooling consumption coefficient.

(4) Damage cost of fresh agricultural products (C_4)

During the distribution process, the delivery vehicle can use its own refrigeration equipment to keep the compartment at a safe temperature. Therefore, the damage cost of fresh agricultural products is only related to transportation time, times of opening the compartment doors and unloading time. Similar to the analysis on cooling cost, the total number of times of door opening and the total unloading time are determined, so the cost of cargo damage can be expressed as:

$$C_4 = \sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} qx_{kij}t_{ij} + p = \sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} qx_{kij}\frac{L_{ij}}{V_0(1-r_{ij})} + p \qquad (6)$$

Wherein, *q* is the damage cost coefficient, and *p* represents the cargo damage constant caused by opening the compartment doors and unloading.

(5) Penalty cost for exceeding customer's required time window (C_5)

It's assumed that the time window of cold chain distribution required by customer *j* is $[d_j, u_j]$, and the maximum tolerable time window is $[D_j, U_j]$ ($D_j \le d_j$, $u_j \le U_j$). That is to say, if the delivery time is within $[d_j, u_j]$, the penalty cost is 0; if it is over $[d_j, u_j]$ but within $[D_j, U_j]$, there is a penalty cost; if it is over $[D_j, U_j]$ and there is rejection, the penalty cost is $+\infty$. The penalty coefficient delivered before the time window $[d_j, u_j]$ is w_1, and the penalty coefficient delivered after the time window $[d_j, u_j]$ is w_2, and T_j is the time point at which the delivery vehicle arrives at the customer *j* ($D_j \le T_j \le U_j$). The penalty cost for exceeding customer's required time window can be expressed as:

$$C_5 = w_1\sum_{j=1}^{N}\max\{d_j - T_j,\ 0\} + w_2\sum_{j=1}^{N}\max\{T_j - u_j, 0\} \qquad (7)$$

Optimized cold chain routing model

According to the analysis in the previous section, the optimized model of cold chain routing of agricultural products based on real-time urban traffic conditions is to find a distribution route that minimizes the total distribution cost under the premise of meeting resource constraints (constraints).

The objective function *C* is composed of fixed cost, transportation cost, cargo damage cost, cooling energy cost and penalty cost of exceeding time window.

The condition for the total number of delivery routes not exceeding the total number *M* of vehicles in the distribution center is:

$$\sum_{k=1}^{M}\sum_{j=0}^{N} x_{kij} \le M, \quad (i=0) \tag{8}$$

Constraint condition for that both the starting point and the destination of each distribution route are at the distribution center v_0 is:

$$\sum_{j=1}^{N} x_{kij} = \sum_{j=1}^{N} x_{kji} \le 1, \quad (i=0, k=1,2,3,\cdots,M) \tag{9}$$

Constraint condition for that only one delivery vehicle delivers goods to each customer point once is expressed as:

$$\sum_{k=1}^{M}\sum_{i=0}^{N} x_{kij} \le 1, \quad (j=1,2,3,\cdots,N,\ i \ne j) \tag{10}$$

$$\sum_{k=1}^{M}\sum_{j=0}^{N} x_{kij} \le 1, \quad (i=1,2,3,\cdots,N,\ i \ne j) \tag{11}$$

For the total customer demand on each delivery route not exceeding the maximum cargo capacity of a single refrigerated vehicle, the constraint condition is expressed as:

$$\sum_{i=0}^{N} g_i \sum_{j=0}^{N} x_{kij} \le G, \quad (k=1,2,3,\cdots,M,\ i \ne j) \tag{12}$$

Wherein, g_i represents the demand of the *i*-th customer and G represents the maximum cargo capacity of each refrigerated vehicle. To ensure that the maximum distance of delivery of each vehicle is less than the maximum endurance mileage S of each vehicle, the constraint condition is expressed as:

$$\sum_{i=0}^{N} {}_i \sum_{j=0}^{N} L_{ij} x_{kij} \le S, \quad (k=1,2,3,\cdots,M,\ i \ne j) \tag{13}$$

The time required for the delivery vehicle to reach the customer point must be within the maximum tolerable time window. The constraint condition is expressed as:

$$D_i \le T_i \le U_i, \quad (i=1,2,3,\cdots,N) \tag{14}$$

In summary, the optimized mathematical model of cold chain routing of agricultural products based on real-time traffic conditions is constructed as follows:

$$MinC = Min\{C_1 + C_2 + C_3 + C_4 + C_5\}$$

$$= Min\Big\{\ f\sum_{i=1}^{M} sign(Car_i) + \sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} h x_{kij} L_{ij}$$

$$+\sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} b x_{kij} \frac{L_{ij}}{V_0(1-r_{ij})} + a$$

$$+\sum_{k=1}^{M}\sum_{i=0}^{N}\sum_{j=0}^{N} q x_{kij} \frac{L_{ij}}{V_0(1-r_{ij})} + p$$

$$+w_1 \sum_{j=1}^{N} \max\{d_j - T_j, 0\} + w_2 \sum_{j=1}^{N} \max\{T_j - u_j, 0\}\ \Big\}$$

$$
s.t.\begin{cases}
\sum_{k=1}^{M}\sum_{j=0}^{N} x_{kij} \le M, & (i=0) \\
\sum_{j=1}^{N} x_{kij} = \sum_{j=1}^{N} x_{kji} \le 1, & (i=0, k=1,2,3,\cdots,M) \\
\sum_{k=1}^{M}\sum_{i=0}^{N} x_{kij} \le 1, & (j=1,2,3,\cdots,N, \quad i \ne j) \\
\sum_{k=1}^{M}\sum_{j=0}^{N} x_{kij} \le 1, & (i=1,2,3,\cdots,N, \quad i \ne j) \\
\sum_{i=0}^{N} g_i \sum_{j=0}^{N} x_{kij} \le G, & (k=1,2,3,\cdots,M, \quad i \ne j) \\
\sum_{i=0}^{N} i \sum_{j=0}^{N} L_{ij} x_{kij} \le S, & (k=1,2,3,\cdots,M, \quad i \ne j) \\
D_i \le T_i \le U_i, & (i=1,2,3,\cdots,N)
\end{cases} \tag{15}
$$

Solution of Optimized Cold Chain Routing Model

This model seeks the optimal distribution path for minimizing distribution cost in cold chain routing. For the case of many influencing factors and constraints, it is very difficult to use an accurate algorithm. Ant colony algorithm is a random search algorithm that mimics the behavior of the ant colony's foraging process. It is to find the shortest path and is widely used in the fields of vehicle height, task assignment, coloring, large-scale integrated circuit design, and communication network. Finding the shortest (optimal) distribution route for vehicles is very similar to ant foraging, and the ant colony algorithm has short search time, high efficiency, and good optimization effect. Therefore, this paper uses the ant colony algorithm to find a cold chain distribution scheme of agricultural products with the lowest total cost of distribution based on real-time traffic conditions and meeting the required time window for delivery.

1. Algorithm Design

The number of ants in the algorithm is the number *M* of delivery vehicles, the amount of foods, that is, the number of demand points, is *N*, and $\tau_{ij}(T)$ is the amount of information left by ants (delivery vehicles) from the food (demand point) *i* to the demand point *j* at time *T*. At the same time, after ant *k* passes through a demand point, serial number of the demand point is added to the tabu list $tabu_k$ of ant *k*. Assume $P_{ij}^{k}(T)$ denotes the probability that the *k*-th ant moves from the demand point *i* to the demand point j at time *T*, then $P_{ij}^{k}(T)$ is defined as follows:

$$
P_{ij}^{k}(T) = \begin{cases}
\dfrac{\tau_{ij}^{\alpha}(T)\eta_{ij}^{\beta}(T)}{\sum_{l \in allow_k} \tau_{il}^{\alpha}(T)\eta_{il}^{\beta}(T)}, & j \in allow_k \\
0 \quad , & others
\end{cases} \tag{16}
$$

In the above formulae (16), $allow_k$ = {1, 2,...,*N*} represents a set of demand points that ant *k* has not yet accessed, that is, a set adjacent to the current demand point but not including the visited demand point. After ant *k* completes a cruise, if *N* demand points are filled in the tabu list $tabu_k$, its cruise path is a feasible solution to find the optimal path.

α and β are respectively two weight coefficients, where α indicates the influence of the pheromone on the residual path *ij* on the subsequent ant to selecting path. When $\alpha = 0$, it means that there is no influence on the ants, and they will choose the path at random. β is a priori knowledge heuristic factor, indicating the degree of influence of priori knowledge (predictability) on ants' selection of path. When $\beta = 0$, it indicates that the ants will choose according to the pheromone concentration.

$\eta_{ij}(T)$ is a heuristic function, indicating the probability that an ant will move from *i* to *j*. According to the specific problem of this paper, it is defined as:

$$\eta_{ij}(T) = \frac{1 - r_{ij}}{L_{ij}} \quad (17)$$

Here L_{ij} is the distance between the demand point *i* and the demand point *j*, and r_{ij} is the congestion coefficient of the road.

Since pheromone concentration is an important factor affecting the ant's path selection, it is necessary to update the pheromone in time. The pheromone updating formula is:

$$\tau_{ij}(T+1) = (1-\rho)\tau_{ij}(T) + \Delta\tau_{ij}(T, T+1) \quad (18)$$

In the above formulae (18), ρ is the pheromone volatilization coefficient, and its value range is $0 < \rho < 1$ for avoiding an infinite increase in the pheromone on the path; $\Delta\tau_{ij}(T)$ represents the pheromone increase released by the ant during its movement from the demand point *i* to the demand point *j*. Generally, the initial pheromone $\tau_{ij}(T) = 0$, $\Delta\tau_{ij}^{k}(T)$ represents the pheromone concentration released by ant *k* on *ij*, and $\Delta\tau_{ij}(T, T+1)$ represents the pheromone increase after the ant passes the *ij* path:

$$\Delta\tau_{ij}(T, T+1) = \sum_{k=1}^{M} \Delta\tau_{ij}^{k}(T, T+1) \quad (19)$$

If the ant updates the pheromone after accessing all the cities, the updating formula of pheromone is:

$$\tau_{ij}(T+N) = (1-\rho)\tau_{ij}(T) + \Delta\tau_{ij}(T, T+N) \quad (20)$$

$$\Delta\tau_{ij}(T, T+N) = \sum_{k=1}^{M} \Delta\tau_{ij}^{k}(T, T+N) \quad (21)$$

After passing all the demand points, the tabu list $tabu_k$ has been filled. Calculate the comprehensive cost of distribution of each ant (distribution vehicle), and find out the less comprehensive cost of distribution by pairwise comparison, i.e., the better path. Then repeat to find a better solution till the optimal path is found.

2. Algorithm Implementation

Construct an ant colony in certain scale. From the starting point (distribution center), each ant chooses a path to move to the next node (demand point) according to the pheromone concentration on each path, and each path is determined as good or bad based on the amount of released information. Each ant's transfer process is a solution, and the optimal solution is to be found by repeating and looping. The algorithm implementation steps are as follows:

Step 1: Initialize each parameter, make T = 0, the number of iterations N_{co} = 0, maxN_{co} be the maximum number of iterations, the initial pheromone quantity $\tau_{ij}(0) = c$ (c is a constant), the pheromone increment $\Delta\tau_{ij}(0) = 0$, and define and clear the tabu table *tabu*;

Step 2: Place M ants at N demand points;

Step 3: Start cycle count $N_{co} = N_{co}+1$;

Step 4: Let index number of the tabu table k=1;

Step 5: $k = k+1$;

Step 6: Calculate the probability that the ant selects the demand j according to the transition probability formulae (6);

Step 7: Compare the transfer probability of each demand point, and then move the ant to the demand point with the highest transfer probability, and this point is included in the tabu table $tabu_k$;

Step 8: If $k < N$, which indicates that some demand points are still not accessed, return to Step 5, otherwise go to the next step;

Step 9: Calculate the comprehensive cost C_k for the ant (distribution vehicle) having passed the paths, and update the pheromone according to formulae (19), (20), and (21);

Step 10: If the number of iterations N_{co} < maxN_{co}, empty the tabu table and go to Step 3, otherwise terminate the loop s and obtain the result.

Case Analysis

1. Data source

A dairy company in Nanning of China distributes bottled fresh milk from its distribution center to 22 fresh milk demand points (secondary distribution stations, kindergartens, retail stores, etc.) in the urban area. Each bottle of fresh milk weighs about 380g and they will be transported under refrigeration. The temperature of the refrigerated compartment needs to be maintained at 2-6 °C.

The distribution center and each demand point as distribution nodes are numbered, where the distribution center is 0, and each demand point is numbered 1 to 22 respectively. The specific address, demand volume and required time (agreed time window and acceptable time window) of each delivery node are known.

It is to query the shortest route distance between each distribution node on the Baidu map to get the distribution distance between the nodes.

2. Parameter setting

Parameter selection of the ant colony algorithm plays a crucial role in search ability of optimal result and convergence effect. In this paper, referring to the existing research results and repeated data experiments, the pheromone heuristic factor, the expectation heuristic factor, and the pheromone volatilization coefficient are taken as 1, 3 and 0.4, respectively. The values and meanings of the specific parameters of this example are shown in Table 1.

Table 1 Parameter values and meanings

Parameter	Parameter Value	Parameter Meaning	Parameter	Parameter Value	Parameter Meaning
G	2.0	Maximum load of distribution vehicle (T)	$t0$	6:00	Time of starting distribution
S	90	Maximum travel distance of distribution vehicle (Km)	u	0.001	Rate of unloading (h/Kg)
V_0	30	Average speed of distribution vehicle (Km/h)	M	3	Number of distribution vehicles
h	2.1	Running cost of distribution vehicle (Yuan/Km)	N	22	Number of demand points
f	120	Fixed cost of each vehicle (Yuan/time)	$maxN_{co}$	200	Maximum number of iterations
a	300	Fixed cooling cost (Yuan)	Ant	15	Number of ants
b	6.5	Cooling consumption coefficient (Yuan/h)	α	1	Pheromone heuristic factor
q	3	Cargo damage cost coefficient (Yuan/h)	β	3	Expectation heuristic factor
p	60	Cargo damage constant per time (Yuan)	ρ	0.4	Pheromone volatilation coefficient
w_1	5	Penalty coefficient for delivery before time window	Q	100	Pheromone intensity
w_2	20	Penalty coefficient for delivery after time window	c	1	Initial pheromone

According to the real-time traffic conditions of the urban area from Baidu Map, the road congestion coefficient is determined. The real-time traffic conditions are divided into four levels: "unblocked", "slowly", "crowded" and "seriously congested". The most frequent level indicates the traffic condition on one road. The congestion coefficients of the four grades defined by the equal proportion method are 0.2, 0.4, 0.6 and 0.8, respectively.

3. Calculation results

Using the model and algorithm of this paper, the above example is solved, and MATLAB programming is used to run 5 times on a personal computer. The results are shown in Table 2.

Table 2 Solution results

Number of calculations	Optimal solution	Corresponding delivery path
1	1166.86	0-17-20-15-22-19-8-18-0 0-2-12-16-4-7-9-21-0 0-1-14-13-11-3-10-5-6-0
2	1165.66	0-17-20-15-22-19-8-18-0 0-2-12-16-4-7-9-21-0 0-1-14-13-11-10-3-5-6-0
3	1162.63	0-17-20-15-22-19-8-18-21-0 0-2-12-16-4-7-9-0 0-1-14-13-11-3-10-5-6-0
4	1181.36	0-17-20-15-22-19-8-18-21-0 0-9-16-12-4-1-7-9-0 0-14-13-11-3-10-5-6-0
5	1166.86	0-17-20-15-22-19-8-18-0 0-2-12-16-4-7-9-21-0 0-1-14-13-11-3-10-5-6-0

From the calculation results, considering the real-time traffic conditions, the optimal cold chain distribution scheme for fresh milk is:

Distribution line of vehicle 1: 0-17-20-15-22-19-8-18-21-0; vehicle 2: 0-2-12 -16-4-7-9-0; vehicle 3: 0-1-14-13-11-3-10-5-6-0.

4. Analysis of results

In this case, considering the real-time traffic conditions, the total cost of cold chain logistics distribution is at least 1,162.63 yuan, and three refrigerated vehicles are adopted.

Without considering the real-time traffic conditions of urban roads, the original distribution plan of the distribution center is: distribution line of vehicle 1: 0-17-20-15-22-19-8-1-2-0; vehicle 2: 0 -2-16-12-4-1-7-9-0; vehicle 3: 0-14-13-11-3-10-5-6-0. The actual distribution cost of the original scheme on the same day (the same situation of road congestion) was 1,210.35.

Table 3 shows comparative analysis on costs between the optimization scheme based on real-time traffic conditions and the original distribution scheme.

Table 3 Cost analysis between optimization scheme based on real-time traffic conditions and original distribution scheme

Scheme	Total distribution cost	Fixed cost of vehicle	Transport cost	Cooling cost	Cargo damage cost	Penalty cost of time window
Original scheme	1,210.35	360.00	329.49	345.29	80.90	94.66
Optimization scheme based on real-time traffic conditions	1,162.63	360.00	318.78	345.18	80.85	57.83

It can be seen from Table 3 that the optimization scheme of cold chain distribution based on real-time traffic conditions reduces the total distribution cost by 3.94% without increasing any fixed investment, especially the penalty cost is reduced by 39.81%, the decline was most pronounced. This shows that the optimization scheme of cold chain distribution based on real-time traffic conditions can flexibly adjust the refrigerating vehicle's distribution strategy according to the real-time traffic congestion information, effectively improve the timely delivery rate of products, and improve the customer satisfaction while reducing the distribution cost.

Conclusion

Based on real-time traffic conditions, this paper constructs an optimization model for cold chain distribution path of agricultural products. It considers time window, distribution vehicle constraints, customer demand and real-time road congestion for achieving the minimum total cost of distribution. It uses ant colony algorithm to design the solution method of the model. This algorithm, in which each ant searches for the optimal solution independently and in parallel in multiple points, has a strong global search capability, and strengthens the positive feedback ability of the ant colony system by improving the calculation rules of the ant state transfer probability, and guides the whole system to accelerate the evolution towards the optimal solution.

An example is provided to verify that after considering the real-time congestion information of urban roads acquired at zero cost, the path optimization scheme with lower distribution cost and higher customer satisfaction can be obtained.

References

Azi, N., Gendreau, M. & Potvin, J. Y. (2007). An exact algorithm for a single–vehicle muting problem with time windows and multiple routes. *European Journal of Operation Research*, *178*(3), 755-766.

Chen, H. K., Hsueh, C. F. & Chang, M. S. (2009). Production scheduling and vehicle routing with time windows for perishable food products. *Computers & Operations Research*, *36*(7), 2311-2319.

Dantzig, G. B. & Ramser, J. H. (1959). The Truck Dispatching Problem. *Management Science, 6*(1), 80-91.

Liu, H. Y. & Ru, Y. H. (2016). Consistent vehicle routing problem considering traffic congestion and workload balance. *Journal of Southwest Jiaotong University*, *51*(5), 931-937. [in Chinese]

Lv, J. J. & Sun, S. S. (2013). Study on vehicle routing optimization of fresh agricultural products in cold-chain. *Guangdong Agricultural Sciences*, *33*(9), 178-181. [in Chinese]

Miao, X. H., Zhou, X. N., Lin, S., Fang, W. C., Wang, X. M. & Lin, L. J. (2011). Study on Routing Optimization for Cold-chain Logistics Distribution of 3PL. *Operations Research and Management Science*, *20*(4), 32-38. [in Chinese]

Osvald, A. & Strin, L. Z. (2008). A vehicle routing algorithm for the distribution of fresh vegetables and similar perishable food. *Journal of Food Engineering*, *85*(8), 285-295.

Pan, X. X. & Gan, H. C. (2016). Study on Cold Chain Logistics Distribution Path Optimization of Considering Carbon Emissions. *Mathematics in Practice and Theory*, *46*(2), 62-68. [in Chinese]

Shi, Z. & Fu, Z. (2013). Distribution location routing optimization problem of food cold chain with time window in time varying network. *Application Research of Computers*, *30*(1), 183-188. [in Chinese]

Tarantilis, C. D. & Kiranoudis, C. T. (2002). Distribution of fresh meat. *Journal of Food Engineering*, *51*(1), 89-91.

Worawattawechai, T., Intiyot, B. & Jeenanunta, C. (2016). Cuckoo search algorithm for the vehicle routing problem with backhauls and time windows. *Panyapiwat Journal, 8*(2), 136-149.

Xiao, J., Wang, C., Chen, P. & Niu, Y. (2017). The multi-energy heterogeneous fleet vehicle routing optimization under urban traffic restriction. *Systems Engineering-Theory & Practice*, *37*(5), 1339-1348.

Zhao, Y. Y. (2009). Optimization of food cold chain logistics delivery with soft window models. *Journal of Anhui Agricultural Sciences*, *37*(17), 8235-8238. [in Chinese]

Zhou, X. D. (2015). Research on the strategic co-evolution of the agricultural products logistics system based on the self-organization. *Chia Business and Market*, *29*(6), 45-52. [in Chinese]

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