Cold Chain Logistics Distribution Routing Optimization Based on Realistic Delivery Time and Ant Colony

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Abstract. In recent years, cold chain logistics, especially for agricultural products has been greatly developed. It aims to keep agricultural product fresh before arrive to the designated locations. In this paper, the definition and current situation of cold chain logistics are introduced first. Then a novel approach for path distribution of cold chain is proposed according to time-consumption. After that, we introduce the Ant Colony Optimization (ACO) method and the way to get realistic deliver time. At last, we put forward a method for distribution path optimization based on delivery time and ACO. Experiments show that the proposed method can achieve the optimal solution effectively.

1. Introduction
To keep food fresh throughout the whole transportation, low temperature environment should be kept to refrigerate and frozen them through all links until arrive at consumers. This is the main function of cold chain logistics. Cold chain has been applied to many fields, includes: primary agricultural product, aquatic products, flower products, processed food and other packaging cooked food. So cold chain logistics is a huge system engineering which has higher and more complex requirements than ordinary normal temperature logistics system. According to relevant media reports, the value of rotten fruits, vegetables and other food during transportation is about 70 billion yuan each year, causing huge economic waste. The development of cold chain logistics can promote the circulation of commodities such as poultry meat, aquatic products, vegetables and fruits, reduce the loss of resources, and enhance the utilization rate of social resources. So there is a huge space for the growth of cold chain logistics [1-3].

Due to the late start and backward technology, the cold chain logistics in China is relatively backward. There are three factors restricting the development of China's food cold chain industry. First of all, facilities and equipment are insufficient. Most agricultural products are transported by ordinary trucks. Secondly, the absence of technical standards. China's cold chain system is still an early market of refrigeration equipment, which is far behind developed countries. Third, China's food cold chain industry has not formed an independent and perfect operation system [4]. Saving the transport time by path optimization of the vehicle line is an important method to reduce the loss of cold chain. The problem of cold chain distribution Vehicle Routing Problem (VRP) can be defined as: under certain constraints, the driving route is reasonably planned, so that the total transport time is the shortest. It is a typical NP hard problem. Ant Colony Optimization (ACO) which has good robustness, fast convergence, and intelligent search has been widely used in solving the NP hard problem.
2. VRP over realistic travel time

2.1. VRP and travel time

VRP was first proposed by Dantzig and Ramser in 1959. It is a typical Non-deterministic Polynomial (NP) hard problems. The VRP of cold chain logistics can be described as follows: There are a certain number of customers and a distribution center with a certain number of transport vehicles. Each customer has a different number of goods needs, and the transport vehicle is responsible for distributing goods to each customer with correct goods and minimum cost, time and so on[5]. To solve this problem, values of delivery time between two points is important. But the travel time usually is infused by changing traffic and weather conditions, such as congestion, accidents, snowing, raining etc. Thanks to state-of-the-art map technologies we can overcome the mentioned shortcomings and achieve realistic time consuming between two points in the real road conditions.

2.2. Realistic travel time

The real-time traffic information can be achieved through some map public platforms. In our study, Baidu map public platform is adopted. First, latitudes and longitudes of distribution center and all demand points are collected. Then, according to Baidu map API, the high accuracy travel times between every pair of nodes can be achieved [6]. The dispatching center optimize distribution path based on these data about realistic travel time and sent new instructions to drivers at any time.

As Figure 1 shows, two pair of latitudes and longitudes of point 1 and point 2 can get from the Baidu map open platform.

![Figure 1. Coordinates of the two points](image)

The distance and time consuming between the two points can be counted by Baidu map API. The result is shown as Figure 2, the distance between point 1 and point 2 is 29.5 kilometers and the travel time is 258 minutes. These result are all based on traffic conditions in real time.

![Figure 2. The distance and travel time between the two points in real time](image)
3. Cold chain logistics distribution routing problem

The distribution optimization model of cold chain which belongs to a type of VRP is defined as follows:

K is the trucks number of distribution centers. Q_k and T_k(k=1,2,...,K) are the deadweight and the maximum traveling time of per vehicle. q_i(i=1,2,...,L)is the needs for each customer point. t_{ij} means the delivery time from demand point i to j. n_k is the number of demand points in the k path; R_k means a K path; r_ki is point i int the path k. r_{k0} represents distribution center int the path k [7]:

\[
\min Z = \sum_{k=1}^{K} \left[ \sum_{i=1}^{n_k} t_{r_{k(i-1)i}} + t_{r_{k0}r_{k0}} \text{sign}(n_k) \right] 
\]

s.t.

\[
\sum_{i=1}^{n_k} q_{r_{ki}} \leq Q_k 
\]

\[
\sum_{i=1}^{n_k} t_{r_{k(i-1)i}} + t_{r_{k0}r_{k0}} \text{sign}(n_k) \leq T_k 
\]

\[0 \leq n_k \leq L \]

\[\sum_{k=1}^{K} n_k = L \]

\[R_k = \{r_{ki} | r_{ki} \in \{1,2,...,L\}, i = 1,2,...,n_k \} \]

\[R_{k_1} \cap R_{k_2} = \emptyset \quad \forall k_1 = k_2 \]

\[\text{sign}(n_k) = \begin{cases} 
1 & n_k \geq 1 \\
0 & \text{other} 
\end{cases} \]

As Equation (1) shows, the objective function is to find the minimum total transport time. Equation (2) means the total demand is less than the vehicle load in k path. As Equation (3) shows, in k path the total delivery time is less than the maximum traveling time of the vehicle. Equation (4) means, the number of customers in k path is less than the total number of customers. From Equation (5), we can see that the total demand points of all path equals the total demand points. Equation (6) is the definition of the k path. Equation (7) means each demand point is only in one path. Equation (8) shows the relationship between the number of customers and the number of cars used in k path.

4. Ant colony optimization algorithm

ACO algorithm was first proposed by Italian scholars Dorigo and maniezzo in the 1990s. They found that ants will release a substance called pheromone in the path they pass and they will walk along the path with high concentration of pheromone. Other more, every passing ant will leave pheromone on the path. After a period of time, the shortest route to the food source will be found.

The principle to solve the optimization problem based on ACO is as follows: each ant’s walking path represents a feasible solution of the optimization problem. Equation (9) represents the choice of probability for ants to select paths, and Equation (10) is the pheromone update over time [8].

\[
p_{ij}^k(t) = \begin{cases} 
\frac{\tau_{ij}^\alpha(t) \eta_{ij}^\beta(t)}{\sum_{s \in \text{allowed}_k} \tau_{is}^\alpha(t) \eta_{is}^\beta(t)} & \text{if } j \in \text{allowed}_k \\
0 & \text{otherwise} 
\end{cases} 
\]
\[ \tau_{ij}(t + n) = \rho \tau_{ij}(t) + \Delta \tau_{ij} \]
\[ \Delta \tau_{ij} = \sum_{k=1}^{\text{allowed}} \Delta \tau_{ij}^k \]  

(10)

In the above formula, \( p_{ij}^k \) is probability for kth ant to select the net point j at time t; \( \eta_{ij}(t) \) is the heuristic function; \( \tau_{ij}(t) \) means the pheromone concentration on the path at time t; \( \text{allowed}_k \) represents points that ant k is allowed to access in the next step; \( \rho \) is the pheromone factor; \( \Delta \tau_{ij}^k \) represents the pheromone enhancer.

5. Experimental results and discussion

5.1. Data set description

For our experiments we chose a distribution center and 29 demand points. Figure 3 is the map of the distribution center and its customers. The demand of each customers is shown in figure 4. The travel time matrix among these points are counted based on Baidu map API.

Figure 3. Map of center and its customers
Figure 4. the demands of customers

5.2. Experimental Result and Discussion

Cold chain distribution routing problem is performed based on our proposed approach. The optimal distribution routing scheme based on the proposed method are listed: Route 1: 1-22-1; Route 2: 1-2-6-5-4-23-21-20-1; Route 3: 1-7-2-25-26-30-28-29-27-1; Route 4: 1-19-24-11-12-13-9-15-10-18-9-14-17-16-1. Figure 5 shows the optimal path plan which has the shortest delivery time. Thus, ACO with reality travel time consuming can be used to get the optimal solution effectively for VRP of cold chain logistics.

Figure 5. The optimal path plan
6. Conclusion
In cold chain system, the optimization of distribution path can reduce time consumption, avoid more food loss and enhance economic efficiency. We proposed a heuristic approach about ACO with travel time to solve the VRP of agricultural cold chain logistics. Experimental results show that our proposed method can select the optimal distribution routing path effectively and save delivery time significantly.

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