Vehicle Routing Problem of Fresh Agricultural Products Considering Decaying Factors

Shuxia Li¹, Zhiying Liu¹, Huiming Fang¹ and Liping Liu¹*

¹ School of Business, East China University of Science and Technology, Shanghai, 200237, China
*Corresponding author’s e-mail: lpliu@ecust.edu.cn

Abstract. The vehicle routing problem of fresh agricultural products is different from ordinary goods due to their perishability. Therefore, we are concerned with the impact of the decaying factor on the total distribution cost and delivery routes when delivering multiple fresh agricultural products simultaneously. Based on the fact that customers often want to receive products within the expected service times, this paper proposes a multi-objective VRP optimization model for multiple fresh products to minimize both transportation costs and variance of loss quantity of fresh agricultural product. An ant colony algorithm is proposed and implemented on MATLAB to solve a given VRP problem. The impact of different exponential decaying rates and weight coefficients on the total distribution cost and the variance of loss quantity are discussed to draw managerial insights. Results indicate that suppliers need to sacrifice some benefits to improve customer satisfaction.

1. Introduction

Fresh agricultural products have the characteristics of perishability, vulnerability and perishability, and the decaying factor of different types of fresh agricultural products are also different. Therefore, the problem of vehicle routing is different from that of ordinary products. It is crucial to speed up the construction of fresh agricultural product logistics system.

In recent years, many scholars have introduced the time window in which customers are allowed to be accessed to the vehicle path problem. Osvald and Stirn[1] proposed a vehicle routing optimization model for fresh agricultural products transportation. Considering the time window and travel time factors, the tabu search algorithm was used to solve the problem. Gong and Fu[2] analyzed the problems in the distribution of fresh products in big cities, established a multi-objective model with time window constraints, and improved the ant colony algorithm to solve the problem. Ma et al.[3] combined order selection and time-varying vehicle routing problems with time windows to maximize profit, and used a hybrid ant colony algorithm with local search operators to solve the problem. Govindan et al.[4] optimized the economic and environmental benefits of fresh products in distribution and constructed a path optimization model with time windows.

The perishability of fresh agricultural products makes it different from the transportation of ordinary goods. Zhang et al.[5] transformed the decaying of fresh agricultural products into time constraints and brought them into the model to ensure that the quality of fresh produce meets customer expectations. Yang et al.[6] introduced that the freshness decaying and transportation distance of fresh agricultural products showed an exponential relationship change during the distribution process. Amorim and Almada-Lobo[7] discussed the perishable factors affecting agricultural products in the process of agricultural product distribution, and constructed a dual-objective optimization model to minimize
distribution costs and maximize product freshness. Xu Jianhua\[8\] introduced the fresh food integrity rate function based on the life cycle of fresh produce to indicate the quality decaying of fresh products in transit, and established the lowest total cost and the highest service level.

In measuring customer satisfaction, Shao et al.\[9\] used the time window represented by the fuzzy membership function to reflect the level of customer satisfaction. Song and Ko\[10\] explored the vehicle routing problem for hybrid transportation of cold chain models and common models used for transportation of various fresh produce products. Customer satisfaction depends on the freshness of the products delivered to customers.

Due to the complexity of the vehicle routing problem of fresh agricultural products, the current research still has some shortcomings. There are few studies on customer satisfaction function, and is a lack of mixed distribution research on fresh agricultural products with different decaying factor. In real life, customers usually need a variety of fresh agricultural products at the same time. Therefore, this paper proposes a two-objective model for the distribution of a variety of fresh agricultural products under the influence of the decaying factor. The aim is to study the mixed distribution process of various fresh agricultural products and the influence of objective weights on the distribution route.

2. Problem description and model construction

2.1. Problem Description
A supplier has a distribution center that delivers a variety of fresh products to several customers in a certain area. The distribution center dispatches a number of vehicles to deliver the goods to the customers in the area. The capacity of the transportation vehicles is limited, and the suppliers need to complete the transportation requirements within the specified time as much as possible. The delivery time requested by the customer is indicated by a soft time window. If the vehicle arrives earlier or later than the time window, the corresponding penalty cost will be incurred. Each car can be delivered to multiple customers, but each customer's goods are only delivered by one car, and each car must be returned to the distribution center after the delivery is completed. Assuming that traffic conditions such as road congestion during transportation are not considered, the goods required by each customer can be satisfied, and there is no shortage of goods.

2.2. Model Construction

| Symbol | Explanation |
|--------|-------------|
| $G = (V, A, K, L)$ | the undirected complete graph of the networks |
| $V=${0,1,...,n} | the node set, including the distribution center |
| $V'$ = {1,...,n} | the node set of customers, without the distribution center |
| $K$ = {1,...,m} | the total number of vehicles |
| $A = \{i,j,k | i,j \in V, k \in K, i \neq j\}$ | the set of distribution vehicles |
| $L$ = {1,...,l} | the set of distributed products |
| $s_{ij}$ | distance from customer $i$ to customer $j$ |
| $c$ | the cost of each unit distance |
| $Q$ | the vehicle capacity |
| $f^l$ | The decaying rate of product $l$ |
| $p^l$ | Unit loss price of agricultural product $l$ |
| $d_i^l$ | Customer $i$'s demand for product $l$ |
| $Q_{ik}^l$ | The amount of vehicle $k$ loaded with agricultural products $l$ |
| $y_{kj}^l$ | the departure time from the distribution center of vehicle $k$ |
| $y_{ki}^l$ | the arrival time of vehicle $k$ at customer $i$ |
| $t_{ij}$ | time from customer $i$ to customer $j$ |
| $u_i$ | service time of customer $i$ |
| $[r_i, s_i]$ | the time window of customer $i$ |
According to the analysis above, the two-objective optimization model of fresh agricultural products vehicle routing problem can be formulated as the following:

$$
\begin{align*}
\min z_1 &= \sum_{l \in L} \sum_{j \in J} \sum_{k \in K} c_1 x_{ij}^k + p_1 \sum_{l \in L} \sum_{j \in J} \sum_{k \in K} z_{ij}^k \ast d_{ij}^k \ast \left(1 - e^{-f_{ij}(y_{ij}^k + u_i - y_{ij}^k)}\right) + \\
&\quad c_2 \sum_{k \in K} \max[(\tau_i - y_{ij}^k), 0] + c_2 \sum_{k \in K} \max[(y_{ij}^k - s_i), 0],
\end{align*}
$$

(1)

$$
\begin{align*}
\sum_{k \in K} z_{0i}^k &= m, \\
\sum_{i \in V'} d_{ij}^k &\leq Q_{lk} \quad \forall k \in K
\end{align*}
$$

(2)

$$
\begin{align*}
\sum_{i \in V} x_{ij}^k &= z_{ij}^k \quad \forall j \in V', k \in K
\sum_{i \in V} x_{ij}^k &= 1 \quad \forall j \in V, k \in K, \\
\sum_{j \in V'} z_{ij}^k &= \sum_{i \in V} x_{ij}^k \quad \forall i \in V
\end{align*}
$$

(3)

The objective function (1) represents the total cost of the two products transported by the vehicle. The objective function (2) represents the variance of the cargo loss of the two agricultural products. The constraint (3) represents the m vehicle from the distribution center. The constraint condition (4) indicates that a customer can only be delivered by one vehicle. Constraints (5) and (6) indicate that the vehicle must be out of the customer after it arrives at a customer. The constraint (7) indicates that each customer is only one. The vehicle is visited once. The constraint condition (8) is the vehicle capacity constraint, ensuring that the quantity of any kind of agricultural products loaded in each delivery vehicle can meet the needs of the customer of the service. The constraint condition (9) indicates that the sum of the various agricultural products transported cannot exceed the load of the vehicle. The constraint condition (10) indicates that the loss of the quantity of the goods required by the customer cannot exceed the demand of the vehicle. The constraints (11) and (12) are time constraints, and the time to reach any two customers is not contradictory. (13) is a decision variable.

3. Algorithm

Under the influence of the loss rate, the mixed distribution problem of a variety of fresh agricultural products belongs to the NP-hard problem, which is difficult to solve by an accurate algorithm. And the proposed ant colony algorithm is used to solve the proposed bi-objective optimization model.

The specific execution process of the algorithm is as follows:

Step 1: The initial position of each ant is selected as the distribution center, and the coefficient variables, $\tau_0$ and $\tau_{ij}$ are initialized.

Step 2: Construct a taboo table. Initially, the taboo table stores the location of the distribution center. Each ant selects the next client node to be traversed according to the transfer rule. Each node is traversed to join the node in the taboo table to prevent the taboo table from being The element is traversed twice. When all the numbers of the client node are stored in the taboo table, it indicates that the ant has
completed a traversal, and the program completes an iteration. At this time, the total length of the walking path is calculated, and the local pheromone is updated.

Step 3: After an iteration of the algorithm ends, the global pheromone is updated on the path that has been traversed, the total length of all ant search paths is compared, and the optimal solution of the current optimization is stored.

Step 4: Clear the taboo table and repeat step 2 for the second iteration.

Step 5: When the number of iterations reaches the set maximum number of iterations, it indicates that the stop condition has been met, the loop is exited, and the current shortest path length and the corresponding shortest routing are output.

4. Computational results

4.1. Initial Data

A distribution center has 4 vehicles with a load capacity of 11t, and is responsible for distributing three fresh agricultural products to 20 customers. Assume that the transported products are A, B and C. The loss price of A, B and C is $p^1=5$ yuan, $p^2=10$ yuan and $p^3=15$ yuan. The decaying rate is $f^1=0.0001$, $f^2=0.0003$ and $f^3=0.0005$. the traveling speed of the vehicle is 30 km/h, and the transportation cost of the vehicle is $C=2$ yuan/km. Time window penalty factor $c_1 = 2$ yuan / min, $c_2 = 10$ yuan / min. It is required to arrange the route reasonably so that after all the delivery tasks are completed, the total cost is the least, and the variance of the agricultural product damage is the smallest. The data of the distribution center and customer needs are shown in Table 2.

| Number of customer | X-axis(km) | Y-axis(km) | The demand of A | The demand of B | The demand of C | Starting time(min) | Ending time(min) | Service time(min) |
|--------------------|------------|------------|-----------------|-----------------|-----------------|-------------------|------------------|------------------|
| 0                  | 25         | 25         | 0               | 0               | 0               | 0                 | 0                | 0                |
| 1                  | 40         | 48         | 0.27            | 0.73            | 1.01            | 159               | 180              | 11               |
| 2                  | 35         | 18         | 0.09            | 1.01            | 0.82            | 59                | 79               | 10               |
| 3                  | 54         | 23         | 1.01            | 0.99            | 1               | 117               | 147              | 12               |
| 4                  | 20         | 55         | 0.5             | 0.1             | 0.74            | 80                | 91               | 7                |
| 5                  | 55         | 60         | 1.31            | 0.29            | 0.33            | 97                | 127              | 15               |
| 6                  | 30         | 60         | 0.73            | 0.97            | 0.55            | 103               | 133              | 13               |
| 7                  | 30         | 15         | 0.8             | 1.5             | 61              | 90                | 8                | 8                |
| 8                  | 10         | 20         | 1.67            | 0.23            | 0.96            | 45                | 85               | 14               |
| 9                  | 44         | 64         | 0.63            | 0.27            | 0.84            | 125               | 135              | 8                |
| 10                 | 60         | 20         | 0.7             | 0.7             | 170             | 180               | 6                | 6                |
| 11                 | 53         | 45         | 0.86            | 0.44            | 0.19            | 95                | 117              | 11               |
| 12                 | 52         | 34         | 1.38            | 0.12            | 0.49            | 57                | 74               | 14               |
| 13                 | 21         | 42         | 0.48            | 0.82            | 0.56            | 67                | 82               | 10               |
| 14                 | 15         | 55         | 1.56            | 0.04            | 1.01            | 124               | 155              | 13               |
| 15                 | 5          | 35         | 1.54            | 0.66            | 0               | 137               | 167              | 4                |
| 16                 | 60         | 30         | 0.5             | 0               | 0.7             | 156               | 166              | 5                |
| 17                 | 55         | 9          | 2.04            | 0.76            | 0.55            | 47                | 77               | 24               |
| 18                 | 45         | 15         | 0.33            | 1.37            | 0.87            | 75                | 100              | 15               |
| 19                 | 10         | 47         | 0.49            | 0.41            | 0.69            | 70                | 110              | 9                |
| 20                 | 45         | 22         | 1.18            | 0.12            | 0.36            | 54                | 74               | 10               |

The number 0 is the distribution center, and the rest are the customers.

In the ant colony algorithm, the number of ants is $m=30$, the pheromone important factor $\alpha=1$, the heuristic function important factor $\beta=0.5$, the pheromone volatilization factor $\rho=0.1$, and the number of iterations max NC=500. According to the established model and the set data, the ant colony algorithm
is used to solve the distribution cost and the volume loss variance of the three agricultural products as shown in Table 3.

Table 3. Cost and variance of the three products

| Products | A       | B       | C       |
|----------|---------|---------|---------|
| Total demand | 17.27   | 13.87   | 10.13   |
| Transportation cost | 1822.26 | 1364.12 | 874.33  |
| Decaying rate | 0.0001  | 0.0003  | 0.0005  |
| Cost of goods loss | 1.22    | 5.46    | 8.84    |
| Penalty cost | 6055.28 | 6356.72 | 6547.14 |
| Variance of goods loss | 0.00009 | 0.00031 | 0.00050 |
| Total cost | 7878.76 | 7726.30 | 7430.31 |

It can be observed from Table 3 that the total demand decreases, the transportation cost of the product decreases. But the loss rate of the three products, the cost of goods loss and the variance of the loss of goods increases, that is, the customer satisfaction level decreases. It can be seen that the loss rate is the main factor affecting customer satisfaction. When distributing fresh agricultural products with different loss rates, the products with the highest loss rate have the greatest impact on customer satisfaction. In addition, as the loss rate increases, the penalty cost increases significantly, which means that in order to reduce the variance of the volume loss and improve customer satisfaction, the vehicle no longer meets the time window requirements of each customer, but chooses as fast as possible. And the emphasis on customer satisfaction will lead to an increase in total cost. At the same time, faster delivery means that the vehicle is “close to the delivery” and the transportation distance is reduced, which is why the transportation cost of different products decreases with the increase of the loss rate.

In order to transform the proposed two-objective model into a single-objective problem, the influence of different weight coefficients on the distribution path is explored, and the linear weighting method is used to assign weights k1 and k2 with different variances of cost and cargo loss. The example selects two different weights for comparison. In the first case, k1=0.3, k2=0.7, in the second case, k1=0.7, k2=0.3, and the different delivery paths are shown in Table 4.

Table 4. Distribution paths under different weight coefficients

| k1=0.3, k2=0.7 | k1=0.7, k2=0.3 |
|----------------|----------------|
| the route of first vehicle | 0→7→2→20→12→5→0 | 0→7→8→15→19→4→0 |
| the route of second vehicle | 0→8→15→19→13→1→0 | 0→2→20→3→16→12→0 |
| the route of third vehicle | 0→18→17→3→16→0 | 0→13→14→6→9→1→0 |
| the route of fourth vehicle | 0→4→14→6→9→11→10→0 | 0→18→17→10→11→5→0 |

It shows that there are significant differences between the customer service and the delivery route under the two different weight coefficients, which indicates that the selection of the weight coefficient will have a greater impact on the vehicle delivery route. In the real world, the weighting factor of the variance of the cost and the volume of the loss of goods is determined by the decision maker. The decision maker can choose to pay more attention to the reduction of cost or pay more attention to the improvement of customer satisfaction according to his own preference, giving the cost and the variance of the loss of goods different. The weighting factor is taken to take the most appropriate action.

5. Conclusion

This paper considers the situation that suppliers supply three agricultural products to customers at the same time. The minimum variance of the total cost and the of loss of products is the optimization goal. Taking the distribution of three agricultural products with different loss rates as an example, the ant colony algorithm is used to solve the problem. First of all, through the analysis of the example, it is found that when a variety of fresh agricultural products are delivered at the same time, the transportation cost of the products with the most demand is the highest. Secondly, the products with the highest loss rate have the most cost of goods in the transportation process, and the largest variance of the volume of goods, which has a great impact on customer satisfaction. Explain that when distributing a variety of fresh produce, policymakers need to focus on the products with the highest attrition rate and make...
appropriate decisions to improve customer satisfaction. Finally, this paper analyzes the influence of different weights on the distribution route in double target, and finds that in order to save transportation time and reduce the loss during cargo transportation, the vehicle will select the customers of adjacent nodes to distribute as much as possible, and the vehicle delivery route is roughly rings, and different weight coefficients, vehicle paths are different, decision makers should choose the best path according to their own preferences. In the future research, the relationship between the decaying rate and the product type, ambient temperature, attenuation law and other factors can be considered more comprehensively. And the traffic conditions is also can be considered.

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