Optimization of Dairy Distribution Path Based on Genetic Algorithm

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Abstract. The distribution of dairy products is a key factor affecting the distribution cost, delivery time and service level of dairy products. In order to improve the efficiency and reduce the costs, it is necessary to optimize the distribution path of the dairy products. In this paper, the distribution of a local dairy enterprise is taken as the research object. On the basis of analyzing the existing distribution path, the mathematical model of the distribution path is constructed, and the genetic algorithm is designed. Then the optimized distribution path is obtained through programming and solving by MATLAB. By comparing before and after optimization, it is found that after the optimization, the total distribution distance is shortened, and the transportation cost and fixed cost are reduced. In addition, the penalty cost is avoided. Therefore, a reasonable distribution path is of great significance for the enterprises to improve the efficiency, reduce the costs, shorten the delivery time and other indicators.

1. Introduction
Due to the improvement of people's living standards, the demand for dairy products containing large amounts of protein is also growing. Usually the shelf life of dairy products is short, and the requirements for temperature and storage conditions are also high. If transport or storage is not appropriate, it can easily deteriorate and endanger people's health. Therefore, it is necessary to study the distribution of dairy products.

2. Distribution Status

2.1. Distribution Path
There are many types of the customers served by this enterprise. In this paper, only 16 customers with known demands and a single order with the quantity exceeding 20kg are selected as the customer nodes in the distribution path. The current distribution path is shown in Figure 1. The current distribution path can be divided into four sub-paths. Path 1 is 0-4-15-13-0, and the total distance is 24.4km; Path 2 is 0-1-6-8-0, and the total distance is 28km; Path 3 is 0-4-7-10-9-11-3-5-2-0, and the total distance is 36.4km; Path 4 is 0-12-14-16, and the total distance is 26km; The total distance of the four routes is 114.8km. A total of four vehicles are arranged for the distribution.

2.2. Service Level
The level of the distribution service includes whether the distribution service can meet customer requirements, ensure the safety of goods and timely delivery. Since the enterprise has not investigated the expected delivery time of the customers, it is now arranging the delivery order at will, so it often
receives complaints from customers. Table 1 shows the number of the customer complaints received in a given month. It can be seen that almost half of the customers have complained about this enterprise, so it is necessary to introduce the time window for analysis and research.

Table 1. Customer complaint form

| Customer serial number | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Delay time (min)       | 30 | 10 | 15 | 15 | 0  | 30 | 25 | 0  | 30 | 15 | 0  | 0  | 20 | 15 | 10 | 15 |
| Deferred Ratio (%)     | 6.67 | 3.33 | 3.33 | 0.00 | 6.67 | 3.33 | 0.00 | 10.0 | 3.33 | 0.00 | 0.00 | 0.00 | 6.67 | 3.33 | 3.33 |

Note: Postponement ratio = (Days postponed in a month /30) *100%

3. Mathematical Modeling of Distribution Path

3.1. Conditional Hypothesis
Considering the reality, make the following assumptions:

(1) There is only one distribution center. All distribution vehicles start from the distribution center and return to the distribution center after completing the distribution task.
(2) The demand studied is static and the inventory of distribution center is sufficient.
(3) There are interconnected paths between the distribution centers and customer nodes, as well as between the customer nodes.
(4) The total demand of customers on each sub-path does not exceed the maximum load of the distribution vehicle.
(5) The single delivery distance should not exceed the maximum driving distance of the vehicle.
(6) Each route is distributed by one vehicle, and each vehicle has only one route.

3.2. Objective Function
The objective function of this paper consists of three parts: transportation cost, fixed cost and penalty cost.

(1) Transportation cost
Transportation cost is the fuel used by the vehicle in the process of transferring the vehicle from the distribution center to the customer node. Total transport cost $Z_1$ can be expressed as:

$$Z_1 = \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{m} d_{ij} * c * x_{ij}$$

In the formula, $n$ is the number of the customer nodes, $m$ is the number of the vehicles participating in the distribution, $d_{ij}$ is the distance between customer $i$ and $j$ ($i = 0$ indicates the distribution center), $c$ is the transportation cost of the unit distance, $x_{ij}^k$ is to distribute the vehicle $k$ through the customer node $i$, and to distribute the goods for the customer node $j$. 
(2) Fixed cost
Vehicle fixed costs are usually divided into the maintenance costs and labor costs. Fixed cost $Z_2$ is expressed as follows:

$$Z_2 = \sum_{k=1}^{m} C \cdot n_k$$  \hspace{1cm} (2)$$

In the formula, $C$ is the fixed cost for each distribution vehicle to complete a distribution task, and $n_k$ is the number of the customer nodes that the distribution vehicle $k$ passes through during the distribution process.

(3) Penalty cost
According to the actual situation, the soft time window is chosen as the constraint condition when building the model. That is, if the delivery vehicle delivers the goods within the acceptable time window of the customer, there will be no penalty fee. Otherwise, there will be a certain penalty fee. The penalty cost $Z_3$ is:

$$Z_3 = q \cdot (ET_i - T_i) + s \cdot (LT_i - T_i)$$  \hspace{1cm} (3)$$

In the formula, $[ET_i, LT_i]$ is the time window acceptable to the customer node $i$. $q$ is the waiting time cost for the delivery vehicle to arrive at the customer in advance, $s$ is the penalty cost for the delivery vehicle to arrive at the customer later than the time window.

(4) Objective function
From the above expressions of the transportation cost, fixed cost and penalty cost, the final objective function model can be written as follows:

$$Z = \sum_{i=1}^{n} Z_i = \sum_{i=0}^{n} \sum_{j=0}^{m} \sum_{k=1}^{m} d_{ij} \cdot c \cdot x_{ij}^k + \sum_{k=1}^{m} C \cdot n_k + q \cdot (ET_i - T_i) + s \cdot (LT_i - T_i)$$  \hspace{1cm} (4)$$

The constraints are:

$$\sum_{j=0}^{n} x_{i0}^k = 1 , \ k=1,2,\ldots,K $$  \hspace{1cm} (5)$$

$$\sum_{i=0}^{n} y_{ik} = 1 , \ k=1,2,\ldots,K$$  \hspace{1cm} (6)$$

$$\sum_{i=0}^{n} y_{0i} = m , \ k=1,2,\ldots,K$$  \hspace{1cm} (7)$$

$$\sum_{i=0}^{n} q_i y_i^k \leq W , \ k=1,2,\ldots,K$$  \hspace{1cm} (8)$$

$$\sum_{i=0}^{n} \sum_{j=0}^{n} x_{ij}^k d_{ij} \leq L , \ k=1,2,\ldots,K$$  \hspace{1cm} (9)$$

Form (5) means that the distribution vehicle starts from the distribution center and must return to the distribution center after the completion of distribution. Form (6) means that only one distribution vehicle serves each customer node. Formula (7) denotes that the distribution centers share $m$ vehicles to complete distribution tasks. Formula (8) means that the single delivery volume of vehicle $k$ cannot exceed its maximum load. Formula (9) indicates that the vehicle $k$’s distribution distance cannot exceed its maximum travel distance.
4. Genetic Algorithms Design

4.1. Coding design
This paper adopts the natural number coding method of direct arrangement of the customer nodes, and the overall structure of the chromosome is the arrangement of m natural numbers. If the chromosome structure is 1-3-5-6-9-4-7-11-14-10-15-2-8-12-16, the possible distribution path is shown in Figure 1. Customer nodes are sequentially programmed into each distribution path in accordance with the constraints described above.

4.2. Initial population
If the population size is too large, the calculation amount will be large, and the process of finding the optimal solution will consume a long time; If the population size is too small, the number of the algorithm choices may not be enough, and the final result may not be optimal. Generally, for the feasible solutions with small population size, the initial population number of 20~200 is more appropriate. In this paper, the initial population size N=100 is taken.

4.3. Fitness function design
This paper takes the minimum total cost in the distribution process as the objective function and optimizes the minimum total cost of transportation as the objective. Therefore, the fitness function value in this paper is set as the inverse of the target function value. The smaller the target function value is, the larger the fitness function value is, indicating the higher the feasibility of this path. The expression is as follows:

\[ F_i = \frac{1}{Z_i}, i=1,2,3,\ldots,N \]  

Where, \( F_i \) represents the individual fitness value. \( Z_i \) represents the cost corresponding to the ith individual. N is the population size.

4.4. Operator selection design
In this paper, the roulette wheel selection and the best reservation selection are selected for the chromosome replication. The operation procedure is as follows: All chromosomes are arranged according to their advantages and disadvantages, and the best ones are retained without mutation and crossover; The rest of the next generation of the chromosomes, must be based on the previous generation of chromosome fitness roulette selection.

4.5. Crossover operator design
The suitable natural number coding crossover operator the use of Partial Matched Crossover (PMX). The operation is as follows: Firstly, two intersection positions are generated in a random way, and these two intersection positions are called regions to be matched. Then, the area to be matched between the two intersections is exchanged, and the area to be matched after the interchange is called the matching area. Then the same gene outside the matching area is replaced with the corresponding gene in the matching region, and finally two daughter chromosomes are obtained.

4.6. Mutation operator design
The design process of the mutation operator is as follows: Firstly, generate a random number \( x \), which is greater than 0 and less than 1. Then determine whether the random number \( x \) is less than or equal to the mutation probability \( P_m \). If so, two genetic variation points are randomly generated. Finally, the genes of the two mutation points are exchanged.
5. Matlab Programming Solution

5.1. Model parameters and algorithm parameters
The main parameters of the mathematical model established in this paper are respectively: Customer number \( n \) is 16, the unit of distance transportation cost \( c \) is 0.6 yuan, the fixed cost \( C \) of the vehicle to complete a delivery task distribution is 300 yuan, the largest weight \( W \) of the distribution vehicle is 1000 kg, the delivery vehicle maximum distance \( L \) is 1000km, the early waiting for the cost of the distribution vehicle \( q \) is 30 yuan/h, the penalties for late delivery vehicle cost \( s \) is RMB 90 yuan/h.

The values of the algorithm parameters are: The initial population size \( N \) is 100, the iteration number \( m \) is 100, the crossover probability \( P_c \) is 0.75, and the mutation probability \( P_m \) is 0.1.

5.2. Customer time window
According to the investigation of 16 customers' expected delivery time, the time window shown in table 2 is obtained after sorting.

| Customer serial number | Time window \( 7:00 \) - \( 9:00 \) | Time window \( 8:00 \) - \( 10:00 \) | Time window \( 6:00 \) - \( 8:00 \) | Time window \( 7:30 \) - \( 9:30 \) | Time window \( 8:30 \) - \( 10:30 \) | Time window \( 7:40 \) - \( 9:40 \) | Time window \( 7:00 \) - \( 9:00 \) | Time window \( 8:00 \) - \( 10:00 \) |
|------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|

| Customer serial number | Time window \( 7:00 \) - \( 9:00 \) | Time window \( 8:00 \) - \( 10:00 \) | Time window \( 6:00 \) - \( 8:00 \) | Time window \( 7:30 \) - \( 9:30 \) | Time window \( 8:30 \) - \( 10:30 \) | Time window \( 7:40 \) - \( 9:40 \) | Time window \( 7:00 \) - \( 9:00 \) | Time window \( 8:00 \) - \( 10:00 \) |
|------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|

5.3. MATLAB solution results
According to the process of the genetic algorithm and relevant data and parameters, MATLAB programming is used to complete the optimization of the distribution path. Figure 2 is the trend chart of the fitness function value of the genetic algorithm.

![Fitness Function Value Change Chart](image)

It can be seen from the figure that, in the optimization process, the fitness value presents a gradual upward trend at the beginning. However, as the number of iterations increases, the fitness value gradually becomes stable. It shows that the genetic algorithm is feasible to solve the problem of the dairy distribution path optimization with time window.

The optimized distribution path scheme is shown in table 3, and the distribution path is shown in Figure 3.
Table 3. Optimized Distribution Route Scheme

| Number | Path arrangement         | Total distance/km | Transportation costs/Yuan |
|--------|--------------------------|-------------------|--------------------------|
| Route 1| 0-4-15-13-1-6-8-0        | 32.8              | 19.68                    |
| Route 2| 0-7-10-9-11-3-5-2-0      | 36.4              | 21.84                    |
| Route 3| 0-12-14-16-0             | 26                | 15.6                     |

Figure 3. Optimized distribution path diagram

6. Conclusion
Distribution paths and costs before and after the optimization are shown in table 4. It can be seen from the table that 4 distribution paths are adopted before the optimization, and 4 distribution vehicles are needed. After the optimization, three distribution routes are adopted, and only three delivery vehicles are needed, saving 300 yuan in fixed costs. The optimized total distance is saved by 19.6km, the transportation cost is saved by 11.76 yuan, and the penalty cost is avoided. The total distribution cost before the optimization is 1801.38 yuan, while the total distribution cost after optimization is 957.12 yuan, saving 844.26 yuan. This shows that the design method achieves the purpose of optimizing the distribution path and saving cost.

Table 4. Optimization Before and After Comparison Table

| Distribution Route | Distance/km | Transportation costs/Yuan | Fixed costs/Yuan | Penalty costs/Yuan |
|--------------------|-------------|---------------------------|-----------------|-------------------|
| Before optimization|             |                           |                 |                   |
| 0-4-15-13-0        | 24.4        | 14.64                     | 300             | 75                |
| 0-1-6-8-0          | 28          | 16.8                      | 300             | 262.5             |
| 0-7-10-9-11-3-5-2-0| 36.4        | 21.84                     | 300             | 150               |
| 0-12-14-16-0       | 26          | 15.6                      | 300             | 45                |
| Total              | 114.8       | 68.88                     | 1200            | 532.5             |
| After optimization |             |                           |                 |                   |
| 0-4-15-13-1-6-8-0  | 32.8        | 19.68                     | 300             | 0                 |
| 0-7-10-9-11-3-5-2-0| 36.4        | 21.84                     | 300             | 0                 |
| 0-12-14-16-0       | 26          | 15.6                      | 300             | 0                 |
| Total              | 95.2        | 57.12                     | 900             | 0                 |

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