Study on risk assessment modeling and solution method of fresh agricultural products cold chain logistics

Ying Zhang and Xueyang Ge
Shenyang University of Technology, Shenyang, 110870, China

Email: 715743717@qq.com

Abstract. Under the market economy environment, consumers' demands for quick delivery and quality of fresh agricultural products are increasing. At present, the circulation is an important link in the whole industrial chain from production to sales, but there are still problems such as delayed distribution, high logistics cost and serious product loss, which reduce customers' trust and satisfaction with fresh agricultural products and increase the management risk of fresh agricultural cold chain logistics. In this paper, starting from the systematic management, we maximize customer satisfaction as the important indexes for evaluation of logistics risk, we analyse the distribution of a variety of cost and research with time window of fresh agricultural products cold chain logistics distribution problem, a optimization of fresh agricultural products distribution mathematical model is established, we use genetic algorithm and show the feasibility and effectiveness of the solution through simulation examples.

1. Introduction
With the continuous improvement of people's living quality and consumption level, people's requirements for quality are also gradually improved, and the cold-chain logistics industry has entered a stage of rapid development. In the process of distribution, cold chain logistics distribution products have the characteristics of perishable, greatly increasing the difficulty of distribution, cold chain logistics enterprises not only in the whole process of distribution to ensure the quality of products, but also to ensure the timeliness of distribution. As the core link of logistics distribution, it is particularly important to arrange distribution routes reasonably to minimize the total cost of distribution under the condition of maximum customer satisfaction.

At present, there are many literature on the optimization of cold chain logistics distribution path. Most of them take the lowest transportation cost [1] as the optimization objective. Qian Guang-yu [2] established the cold chain distribution path optimization model of fresh agricultural products with the objective function of minimizing the total cost of distribution enterprises considering carbon emission as the objective function. Wang Jiao [3] proposed a multiple-objective decision based optimization model of fresh food e-commerce joint distribution vehicle path. On the one hand, customer satisfaction was analyzed from the perspective of customer time tolerance zone and time tolerance. On the other hand, the joint distribution cost function is established, but the distribution cost does not include carbon emission cost. Liu Lu [4] considered that distribution enterprises use refrigerated vehicles with different refrigeration capacities for mixed distribution, so as to find a balance between cost control and customer satisfaction, which is more targeted. Most of the methods used in the above literatures are genetic algorithms. John Holland [5] first proposed genetic algorithms in the “Adaptation in natural artificial systems” in 1975. As an efficient tool, more and more scholars are devoted to the research of genetic
algorithms and apply them to practical optimization problems. Chebbi [6] etc successfully designed the application of genetic algorithm in solving complex multi-objective problems. Based on the above literatures, this paper will establish a two-objective optimization model of cost and satisfaction. When solving the model, the two objective functions will be optimized and solved respectively, and finally the optimal scheme will be compared quantitatively and selected.

2. Problem description
A distribution center has several vehicles, the quantity of goods can meet the needs of customers in a given area. Each distribution vehicle starts from the distribution center and serves different customers (different geographical locations, different time periods, different goods demand, etc.), each vehicle finally returns to the distribution center. Among them, each customer only needs one car to complete the required service at one time. On the premise of successful completion of distribution services, it is required to improve customer satisfaction as far as possible and minimize distribution costs, including fixed cost of vehicles, transportation cost, damage cost of goods, refrigeration cost, penalty cost and carbon emission cost.

3. Establishment of mathematical model

3.1. Variable descriptions and conditional assumptions
The variables involved in the modeling process are respectively: $m$ is the number of vehicles; $C_1$ is the fixed cost of each vehicle; $C_2$ is the freight cost per unit distance; $d_{ij}$ is the distance from the customer $i$ to $j$; $x_{ik}$ is the 0-1 variable, if the vehicle drives from the customer $i$ to $j$, the value is 1, otherwise it is 0; $y_{ij}$ is the 0-1 variable, when the vehicle services the customer $i$, the value is 1, otherwise it is 0; $P$ is the unit price of agricultural products; $q_i$ is demand of the customer $i$; $\alpha_1$ is the product metamorphism rate at a certain temperature in the transportation of agricultural products and $\alpha_2$ is the product metamorphism rate in the open door unloading process; $t_{ij}$, $t_{0k}$ and $t_{ni}$ are respectively the arrival time of customers $i$, the departure time of vehicle $k$ from the distribution center, and the service time of customer $i$; $p_1$ and $p_2$ are the penalty factors earlier than and later than the service window, respectively; $C_3$ is the unit refrigeration cost; $G_{1i}$ and $G_{12}$ are respectively the hot load in operation and the hot load in unloading; $t_{jk}$ is the time that serving the last customer for the vehicle $k$; $t_{0i}$ is the departure time of the vehicle $k$; $\tau(q_{ij}) = \rho_0 + (\rho^* - \rho_0)q_{ij}$; $\rho_0$ is equal speed fuel consumption without load, $\rho^*$ is equal speed fuel consumption when loading goods. $e_0$ is the carbon dioxide emission coefficient, $\delta$ is the emission generated by the refrigeration of the driving distance of the product of the distribution unit weight, $Q_{ij}$ is the car load from customer $i$ to customer $j$ on the road.

The model is established based on the following assumptions: (1) distribution center vehicle brand, load, model is identical; (2) the goods required by the customers can be shipped in a carload; (3) each customer demand point can only be delivered by one car, and only once, but one car can deliver multiple customer demand points; (4) the quantity of goods and the transportation capacity of vehicles in the distribution center can meet the requirements of customers; (5) all distribution vehicles start from the distribution center, and must return to the distribution center after completing the task, and only delivery, there is no halfway receipt of goods; (6) average temperature and average speed are taken into account in the distribution process.

3.2. Risk analysis
We take customer satisfaction as an important indicator of risk analysis, the higher the customer satisfaction is, the lower the risk is; conversely, the higher the risk is. Customer satisfaction, as one of
the goals of the model, is an attempt to express customer satisfaction with the punctuality of delivery, which is used to measure risks. In this paper, the trapezoidal fuzzy number is used to express the satisfaction. In order to quantify the satisfaction, the fuzzy membership function is introduced to express the customer satisfaction by the time point when the delivery vehicle arrives at the customer. The value range of satisfaction is [0,100%]. The following is a brief introduction to how the membership function represents satisfaction.

If the vehicle reaches the customer point between b and c, the satisfaction is 1; If it arrives between a and b and the arrival time is $t_1$, then the satisfaction degree is $(t_1 - a)(b - a)^{-1}$; If it arrives between c and d and the arrival time is $t_2$, then the satisfaction degree is $(d - t_2)(d - c)^{-1}$; If it arrives outside a and d, the satisfaction rate is 0.

Customer satisfaction in the model is expressed by fuzzy membership function. Suppose the period of service that the customer can accept is $[T_{Mi}, T_{Ni}]$, and the period of complete customer satisfaction is $[T_{mi}, T_{ni}]$, the fuzzy membership function of satisfaction is expressed as follows:

$$S_{f}(t_i) = \begin{cases} 0, & t_i \in [0, T_{Mi}] \text{ or } t_i \in [T_{Ni}, +\infty] \\ (t_i - T_{Mi})/(T_{ni} - T_{Mi})^{-1}, & t_i \in (T_{Mi}, T_{mi}) \\ (T_{Ni} - t_i)/(T_{Ni} - T_{ni})^{-1}, & t_i \in [T_{mi}, T_{Ni}] \\ 1, & t_i \in [T_{mi}, T_{ni}] \\ \end{cases}$$

$T_{Mi}$: the earliest service time acceptable to customers; $T_{Ni}$: the latest service start time acceptable to customers; $T_{mi}$: the earliest service time when the customer is completely satisfied; $T_{ni}$: the latest service time for customers' full satisfaction; $t_i$ is the time to arrive at the customer $i$.

Customer satisfaction should also consider "customer importance", that is, the weight of customer satisfaction. This index can directly reflect the "status" of a customer in the enterprise, that is, the degree of importance. After enterprise managers get the specific value of "customer importance", they can carry out targeted management and service for customers. Assuming that the enterprise's disposable resources cannot meet all customers at a certain time, it should try to meet the requirements of key customers. After all, these customers are an important source of value for the enterprise. Customer importance is considered from five aspects: customer profit, demand, service cost, customer loyalty and customer performance. Finally, the fuzzy comprehensive evaluation method is used to calculate the "customer importance", and then multiply by the "customer satisfaction" to obtain the weighted satisfaction. That is, one of the objective functions is $S = \sum_{i=1}^{n} \lambda_i S_{f}(t_i)$.

### 3.3. Cost analysis

Costs [7] include vehicle fixed cost, vehicle transportation cost, cargo damage cost, penalty cost, refrigeration cost and carbon emission cost.

Fixed cost of vehicles is expressed as: $C_f = mC_1$.

Transportation cost is $C_t = C_2 \sum_{i=0}^{n} \sum_{j=0}^{n} d_{ij} x_{ijk}$.

Cost of damage to goods can be expressed as:

$$C_d = \sum_{k=1}^{m} \sum_{i=0}^{n} y_{ik} \cdot p \cdot [q_i(1 - e^{-\alpha_i(t_i - t_{in})}) + Q_{in}(1 - e^{-\alpha_{in}t_{in}})].$$

The penalty cost is expressed as: $C_p = p_1 \sum_{i=1}^{n} \max(T_{mi} - t_j, 0) + p_2 \sum_{i=1}^{n} \max(t_j - T_{ni}, 0)$.
The refrigeration cost is expressed as: 

$$C_r = C_3 \sum_{k=1}^{m} G_{ik} (t_{jk} - t_{ijk}) + \sum_{k=1}^{m} \sum_{i,j=0}^{n} G_{ik} t_{sl} y_{ik}$$

Carbon emission cost can be represented as: 

$$C_c = C_4 \sum_{k=1}^{m} \sum_{i,j=0}^{n} x_{ijk} d_{ij} (e_0 \tau(Q_{ij}) + \partial Q_{ij})$$.

To sum up, the model established is as follows: 

$$\min Z = C_f + C_c + C_r + C_p + C_v$$

$$\max S = \sum_{i=1}^{n} \lambda_i S_{ij}(t_i)$$

s.t.

$$\sum_{k=1}^{m} \sum_{j=0}^{n} x_{ijk} \leq m, i = 0$$

$$\sum_{j=0}^{n} x_{ijk} = y_{ik}, i = 1,2,\ldots,n, \forall k$$

$$\sum_{j=0}^{n} x_{ijk} \leq Q$$

$$t_j = t_i + t_{ij} + t_{sl}, j = 1,2,\ldots,n$$

$$\sum_{i=1}^{n} y_{ik} \leq n, l = 1,2,\ldots,n$$

$$\sum_{i=1}^{n} x_{ijk} = 1, i = 1,2,\ldots,n, k = 1,2,\ldots,m$$

$$\sum_{i=1}^{n} x_{ijk} = 1, j = 1,2,\ldots,n, k = 1,2,\ldots,m$$

$$t_i \in [T_{Mi}, T_{Ni}]$$

$$\sum_{i=1}^{n} x_{ijk} = \sum_{j=1}^{n} x_{ijk}, i = 1,2,\ldots,n; h \in \text{customer set}, k = 1,2,\ldots,m$$

Formulas (1) and (2) are objective functions; (3) means the number of vehicles in the distribution center can meet the number of vehicles used for distribution; (4) means that each customer has and only has one car service; (5) means that the carrying capacity of each vehicle does not exceed the maximum carrying capacity; (6) represents the time to arrive at the customer; (7) means that the number of customers for distribution service does not exceed the total number of customers; (8), (9) and (11) mean that the distribution vehicle must start from the distribution center and return to the distribution center after completing the distribution tasks; (10) is the time window limit.

4. Research on model solving methods

In multi-objective optimization model, multiple targets can be combined for algorithm optimization. However, if the data volume is not large, the solution space will shrink and local optimization will occur. In addition, multi-objective optimization problems in logistics often have the phenomenon of benefit reversal. Therefore, in this paper, when solving such problems, multiple objectives are generally processed separately, and the optimal scheme is finally selected quantitatively through a unified index. In actual operation, this paper will optimize with the single objective of minimum total cost and maximum satisfaction respectively. Firstly, after the optimization with the minimum total transportation cost as the single objective, several excellent chromosomes were obtained. The weighted customer
satisfaction of chromosomes was calculated by using the satisfaction membership function and satisfaction weight coefficient, and the "cost required for unit satisfaction" index was used to select the optimal one. Then, the optimization was carried out with the highest customer satisfaction as the single objective, and several excellent chromosomes were obtained. Then, the optimization was selected based on the "cost per unit satisfaction" index. Finally, the "cost per unit satisfaction" index was used again to select the optimal result between the two as the final solution.

There are many algorithms to solve this kind of problem, each has its advantages and disadvantages. Considering the reliability and speed of solution, this paper chooses genetic algorithm to solve this kind of problem.

Genetic algorithm [8] is a kind of fuzzy random optimization method and automatic optimization. In the algorithm principle, it adopts the way of coding and genetic operator to reflect the internal connection and optimization logic of complex problems, so as to achieve the purpose of solving complex problems. The steps of genetic algorithm are as follows:

Initialization of population and chromosome coding. Generated by random way size of initial population, USES the natural number coding way of chromosome coding, 0 means distribution center, if have three cars, 7 customers, produce a set of code of 02560370140, its meaning is the first car service customer for 2, 5, 6, the second car service customers for 3, 7, a third car for 1, 4, service customers.

Calculate the fitness value of the individuals in the generated population. In the model, the objective function is the problem of finding the minimum value, which is transformed into the problem of finding the maximum value of the objective function.

Population evolution. Selection, the selection operator is used to select some pairs of parent population to form new individuals. The new individuals were separated and the mutation was carried out according to a certain probability to form candidate individuals. Among the candidate individuals, 100 individuals were selected according to individual fitness to form a new generation population.

Terminate the test. The termination condition is that the maximum number of iterations is 200. If the stop-stop condition is met, the output results; otherwise, go to step (2) to continue the execution.

In this paper, double-point crossover is adopted for crossover. In general, the probability of crossover is between 0.4 and 0.9. In the process of mutation, two gene points are randomly selected as the mutation nodes, and then the genes between the two gene points are reversed. The probability of mutation is usually between 0.001-0.1. There are two issues to note when performing mutation operations in the manner described above. First, if both selected mutation nodes are 0, the mutation operation is invalid, and the result of the operation is only to reverse the subpath. Second, if one of the selected mutation nodes is 0 and the adjacent gene point of the other node (within the non-mutation gene fragment) is 0, then the chromosome structure obtained through the above mutation operation has two adjacent 0's, which are illegal chromosomes. Therefore, after the selection of two mutation nodes, it is necessary to use the program to determine, and then filter, to avoid the occurrence of these two invalid cases.

5. The simulation results

5.1. The overview
The fresh food logistics distribution center in this paper distributed agricultural products to 8 customers. The vehicles participating in the distribution started from the distribution center and returned to the distribution center after delivering the goods. Assuming that the vehicle travels at a uniform speed of 50 km/h, the unit transport cost is 7 yuan /km, and the fixed cost of each distribution vehicle is 200 yuan/vehicle. Assume that the external temperature is 27 degrees, the internal temperature is 6 degrees, the maximum load of the distribution vehicle used is 5t, and the distance between the distribution center and customers, customers and customers is known, as shown in Table 1, customer information is shown in Table 2.
Table 1. Distance between distribution center and customers(km).

| $D_{ij}$ | 0   | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0        | 0   | 40.6| 40  | 40  | 37.5| 19.15|50.2 |35.6 |43.4 |
| 1        | 0   | 26.2| 35.3| 57.15|57.7 |83.6 |53.9 |83.4 |
| 2        | 0   | 56.6| 70.8| 59  |67.3 |33.3 |75.1 |
| 3        | 0   | 27.7| 46.1| 90.1|71.5 |78.8 |
| 4        | 0   | 30.6| 80.5| 73.1|62  |
| 5        | 0   | 50  |48.5 |33  |
| 6        | 0   | 34.8|27.2 |
| 7        | 0   | 49.4|
| 8        | 0   | 0   |

Table 2. Customers information.

| customers | demand | service time |
|-----------|--------|--------------|
|           | 0.5    | 1            |
|           | 2.5    | 2            |
|           | 1.5    | 1            |
|           | 2      | 5            |
|           | 0.5    | 6            |
|           | 2      | 7            |
|           | 2      | 8            |

$[T_{mi}, T_{ni}]$  
$[T_{mi}, T_{ni}]$  

The parameters in the model are as follows: $C_1$ is 0.02 yuan; $C_4$ is 10 yuan; $G_{k1}$ is 441; $G_{k2}$ is 963.9; $e_0$ is 2.63; $\delta$ is 0.0066; $p$ is 10; $\alpha_1$ and $\alpha_2$ are 0.002,0.003; $p_1$ and $p_2$ are 0.5,1; $\rho_0$ is 0.165; $\rho^*$ is 0.377.

5.2. Calculate customer importance

The customer importance calculated here is the index $\lambda_i$ and the weight of customer satisfaction. The specific steps are as follows:

(1)There is the set of evaluation objects with the existing 8 customers $U = \{U_1, U_2, ..., U_8\}$, the index set is $V = \{V_1, V_2, ..., V_5\}$, where $V_1$, $V_2$, $V_3$, $V_4$ and $V_5$ are respectively customer profit, demand, service cost, customer loyalty and customer performance.

Determine the index weight vector, and the judgment matrix and index weight are shown in Table 3.

Table 3. Calculation table of judgment matrix and index weight.

| $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ |
|-------|-------|-------|-------|-------|
| 1     | 2     | 1     | 1/5   | 1/3   |
| $V_2$ | 1/2   | 1     | 1/2   | 1/7   | 1/6   |
| $V_3$ | 1     | 2     | 1     | 1/3   | 1/2   |
| $V_4$ | 5     | 7     | 3     | 1     | 2     |
| $V_5$ | 3     | 6     | 2     | 1/2   | 1     |

Establish evaluation matrix. Score each index of 8 customers (full score is 9), see Table 4 for the score; After normalization, Table 5 is obtained.

The importance of each customer can be obtained by using the index weight vector and the normalized matrix.
Table 4. Score table of each index for each customer.

|    | $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ |
|----|-------|-------|-------|-------|-------|
| $U_1$ | 5     | 3     | 6     | 7     | 5     |
| $U_2$ | 6     | 9     | 3     | 5     | 6     |
| $U_3$ | 8     | 5     | 5     | 8     | 5     |
| $U_4$ | 3     | 7     | 7     | 6     | 9     |
| $U_5$ | 4     | 3     | 4     | 9     | 9     |
| $U_6$ | 9     | 7     | 5     | 6     | 6     |
| $U_7$ | 5     | 7     | 5     | 3     | 5     |
| $U_8$ | 3     | 4     | 9     | 7     | 5     |

Table 5. Normalized matrices.

|    | $V_1$  | $V_2$  | $V_3$  | $V_4$  | $V_5$  |
|----|--------|--------|--------|--------|--------|
| $U_1$ | 0.1163 | 0.0667 | 0.1364 | 0.1373 | 0.1000 |
| $U_2$ | 0.1395 | 0.2000 | 0.0682 | 0.0980 | 0.1200 |
| $U_3$ | 0.1860 | 0.1111 | 0.1136 | 0.1569 | 0.1000 |
| $U_4$ | 0.0698 | 0.1556 | 0.1591 | 0.1176 | 0.1800 |
| $U_5$ | 0.0930 | 0.0667 | 0.0909 | 0.1765 | 0.1800 |
| $U_6$ | 0.2093 | 0.1556 | 0.1136 | 0.1176 | 0.1200 |
| $U_7$ | 0.1163 | 0.1556 | 0.1136 | 0.0588 | 0.1000 |
| $U_8$ | 0.0698 | 0.0889 | 0.2045 | 0.1373 | 0.1000 |

The importance of each customer was calculated as 0.1522, 0.1370, 0.1364, 0.1293, 0.1258, 0.1209, 0.1103 and 0.0881, respectively.

5.3. Solution model
In practice, by setting the different algorithm parameters, repeatedly using the genetic algorithm optimization model of distribution center vehicle routing with time Windows, get some approximate optimal solution, and then by fuzzy membership function of satisfaction with satisfaction weight coefficient calculating weighted satisfaction of various solutions, reuse satisfaction "unit cost" index to select the optimal; Then, the algorithm is optimized with customer satisfaction as the single objective of the model. Several chromosomes can be obtained after multiple operations. Then, the optimal algorithm is selected by combining the "cost per unit satisfaction" index. Finally, the "cost per unit satisfaction" index is used again to select the optimal result between the two as the final solution.

5.3.1. Choose the route based on the minimum total cost and satisfaction. After running the algorithm for ten times, three kinds of excellent chromosomes were obtained. The specific chromosome structure is shown in the following Table 6:

Table 6. Low-cost chromosome structure.

| chromosome | occurrences | total cost(yuan) |
|------------|-------------|-----------------|
| 031204507680 | 3           | 5672.37          |
| 031207406850 | 2           | 5696.41          |
| 012034507680 | 5           | 5587.46          |

Then, fuzzy membership function of satisfaction was used to calculate the satisfaction value of each excellent chromosome, and the weighted satisfaction was 73.26%, 75.81% and 69.52%, respectively.
The "cost per unit satisfaction" of chromosome 2 is the smallest, so it is reasonable to choose chromosome 031204507680 with higher satisfaction.

5.3.2. Choose the route based on the highest satisfaction and combined with the total cost. The above selection process takes the minimum total cost of distribution as the single objective of the model for algorithm optimization, and then uses the satisfaction membership function to find the chromosome with the highest satisfaction in the optimization result as the final selection result. However, such an algorithm can easily avoid the route with higher satisfaction, so this paper decided to take the highest customer satisfaction as the single goal of the model and optimize the algorithm again. The following satisfactory results are obtained through genetic algorithm optimization:

Table 7. Chromosome structure with high satisfaction.

| chromosome          | 076031204850 | 031507680420 | 031206850740 |
|---------------------|--------------|--------------|--------------|
| satisfaction        | 82.36%       | 77.27%       | 75.81%       |
| total cost(yuan)    | 6359.36      | 5872.32      | 5696.41      |

As can be seen from the above Table 7, it is possible to miss the distribution route with high customer satisfaction. At the same time, chromosome 031204507680 reappeared in the results, indicating that it not only has a small total cost, but also has a high degree of customer satisfaction. The first chromosome is the most satisfying, but it costs more.

5.3.3. Determination of the optimal scheme. From the above two aspects, we get two excellent chromosomes, one has the highest satisfaction and the other has a low cost, so a choice needs to be made. 031204507680 unit satisfaction needs a smaller cost, so the final route is 0-3-1-2-0, 0-7-4-0, 0-6-8-5-0. The delivery cost is 5696.41 yuan, and the satisfaction rate is 75.81%.

6. Conclusions
Aiming at maximum satisfaction and minimum distribution cost, an optimization model of fresh agricultural product risk assessment was established. Then, genetic algorithm is used to solve the model. The model and algorithm in this paper can provide method support for logistics enterprise distribution optimization under the market economy environment and have reference value.

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