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Cool Chain Logistics Distribution Routing Optimization for Urban Fresh Agricultural Products Considering Rejection of Goods

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***Abstract*—Fresh agricultural products are essential necessities for daily life of urban residents. With the continuous improvement of urban residents' the living standards, the development of internet technology and e-commerce in China, fresh product e-commerce provides a new channel for urban residents to purchase fresh agricultural products. In this new way, urban residents pay more attention to the quality of fresh agricultural products. Therefore, the problem of distribution routing optimization in this emerging mode needs to consider not only the choice of the route, but also the impact of temperature on product quality, energy consumption during distribution, and customer's rejection due to poor quality of delivered goods. A distribution routing optimization model is established comprehensively considering those mentioned factors, and a numerical example is carried out by using genetic algorithms to solve the problem and testifies validity of the model.**

Keywords—rejection of goods; cool chain logistics; distribution routing optimization; fresh agricultural products

I. INTRODUCTION

With the improvement of national income and the continuous advancement of urbanization in China, the urban population increases, the living standards of urban residents continue to improve, and the demand and consumption of fresh agricultural products have undergone major changes. Not only does it increase in consumption, it also puts high requires on quality, taste, safety and nutritional value of fresh agricultural products. At the same time, with the development of the Internet and logistics industry, many fresh product e-commerce companies have emerged in China [1]. In 2017, the transaction volume of China's fresh product e-commerce market was about 139.13 billion yuan, a year-on-year increase 59.7%. Browsing and purchasing commodities delivered directly to the home through the internet or mobile phone saves consumption time and brings convenient to customer. It is the purchase mode that most Chinese consumers will choose, and is likely to be the main purchase mode for fresh agricultural products in the future.

Perishable nature and short shelf life are the main characteristics of fresh agricultural products, and the degree of freshness is an important indicator to measure the value of fresh agricultural products. Therefore, temperature control is very important in the circulation of fresh agricultural products [2]. Compared with the traditional mode, fresh product e-commerce suppliers should pay more attention to the optimization of distribution routes in order to provide consumers with a better experience. In real life, consumers buy fresh agricultural products online may refuse to accept the goods when they arrive due to poor quality. So, this condition will be considered in the problem of vehicle routing optimization in this paper.

At present, there are many studies on the routing optimization of cool chain logistics distribution. In addition to considering the transportation cost, these studies usually considered other factors, such as the loss of fresh agricultural products, the limitation of time window and so on. However, with the deepening of studies, more and more influencing factors are added to the problem, which makes the solution of the problem more complicated [3]. For example, H. Lan transformed the road smoothness into road traffic conditions, and converted the distribution distance into the delivery time under different road traffic conditions to study the cool chain logistics distribution routing optimization considering road traffic conditions [4]. G. Michel optimized the vehicle scheduling problem for real-time additional requirements for receiving and distributing goods [5]; J. Li proposed and optimized the vehicle routing problem with time windows aiming at minimum fuel consumption [6]. The optimization methods for cool chain logistics distribution routing can be divided into precise algorithm, classical heuristic algorithm and modern heuristic algorithm [7]. The precise algorithm introduces a rigorous mathematical method, which can only effectively solve small-scale vehicle routing problems, and has poor applicability. Therefore, its application range is limited in practice. Classical heuristic algorithms include 2-opt, 3- opt, Sweep, C-W saving heuristic algorithm etc. For example, Xuetian Ren et al. used an improved saving algorithm to solve the vehicle scheduling model of third-party cool chain logistics enterprises [8]. Modern heuristic algorithms include particle swarm optimization, tabu search algorithm, genetic algorithm, simulated annealing algorithm, etc. These algorithms have become important and effective methods to

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solve complex VRP problems. For example, P. Li et al. used an improved genetic algorithm to solve the vehicle routing problem considering impairment of fruits and vegetables distributed through different road grades [9]. Y. Xiao and A. Konak used the simulated annealing algorithm to calculate the vehicle routing model [10]. Among them, the genetic algorithm has been widely used because of its high efficiency. This method will also be chosen to solve the optimization model here.

II. PROBLEM DESCRIPTION

For fresh agricultural products, the choice of distribution route affects the delivery time, which affects the quality of products in turn. So, the lowest transportation cost and the shortest route should be considered in the distribution objectives. Furthermore, the temperature control of the vehicle is a very important factor affecting the quality of fresh agricultural products, and it is also closely related to the energy consumption. Hence, the temperature control and energy consumption are introduced into the objective function. When a customer refuses to accept the goods, it means that the delivery task of the customer fails, and the subsequent reorganization of the distribution is required. Only the loss of goods caused by the refusal will be considered in the objective function. There are two main reasons why customers refuse to accept the goods. One is that the quality of products is lower than expected; the other is that distributor fails to comply with the customer's delivery time, and the customer cannot receive the goods. The loss of goods caused by the former is considered to be equal to the value of goods, and the latter will be treated according to the soft time window.

The cool chain logistics distribution routing optimization problem studied in this paper refers to the use of same type refrigerated vehicles to distribute a single fresh agricultural product for customers by a single distribution center. Under the condition of satisfying customers' demand for goods, the capacity limitation of vehicles and so forth, the vehicle's comprehensive distribution cost is required to be the lowest. In order to facilitate the construction and solution of the model, the following assumptions are made for the model.

- The distribution center can meet the needs of all customers.
- Each vehicle only carries out the delivery operation and starts from the distribution center. Product that fails to be delivered caused by the first reason, is returned to the distribution center with the vehicle.
- The number of vehicles in the distribution center is fixed and known, the model and load of these vehicles is the same and known. Each vehicle has a certain load capacity limit, but the capacity of a single vehicle is greater than or equal to the total demand of customers on its distribution route. All vehicles should return to the distribution center at the specified time.
- Each customer's demand, location, and time window are known. The required product is serviced by one vehicle only. All customers should be served when arranging delivery routes.
- The temperature's change over time outside of the refrigerated vehicle is not taken into account during distribution.
- The vehicle travels at a constant speed on the way regardless of the traffic conditions, and serves the customer with a fixed time for loading and unloading.

III. MODEL CONSTRUCTION AND ALGORITHM IMPLEMENTATION

A. Model Construction

According to the decision-making goal, the model takes the lowest comprehensive cost as the objective function. The comprehensive cost includes the transportation cost, the refrigeration cost of vehicles, the damage cost caused by corruption during the delivery and customer's refusal to accept the goods, and the penalty cost beyond the customer's time window.

1) Transportation Cost

Transportation cost of distribution vehicles includes fixed cost and variable cost. The fixed cost is constant, which is not directly related to the transportation mileage and the number of customers. Hence, it is not considered for the convenience of calculation. The variable cost of distribution vehicles is proportional to the mileage of vehicles. Then, the transportation cost of distribution vehicles is shown in formula (1).

$$C_1 = \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{m} a d_{ij} x_{ijk} \tag{1}$$

Where, a is the unit transportation cost of delivery vehicles; d_{ij} indicates the distance between customer i and customer j; x_{ijk} is a 0-1 variable, if the k-th vehicle goes from customer i to customer j, the variable is 1, otherwise it is 0.

2) Refrigeration Cost

The calculation of refrigeration cost mainly considers two types of situations. One is the cost of maintaining the temperature inside the van under the condition of heat transfer caused by the temperature difference between inside and outside of the refrigerated vehicle. The other is the cost of compressor work under the condition of heat exchange due to air convection when serving customer for loading and unloading. The heat load caused by the first kind of situation can be expressed by formula (2) in [11].

$$\tau_1 = (1+\alpha)\times K \times S \times \Delta T \tag{2}$$

Where, α denotes the depreciation degree of the vehicle; K represents the coefficient of heat conduction, and its value here is 0.38W/m^2·K; $S=\sqrt{S_w S_n}$ represents the average surface area of the vehicle, S_w denotes the external surface area of the van, S_n denotes the internal surface area of the van. The refrigeration cost caused by the first situation is shown in formula (3).

$$C_{21} = \sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=1}^{n} x_{ijk} y_{kw} \tau_1 t_{ij} P_g / q_e \tag{3}$$

Where, y_{kw} is a 0-1 variable, if the k-th vehicle drives from the customer i to the customer j with the temperature w , $y_{kw} = 1$, otherwise, $y_{kw} = 0$; t_{ij} represents the transportation time of the vehicle from customer i to customer j; P_g denotes the unit refrigeration cost; q_e is the latent heat of refrigerant. The refrigeration cost caused by the second situation is shown in formula (4).

$$C_{22} = \sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=1}^{n} x_{ijk} y_{kw} \beta \tau_1 t_u P_g / q_e \tag{4}$$

Where, β is the door opening frequency coefficient, the value of which is 0.25 for the vehicle's door is not opened during distribution; 0.5 for the door is opened 6 times or less; 0.75 for the door is opened 7-12 times; 1 for the door is opened more than 12 times. t_u is the service time of each distribution point. The total refrigeration cost should be the sum of the above two parts.

3) Damage Cost

It is assumed that fresh agricultural product in distribution is kept in refrigerated vehicles within a certain temperature range, without considering other factors affecting spoilage and deterioration. The spoilage and deterioration of the fresh agricultural product is mainly related to the delivery time and the times of door opening in the delivery service. At the same time, customers refuse to accept the goods because of low quality due to these two reasons which also will cause damage to the goods. Therefore, it is believed that the damage is caused by these three aspects. Damage cost can be calculated by formula (5).

$$C_3 = p(1-\gamma)\sum_{i=0}^{n}\sum_{j=1}^{n}\sum_{k=1}^{m} x_{ijk}(a_1 + a_2) q_j + p\gamma \sum_{j=1}^{n} q_j \tag{5}$$

Where, p is the unit price of fresh agricultural product; q_j is the demand of product for customer j. Usually the percentage of customers who refuse to accept the goods can be obtained from historical statistics, expressed in γ . a_1 is the proportion of fresh agricultural product damage caused during transportation. a_2 is the proportion of fresh agricultural product damage caused by opening and closing door. Since the change of temperature and time has a great influence on the deterioration rate of agricultural products during the distribution process [12], the Arrhenius equation is introduced as shown in formula (6) to determine these two proportional coefficients.

$$k_{Ar}(T) = Ae^{-\frac{E_a}{RT}} \tag{6}$$

Where, $k_{Ar}(T)$ represents the reaction rate constant at temperature T; R is the molar gas constant with a value of 8.314 J/(mol·K); T is the thermodynamic temperature; E_a is the apparent activation energy; A is the pre-exponential, also known as the Arrhenius constant. So, a_1 and a_2 can be obtained from formula (7) and (8), respectively.

$$a_1 = 1 - e^{t_j k_{Ar}(w)} \tag{7}$$

$$a_2 = 1 - e^{b_j t_u k_{Ar}(T_0)} \tag{8}$$

Where, t_j is the time spent on the transportation of agricultural product for customer j, which can be determined by s_j / v . s_j is the driving distance of the vehicle from the distribution center to the customer j; v is the speed of the vehicle. b_j is the total times of loading and unloading until after its unloading that customer j's product have experienced. $k_{Ar}(w)$ refers to the deterioration reaction rate of fresh agricultural product when the vehicle runs at temperature w . $k_{Ar}(T_0)$ refers to the deterioration reaction rate of fresh agricultural product exposed to the outside temperature T_0 when the vehicle door is opened during loading and unloading.

4) Penalty Cost beyond Time Window

Use AT_j to indicate the moment when the vehicle arrives at customer j. If the vehicle does not arrive within the specified time window, a certain penalty will be imposed. The unit loss cost of vehicles' early arrival and late arrival is respectively indicated by e and d. $[E_j, L_j]$ indicates the time window of the customer j. Then, the penalty cost beyond time window in the distribution can be expressed as formula (9).

$$C_4 = e\sum_{j=1}^{n} \max(E_j - AT_j, 0) + d\sum_{j=1}^{n} \max(AT_j - L_j, 0) \tag{9}$$

Comprehensive Distribution Cost

To sum up, the cool chain logistics distribution routing optimization model is shown in formula (10).

$$\min C = C_1 + C_{21} + C_{22} + C_3 + C_4 \tag{10}$$

$$\text{s.t.} \sum_{i=0}^{n}\sum_{j=1}^{n} x_{ijk} q_j \le q, k = 1, 2, \cdots, m \tag{10.1}$$

$$\sum_{i=0}^{n}\sum_{k=1}^{m} x_{ijk} = \sum_{j=0}^{n}\sum_{k=1}^{m} x_{ijk} = 1, i, j = 1, 2, \mathrm{L}\ , n \tag{10.2}$$

$$\sum_{i=1}^{n} x_{i0k} = \sum_{j=1}^{n} x_{0jk} = 1, k = 1, 2, \mathrm{L}\ , m \tag{10.3}$$

$$\sum_{w \in \mathrm{T}} y_{kw} = 1, k = 1, 2, \mathrm{L}\ , m \tag{10.4}$$

Where, formula (10) represents the objective function of the optimization model; formula (10.1) indicates that the load of each vehicle does not exceed the maximum load of the vehicle; formula (10.2) means that each customer is served and only served once; formula (10.3) means that each vehicle starts from the distribution center and finally returns to the distribution center; formula (10.4) means that only one temperature can be selected for each vehicle during the whole distribution process.

B. Algorithm Implementation

Genetic algorithm will be chosen to solve the distribution routing optimization model in this paper. It is one of modern intelligent iterative search algorithm and has great advantages for solving the complex problem.

1) Coding Method

The algorithm adopts natural number coding method, and uses natural number to represent those customers to be served. The number of vehicles needed in distribution is m. A few zeros are randomly inserted into the random ordered natural number to form the distribution path of m vehicles. Then natural numbers of a certain range are randomly generated corresponding to the temperature of m vehicles. A chromosome with length of n+2m+1 is compiled, such as $G=(0,i_{11},i_{12},\cdots,i_{1l},0,\cdots,0,i_{m1},i_{m2},\cdots,i_{mr},0,w_1,w_2,\cdots,w_m)$. Each chromosome represents a solution to the problem of distribution routing optimization. The chromosome consists of a path gene string and a temperature gene string. The path gene string represents the distribution path of each vehicle, and the temperature gene string corresponds to the temperature selected by each vehicle during distribution.

2) Fitness Function

The objective function of the distribution routing optimization is the minimization function, but, the reciprocal of the objective function is selected as the fitness function in order to facilitate the operation of genetic algorithm.

3) Selection and Crossover

Roulette is used in the algorithm for selection, and the probability of selection for each individual is $P_J = f_J / \sum_{J=1}^{N} f_J$. J is the J-th individual and N is the number of individuals in the population. The crossover operation adopts the double-cut point crossover method. Mating regions are randomly selected and cross in the path gene string and the temperature gene string of the parent individuals. In particular, in the path gene string, it is necessary to determine the mapping relationship according to corresponding relationship between the natural numbers of the mating region, and the natural number of the non-mating region is adjusted according to the mapping relationship.

4) Mutation

The uniform mutation method is used to generate a mutation point in the path gene string and the temperature gene string respectively. It is particularly important to note that the new gene value at mutation point should form a mapping relationship with its original gene value in the path gene string. The new individual needs to change the gene value of the non-mutation point according to the mapping relationship.

TABLE I. DISTRIBUTION DISTANCE AND DEMANDS

DP	Distribution distance(km)													Demand (t)
	0	1	2	3	4	5	6	7	8	9	10	11	12	
0	0	43.7	8.1	44.3	29.4	30	21.2	24.9	26.4	6.7	47.4	14.8	53.7	-
1	43.7	0	34.5	49.9	16.4	37.7	23.3	53.5	31.7	46.9	42	42.1	40.6	0.2
2	8.1	34.5	0	45.1	22.4	22.6	17.6	28.7	24	13.3	32.5	18.6	44.3	0.15
3	44.3	49.9	45.1	0	40.6	64.7	36.2	37.3	27.9	49.3	98.3	36.6	93.1	0.25
4	29.4	16.4	22.4	40.6	0	36.8	12.4	38.4	18.8	33.3	42.9	28.3	51.9	0.18
5	30	37.7	22.6	64.7	36.8	0	35.7	50.6	44.7	30.4	10.4	40.4	35.4	0.43
6	21.2	23.3	17.6	36.2	12.4	35.7	0	31.1	13	26.2	40.6	21	47.9	0.27
7	24.9	53.5	28.7	37.3	38.4	50.6	31.1	0	30.7	30.4	67.8	10.4	88	0.25
8	26.4	31.7	24	27.9	18.8	44.7	13	30.7	0	31.9	51.5	25	58.9	0.3
9	6.7	46.9	13.3	49.3	33.3	30.4	26.2	30.4	31.9	0	50.2	19.8	65.7	0.5
10	47.4	42	32.5	98.3	42.9	10.4	40.6	67.8	51.5	50.2	0	58.5	64.5	0.4
11	14.8	42.1	18.6	36.6	28.3	40.4	21	10.4	25	19.8	58.5	0	60.1	0.35
12	53.7	40.6	44.3	93.1	51.9	35.4	47.9	88	58.9	65.7	64.5	60.1	0	0.3

IV. NUMERICAL EXAMPLE

In order to verify the validity of the model and the genetic algorithm, the cool chain distribution of fresh agricultural products in a logistics company is taken as an example. The customers close to each other in the urban area is gathered to form a distribution point, resulting in a total of 12 distribution points. The distribution center is denoted by the number 0, and distribution points are sequentially denoted by natural numbers 1-12. The delivered goods are fresh vegetables such as Chinese cabbage, greengrocery and lettuce. It is supposed that there is only one kind of goods. Its best preservation temperature is 1-8 ℃, and its unit price is 8 yuan/kg. The outside temperature of the refrigerated vehicle is 35℃. The distance between each distribution point (DP) and the demand of each distribution point are shown in Table I.

TABLE II. TIME WINDOW OF EACH DISTRIBUTION POINT

DP	Time Window
0	8：00-18：00
1	11：00-13：00
2	10：00-12：00
3	12：00-15：00
4	9：00-11：00
5	9：00-13：00
6	10：00-12：00
7	9：00-13：00
8	10：00-13：00
9	10：00-13：00
10	12：00-14：00
11	9：00-10：00
12	12：00-16：00

Assume that all driving sections are non-forbidden sections. A small refrigerated vehicle with a rated load of 1.5t is used, the average speed of the vehicle is 40km/h, and the unit transportation cost is 2 yuan/km. According to formula $m=\lceil \sum q_j/q \rceil$, the number of vehicles required is calculated to be 3. The depreciation degree of the vehicle is 5%, the outer dimensions of the van are 4750mm×1780mm×2700mm, and the interior dimensions of the van are 3350mm×1640mm×1650mm. The latent heat of refrigerant used by the vehicle is 197.08 kJ/kg, and the unit refrigeration cost is 0.056 yuan/kg. Vitamin C content in the vegetable is chosen as the index of the quality change during the distribution according to the research in [13]. Values of the pre-exponential factor and the apparent activation energy are obtained through their research, that is, the pre-exponential factor value is -2.39×10^{15}, the apparent activation energy has a value of 9.03×10^{4}J/mol. The time window constraints of each distribution point are shown in Table II. The unit loss costs for early arrival and late arrival of vehicles both are 50 yuan/h, and the service time of each distribution point is 15 minutes. The proportion of customers who refuse to receive goods due to quality dissatisfaction in the distribution is 0.01.

The genetic algorithm mentioned above is used to solve the problem by means of MATLAB, in which the population number is 80, the maximum number of iterations is 500, the crossover probability is 0.9, and the mutation probability is 0.02. The comprehensive cost of distribution after calculation is 7402.9 yuan. Distribution paths are 0→6→10→1→2→0, 0→5→3→8→7→0 and 0→9→11→4→12→0. The distribution temperature of each vehicle is 2 ℃, 4 ℃ and 3 ℃ respectively.

V. CONCLUSION

It has become a trend to purchase fresh agricultural products through e-commerce with the improvement of people's living standards, and the rapid development of e-commerce and cool chain logistics. So, the routing optimization problem is discussed when the fresh product e-commerce provides the cool chain distribution service. By analyzing the transportation cost, refrigeration cost, damage cost and penalty cost beyond time window in the distribution process, the distribution model is established. In the model, customers' rejection of goods is specially considered. A numerical example is given and calculated by genetic algorithm to verify the validity of the model in this paper. Due to space limitations, the result does not be analyzed in-depth. In the future, it is necessary to further explore and consider the comparative analysis of customers' rejection and reception of goods.

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