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Research on Optimization of Cold Chain Logistics Network of Fresh Agricultural Products in Large Chain Supermarket

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Abstract. This paper analyzes the content of the cold chain logistics network optimization of fresh agricultural products in large supermarket chain and constructs an optimization model based on double layer programming. The upper model is the total cost optimization model of the cold chain logistics network, and the lower layer model is the customer time satisfaction optimization model. The improved genetic algorithm is used to solve the bi-level programming model, and the case study of the large supermarket chain Y is carried out.

Key words: Cold Chain Logistics; Network Optimization; Bi-level Programming; Genetic Algorithm.

INTRODUCTION

The development of China's cold chain logistics industry is still at the initial stage, and the quality of service cannot meet the needs of consumers. According to the relevant statistics [6], the total loss of fresh agricultural products in the circulation process is more than 100 billion yuan due to decay and deterioration. This loss is caused by the unreasonable distribution of the cold chain logistics network and the improper transportation mode. Therefore, the scientific and reasonable optimization of the cold chain logistics network can ensure the quality and safety of the fruits and vegetables in the circulation process, reduce the loss and improve the service level of the whole cold chain logistics industry in our country.

Based on the existing cold chain logistics mode and network structure of large supermarket chains, combined with the analysis of the influencing factors of network optimization. The content of the cold chain logistics network optimization of the fresh agricultural products of large supermarket chain includes three aspects: the optimization of the location selection of the chain supermarket, the optimal distribution of the demand attraction of the supermarket and the optimization of the vehicle path. At the same time, the objectives of the cold chain logistics network optimization mainly include the minimum total cost of the network and the total time satisfaction of the customers. Among them, the smallest total cost of the network is the primary goal of the optimization of the cold chain logistics network of fresh supermarket products, and the upper goal of the bi-level programming model. The total cost includes the construction cost of the supermarket and the distribution cost optimized by the cold chain logistics route. The distribution cost includes the fixed cost, the transportation cost, the loss cost and the energy cost. The total time satisfaction of customers is the secondary goal of network optimization and the lower level goal of bi level programming model. Customer time satisfaction indicates customer satisfaction with the time required for supermarket chains to respond to their needs. It can be expressed as a customer's satisfaction with the supermarket's distance from its shortest path or the customer's satisfaction with the time needed to go to the supermarket.

OPTIMIZATION MODEL OF COLD CHAIN LOGISTICS NETWORK OF FRESH AGRICULTURAL PRODUCTS IN LARGE CHAIN SUPERMARKET

Problem Description

In a certain area, a large supermarket chain needs to establish a number of supermarkets in M candidates. The location of N customers and the demand for fresh agricultural products are known, which requires that the supermarket set up can cover all the customers' demand for fresh agricultural products. After obtain the number and location of the supermarket, and to find the demand of each supermarket in accordance with the principle of the maximum customer's total time satisfaction, the vehicle distribution path from the distribution center to these supermarkets is established under the condition of K vehicles in the distribution center, which makes the total network cost of the enterprise minimum.

Symbolic Description

The model symbol and the meaning of the representation are shown in Table 1.

TABLE 1. Model symbols and meanings.

Symbol	Meaning	Symbol	Meaning
I	Customer demand point	J	Supermarket candidate
K	Vehicle collection	P	Distribution centre
U	Total investment in the planned construction of supermarkets.	S_j	The fixed construction cost of the supermarket candidate j.
h_i	Demand for fresh agricultural products of demand point i.	C_{ab}	Unit distance transport cost of node a to node b.
E_j	Maximum supply capacity of fresh agricultural products from supermarket candidates j.	r_{ij}	The requirement point i accepts the shortest path distance of the supermarket j service.
L_{ab}	The distance from the node a to the b	C^k	The fixed cost of the refrigerator car k
CAP^k	The maximum carrying capacity of the refrigerator car k.	ML	Maximum allowable distance for each vehicle to perform a delivery task.
d_j	The demand for fresh agricultural products in supermarket j.	$F(r_{ij})$	Customer satisfaction with demand point I responds to j response time, satisfying linear time satisfaction.
Z_j	The value of 1 indicates that a supermarket is established at the candidate j, otherwise it is 0.	Y_{ij}	The value is 1 indicating that the demand point i accepts the service at the supermarket at j, otherwise it is 0.
X_{ab}^k	The value of 1 indicates that the k car is running on the road (a, b), otherwise it will be 0.	W_j^k	The value is 1 indicating that the supermarket j is served by the k vehicle, otherwise it is 0.
N^k	The value of 1 means that the k car is used, otherwise it is 0.	α	Cost of loss of goods per unit of goods.
β	Energy cost per unit time of refrigerator car.	η	Total time satisfaction of the acceptable customer.
v_1	Driving speed during the transportation of a refrigerator car.	v_2	Loading and unloading speed of goods in the supermarket.
Q_0	Initial quality of fresh agricultural products.	E_a	Activation energy
K_{max}	Temperature independent reaction velocity constant.	ΔQ	Quality change of fresh agricultural products.
R	Gas constant	T	Thermodynamic temperature

Model Building

Upper Level Model

The upper level model is a network optimization model, which can be described as the following mathematical models for solving the supermarket distribution problem and the cold chain logistics vehicle routing problem.

$$
\begin{aligned}
MinF = & \sum_{j\in J} S_j Z_j + \sum_{k\in K} C^k N^k + \sum_{k\in K}\sum_{a\in J\cup P}\sum_{b\in J\cup P} C_{ab} L_{ab} X_{ab}^k \\
& +\alpha \sum_{j\in J} W_j^k \left[\left(1-e^{-\delta_1 t_1}\right)\times 100\% \times M_j\left(t_1\right)+\left(1-e^{-\delta_2 t_2}\right)\times 100\% \times M_j\left(t_2\right)\right] \\
& +\beta\lambda_2 \sum_{k\in K} N^k \left(\sum_{a\in J\cup P}\sum_{b\in J\cup P}\frac{L_{ab}X_{ab}^k}{v_1}+\sum_{j\in J}\frac{d_j W_j^k}{v_2}\right)
\end{aligned} \quad (1)
$$

$$\sum_{j\in J} S_j Z_j \le U \quad (2)$$

$$\sum_{j\in J} Z_j E_j \ge \sum_{i\in I} h_i \quad (3)$$

$$\sum_{i\in I}\sum_{j\in J} h_i F\left(r_{ij}\right) Y_{ij} \ge \eta \quad (4)$$

$$d_j = \sum_{i\in I} Y_{ij} h_i \qquad \forall j \in J \quad (5)$$

$$\sum_{j\in J} d_j W_j^k \le CAP^k \qquad \forall k \in K \quad (6)$$

$$\sum_{a\in J\cup P} X_{aj}^k \le N^k \qquad \forall k \in K \qquad \forall j \in J\cup P \quad (7)$$

$$\sum_{a\in J\cup P} X_{ja}^k \le N^k \qquad \forall k \in K \qquad \forall j \in J\cup P \quad (8)$$

$$W_j^k = Z_j \sum_{a\in J\cup P} X_{aj}^k \qquad \forall k \in K \quad (9)$$

$$\sum_{k\in K} W_j^k = Z_j \qquad \forall j \in J \quad (10)$$

$$\sum_{a\in J\cup P}\sum_{b\in J\cup P} L_{ab} X_{ab}^k \le ML \qquad \forall k \in K \quad (11)$$

$$\sum_{a\in J\cup P} X_{aj}^k - \sum_{b\in J\cup P} X_{jb}^k = 0 \qquad j \in J\cup P \qquad \forall k \in K \quad (12)$$

$$Z_j = \begin{cases} 1 & \text{Building a supermarket at the candidate j} \\ 0 & \text{Otherwise} \end{cases} \qquad \forall i \in I \quad (13)$$

$$Y_{ij} = \begin{cases} 1 & \text{Customers at the demand point i accept service at the supermarket in j} \\ 0 & \text{Otherwise} \end{cases} \qquad \forall i \in I, \forall j \in J \quad (14)$$

$$X_{ab}^{k}=\begin{cases}1 & \text{The k car runs on the (a,b)}\\0 & \text{Otherwise}\end{cases} \tag{15}$$

$$W_{j}^{k}=\begin{cases}1 & \text{Supermarket j is served by car k}\\0 & \text{Otherwise}\end{cases} \tag{16}$$

$$X_{k}=\begin{cases}1 & \text{Vehicle k is used}\\0 & \text{Otherwise}\end{cases} \tag{17}$$

The formula (1) is the objective function formula, which indicates that the total cost of the cold chain logistics network is the smallest. The formula (2) indicates that the total construction cost of a supermarket should not exceed the maximum construction investment of a supermarket. The formula (3) indicates that the sum of the maximum service capacity of all supermarkets built is greater than that of all customers. The formula (4) indicates that the total time satisfaction level of the customer is greater than that of the customer. The formula (5) indicates that the demand of supermarket j is equal to the demand of all customers covered by the supermarket. The formula (6) indicates that the distribution of fresh agricultural products on each path will not exceed the maximum carrying capacity of each refrigerated vehicle. Formula (7) to formula (8) indicates that the k car does not pass any point if it is not used, and if the k car is put into use, the car is not more than 1 times at the point of j. Formula (9) if k car passes j point and j point is supermarket, the fresh produce of supermarket j is delivered by vehicle k. The formula (10) indicates that the supermarket j can only be delivered by one vehicle. The formula (11) represents the longest distance allowed by a k vehicle to perform a task. The formula (12) indicates that the vehicle reaches a supermarket and then starts from the supermarket. Formula (13) to formula (17) is the 0-1 constraint of decision variables.

Lower Layer Model

The lower level model mainly uses the maximum coverage model based on customer time satisfaction to solve the optimal allocation problem of the demand attraction of supermarkets. The concrete mathematical model is as follows.

$$MaxG = Max\sum_{i\in I}\sum_{j\in J} h_i F\left(r_{ij}\right) Y_{ij} \tag{18}$$

$$\sum_{j\in J} Y_{ij}=1 \qquad \forall i\in I \tag{19}$$

$$Y_{ij}\le Z_j \qquad \forall i\in I,\forall j\in J \tag{20}$$

$$\sum_{i\in I} Y_{ij}h_i \le E_j Z_j \qquad \forall j\in J \tag{21}$$

$$F(r_{ij})=\begin{cases}1 & r_{ij}\le L_i\\ \dfrac{U_i-r_{ij}}{U_i-L_i} & L_i<r_{ij}\le U_i\\ 0 & r_{ij}>U_i\end{cases} \qquad \forall i\in I,\forall j\in J \tag{22}$$

$$Z_j=\begin{cases}1 & \text{Building a supermarket at the candidate j}\\0 & \text{Otherwise}\end{cases} \qquad \forall i\in I \tag{23}$$

$$Y_{ij}=\begin{cases}1 & \text{Customers at the demand point i accept service at the supermarket in j}\\0 & \text{Otherwise}\end{cases} \qquad \forall i\in I,\forall j\in J \tag{24}$$

The formula (18) is the objective function, which indicates that the total time satisfaction of customers is the greatest. The formula (19) indicates that each customer must and can only get one supermarket service. The formula (20) indicates that the premise of a customer's acceptance of a supermarket's service is the supermarket. The formula (21) indicates that the total customer demand under the supermarket coverage does not exceed the maximum service capacity of the supermarket. The formula (22) is a customer satisfaction function, which is a linear satisfaction function. Formula (23) and formula (24) are 0-1 constraints of decision variables.

MODEL SOLUTION

The improved genetic algorithm is used to solve the model. The basic idea is: first select the decision variables of the supermarket distribution scheme in the upper model of the model to form the initial population, transfer the initial population to the lower model, and the lower layer will make the optimal response to the optimal distribution of the demand attraction of the supermarket according to the layout scheme. The results of these optimal responses are fed back to the upper level, and the upper layer makes the optimal decision of distribution path planning. Then according to the solution of the solution to determine whether or not to terminate, the end is the output of the optimal solution, or otherwise, repeated genetic operations, until the network to find the minimum total cost and the maximum customer satisfaction of the optimal decision.

The model established in this paper has the location of supermarket points, the optimal allocation of the demand attraction of supermarkets and the optimization of vehicle routing problem. Because of the order of the solution, the 0-1 variables, the flow distribution variables and the distribution path variables are divided into three different chromosomes. In the problem of supermarket location selection, the decision variables use binary 0-1 code, and the j gene code is 1, which means that the supermarket is set up at the point j, and the 0 is not to establish the supermarket. In the optimal allocation of supermarket demand, the chromosome is encoded in natural number. If there are n customers, there are 2n genes in the chromosome. The chromosomes are divided into two segments. The arrangement of the customers is represented by the full array of natural numbers (not repeated) between the first n 1-n. The arrangement of the supermarket is represented by the arrangement of any natural number (which can be repeated) between the second segments of n. In the vehicle routing problem, natural number coding is also adopted.

First, select the initial population of the problem. After selection, crossover, mutation and other genetic operations, the new population is introduced into fitness function for population evaluation. The optimal solution of the problem is obtained by iterative iteration. The penalty function is obtained by adding constraint conditions to the fitness function. The fitness function of the upper level model and the fitness function of the lower level model are shown in formula 25.

$$f^{'} = \frac{1}{F} + M\sum_{i=1}^{11} P_i(X),\quad g^{'} = G + M\sum_{i=12}^{14} P_i(X) \tag{25}$$

EXAMPLE ANALYSIS

Example Background

There are 1 distribution centers, 10 supermarket candidates and 20 customer demand points for a Y enterprise to conduct supermarket distribution in a certain area. The distance between distribution centers and supermarket candidates and the distance between supermarkets and supermarkets are shown in Table 2. The distance between the customer and the supermarket is shown in Table 3. Customer demand is shown in Table 4.

Numerical Example Solution

In this paper, MATLAB algorithm is used to solve the bi-level programming model. First, the location and demand of customers, the location and quantity of large supermarket chains, the location and quantity of the distribution center, and the parameters of the model are brought into the program. After 400 iterations, the total cost change trend of the cold chain logistics network is shown as Figure 1 convergence curve, and the total customer satisfaction change trend is shown in Figure 2 convergence curve.

TABLE 2. Distance between distribution centers and supermarket candidates and between each supermarket candidates.

	P	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
P	0	2.8	6.1	3.8	5.4	7.2	5.9	7.5	7.9	9	9.8
A1	2.8	0	3.4	3.7	3.9	4.6	6.1	6.9	6.3	8.8	8.8
A2	6.1	3.4	0	5.8	4.4	2.1	7.9	7.6	5.6	9.8	8.7
A3	3.8	3.7	5.8	0	2.4	5.5	2.4	3.7	4.6	5.3	6.1
A4	5.4	3.9	4.4	2.4	0	3.5	3.7	3.3	2.6	5.5	4.9
A5	7.2	4.6	2.1	5.5	3.5	0	7.2	6.3	3.7	8.5	6.9
A6	5.9	6.1	7.9	2.4	3.7	7.2	0	2.4	4.9	3.1	4.9
A7	7.5	6.9	7.6	3.7	3.3	6.3	2.4	0	3.1	2.2	2.4
A8	7.9	6.3	5.6	4.6	2.6	3.7	4.9	3.1	0	5	3
A9	9	8.8	9.8	5.3	5.5	8.5	3.1	2.2	5	0	3.1
A10	9.8	8.8	8.7	6.1	4.9	6.9	4.9	2.4	3	3.1	0

TABLE 3. The distance between the customer and the supermarket candidate.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
B1	1.7	5.1	3.9	4.9	6.2	6	7.4	7.4	9.1	9.6
B2	1.4	3.7	5	5.2	5.4	7.4	8.3	7.6	10.2	10.2
B3	0.6	3.5	3.2	3.3	4.4	5.6	6.3	5.8	8.3	8.3
B4	2	5.1	2	3.3	5.5	4.3	5.6	6	7.3	7.9
B5	3.7	6	0.3	2.5	5.8	2.4	3.9	4.9	5.4	6.3
B6	2.1	2.6	3.3	2.1	2.7	5.3	5.4	4.2	7.6	7
B7	1.9	2	5.3	4.7	3.8	7.7	8	6.7	10	9.5
B8	3.7	1.1	5.3	3.6	1.1	7.2	6.7	4.6	9	7.6
B9	4.8	1.8	7.6	6.3	3.5	9.7	9.4	7.2	11.6	10.3
B10	5.6	3.3	6	3.6	1.2	7.1	5.8	2.5	8	6
B11	6.1	7.6	2.4	3.2	6.7	0.5	1.9	4.3	3	4.3
B12	4.5	5	2.6	0.7	3.9	3.3	2.6	2.1	4.8	4.2
B13	7.5	6.5	5.8	3.8	4.5	5.7	3.5	1.2	5.2	2.6
B14	7.6	9.4	3.9	5.1	8.6	1.6	3	5.9	2.5	5.1
B15	7	7.9	3.7	3.5	6.5	2.1	0.4	3.4	2	2.6
B16	7	6.8	4.6	3	5.1	4.1	1.8	1.4	3.6	1.8
B17	9.2	10.3	5.7	5.9	8.9	3.4	2.7	5.4	0.5	3.3
B18	10.6	11.8	7.1	7.3	10.2	4.8	4.1	6.7	1.9	4.1
B19	9.6	9.9	6.5	5.9	8.3	4.8	2.8	4.5	2	1.5
B20	10	9.6	7.3	6.1	7.7	6.1	3.7	4	3.9	1.3

TABLE 4. Demand for fresh agricultural products by each customer.

Customer	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Requirement	0.6	0.54	0.81	0.96	0.45	0.66	0.9	0.78	1.12	1.05
Customer	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20
Requirement	0.75	1.2	1.36	0.69	0.8	0.87	0.54	0.96	0.51	1.02

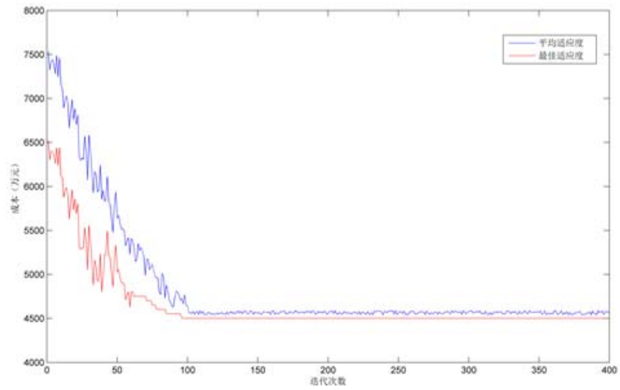

FIGURE 1. Total cost convergence curve of cold chain logistics network.

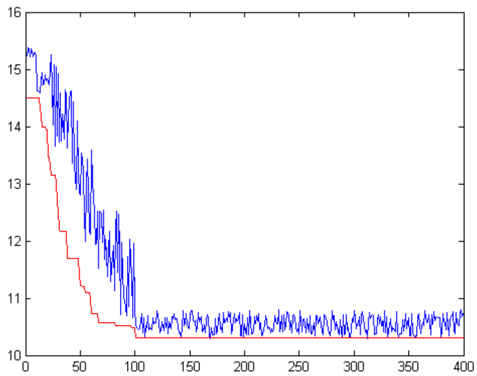

FIGURE 2. Convergent curve diagram of customer's total time satisfaction.

According to the total cost convergence curve of the cold chain logistics network and the total customer's time satisfaction convergence curve, it can be seen that the population is optimal when the population is around 100 times. The optimal value of the total network cost is 45025168 yuan, and the total customer satisfaction level is 10.293, accounting for 65.15% of the total customer demand 15.8, which meets the goal of network optimization. The cold chain logistics network optimization plan is: the enterprise set up the supermarket at the candidate points A1, A2, A3, A8, A9, A10. Supermarket A1 services B1, B2, B3, B4, B6. Supermarket A2 services B7, B8, B9. Supermarket A3 service B5, B11, B12. Supermarket A8 service B10, B13. Supermarket A9 service B14, B17, B18. Supermarket A10 service B16, B19, B20. The distribution center has two refrigerated vehicles for the six supermarkets to deliver fresh agricultural products, the vehicle 1 distribution route is 0-3-2-1-0; the vehicle 2 distribution route is 0-8-10-9-0. 0 expresses the distribution center.

CONCLUDING REMARKS

This paper aims at the existing shortcomings of the existing cold chain logistics network in large supermarket chains and establishes a double layer programming model and designs an improved genetic algorithm to optimize the network. Taking the minimum total cost of the network as the overall objective, we consider the customer's time satisfaction. The example shows that the model of the paper effectively solves the optimization of cold chain logistics network of fresh agricultural products in large supermarket chain and provides reference and guidance for large chain supermarket enterprises and other related enterprises.

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