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Optimization of cold chain logistics distribution path based on genetic algorithm

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Abstract: *In this paper, a cold chain logistics path optimization problem model with time window is proposed, and the problem is solved by genetic algorithm. In order to solve the multi-path distribution problem, we add penalty function and time window to the model to better describe the problem. By solving the genetic algorithm, the optimal transportation path of the cold chain truck can be obtained for the demand points in a certain region, so as to reduce the distribution cost. The experimental results show that the model in this paper can better describe the optimization problem of cold chain logistics path with time window, achieve the goal of reducing distribution cost and distribution mileage, and has practical significance for cold chain logistics and related industries.*

Keywords: *Vehicle routing optimization; Genetic algorithm; Cold chain logistics; Time window*

1. Introduction

With the continuous development of economy and the increasing improvement of people's living standards, people's food consumption concept has also changed from the traditional simple type to the modern diversified and fast type [1]. As a widely recognized means of food quality assurance, cold chain logistics has been popularized worldwide since the middle of the 20th century and is an important element of agricultural product supply chain [2]. In recent years, China's logistics industry is in a period of rapid development, and cold chain logistics has gradually become a hot spot in the industry. The demand and scale of cold chain logistics market are showing a trend of substantial growth [3]. It has the following distribution characteristics: 1) It has a distribution center [4]. (2) Different user points have different demand points [5]. (3) Cost diversity [6]. The above characteristics determine that the cold chain logistics problem in this case belongs to the cold chain logistics distribution problem with time window. In this paper, genetic algorithm is used to solve this problem.

2. VRPTW model construction

In domestic agricultural, sideline and seafood transportation, cold chain transportation is favored by more distribution centers because of its flexibility, speed, high reliability and door-to-door realization. However, due to the cost limitation, the establishment of the optimization model of cold chain logistics distribution path should be based on the actual situation, and the optimization model should be combined with the actual distribution environment. However, if all conditions in reality are considered, not only the difficulty of solving will be greatly increased, but also the time required for solving will be prolonged [7]. Therefore, this model makes assumptions for specific problems: there is only one distribution center; Only one type of delivery vehicle is available; Distribution vehicles will not be affected by natural and other force majeure factors during transportation.

Model symbolic representation:

Let V be the set of distribution points, where 0 is the distribution center, $V = \{0\} \cup D = \{0,1,2,\cdots,n\}$; D is the set of n customers with points; Let M be the set of vehicle models, $M = \{1,\cdots,h\}$, a total of class h. Relevant variables and parameters of the model are expressed as follows:

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β : Penalty cost for lateness;

C^m : Rated deadweight of model m , $m \in M$;

K^m : Available quantity of model m , $m \in M$;

E^m : Model m rated energy consumption, $m \in M$;

P_{11} : Cooling cost per unit time during cold chain transportation;

P_{12} : Refrigeration cost per unit time in the process of cold chain loading, unloading and handling;

ρ^m : Model m fixed cost, $m \in M$;

ε^m : Model m transport unit distance cost, $m \in M$;

$t_{i,j}$: The travel time from point i to point j , $i \in V, j \in D$;

$e_{i,j}$: Energy consumption per unit to travel from point i to point j , $i \in V, j \in D$

$d_{i,j}$: The distance traveled from point i to point j , $i \in V, j \in D$;

$c_{i,j}$: The delivery cost from point i to point j , $i \in V, j \in D$;

g_i : The quantity demanded at customer point i , $i \in D$;

a_i : Loading, unloading and handling time at customer point i , $i \in D$;

w_i : Time when loading, unloading and handling start at customer point i , $i \in D$;

$\left[e_i, l_i\right]$: Loading, unloading and handling time window at customer point i ;

$\left[e_t, l_t\right]$: Maximum warranty time window for cold chain cargo;

$x_{i,j}^{m,k} = 1$, Model m k car from point i to point j ;

$x_{i,j}^{m,k} = 0$, or else;

$$\min Z = \sum_{m=1}^{h}\sum_{k=1}^{K^m}(\sum_{i=0}^{n}\sum_{j=0}^{n} c_{i,j}^{m} \bullet x_{i,j}^{m,k}) + \beta\sum_{i=0}^{n}\max(w_i - l_i, 0) + \sum_{m=1}^{h}\sum_{k=1}^{K^m}\sum_{j=1}^{n} \rho^m \bullet x_{0,j}^{m,k}$$
$$+\sum_{m=1}^{h}\sum_{k=1}^{K^m}(\sum_{i=0}^{n}\sum_{j=0}^{n} P_{11} \bullet t_{i,j} \bullet x_{i,j}^{m,k}) + \sum_{m=1}^{h}\sum_{k=1}^{K^m}\sum_{j=0}^{n} P_{12} \bullet a_j^k \tag{1}$$

$$\sum_{j=1}^{n}\sum_{k=1}^{K^m} x_{0,j}^{m,k} \le K^m, m \in M \tag{2}$$

$$\sum_{j=1}^{n} x_{0,j}^{m,k} = \sum_{i=1}^{n} x_{i,0}^{m,k} \le 1, m \in M, k \in \left\{1, \cdots, K^m\right\} \tag{3}$$

$$\sum_{i=0}^{n}\sum_{m=1}^{h}\sum_{k=1}^{K^m} x_{i,j}^{m,k} = 1, j \in D \tag{4}$$

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$$\sum_{j=0}^{n}\sum_{m=1}^{h}\sum_{k=1}^{K^m} x_{i,j}^{m,k} = 1, i \in D \tag{5}$$

$$\sum_{i=0}^{n}\sum_{j=0}^{n} g_j \bullet x_{i,j}^{m,k} \le C^m, m \in M, k \in \{1, \cdots, K^m\} \tag{6}$$

$$\sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{m=1}^{h} x_{i,j}^{m,k} \bullet e_{i,j} \bullet d_{i,j} \le E^m, m \in M \tag{7}$$

$$c_{i,j}^m = d_{i,j} \bullet \varepsilon^m \tag{8}$$

$$e_t \le t_{i,j} \le l_t \tag{9}$$

$$w_j = w_i + \max(e_i - w_i, 0) + a_i + t_{i,j}, \quad w_0 = 0, i \ne j, i, j \in V \tag{10}$$

The meanings of each expression of the above model are as follows: (1) The total distribution cost of the objective function is the minimum, including distribution distance cost, penalty cost, fixed cost and refrigeration cost; (2) It means that the number of vehicles of each type used in the distribution center shall not exceed the available number of vehicles of this type; (3) means that all vehicles depart from and return to the distribution center; (4) Each customer point is served only once; (5) The vehicle arrives at the next customer point or returns to the distribution center after serving the customer point; (6) indicates that the total demand of each route is not higher than the distribution vehicle capacity of this route; (7) indicates that the energy consumption of each type of transportation cold chain cargo is not higher than the rated energy amount; (8) represents the distribution cost calculation method in the objective function; (9) Transport time is not higher than the maximum shelf life of cold chain goods; (10) Represents the update method of the start service time of the customer point.

3. Algorithms and experiments

Algorithm is introduced:

It is a kind of random search algorithm that draws lessons from natural selection and natural genetic mechanism in the biological world. Genetic algorithm is simulated in the process of natural selection and natural genetic reproduction, crossover and mutation phenomenon, keep a set of candidate solutions in each iteration, and according to some indicators from XieQun select the optimal individual, using genetic operators (selection, crossover and mutation) of these individuals are combined, produce a new generation of candidate XieQun, repeat this process, Until a certain convergence index is met [8].

The running parameter setting of genetic algorithm has great influence on the performance of genetic algorithm. The parameter selection of genetic algorithm generally includes population size, convergence criterion, hybridization probability and mutation probability. Parameter selection is related to the accuracy, reliability and computation time of genetic algorithms, and affects the quality of results and system performance. Therefore, the study of parameter selection in genetic algorithm is very important [9]. Table 1 describes the running parameter values

Table 1: Design of related parameters of genetic algorithm

Parameter	Implication	C101	RC208
N	Length of chromosome	100	100
NIND	Length of chromosome	100	100
P_c	Crossover probability	0.9	0.9
P_m	Mutation probability	0.05	0.05
MAXGEN	Terminated evolutionary algebra	50	50

The main flow of genetic algorithm is as follows:

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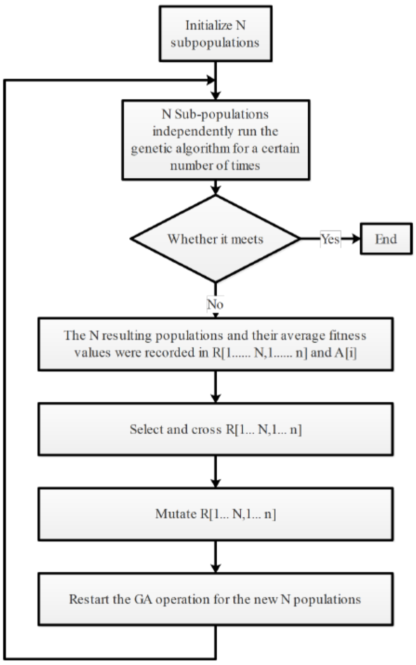

Figure 1: Flowchart of genetic algorithm

The explanation of the calculation example

Solomon example is a VRPTW standard test question bank designed in 1983. The question bank consists of 56 different examples, which are assumed to solve the VRPTW problem of a single distribution center and a single vehicle type. The Solomon question bank can be divided into three separate data sets of type C, R, and RC. The assumptions for all questions in the question bank are as follows:

(1) Each question contains 100 customer points, and each customer has customer number, location X and Y coordinates, customer demand, customer opening and closing time, and fixed service time

(2) Single distribution center, and limit the latest return time of vehicles

(3) There is a limit on the maximum number and capacity of a single service vehicle

(4) All customers are distributed on relatively fixed plane coordinates

(5) The distance during distribution is calculated by the Euclidean distance formula, and the time and distance are converted in the same unit [10].

Experimental data

To ensure the feasibility and scientific nature of numerical examples, the paper defines C101 RC208 examples and calculation examples of the requirements of the customer service at the earliest time is greater than the distribution center of the earliest work time, service time is less than the latest distribution center working hours at the latest, at the same time to meet all customer demand for the goods are not more than the vehicle capacity constraints, a description of two examples are as follows:

Example C101 and example RC208

The problem can be described as follows: one distribution center serves 100 customers with different needs around it. Where the vehicle is the same, with the same load of 200 units; The time window of the distribution center is set as [0,1236]; The service time of the customer where the vehicle is located is 90 units (hours). Figure 1 below shows the distribution of demand points in the C101 example. The basic data amount of RC208 is the same as that of C101. The time window of the distribution center is set as [0,960]; The service time of the customer where the vehicle is located is 10 units (hours). Figure 2 below shows the distribution of demand points in examples C101 and RC208.

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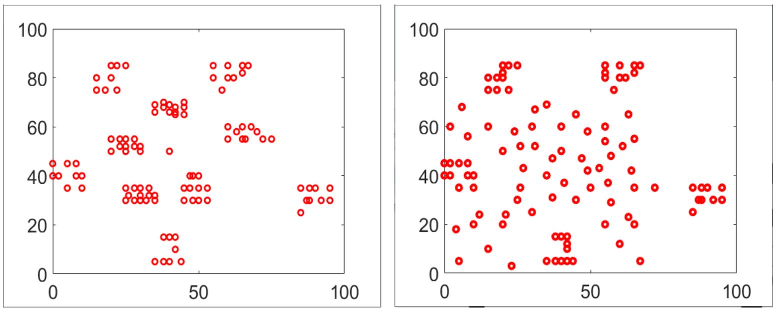

Figure 2: Distribution of C101 example customer points (left) and RC208 example customer points (right)

Experimental parameter setting

In this paper, examples C101 and RC208 are used as experimental data, and genetic algorithm is used to solve the VRPTW problem of how to arrange the path to make the vehicle travel distance shortest. During the process, set related parameters as follows:

(1) Model parameter setting

According to the above description of the calculation example, the model parameters are set as shown in Table 2:

Table 2: Model parameter setting table

Parameter	Implication	C101	RC208
α	The coefficient of the penalty function for violating the capacity constraint	10	10
β	The coefficient of penalty function for violating the time window constraint	100	100
v	Average speed of cold chain truck （km/h）	40	40
P_{11}	Refrigeration cost per unit time during transportation	1000	1000
P_{12}	Cooling cost per unit time during loading and unloading	500	500
ρ	Enable fixed cost per unit vehicle	60	60
ε	Transport cost per unit distance	20	20
e	Energy consumption per unit distance of transport	50	50

Experimental results and analysis

Based on the above analysis, MATLABR2022a is run on the computer with Intel(R) Core(TM) i5-9300H CPU @ 2.40GHz, memory of 8G and operating system of Windows10 to solve the RC208 path optimization problem to be solved in this paper. In order to make the obtained solution more scientific and effective, this paper conducts 10 random tests on the RC208 example, and the optimal experimental results obtained in the 10 tests are shown in Table 3.

Table 3: Optimal distribution scheme path and shortest distance

Path	Optimized path	Shortest distance
1	0->69->53->14->78->60->6->7->8->3->70->55->0	
2	0->81->71->31->29->30->28->33->63->85->51->76->89->21->49->20->0	
3	0->98->82->52->86->87->75->58->77->74->57->64->56->90->0	
4	0->72->41->37->35->36->38->39->40->42->54->0	
5	0->83->24->25->23->48->18->19->22->66->0	1263
6	0->95->84->62->50->32->26->27->34->67->93->96->0	
7	0->16->15->11->9->99->65->80->94->92->91->0	
8	0->61->44->43->2->4->46->45->5->1->100->68->0	
9	0->88->79->73->17->47->12->10->13->97->59->0	

The optimal solution of the RC208 example is 1263.1, and the optimal distribution path combination

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composed of 9 paths is generated. After inspection, all paths meet the vehicle capacity limit and the latest return to the distribution center time constraint. Its optimal distribution path scheme and genetic algorithm iteration process are shown in Figure 3.

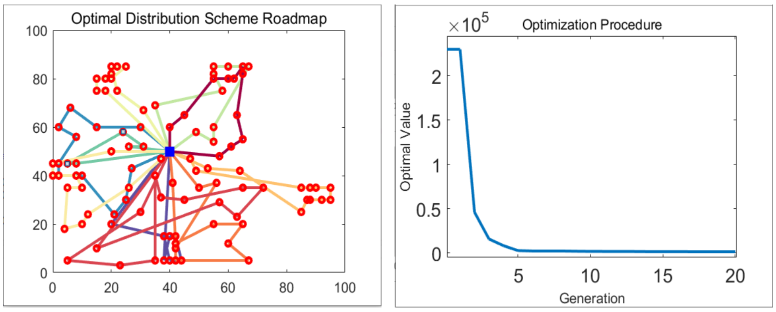

Figure 3: Roadmap of the optimal distribution scheme

According to the requirements, the cold chain distribution vehicle starts from the distribution center to each demand point in the city. In order to meet the needs of the shortest driving distance, the least consumption time, the customer demand time window and the penalty function, MATLAB is used to draw the optimal distribution scheme roadmap. It can be seen from Figure. 2 that, through the genetic algorithm, the system determines nine distribution route schemes and draws nine different colors as road maps, among which the shortest distance is 1263.0791m. At the same time, it can be seen that at the beginning of the optimization process, the optimization curve drops steeply, and with the evolution process, the change of the optimization curve tends to be gentle, and the solution of this problem converges to 1263.0791m in the 47th generation.

4. Conclusions

The mathematical model of VRPTW is established in this paper, which belongs to a logistics scenario with a single distribution center, customer demand time window, relatively dense supply time and single vehicle type. It can be applied to agricultural products supermarket, convenience store chain, cold chain transportation and other occasions. The genetic algorithm is used to solve the problem, and finally a reasonable solution is obtained, which proves that the model has certain feasibility. Therefore, the path optimization model of single distribution center with time window proposed in this paper can fill the problem of distribution optimization in the field of cold chain logistics and has certain practical significance.

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