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Cold Chain Logistics Path Planning Based on Particle Swarm Optimization

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Abstract: ***Reasonable planning of logistics paths is of great significance for reducing transportation costs in the cold chain industry. In this paper, based on the analysis of the constraints of the vehicle routing problem, a mathematical model of routing is established. The particle swarm optimization algorithm is used to optimize the constructed mathematical model, and the implementation process and flow chart are given. Using Matlab software combined with actual data information for simulation calculation, the experimental results show that the particle swarm optimization algorithm can effectively solve the problem of route planning, and the distribution route obtained is more reasonable.***

Keywords: path planning; mathematical model; particle swarm optimization

1. Introduction

With economic development and social progress, people's demand for fresh products continues to grow, and reasonable planning of vehicle distribution routes can reduce the cost of logistics transportation [1] [2]. The vehicle distribution path of logistics transportation, namely Vehicle Routing Problem (VRP), has attracted the attention of many scholars at home and abroad [3]-[5]. The vehicle path planning problem is a multi-constrained optimization problem, most of which are solved by intelligent optimization algorithms, such as heuristic algorithms using time windows, genetic algorithms, simulated annealing algorithms, etc., all of which have achieved more reasonable distribution routes [6]-[9].

Particle Swarm Optimization (PSO) abstracts concepts such as position, speed, and multi-dimensional search to solve the problem. It has strong search ability and fast convergence speed. In this paper, after analyzing the constraints of the vehicle routing problem, the mathematical model of the vehicle routing problem is established. The particle swarm optimization algorithm is used to optimize the solution, and the actual distribution data is used for simulation verification.

2. Mathematical model

This section briefly describes the vehicle path planning problem, and then analyzes the strategy and requirements of the path planning problem. Next, gives the mathematical description and parameter definition of the path planning problem, and finally, constructs the mathematical model of the vehicle planning problem.

2.1 Mathematical description of vehicle path planning

The problem of vehicle route planning was first proposed by Dantzig and Ramser in 1959. We usually describe it as: known distribution center location, known customer point location and demand, and known vehicle assembly specifications. The question we need to study is: how to obtain a reasonable vehicle travel route, make the logistics cost the lowest, the shortest travel path or the shortest transportation time under certain constraints. Path planning problems are shown in Figure 1.

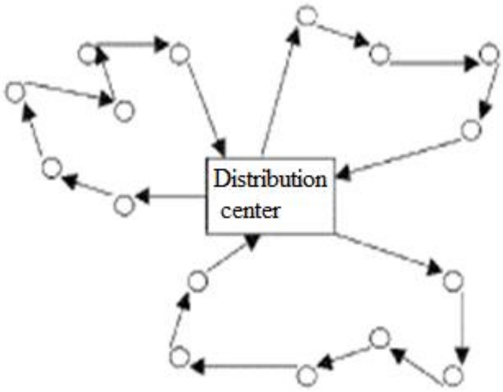

Figure 1:VRP schematic.

Figure 1: The framework of the proposed algorithm

From the mathematical description of VRP, it can be seen that the influencing factors of vehicle routing problems include: distribution centers, customer points, distribution vehicles, and planning objectives.

1) Distribution center: The distribution center is also the center for the distribution of logistics vehicles.
2) Customer point: The service object of the distribution center, in specific problems, they may be supermarkets, wholesale markets, consumers, etc..
3) Distribution vehicles: The ways and tools used by the distribution center to serve customer sites. Due to the different types of vehicles, different constraints (speed, fuel consumption, load, etc.) will be generated.
4) Planning objectives: From the perspective of the customer, the objective may be customer satisfaction and the shortest transportation time. From the perspective of the distribution center, the objective may be the lowest distribution cost and shortest distribution path.

2.2 Optimization model of vehicle path planning

In the context of cold chain logistics, due to the freshness of food ingredients, plus the refrigeration unit equipped with the vehicle itself, there are certain requirements for the vehicle load. The research object of this paper is: study the distribution plan from the distribution center to the customer point, under the condition that each delivery vehicle has the same known load capacity, and the demand of each city customer point is different. The solution must meet certain loading weight constraints and meet the requirement of the shortest exercise distance.

Known distribution centers and customer points $P(i,j)$, $i,j=(0,1,2,\ldots,L)$, where the distribution center number is 0, and the number of each customer point is $(1,2,\ldots,l,l+1,\ldots,L)$, E represents a selectable set of paths. K represents the number of vehicles in the distribution center; Q_k represents the load capacity of each vehicle; b_i represents the demand of each customer point.

The task of customer point i is completed by vehicle k, described as,

$$Y_{ki}=\begin{cases}1, & \text{customer } i \text{ completed by vehicle } k \\ 0, & \text{else}\end{cases} \tag{1}$$

Vehicle k travels from point i to point j, described as,

$$X_{ijk}=\begin{cases}1, & \text{Vehicle } k \text{ travels from } i \text{ to } j \\ 0, & \text{else}\end{cases} \tag{2}$$

The Euclidean distance between two customer points is defined as,

$$M_{\mathbf{ij}}=\sqrt{(x_{i1}-x_{j1})^2+(x_{i2}-x_{j2})^2} \tag{3}$$

Where, x_{i1} and x_{i2} represent the coordinates of customer i, x_{j1} and x_{j2} represent the coordinates of customer j.

According to the mathematical description and design requirements of the vehicle path planning problem, set the following constraints.

1) Each logistics distribution path should meet the vehicle load constraints:

$$\sum_{i=0}^{L} b_i Y_{ik} \le Q_k \qquad (k=1,2,\ldots,K) \tag{4}$$

2) Ensure that each customer point will only be served by one logistics vehicle:

$$\sum_{k=1}^{K} Y_{ik}=1 \qquad (i=1,2,\ldots,L) \tag{5}$$

3) Guarantee flow conservation:

$$\sum_{j=0}^{L} X_{ijk}=Y_{ik} \; (k=1,2,\ldots,K) \tag{6}$$

$$\sum_{i=0}^{L} X_{ijk}=Y_{ik} (k=1,2,\ldots,K) \tag{7}$$

4) Ensure that all logistics vehicles will finally return to the distribution center:

$$\sum_{i=0}^{L} X_{i0k}=1 (k=1,2,\ldots,K) \tag{8}$$

According to the above conditions, the total distance of vehicle distribution is defined as:

$$minM=\sum_{i=0}^{L}\sum_{j=0}^{L}\sum_{k=1}^{K} M_{ij}X_{ijk} \tag{9}$$

3. Path planning solution based on particle swarm optimization

This section introduces the process of vehicle path optimization based on particle swarm optimization, and gives the implementation steps and flowchart of particle swarm optimization.

3.1 Particle swarm optimization

The particle swarm algorithm is derived from the bird's group foraging behavior. By building a bird flight model, the problem to be solved is analogized to the bird's foraging area, and each bird is called a particle, which is used to represent a candidate of the problem solution, the food found by birds is the optimal solution.

The mathematical description of the particle swarm optimization algorithm is: Let the dimension of the search space be D and the number of population particles be N. The individual optimal position of the i-th particle is $P_i=(p_{i1},p_{i2},\ldots,p_{iD})$, the most optimal population of all particles is P_g. The velocity of each particle is $V_i=(v_{i1},v_{i2},\ldots,v_{iD})$. Particles update their own speed and position according to individual optimal position and group optimal position [10].

$$v_{id}(t+1)=\omega v_{id}(t)+c_1 rand(\cdot)\left[p_{id}(t)-x_{id}(t)\right] + c_2 rand(\cdot)[p_{gd}(t)-x_{id}(t)] \tag{10}$$

$$x_{id}(t+1)=x_{id}(t)+v_{id}(t+1) \tag{11}$$

Where, c_1 and c_2 are learning factors, rand(·) is a random number in the range [0, 1], and the velocity range of the particle is $v_{id}\in[-v_{\max}, v_{\max}]$.

3.2 Implementation process of optimization solution

The core of particle swarm algorithm to solve VRP problem is the establishment of initial particle population and optimization of objective function. If the initial particle swarm contains suitable individuals, the particles will quickly search towards the optimal solution. Establishing an optimal objective function reasonably, namely the fitness function, can effectively evaluate particles and find a reasonable path. Therefore, particle initialization and fitness function construction are very important to effectively search for the optimal particle.

For the VRP problem, this paper sets the search dimension of the particles to $K+L$, each particle is composed of x_a vector and x_b vector, where x_a represents the vehicle serial number, and x_b represents the visit order of customer points. The value range of x_a is 1~K, and the value range of x_b is 1~L. Use formula (9), that is, the total distance of vehicle distribution to evaluate the particles to find the optimal solution.

The flow chart of the particle swarm optimization algorithm to solve the VRP problem is shown in Figure 2. The specific implementation steps are summarized as follows.

Step 1: Set parameters and randomly generate initial particle swarms;

Step 2: Calculate the fitness of all particles according to formula (9), find the individual optimal position and the group optimal position;

Step 3: Update the speed and position of each particle according to formula (10) and formula (11);

Step 4: Calculate the new fitness value, update the individual optimal position and group optimal position;

Step 5: Determine whether to stop the iteration. If the maximum number of iterations is reached, stop the iteration and output the optimal value; otherwise, continue the iteration.

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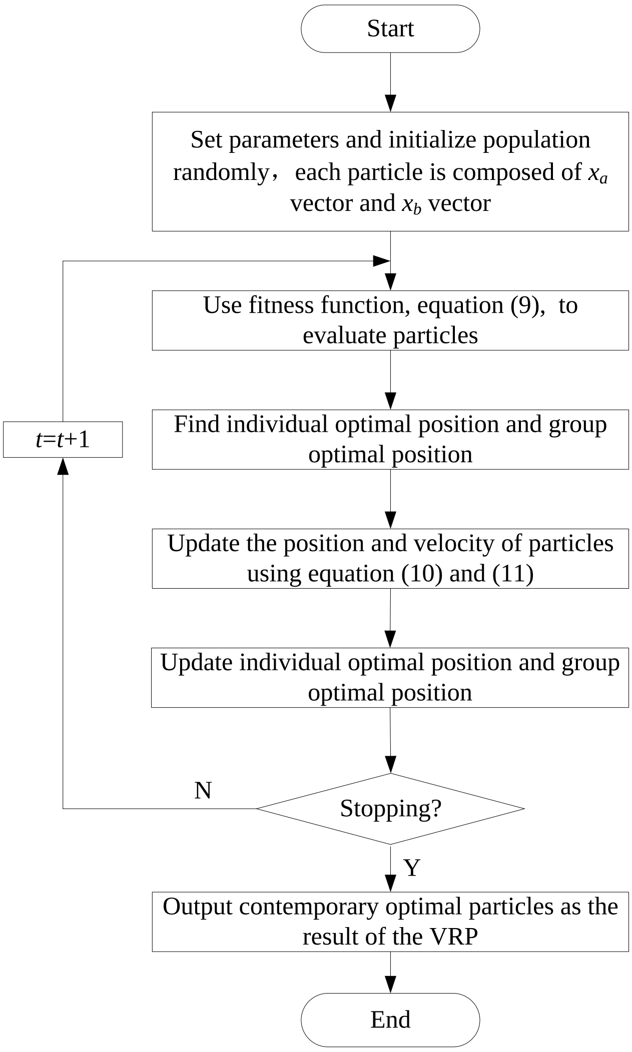

Figure 2: Flow chart of particle swarm algorithm to solve VRP problem

4. Experimental Results and Analysis

4.1 Design example 1

The information of each customer's demand and the coordinates of customer points can be seen from Table 1. The distance matrix of each customer point is seen in Table 2.

Solve the above VRP problem using standard PSO algorithm, set learning factor c_1=c_2=1.5, w=0.8, population number N=80, maximum iteration number G=50, number of logistics vehicles K=3, vehicle capacity Q =1. The particle swarm algorithm tends to be stable after about 10 iterations. The particle vectors obtained by the search are shown in Table 3, and the optimal distribution scheme of the VRP problem is shown in Table 4. According to the global optimal path in Table 4, a schematic diagram of the distribution path can be obtained. As shown in Figure 3, the optimal path distance is 217.81.

4.2 Design example 2

The information of each customer's demand and the coordinates of customer points can be seen from Table 5. The distance matrix of each customer point is seen in Table 6.

Solve the above VRP problem using standard PSO algorithm, set learning factor c_1=c_2=1.5, w=0.8, population number N=80, maximum iteration number G=50, number of logistics vehicles K=3, vehicle capacity Q =1. The particle swarm algorithm tends to be stable after about 10 iterations. The particle vectors obtained by the search are shown in Table 7, and the optimal distribution scheme of the VRP problem is shown in Table 8. According to the global optimal path in Table 8, a schematic diagram of the distribution path can be obtained. As shown in Figure 4, the optimal path distance is 284.45.

Table 1: Parameters setting for Design example 1

Number(L)	0	1	2	3	4	5	6	7
coordinates	18,52	22,59	58,65	70，70	82,47	90,39	25,41	20,38
demand(b_i)		0.89	0.14	0.28	0.33	0.21	0.41	0.57

Table 2: Distance matrix between customer points in design example 1.

Customer points	0	1	2	3	4	5	6	7
0	0	7.2	42.7	55.7	65.5	74.4	13.4	14
1	7.2	0	37.1	50.2	62.6	72.4	18.1	20.3
2	42.7	37.1	0	13.2	34	45.3	43.4	49.4
3	55.7	50.2	13.2	0	27.7	38.6	55.2	61.4
4	65.5	62.6	34	27.7	0	11.3	59.1	65.2
5	74.4	72.4	45.3	38.6	11.3	0	67.1	73
6	13.4	18.1	43.4	55.2	59.1	67.1	0	6.3
7	14	20.3	49.4	61.4	65.2	73	6.3	0

Table 3 Particle vector of design example 1

Customer points	1	2	3	4	5	6	7
x_a vector	1	3	3	3	3	2	2
x_b vector	1	1	2	3	4	2	1

Table 4 Global best path of design example 1

Vehicle number	Optimal Path
1	0-1-0
2	0-7-6-0
3	0-2-3-4-5-0

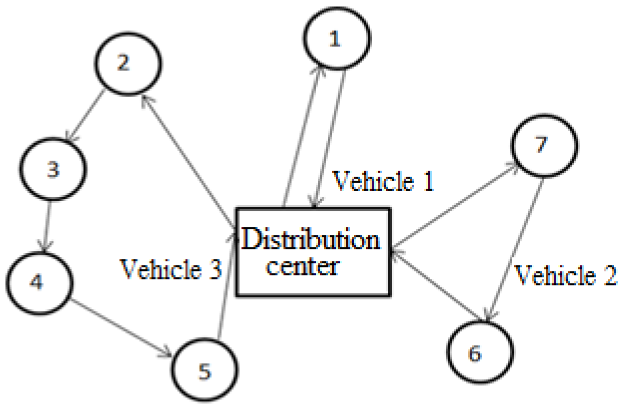

Figure 3: Schematic diagram of the distribution path of design example 1.

Table 5: Parameters setting for design example 2

Number(L)	0	1	2	3	4	5	6	7
coordinates	21,18	15,42	32,35	66,82	48,22	44,18	30,46	52,56
demand(b_i)		0.45	0.12	0.22	0.36	0.12	0.24	0.55

Table 6: Distance matrix between customer points in design example 2.

Customer points	0	1	2	3	4	5	6	7
0	0	24.7	20.2	78.2	27.3	23	29.4	49
1	24.7	0	18.4	64.9	38.6	37.6	15.5	39.6
2	20.2	18.4	0	58	20.6	20.8	11.1	22.8
3	78.2	64.9	58	0	62.6	67.7	48.8	29.5
4	27.3	38.6	20.6	62.6	0	5.7	30	34.2
5	23	37.6	20.8	67.7	5.7	0	31.3	38.8
6	29.4	15.5	11.1	48.8	30	31.3	0	24.1
7	49	39.6	22.8	29.5	34.2	38.8	24.1	0

Table 7: Particle vector of design example 2

Customer points	1	2	3	4	5	6	7
x_a vector	3	2	2	1	1	3	2
x_b vector	2	1	2	1	2	1	3

Table 8: Global best path of design example 2

Vehicle number	Optimal Path
1	0-4-5-0
2	0-2-3-7-0
3	0-6-1-0

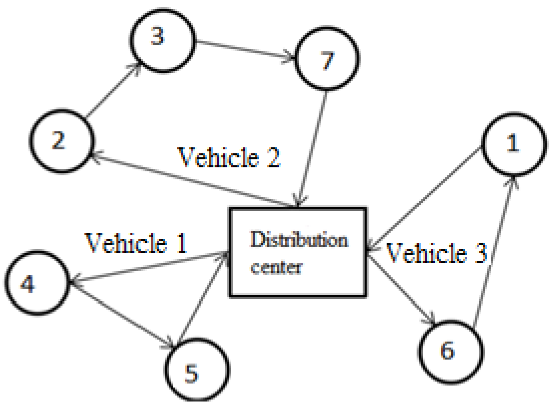

Figure 3: Schematic diagram of the distribution path of design example 2

5. Conclusion

This paper studies the path planning of cold chain logistics vehicles with load limitation, and builds the mathematical model with the shortest path distance. The optimization solution process based on particle swarm optimization is expounded, and the flow chart and implementation steps of particle swarm optimization are given. Combined with specific examples, the particle swarm algorithm is used to solve, and the best path schematic is given. The experimental results fully prove the effectiveness of the particle swarm algorithm to solve the VPR problem.

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Author Profile

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