An optimization model for logistics distribution center location based on immune algorithms and fuzzy c-means realized by the p system

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Abstract

Logistics distribution center(DC) plays an important role in the optimization of a logistics system. With the increasing complexity of logistics, conventional logistics distribution center location techniques have become ineffective. Immune algorithm(IA) is a new method of intelligent computing inspired by the theory of immunology or immune system. This paper presents the site selection's model of logistics distribution center based on immune algorithm, which adopts Fuzzy c-means (FCM) to find the preparation of distribution points and realize the process of choosing logistics distribution center in membrane(P) system. P system has the great parallelism so it can decrease the time complexity of computing. To demonstrate the practicality and effectiveness of the proposed algorithm, simulation experiments are conducted in 31 provinces, the results show that this hybrid algorithm can solve the distribution center location problem effectively.

Keywords

Logistics Distribution Center Location Optimization, Fuzzy C-means, Immune Algorithm, P System.

1. Introduction

The logistics distribution center location problem involves how to select location of potential DC set to minimize the cost and improve the service quality. Based on the importance of distribution center's position, researchers carry out the corresponding research and build a series of algorithm and model[1,2], to sum up, some common algorithms for solving this kind of problems are gravity method, numerical analysis method, mathematical programming method, and mixed integer programming[3,4,5]. when problem size is larger, it is difficult to solve the problem with these classic algorithms. It is well known that DC location problem is NP-hard. Immune algorithm is an important branch of artificial intelligence and IA has been widely applied to solve many complex optimization problems , which provides a new thought for the distribution center location problem.

Membrane computing (P system) is a novel research branch of bio-inspired com-puting, initiated by Păun [6], which is abstracted based on the structure and function of the cell. Objects in membrane system evolve in a maximum parallel mechanism which makes it has higher computing power[7], it reduces the time complexity of data processing and satisfies the requirement of improving the processing speed of the big data [8]. Membrane computing has been widely applied to many fields like combinatorial problem, graph theory problems and finite state[9,10,11]. Using the membrane computing can reduce the time complexity, so it makes sense to combain P system and DC location problem.

In this study, An optimization model for logistics distribution center location based on immune algorithms and Fuzzy c-means realized by the p system is proposed (IAFCMPS algorithm, for short). Fuzzy c-means (FCM)is used to give a general prep-arations of distribution points, for each basic partitioning, taking the logistics cost as the objective function, the immune algorithm is used to optimize the distribution center location. All these computing processe is carried out in Cell-like P systems.

The rest of the article is organized as follows: Section 2 introduces the mathematic model of logistics distribution center location. Section 3 describes the literature review and basic principle of Fuzzy c-means, immune algorithms and P systems. Section 4 describes the IAFCMPS algorithm we propose. Section 5 is the experimental analysis. Section 6 discusses the conclusion.

2. Problem description

The logistics DC selection can be used as an optimization problem. There are two main tasks should be completed, first, select the DC from the demand points. Second, determine the DC for each demand point. During this process, it is required that the demand of each demand point should be satisfied and the transportation cost should be minimized. To facilitate the solution of the problem, given the following three assumptions :

(1) The scale of the distribution center capacity can meet the needs of the demand points.

(2) A demand point is only supplied by a distribution center.

(3) Do not consider the transportation costs from the factory to distribution center.

Based on above three assumptions, the problem can be described as selects the distribution center from the N demand points and distributes goods to the demand point. The objective function is the achievement minimum value of the sum of the distance multiply the demand, which can be stated as:

$$F = \min \sum_{i \in N} \sum_{j \in M_i} w_i d_{ij} Z_{ij} \tag{1}$$

Subject to:

$$\sum_{j \in M_i} Z_{ij} = 1 \tag{2}$$

$$Z_{ij} \le r_j \tag{3}$$

$$\sum_{j \in M_i} r_j = p \tag{4}$$

$$d_{ij} \le s \tag{5}$$

$$Z_{ij},\ r_j \in \{0,\ 1\} \tag{6}$$

where N denotes all demand points, i∈{1, 2, …, N} denotes the index for demand points, M_i denotes potential DCs which distance is less than s from the demand points, M_i∈N, j∈{1, 2, …, M_i} denotes the index for potential DCs, w_i denotes the demand of i-th demand point, d_ij denotes minimum distance from the i-th demand point to the j-th DC, Z_ij∈{0, 1} Z_ij=1 if the distribution point i is allocated to DC j, else Z_ij= 0, r_j∈ {0, 1} r_j=1 if j is selected as the DC, otherwise r_j = 0, P denotes the number of distribution centers that we need, in practice, we usually draw scatterplot of demand points first, to see how many clusters are roughly divided by these points. s denotes limit distance between selected DCs and the demand point, which depends on the type of goods being transported and the vehicle we choose. For example, if we distribute flowers from DC to demand points, we may set a small s, which equals to speed multiplied by the delivery time limit.

In this mathematical model, Eq. (1) is objective function. Eq. (2) assure that each demand point is allocated to a DC. Eq. (3) assure that the demand point is served by the potential DC. Eq. (4) assure that the total number of the selected DCs is equal to P. Eq. (5) assure than the demand point within the scope of the DC.

3. Related works

3.1 Literature review

In the past few years, a large number of methods for locating the DCs have been developed. These models can be divided into three types, that is, discrete, continuous and synthesizing type. Discrete models mean selecting the best DC in several alterna-tives, which have four representative methods, namely mixed integer programming, Baumol-Wolf, P-medium, capacitated facility location problem[12,13]. The continu-ous type refers to select the DC in certain region arbitrarily, the most representative method is gravity method. Synthesizing type mainly includes analytic Delphi method, hierarchy process (AHP) and fuzzy comprehensive rating method[14,15]. In recent years, heuristic algorithms are widely used to solve optimization problems with com-plex nature[16,17]. Various research works are carried out to enhance the perfor-mance of heuristic algorithm such as genetic algorithm (GA)、 immune algorithm (IA), Particle swarm optimization(PSO) and ant colony algorithm (ACO)[18,19,20]. Hua X propose a adaptive particle swarm optimization (APSO) algorithm to solve DC location problem[21]. H Li propose a improved immune algorithm to solve DC loca-tion problem[22].

3.2 Fuzzy C-Means

Fuzzy C-Means clustering method was introduced by Bezdek [23] in 1981, extend from Hard C-Mean clustering method. Let X={X_1,X_2,…,X_n} be a collection of n objects where each object X_i is represented as [X_i1,X_i2,…,X_im], here m is the number of numerical attributes. k is the number of clusters, that are represented by C=[C_1,C_2,…,C_K] ,the objective function used for FCM is as below:

$$J(X,C,U)=\sum_{j=1}^{k}\sum_{i=1}^{n}(u_{i,j})^{a}D_{i,j},\quad 1\le a\le\infty \tag{7}$$

Where U is an n × k known as fuzzy membership matrix and U_ij corresponds to the association degree of membership that an ith object of the given data is having with j-th cluster center c_j. Here, square of Euclidean norm is used as distance measure (similarity measure), i.e,

$$D_{i,j}=\sum_{l=1}^{m}\left(x_{i,l}-c_{j,l}\right)^{2},\quad 1\le i\le n,1\le j\le k \tag{8}$$

Subject to the following condition:

$$\sum_{j=1}^{k}u_{i,j}=1,\quad u_{i,j}\in(0,1],\quad 1\le i\le n \tag{9}$$

To optimize the objective function for FCM, it is needed to minimize its value. The minimization problem is solved by iteratively calculating cluster centers C and fuzzy membership matrix U using the following equations until the change in U is negligible.

$$c_{j,l}=\frac{\sum_{i=1}^{n}(u_{ij})^{m}x_{i,l}}{\sum_{i=1}^{n}(u_{i,j})^{m}},\quad 1\le j\le k,1\le l\le m \tag{10}$$

$$u_{i,j}=\frac{1}{\sum_{l=1}^{k}\left(\frac{D_{i,j}}{D_{l,j}}\right)^{2/(m-1)}},\quad 1\le i\le n,1\le j\le k \tag{11}$$

3.3 Immune algorithm

The natural immune system is a complex adaptive pattern-recognition system that defends the body from foreign pathogens (bacteria or viruses)[24].The immune algorithm and genetic algorithm have similar structures. Unlike the GA, the quality of individuals (antibodies) is evaluated using the affinity (fitness) and concentration in the IA, which reflects the diversities of the immune systems. However, the only evaluation index of the GA is the fitness [25]. So, the IA evaluates the individuals more comprehensively than the GA, which make IA maintain the diversity of the population[26]. The objective function and constraints corresponds to antigen, and the feasible solution corresponds to the antibody. The affinity between the antigen and the antibody corresponds to matching degree of the solution to objective function. The steps of the algorithm are as follows:

Step1: Antibody coding.

According to the characteristics of the model, the feasible solutions are conducted by integer encoding method. Each site selection program can form an antibody with a length of p. (p stand for the number of the DCs). For example, consider the problem that contains 31 distribution points, 1,2,…,31 represents the index of the demand point, 6 demand points are selected as the distribution centers. The antibody [3 5 13 17 24 28] represent a feasible solution, which means 3, 5, 13,17,24,28 are selected as the DC.

Step2: Production of the Initial population.

Produce the initial antibody group with MATLAB software. It randomly generates a matrix which contain n chromosomes. Each row represents an antibody. n is the total number of antibody in the initial population.

Step 3: Objective function evaluate.

Evaluate the fitness of each antibody.

Step 4: Clonal selection of antibody-based incentive.

Affinity is the antibody incentives degree of the final evaluation results.

(1) Calculation of the antibody affinities (A_v).

Affinity between antibody and antigen can be seen as the fitness of the antibody. In order to solve the logistics distribution center location problem, affinity can be described as follows:

$$A_V = \frac{1}{F_V} = \frac{1}{\sum_{i\in N}\sum_{j\in M_i} w_i d_{ij} Z_{ij} - C\sum_{i\in N}\min\{(\sum_{j\in M_i} Z_{ij}) - 1, 0\}} \tag{12}$$

Where F_v is objective function. The second of the denominator denotes the punishment of the violation of distance constraint. C is a positive number.

(2) Calculation of the antibody density(C_v).

Antibody density expresses the diversity of population. When antibody density is too high, it means that the individuals in the population are very similar. When antibody density is too low, it means that the scattered distribution of antibody is not conducive for improving efficiency.

$$C_V = \frac{1}{N} = \frac{1}{N}\sum_{j\in N} S_{V,S} \tag{13}$$

$$S_{V,S} = \frac{k_{vs}}{L} \tag{14}$$

Where k_vs is the the same number of bits between antibody v and antibody s, L is the total length of the antibody.

Clonal selection probability base on the degree of antibody incentives:

$$P = a\frac{A_v}{\sum A_v} + (1-a)\frac{C_v}{\sum C_v} \tag{15}$$

Where a is a constant, antibodies with low concentration and high fitness will be given a greater reproduction expected probability.

Step 5: Production next population

Produce next population with selection ,crossover and mutation

Step 6: Termination test.

Check the stopping criterion. If it is met, output the best antibody; otherwise, go to step 2.

3.4 Cell-like P System

P system is abstracted from the process of cells managing chemical substances as a new membrane computing model. There are three kinds of P systems: cell-like P sys-tems, tissue-like P systems, and neural-like P systems (also known as spiking neural P systems) [27,28,29]. A cell-like P system with promoters and inhibitors consists of three main components: the hierarchical membrane structure, objects and evolution rules. The basic membrane structure is shown in Fig.1. Membranes divide the whole system into different regions. The skin membrane is the outermost membrane (In Fig.1, membrane 1 is the skin membrane). A membrane is a basic membrane if there are no membranes in it (In Fig.1, membrane 2,3, 5, 7, 8 and 9 are basic membranes) and a membrane is a non-elemental membrane otherwise (In Fig.2 membrane 1, 4, and 6 are non-elemental membranes). Rules and objects exist in regions.

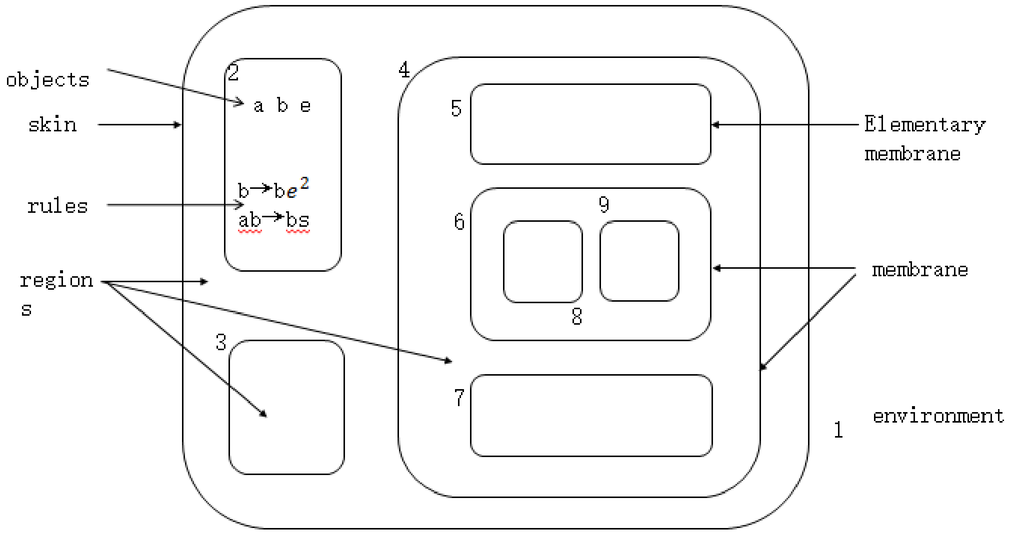

Fig.1 The basic membrane structure.

4. Simulation experiment and analysis

Based on the above analysis, the procedures of the proposed IAFCMPS algorithm is depicted in Fig. 2 and summarized as follows:

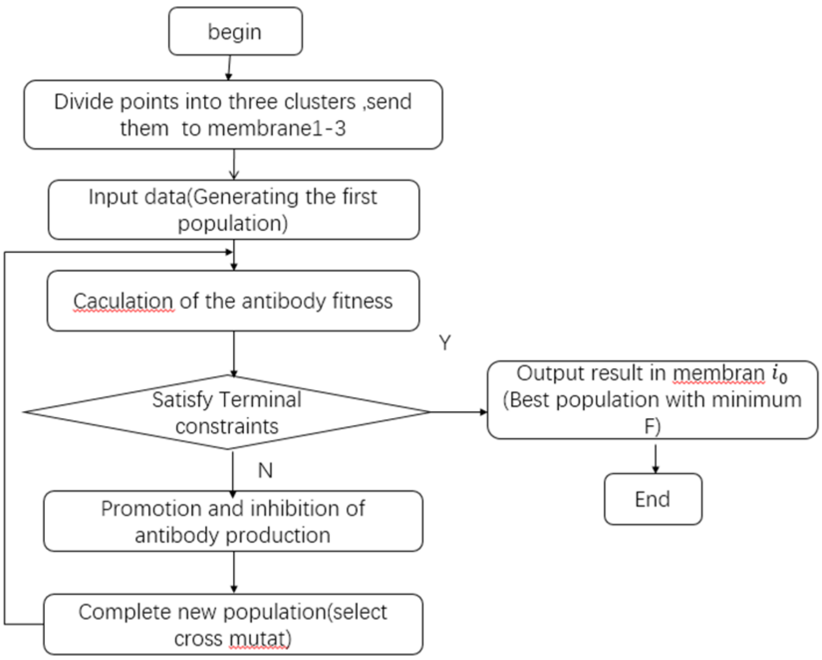

Fig.2 The chart of the proposed IAFCMPS algorithm.

In order to reduce the time complexity of data processing. Membrane computing has been applied to the logistics distribution center location problem, there have four basic membrane. Membrane1,2,3 is used to save each clusters and use immune algorithm to optimize the selection of distribution center .The final results is showed in the membrane i_0.The discription of the proposed membrane system can be seen in Fig.3.

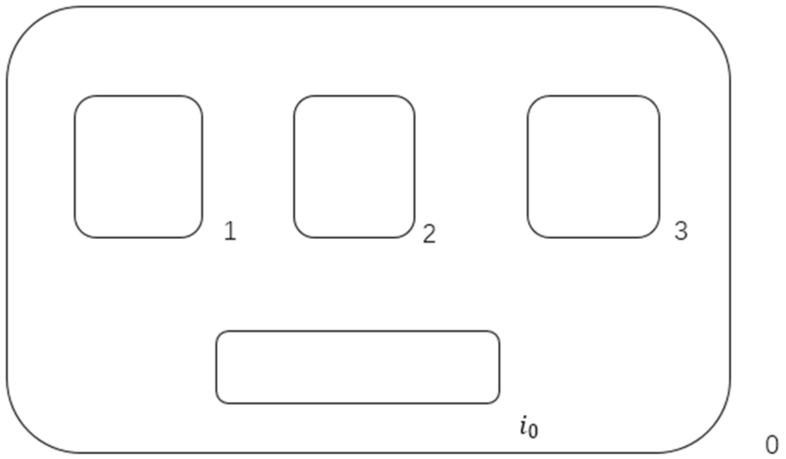

Fig.3 The designed cell-like P system.

Membranes divide the whole system into different regions. Rules and objects exist in regions. The rules are executed in a nondeterministic and maximum parallel way. i_0 indicates the output region. The steps of the proposed IAFCMPS algorithm are as follows:

Step1. Divide the individuals into three portions with fuzzy C-Means clustering method in membrane 0, and send each cluster to membrane 1-3.

Step2. Execute the immune algorithm in membrane 1-3.

Step3. Repeat these steps until attain the maximum iteration criteria, and the final global optimum is showed in the membrane i_0.

In order to evaluate the effectiveness and efficiency of the proposed model and algorithm., The coordinates of 31 provincial capitals of china are collected as date sampling, which include Beijing Tianjin Shanghai Chongqing Lhasa Urumqi Yin-chuan Hohhot Nanning Harbin Changchun Shenyang Shijiazhuang Taiyuan Xining Jinan Zhengzhou Nanjing Hefei Hangzhou Fuzhou Nanchang Changsha Wuhan Guangzhou Haikou Lanzhou Xi'an Chengdu Guiyang Kunming, We use turnover of goods as an indicator of logistics demand. The turnover of goods of each province is collected from China Statistical Yearbook (16-15 Unit: ten billion tons). 1-31 serial numbers represent 31 provincial capitals. Table 1 presents these data.

Fig. 4 shows the basic prepartation of the Fuzzy C-Means clustering method, as can seen from Fig. 4, 31 provincial capitals are divided into three clusters, which is marked by three colors respectively.

According to the distribution center location model, specific parameters in immune algorithm are set the as follows: population size is 50, memory capacity is 30. maxi-mum iteration number T is 100.The probability of crossing and mutating is 0.5 and 0.3 respectively.

As can be seen from Fig. 5, iterative process of IAFCMPS can achieve to the opti-mal fitness value 5.51E + 05 with 22th generation, and the convergence curve of average fitness value is smooth and fluctuation stability. Thus, IAFCMPS can obtain a better global optimal solution and strong stability, indicating that the algorithm is effective and credible.

As can be seen from Fig. 6, six distribution centers (5,9,12,17,20,27) are selected in the 31demand point, the 5-th distribution center can supply the demand for(6), the 9-th distribution center can supply the demand for (25,26,30,31), the 12-th distribution center can supply the demand for (10,11,14), the 17-th distribution center can supply the demand for (1,2,8,13,16,23,24,25,28), the 20-th distribution center can supply the demand for (3,18,19,21,22), and the 27-th distribution center can supply the demand for (4,7,15,29).

Table. 1. Location and demand of provincial capitals.

J	(U,V)	b	J	(U,V)	b	J	(U,V)	b
1	(116,40)	9	12	(123,42)	117	23	(113,28)	39
2	(117,39)	25	13	(114,38)	120	24	(114,31)	57
3	(121,31)	195	14	(123,39)	34	25	(113,23)	149
4	(107,30)	27	15	(102,37)	4	26	(110,20)	12
5	(91,30)	1	16	(117,37)	84	27	(104,36)	22
6	(88,44)	18	17	(114,35)	69	28	(109,34)	33
7	(106,38)	8	18	(119,32)	83	29	(104,310	24
8	(112,41)	42	19	(117,32)	104	30	(107,27)	14
9	(108,23)	41	20	(120,30)	99	31	(103,25)	15
10	(127,46)	15	21	(119,26)	54			
11	(125,44)	14	22	(116,29)	38			

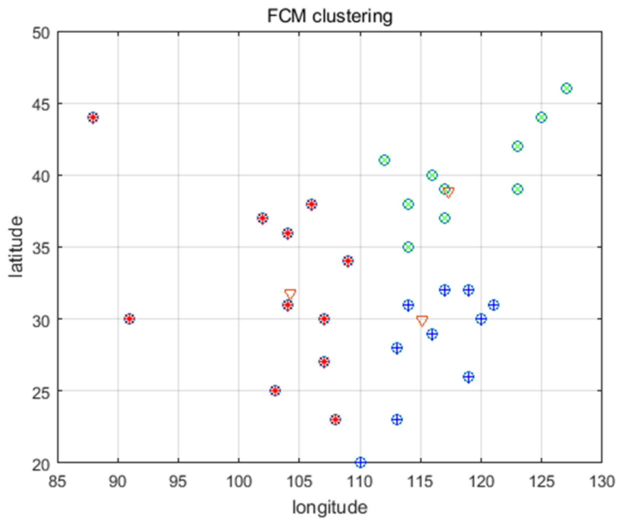

Fig. 4 FCM clustering result.

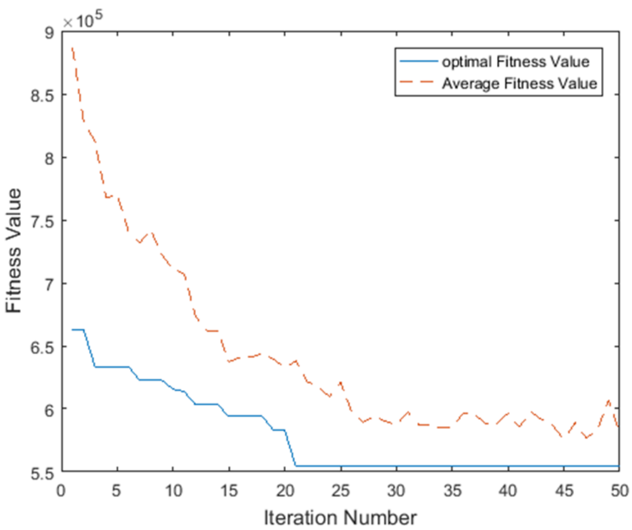

Fig. 5 Convergence characteristic.

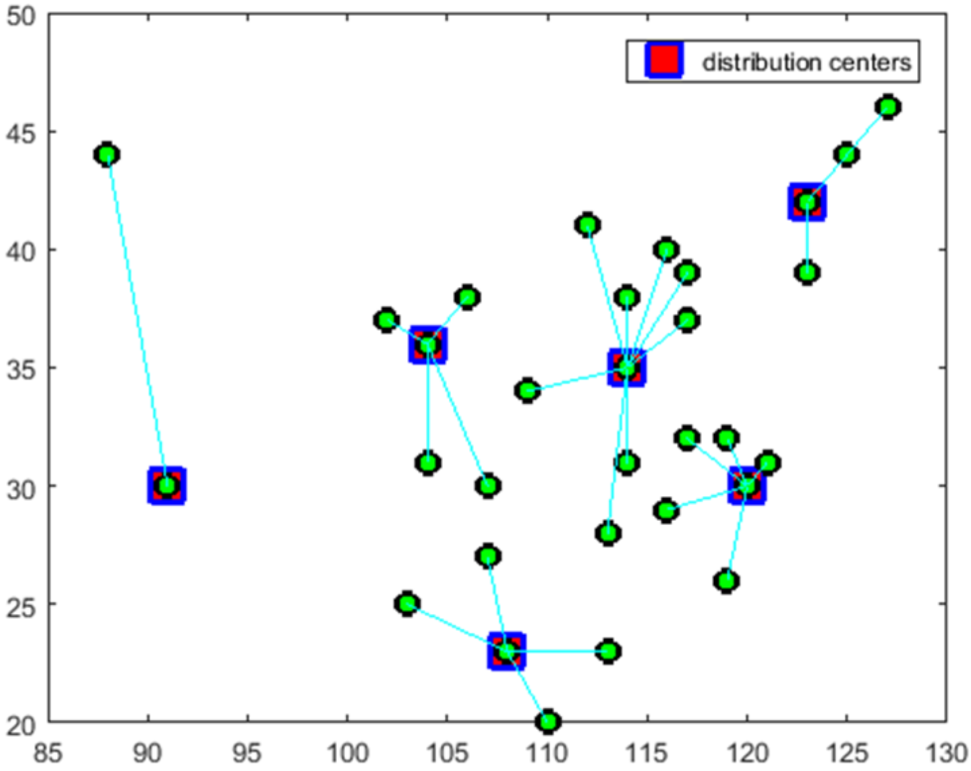

Fig. 6 Logistics distribution center location.

5. Conclusions and future work

The logistics DC location problem is of great significance for improving logistics dis-tribution efficiency and saving the cost of distribution. A new approach IAFCMPS is proposed to solve the optimization of the distribution center location. An experiment was carried out to illustrate the effectiveness of the algorithm.The simulation results show that it can adaptively optimize the distribution center location problem. The further work may concentrate upon using more evolutionary algorithm based on membrane computing in order to solve more optimization problems with constraints.

Acknowledgements

This work is supported by the Natural Science Foundation of China (nos.61472231, 61502283, 61640201), Ministry of Education of Humanities and Social Science Research Project, China(12YJA630152), Social Science Fund Project of Shandong Province, China(16BGLJ06, 11CGLJ22).

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