A New Hybrid Algorithm for Cold Chain Logistics Distribution Center Location Problem

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ABSTRACT According to the perishable characteristics of refrigerated food and the objective of minimizing the total cost, the mathematical optimization model of cold chain logistics distribution center location problem is established by introducing such constraints as the freshness and time window. In order to solve the problems of slow convergence and easy to fall into local optimal solution in the process of the traditional wolf colony optimization, an immune wolf colony hybrid algorithm is proposed to solve the location problem of distribution center. In this hybrid algorithm, the idea of vaccination of immune algorithm is introduced into the wolf colony algorithm. By adjusting the antibody concentration and selecting immune operator, the diversity of the wolf colony algorithm is improved, and then the search space of the solution is expanded; the convergence speed and solution accuracy of the wolf colony algorithm are improved by using immune memory cells and immune vaccine. The simulation results show that the immune wolf colony algorithm can quickly converge to the global optimal solution and optimize the location model of logistics distribution center. The algorithm has good feasibility and robustness.

INDEX TERMS Cold chain logistics, distribution center location, immune algorithm, wolf colony algorithm.

I. INTRODUCTION

With the continuous development of society, people have a higher pursuit of the quality of daily life, especially in the aspect of the freshness of refrigerated food, which is gradually attracting more and more attention of the public. Since China issued the “logistics industry adjustment and revitalization plan” in 2009, cold chain logistics has been highly valued by various industries, which promotes the sustainable, healthy and rapid development of cold chain logistics. However, compared with the development of cold chain logistics in foreign countries, China is still in the primary stage of cold chain logistics development, and the cost of distribution links accounts for a high proportion of the total cost of cold chain logistics, which is not conducive to the healthy development of cold chain logistics [1]. Therefore, how to further improve the efficiency of cold chain logistics and reduce the cost of cold chain logistics has become one of the urgent problems in the development of cold chain logistics.

In recent years, the location of logistics distribution center has been the focus of many scholars. Alfred Weber first proposed the location theory in 1909 [2]. After that, Hakim [3] further proposes the location problem of distribution center, and gives the step location problem model to solve the optimal location problem of distribution center. With the continuous exploration and research on the location of distribution center, different scholars study the location of logistics distribution center from different perspectives. On the one hand, some scholars who study the mathematical model of distribution center location. For example, Li et al. [4] proposed a mixed integer programming model, Li et al. [5] proposed a nonlinear programming model, and Sun et al. [6] proposed a double-layer programming model. In solving the traditional location problem of logistics distribution center, the objective function only considers the minimization of logistics distribution cost, but in the actual cold chain logistics distribution problem, due to the perishable characteristics of refrigerated food, if the total cost is kept to the lowest, then there is more than one goal to be considered. Based on this, a multi-objective mathematical optimization model of cold chain logistics distribution center location problem, which is composed of distribution cost, damage cost, penalty cost and construction cost, is constructed by introducing the damage rate and time window.
On the other hand, some scholars who study the methods of solving mathematical models, such as Yang and Li [7] put forward the center of gravity method, Fan et al. [8] put forward the analytic hierarchy process. The above traditional solution methods lay the foundation for solving the location problem of logistics distribution center. In recent years, swarm intelligence optimization algorithm has shown its superiority in solving complex combinatorial problems, which provides new ideas and methods for location problem. Li et al. [9] present improved particle colony optimization algorithm to solve the multi-objective constrained optimization model. Wen and Zhang [10] considered the circulation of fresh food, and established the cold chain distribution center location model, and the model is proved to be feasible by the simulation of genetic algorithm. Shang et al. [11] introduced the comprehensive mutation strategy and random sine inertia weight to optimize the traditional whale algorithm, and used the improved whale algorithm to solve the location of distribution center. Ho [12] proposed an iterative tabu search heuristic algorithm to solve the single source capacity facility location problem, and combined tabu search with disturbance operator to avoid falling into local optimum.

Although some progress has been made in solving the location problem of logistics distribution center, people pay more and more attention to the method of location problem because of the complexity of multiple constraints and optimization objectives. Wolf colony algorithm (WCA) is one of the new intelligent optimization algorithms, which is inspired by the predatory behavior of wolves in nature and their prey distribution. The WCA has many advantages in solving the problem, such as the diversity of the strategy, the ability of global optimization and the diversity of population. Another algorithm, Immune algorithm (IA) is an intelligent search algorithm based on the basic mechanism of biological immune system [13]. Because of its strong robustness, high precision and convenience for parallel processing, some researchers have organically combined its algorithm theory with other functional algorithms to improve the integrity of the algorithm. Because the WCA has the disadvantages of slow convergence speed and easy to fall into local optimal solution, this paper proposes a hybrid algorithm based on wolf colony algorithm and immune algorithm, and solves the location problem of cold chain logistics distribution center by using the hybrid colony which is called immune wolf colony algorithm (IWCA). Through the MATLAB simulation experiment, it is proved that the IWCA can quickly converge in the process of optimization, improve the accuracy of solution, and provide a more reasonable location scheme, which provides a new theoretical method to solve the location problem of cold chain logistics distribution center.

II. PROBLEM FORMULATION AND MODEL ESTABLISHMENT

A. PROBLEM FORMULATION AND ASSUMPTION

In this paper, the study of the cold chain logistics distribution center location problem is that multiple distribution centers correspond to multiple demand points, specifically described as, determine the location coordinates and requirement of all demand points, select a certain number of demand points to build a distribution center, thus forming a series of distribution areas, so that the total cost of the distribution system established between each distribution center and each demand point is the minimum [14]–[16]. In consideration of relevant costs, the following assumptions are made:

Assumption 1: the total refrigerated food quantity that each distribution center can provide can fully meet the demand of all the demand points of its service, and the distribution center has sufficient distribution and transportation capacity to distribute.

Assumption 2: within the maximum distribution capacity of each distribution center, the demand of all demand points can only be provided by the corresponding distribution center.

Assumption 3: the upper and lower thresholds of the time window for the arrival of refrigerated food at each demand point are known, which does not include the time consumed by the refrigerated food in the loading process.

Assumption 4: the transportation cost of cold chain logistics distribution center is not considered.

Assumption 5: the fixed cost of cold chain logistics distribution center includes operation cost and construction cost, without considering other fixed costs.

B. PARAMETER DEFINITION

Notations and variables of the model are defined as follows: all demand points set \( N = \{1, 2, 3 \ldots n\} \), candidate logistics distribution center set \( M_i \), where \( i \in N, M_i \subseteq N \), the distance between logistics distribution center \( j \) and its service demand point \( i \) is \( d_{ij} \), the maximum distance between chain logistics distribution center \( j \) and its service demand point \( i \) is \( D_{ij} \), the requirement of demand point \( i \) is \( c_i \), construction cost of logistics distribution center is \( w_j \).

The following are decision variables: \( \xi_{ij} = 1 \) when distribution relationship between candidate logistics distribution center \( j \) and demand point \( i \) is enabled, otherwise \( \xi_{ij} = 0 \); \( \tau_j = 1 \) when demand point \( j \) is selected as logistics distribution center, otherwise \( \tau_j = 0 \).

C. FILE FORMATS FOR GRAPHICS

Based on the above problem assumption and parameter definition, aiming at the minimum total cost of cold chain logistics distribution, the mathematical optimization model of cold chain logistics distribution center location problem is established. The total cost of the cold chain logistics distribution center includes the construction cost of the distribution center, the distribution cost of refrigerated food, the damage cost of logistics distribution and the penalty cost of logistics distribution.

1) CONSTRUCTION COST OF COLD CHAIN LOGISTICS DISTRIBUTION CENTER

When a demand point is confirmed to be a logistics distribution center, it needs to be established by investment, so it
will generate construction costs. Since the above assumptions stipulate that the construction cost is a known fixed value, the construction cost of the logistics distribution center can be expressed as:

\[ A_1 = \sum_{j \in M_i} w_j t_j \]  

(1)

2) DISTRIBUTION COST OF COLD CHAIN LOGISTICS DISTRIBUTION

When there is a distribution relationship between the logistics distribution center and the demand point, the logistics distribution center needs to transport the goods to the demand point, so as to generate distribution cost. Distribution cost is related to the requirement and distribution distance of demand point. The distribution cost between the logistics distribution center \( j \) and the demand point \( i \) is calculated as follows:

\[ A_2 = \sum_{i \in N} \sum_{j \in M_i} c_{ij} d_{ij} \]  

(2)

Constraint conditions as follow:

\[ \sum_{j \in M_i} \xi_{ij} = 1 \]  

(3)

\[ \sum_{j \in M_i} t_j = k, \quad k \leq n \]  

(4)

\[ \xi_{ij}, t_j \in \{0, 1\}, \quad i \in N, j \in M_i \]  

(5)

\[ \xi_{ij} \leq t_j, \quad i \in N, j \in M_i \]  

(6)

\[ d_{ij} \leq D_{ij} \]  

(7)

Constrains (3) ensures that each demand point is provided the refrigerated food distribution services with one cold chain logistics distribution center. Constrain (4) indicates that the total number of logistics distribution centers is not more than the total number of demand points. Constrain (6) ensures that the total demand of each demand point can only be delivered by the corresponding logistics distribution center. Constrain (7) ensures that the distance between the logistics distribution center \( j \) and demand point \( i \) is not more than the maximum distribution distance of the distribution center.

3) CARGO DAMAGE COST OF COLA CHAIN LOGISTICS DISTRIBUTION

Considering the perishable characteristics of refrigerated food, its freshness is guaranteed in the process of cold chain logistics distribution. This paper learn from the reference [17] that induced three stages of freshness. When \( t = 0 \), the freshness of refrigerated food is in the first stage, and the deterioration rate is 0. When \( t \in [0, T_0] \), the freshness of refrigerated food is in the second stage, at this time, the quality has declined, but there is no obvious change in the food itself. When \( t \in [T_0, T] \), the freshness of refrigerated food is in the third stage, with the increase of time, the food itself is rotten; when the delivery time more than \( T \), the freshness of refrigerated food is 0, and it cannot be sold. Considering that in the actual distribution process, most of the distribution time of refrigerated food happen to in the second stage and the third stage, the change rate of freshness between the logistics distribution center and each demand point can be expressed by the following linear function

\[ \varphi = \frac{T - t}{T - T_0} \]  

(8)

where \( \varphi \) represents the intact rate of freshness, \( t \) represents current distribution time, \( T_0 \) represents the start time of distribution, \( T \) represents the end time of distribution.

Cargo damage of cold chain logistics distribution is expressed as follows:

\[ A_3 = c_i \zeta_{ij} (1 - \varphi) = c_i \zeta_{ij} \frac{t - T}{T - T_0} \]  

(9)

4) PENALTY COST OF COLD CHAIN LOGISTICS DISTRIBUTION

On the one hand, in order to improve the logistics service level and customer satisfaction, on the other hand, in order to meet the needs of refrigerated food distribution, it needs to be completed in an acceptable time period at the demand point, so it is necessary to introduce the logistics distribution penalty cost with time window [18], [19]. Assumption that \( T_{ij} \) represents the distribution time from cold chain logistics distribution center \( j \) to demand point \( i \), and the acceptable arrival time window of demand point \( i \) is \([T_{\min}, T_{\max}] \), \( T_{\min} \) represents the minimum time of acceptable arrival, \( T_{\max} \) represents the maximum time of acceptable arrival.

When \( T_{ij} < T_{\min} \), the penalty cost of logistics distribution is expressed as follows:

\[ B_1 = \alpha \sum_{i \in N} \sum_{j \in M_i} \left[ \max \left( T_{\min} - T_{ij}, 0 \right) \right] \]  

(10)

When \( T_{ij} < T_{\min} \), the penalty cost of logistics distribution is expressed as follows:

\[ B_2 = \beta \sum_{i \in N} \sum_{j \in M_i} \left[ \max \left( T_{\min} - T_{\max} \right), 0 \right] \]  

(11)

Therefore, the objective function of penalty cost of cold chain logistics distribution as follows:

\[ A_4 = B_1 + B_2 \]

\[ = \alpha \sum_{i \in N} \sum_{j \in M_i} \left[ \max \left( T_{\min} - T_{ij}, 0 \right) \right] + \beta \sum_{i \in N} \sum_{j \in M_i} \left[ \max \left( T_{ij} - T_{\max} \right), 0 \right] \]  

(12)

where \( \alpha \) is a penalty coefficient for the case that the distribution time earlier than the minimum time of time window; \( \beta \) is a penalty coefficient for the case that the distribution time later than the maximum time of time window

5) LOCATION PROBLEM OPTIMIZATION MODELLING FOR COLD CHAIN LOGISTICS DISTRIBUTION CENTER

In conclusion, the objective function of minimizing the total cost of cold chain logistics distribution center as follows:

\[ \min A = \min (A_1 + A_2 + A_3 + A_4) \]
III. RESEARCH ON IMMUNE WOLF COLONY ALGORITHM

A. PRINCIPLE OF THE WOLF COLONY ALGORITHM

Wolf colony algorithm (WCA) is an intelligent optimization algorithm that simulates the hunting behavior of wolves colony in nature. It can show three kinds of intelligent behaviors (wandering behavior, calling behavior and siege behavior) and update mechanism of wolves [20]. In the WCA, the best individual is named as \( \alpha \) wolf, the second best individuals are named as \( \beta \) wolves and third best individuals are named as \( \gamma \) wolves, respectively, and the other individuals are called as \( \omega \) wolves. Wandering behavior refers to exploring the optimal position of wolves in the current area to randomly search for prey. Calling behavior refers to the \( \alpha \) wolf calling the nearby \( \beta \) wolves through howling, and the \( \beta \) wolves rush to the \( \alpha \) wolf quickly. Siege behavior refers to the wolves’ encircling of prey through the natural principle of “survival of the fittest”, the renewal mechanism of wolf pack is to selectively eliminate some wolves with poor ability, and give priority to ensure that the wolves with ability can get enough food, so as to ensure the continuity and development of wolf pack.

1) INITIALIZATION OF THE WOLF COLONY

Assuming that the size of the wolf colony is \( ND \), the dimension of the wolf colony search space is \( D \), and the location of the \( i \) wolf in the early generation is expressed as:

\[
X_i = (x_{i1}, x_{i2}, x_{i3}, \cdots x_{id}, \cdots x_{id})
\]

\[
x_{id} = x_{id}^m + \text{rand} \times (x_{id}^M - x_{id}^m)
\]

where \( \text{rand} \) is a random number in \([0,1]\), \( x_{id}^m \) is the minimum range of iteration \( x_{id} \), \( x_{id}^M \) is the maximum range of iteration \( x_{id} \). By calculating the objective function of wolves, comparing the value of the function, the \( \alpha \) wolf, \( \beta \) wolves and \( \gamma \) wolves are selected from all wolf colony. The \( \alpha \) wolf does not need to perform the next three intelligent behaviors, and directly into the next iteration until it is replaced by a better wolf or terminated. Considering that the location problem of logistics distribution center is to solve the minimum value of objective function, the minimum value of function is the optimal value of fitness.

2) WANDERING BEHAVIOR OF THE WOLF COLONY

After choosing the \( \alpha \) wolf, the \( \beta \) wolves start wandering behavior in the space. The \( \beta \) wolves move in the \( \nu \) direction, and record the fitness value in each direction. Then the \( \beta \) wolves will move in the direction of higher odor concentration, and update the position of the \( \beta \) wolves. After the \( \beta \) wolf moves in the \( p (\beta = 1, 2, \cdots v) \) direction, the position of \( \beta \) wolf in the \( d (d = 1, 2, \cdots D) \) dimension is expressed as:

\[
x_{id}^p = x_{id}^p + \eta \times \text{step}_{\alpha}
\]

where \( \eta \) represents the search factor of the \( \beta \) wolves that is a random number in \([0,1]\), \( \text{step}_{\alpha} \) represents the step of the \( \beta \) wolves.

Compared the fitness value of the \( \alpha \) wolf with the fitness value of the \( \beta \) wolves. If the location of the wolf \( x_{id} \) moves to \( x_{id}^p \), the fitness of \( x_{id}^p \) is better than the current location. The position of the \( x_{id} \) wolf is updated to \( x_{id}^p \). Otherwise, the position of the \( x_{id} \) wolf does not move. The adaptation values of the \( x_{id} \) wolf after updating is compared with the fitness values of the \( \alpha \) wolf. If the fitness value of \( \beta \) wolf better than the \( \alpha \) wolf, the \( \alpha \) wolf will take the place of the \( \alpha \) wolf.

3) CALLING BEHAVIOR OF THE WOLF COLONY

When the end of the wandering behavior, the new \( \alpha \) wolf will summon the surrounding \( \gamma \) wolves, the \( \gamma \) wolves will run to the location of the \( \alpha \) wolf with a faster speed. When wolf \( i \) in the \( k + 1 \) iteration, the position of \( \gamma \) wolf in the \( d (d = 1, 2, \cdots D) \) dimension is expressed as:

\[
x_{id}^{k+1} = x_{id}^k + \xi \times \text{step}_{\beta} \times (x_{ad}^k - x_{id}^k)
\]

where \( \xi \) represents the rush factor of the \( \gamma \) wolves that is a random number in \([-1,1]\), \( \text{step}_{\beta} \) represents the step of the \( \gamma \) wolves, \( x_{id}^k \) represents the position of the wolf \( i \) in the \( d \) dimensional space when the \( k \) generation, \( x_{ad}^k \) represents the position of the \( \alpha \) wolf in the \( d \) dimensional space when the \( k \) generation wolves.

4) SIEGE BEHAVIOR OF THE WOLF COLONY

When the wolf colony finish calling behavior, the \( \alpha \) wolf will command the \( \beta \) wolves, the \( \gamma \) wolves and the \( \omega \) wolves to encircle the prey with the position of the \( \alpha \) wolf. For the \( k + 1 \) generation of wolves, the siege behavior of the wolves is expressed as:

\[
x_{id}^{k+1} = x_{ad}^k + \sigma \times \text{step}_{\gamma}
\]

where siege factor of the wolves that is a random number in \([-1,1]\), \( \text{step}_{\gamma} \) represents the step of the wolves.

When the siege behavior is finished, if the function value of the position of the wolf \( i \) is better than the original function value, the position of the wolf will be updated; otherwise, the position of the wolf will remain unchanged. The adaptation values of the \( x_{id} \) wolf after updating are compared with the fitness values of the \( \alpha \) wolf, \( \beta \) wolves, and \( \gamma \) wolves. The best three wolves were selected as the \( \alpha \) wolf, \( \beta \) wolves, and \( \gamma \) wolves to complete the update of the \( \alpha \) wolf, \( \beta \) wolves, and \( \gamma \) wolves.
B. THE IMMUNE WOLF COLONY ALGORITHM

1) THE DESIGN IDEA OF THE IMMUNE WOLF COLONY ALGORITHM

The immune wolf colony hybrid algorithm proposed in this paper focuses on the combination of wolf colony algorithm and immune algorithm, which makes the hybrid algorithm have the advantages of immune algorithm’s excellent solving performance in combinatorial optimization and wolf colony algorithm’s fast convergence in solving problems, and avoids the disadvantages of immune algorithm’s slow convergence speed in optimization problems and wolf colony algorithm’s easy falling into local extremum. Therefore, the immune wolf colony hybrid algorithm provides new way to solve the NP hard optimization problem.

The basic principle of designing immune wolf colony hybrid algorithm is to use the randomness and global searching of immune algorithm to find the better feasible solution in line with the actual problem at the beginning of algorithm optimization. Combining the immune principle of antibody concentration inhibition mechanism and immune memory function in immune algorithm with the wolf colony algorithm, the wolf colony has the ability of “immunity” by means of vaccination, which not only ensures the stability of the wolf colony algorithm in solving optimization problems, but also improves the global search ability of the algorithm.

When using the immune wolf colony hybrid algorithm to solve the location problem of multiple distribution centers, this paper takes the individual wolf colony as the antibody of the immune algorithm, the odor concentration of prey as the fitness value of the current solution. The process of wolf colony searching and trapping prey is to use immune wolf colony hybrid algorithm to solve the location problem of multiple distribution centers iteratively. In the process of wolf pack updating, it is always hoped that the wolf with high adaptability will be left behind. However, if the superior wolf is too concentrated, it is difficult to ensure the diversity of the whole wolf colony. Therefore, by using the mechanism of antibody concentration inhibition, the antibody with low affinity and high concentration will be suppressed, and the antibody with high affinity and low concentration will be retained. And promote the production, so as to ensure the diversity of antibody groups.

2) THE STEPS OF THE IMMUNE WOLF COLONY ALGORITHM

The implementation steps of the IWCA designed in this paper are as follows:

Step 1. Determine the parameters of immune wolf colony hybrid algorithm, such as the size of wolf colony \(ND\), the maximum number of iterations \(T\), et al.

Step 2. According to (15), randomly generate the first generation of wolves, and record the location of each wolf.

Step 3. Calculate the fitness value of the \(x_u\) wolf, select \(\alpha\) wolf, \(\beta\) wolves, \(\gamma\) wolves and \(\omega\) wolves by comparing the fitness value.

Step 4. Calculate the antibody affinity of each wolf. The affinity between antibodies indicates the degree of similarity between antibodies. In this paper, it is measured by Forrest’s R consecutive matching method. The expression of the affinity function between antibodies calculated can be expressed as:

\[
R_{u,v} = \frac{\omega_{u,v}}{L}
\]

where \(\omega_{u,v}\) represents the number of same bits between antibody \(u\) and antibody \(v\). \(L\) represents the length of antibody.

Then calculate and update the position of each wolf according to the affinity. Determine whether the algorithm termination condition that is to find the optimal solution or to reach the maximum number of iterations \(T\) is met. If the termination condition is met, the optimal solution is output, otherwise, turn to step 5.

Step 5. According to the affinity between the antibody and the antigen, some of the antibodies with higher affinity are stored in the memory bank as immune memory cells.

Step 6. Generate immune vaccine. The selection of immune vaccine determines the accuracy and efficiency of the algorithm to a large extent. Therefore, by analyzing the location problem of logistics distribution center, we can get the characteristic information related to the problem, and then select two best antibodies which are called initial solution of the problem from the antibody group to intersect, and take the public subset as the immune vaccine.

Step 7. Update the position of each wolf by (16)-(18). Generate \(n\) new antibodies after updating, and randomly select \(r\) antibodies from immune memory cells to form the new antibody group of \(n + r\) antibodies.

Step 8. Calculate the expected reproduction rate of the new antibody population. The expected reproduction rate is composed of the affinity between antibody and antigen and antibody concentration.

The affinity between antibody and antigens used to indicate the recognition degree of antibody to antigen, which is called its fitness. The expression of the affinity function between antibody and antigen calculated in this paper can be expressed as:

\[
P_u = \frac{1}{f_u}
\]

where \(f_u\) is the general objective function.

Antibody concentration is the ratio of similar antibody to all antibody groups. The expression of antibody concentration function calculated in this paper is shown as:

\[
C_u = \frac{\sum_{u,v \in N} R_{u,v}}{N}
\]

\[
R_{u,v} = \begin{cases} 
1 & R_{u,v} > a \\
0 & \text{other} 
\end{cases}
\]

where \(C_u\) represents the concentration of antibody. \(N\) represents the size of the antibody population. \(R_{u,v}\) represents...
where \( Y \) represents the expected reproduction rate of the antibody \( u \). \( \theta \) is a constant. It can be seen from the above formula that the affinity between antibody and antigen is directly proportional to the expected reproduction probability, and the antibody concentration is inversely proportional to the expected reproduction probability. Expected reproduction rate that not only promotes the production of high affinity antibodies, but also inhibits the production of high concentration antibodies, thus can ensure the diversity of antibodies. According to the expected reproduction rate of antibody, the new antibodies \( n \) are selected to form the new antibody group.

Step 9. According to the prior knowledge of the problem, according to a certain proportion, vaccinate the antibody with low affinity in the new antibody group. The immune operator is composed of vaccination and immune selection. Its purpose is to prevent population degeneration. Vaccinate the antibody with low affinity to form a new antibody; immune selection is to calculate the affinity of the new antibody. If the affinity of the new antibody is greater than that of the original antibody, then choose to receive the vaccination, otherwise give up the vaccination and retain the original antibody.

Step 10. Turn to step 3, recalculate the antibody affinity of the new antibody group with vaccination, and judge whether the termination conditions of the algorithm are met. If the termination conditions are met, the algorithm will be ended and the optimal solution and logistics distribution center location scheme will be output. Otherwise, repeat the cycle until the maximum number of iterations \( t \) is reached.

The specific flow chart is shown in Fig. 1.

IV. ALGORITHM SIMULATION AND ANALYSIS

In order to verify the feasibility of IWCA in cold chain logistics distribution center location problem, assumed that there are coordinates of 50 cities, and 10 of them need to be selected as logistics distribution centers. The coordinates and demand of each city are shown in Table 1. The simulation results and distribution schemes are compared with the WCA and the IWCA. Especially, the demand in the table is the normalized number, it does not represent real demand.

When the WCA and the IWCA are used to simulate the algorithm, it is necessary to ensure that the parameters of the algorithm are consistent in multiple experiments. The parameters of the wolf colony algorithm are set as follows: wolf colony size is 80, maximum number of iterations is 100, the number of \( \beta \) wolves is 15, search direction is 10, the number of \( \omega \) wolves is 8, search direction is 4, wandering step is 0.9, calling step is 0.6, search dimension is 2. The parameters of immune algorithm are set as follows: population size is 80, memory capacity is 15, maximum number of iterations is 100, crossover probability is 0.7, mutation probability is 0.4, diversity evaluation parameter is 0.95, number of distribution centers is 10.

Fig. 3 and Fig. 5 demonstrate the logistics distribution center location schemes of the proposed WCA and the IWCA according to Table 1. In the figures, the blue squares represent logistics distribution centers, and the green circles represent...
sent each demand point. Each distribution center is built to meet the corresponding cargo requirements of demand points. In Fig. 3, the location scheme of cold chain logistics distribution center obtained by traditional wolf colony algorithm is: {43, 11, 47, 50, 46, 17, 10, 30, 34, 26}, and the total distribution cost after distribution by this scheme is about $1.03 \times 10^6$. In Fig. 5, the location scheme of cold chain distribution center obtained by immune wolf colony hybrid algorithm is: {43, 11, 38, 2, 22, 15, 10, 30, 26, 35, 15}, and the total cost of distribution is about $0.78 \times 10^6$. The IWCA gets more reasonable location scheme for the logistics distribution center with less cost.

Fig. 2 and Fig. 4 present the convergence curves of the proposed the WCA and the IWCA for the best result. The values of X-axis are the number of iterations. The values of Y-axis in the convergence curve figures are obtained fitness values according to the model of the cold chain logistics distribution center location problem mentioned before. As it can be seen from Fig. 2, the traditional wolf colony algorithm converges to the optimal fitness value after 86 iterations, and it can be seen from Fig. 4, the immune wolf colony hybrid algorithm converges to the optimal fitness value after 28 iterations. The IWCA has the fastest convergence speed in comparison with the WCA and it shows the best performance.

V. CONCLUSION

According to the perishable nature of refrigerated food in the process of cold chain logistics distribution, the optimization model of cold chain logistics distribution center location is constructed based on the comprehensive consideration of construction cost, distribution cost, damage cost and punishment cost. Because the location problem of distribution center belongs to NP hard problem, the single heuristic algorithm is not ideal in solving the multi-objective problem, so this paper designs an immune wolf swarm hybrid algorithm to solve it. On the basis of traditional wolf swarm algorithm, the mechanism of antibody concentration regulation and immune operator in immune algorithm are introduced, which has the advantages of excellent solution performance and fast convergence, and overcomes the shortcomings of traditional wolf swarm algorithm, such as easily falling into local optimal solution and slow convergence speed. Finally, the algorithm simulation experiment is carried out by MATLAB software.
The experimental results show that the algorithm convergence speed is faster and the logistics distribution center location scheme provided is more reasonable when the immune wolves hybrid algorithm is used to solve the cold chain logistics distribution center location problem. Therefore, immune wolf swarm algorithm provides a new method for solving the complex location problem of multiple distribution centers, which has a certain social application value.

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