An Artificial Bee Colony Algorithm for Multi-objective Optimization of Cold Chain Distribution Path

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Abstract. Optimization of the distribution path of cold chain distribution path has always been a focus and hot issue in the field of cold chain logistics. In this paper, firstly, a mathematical model with minimum transportation cost and cold cost as the optimization objectives is established, and then an artificial bee colony algorithm to solve the multi-objective model is designed. Finally, an experimental example is generated by combining relevant literature example and random method to verify the effectiveness of the model and algorithm, and the convergence process of the example solution is also given.

Keywords: Cold Chain Distribution Path, Multi-objective Optimization, Artificial Bee Colony Algorithm

1. Introduction
As one of the core parts of the modern urban logistics system, cold chain logistics has a certain particularity compared to other logistics. The reason is that cold storage technology is required during the entire trans portation process, so the cost is relatively high. Therefore, optimization of the distribution path of cold chain has become a hot research issue. At the same time, the intelligent optimization algorithm can find the global optimal solution or the approximate optimal solution in a reasonable time, so it has become the first choice for solving complex logistics optimization problems.

Nabila Azi et al. used a deterministic algorithm to solve the model with a hard time window as constraint [1]. Ping Zhen et al. studied the cold chain distribution path optimization problem with soft time window as constraint [2]. Manish Shukla et al. established a model to minimize total delivery cost and solved it with genetic algorithm [3]. Shuyun Wang et al. constructed a cold chain multi-temperature co-distribution path optimization model under random demand and designed a path optimization algorithm combining K-means clustering algorithm, ant colony algorithm and stochastic dynamic programming algorithm [4]. Weijun Wang et al. used an improved intelligent water drop algorithm to optimize the cold chain distribution path model with time window [5]. Shiqing Fan et al. constructed a cold chain logistics vehicle distribution path optimization model with the objective of minimum total distribution cost, and solved the model with an improved ant colony algorithm [6]. Jiumei Chen et al. established a multi-compartment vehicle path optimization model to minimize cost, and designed a particle swarm algorithm [7].
The research above fully shows that minimizing the total distribution cost is the core objective of
the cold chain logistics optimization problem. Therefore, first, a multi-objective optimization
mathematical model for minimizing transportation cost and cold cost is established first. Meanwhile,
because the ABC (Artificial Bee Colony) algorithm has fewer control parameters, simple structure,
easy implementation [8, 9], and is widely used to solve various optimization problems [10-11], an
ABC algorithm is designed then for the solving of the model. Lastly the model and the algorithm are
verified and analyzed based on experiment result.

2. Model and Hypothesis

2.1. Parameter Description

$n$ is the quantity of the demand points, the number of distribution center is 0, and the numbers of
demand points are $1, 2, 3... n$.

$l$ is the quantity of vehicles. The number of vehicles are $1, 2, 3... l$.

$d_{ij}$ is the distance between point i and point j, $i, j = 0, 1, 2... n$.

$x_{ijk}$ is whether vehicle $k$ delivers from point $i$ to point $j$, $i, j = 0, 1, 2... n, k = 1, 2, 3... l$.

$T_k$ is the transportation cost per unit distance of vehicle $k$, $k = 1, 2, 3... l$.

$C_k$ is the cooling cost per unit time of vehicle $k$, $k = 1, 2, 3... l$.

$q_i$ is the demand quantity of point $i$, $i = 0, 1, 2... n$.

$Q_k$ is the approved load capacity of vehicle $k$, $k = 1, 2, 3... l$.

$V_k$ is the driving speed of vehicle $k$, $k = 1, 2, 3... l$.

$v_k$ is whether vehicle $k$ reaches the demand point $i$, $i = 0, 1, 2... n$.

$Z_1$ is the total cost of transportation.

$Z_2$ is the total cost of cooling.

$T_j$ is time that the distribution vehicle from distribution center reaches point $j$, $j = 0, 1, 2... n$.

2.2. Cost Analysis

(1) Transportation cost

Transportation cost is directly related to the distribution scheme. It is the sum of the products of the
unit transportation cost and mileage of all vehicles, and its expression is shown in Equation (1).

$$Z_1 = \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{l} d_{ij} \cdot T_k \cdot x_{ijk}$$  \hspace{1cm} (1)

(2) Cooling cost

In general, it is considered that the cooling cost in the loading and unloading process is related to
the time required, and has nothing to do with the distribution arrival time, that is, the distribution
scheme. Therefore, only the cooling cost in the transportation process is considered, as shown in
Equation (2).

$$Z_2 = \sum_{i=0}^{n} \sum_{j=1}^{n} \sum_{k=1}^{l} C_k \cdot x_{ijk} \cdot T_j \cdot q_j$$  \hspace{1cm} (2)

The main reason why $j$ starts from 1 instead of 0 is that when the vehicle returns to the center, no
need for cooling.

2.3. Mathematical Model

The model takes the two costs of distribution as objective functions, shown in Equation (3) and
Equation (4).

$$\min Z_1 = \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{l} d_{ij} \cdot T_k \cdot x_{ijk}$$ \hspace{1cm} (3)

$$\min Z_2 = \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{l} C_1_k \cdot x_{ijk} \cdot T_j \cdot q_j$$ \hspace{1cm} (4)
where, 
\[ x_{ijk} = 0 \text{ or } 1 \ (i, j = 1,2,...,n, k=1,2,...l) \] indicates whether vehicle k delivers from point i to point j.
\[ y_{ik} = 0 \text{ or } 1 \ (i, j = 1,2,...,n, k=1,2,...l) \] indicates whether vehicle k reaches point i.
\[ \sum_{i=1}^{n} q_i y_{ik} \leq Q_k \] indicates distribution amount of each vehicle should be less than its maximum loading capacity.
\[ \sum_{i=1}^{n} y_{ik} = \begin{cases} m & (i = 0) \\ 1 & (i = 1,2,...,n) \end{cases} \] indicates each demand point is only served by a vehicle.
\[ \sum_{j=1}^{n} x_{ijk} = y_{ik} \ (i, j = 1,2,...,n, k=1,2,...l) \] indicates that each demand point is delivered only once.

3. Algorithm Design

3.1. Solution Coding
A four-dimension array Foods[f][i][j][k] is defined to represent the f-th food source, indicating whether vehicle k delivers from i to j. If delivers, set Foods[f][i][j][k] as 1, otherwise 0. A complete distribution scheme should be composed of several sub-paths. A sub-path should start from the distribution center, pass through several demand points and then return to the distribution center.

3.2. Population Initialization
According to the above coding method, NP food sources are randomly generated. The specific steps for generating each food source are as follows:
(1) Randomly select a vehicle k that has not completed the delivery task plan.
(2) Determine whether the remaining loading capacity of vehicle k is the same as the original loading capacity. If same, set the distribution starting point i to 0, that is, the distribution center, otherwise set it to the value of the last distribution terminal j.
(3) Traverse all the distribution points to determine whether the remaining load of the current vehicle k is sufficient or all the distribution points have been delivered. If yes, set the distribution end point j to 0, which is the distribution center, otherwise randomly select an undistributed demand point j whose total goods need is not greater than the remaining load of the current vehicle k, and j is set as the distribution point.
(4) Determine whether the value of j is 0, and if it is, set that delivery task plan of vehicle k is completed.
(5) Determine whether the value of j is 0 or the total weight of the goods demand at the current point j is not greater than the remaining load of the current vehicle k, if so, set the current Foods[f][i][j][k] to 1. The remaining load of the current vehicle k minuses the total weight of the goods demand at the current point j, the total weight of the goods demand at the current point j is set to 0 and return to (3) to continue, otherwise return to (2) to continue.
(6) Traverse all the demand points to determine whether there are any distribution points for which vehicles have not been arranged. If so, go back to (1) to continue, otherwise continue to the next step.
(7) Calculate the fitness value of f.

3.3. The Employed Bee Search Phase
The employed bee produces mutation solutions based on different neighborhood search rules. Then apply greedy selection mechanism between the two solutions. The specific search steps are as follows:
(1) Generate a random number rand on [0,1].
(2) If rand<=0.5, then randomly select two demand points distributed by different vehicles, and judge whether the two meet the constraint conditions after exchanging the distribution vehicles. If so, generate a new food source and continue (4), otherwise select again.
(3) If rand>0.5, randomly select two demand points distributed by same vehicle, exchange the distribution order of the two, and produce a new food source.
(4) Calculate the fitness value of the new food source and compare with original food source. If the fitness value of the new food source is smaller than the original food source, replace the original food source with the new one. Set number of searches trial[f] to 0. Otherwise retain the original food source, and the value of trial[f] is increased by 1.

3.4. The Onlooker Bee Search Phase
Each onlooker bee uses roulette to randomly select a food source for neighborhood search. The selection probability of each food source is shown in Equation (5).

\[
p(f) = 1 - \frac{\text{fit}(f)}{\sum_{i=1}^{NP} \text{fit}(i)}
\] (5)

After selecting, the same search process as the employed bee is used.

3.5. The Scout Bee Search Phase
When the number of local searches of a certain food source achieves limit, its corresponding employed bee becomes a scout bee to produce a food source randomly with the method of population initialization.

3.6. The Search Termination Conditions
The termination condition is the maximum iteration number MaxCycle.

4. Experimental Results and Analysis

4.1. Experimental Data and Parameter Setting
To verify the effectiveness of model and algorithm, based on [12], a case example of a fresh dairy product company which delivers student milk in the cold chain to 33 primary and secondary schools, a calculation example was randomly generated according to the principles shown in Table 1.

| Variable | Value setting or random generation rule |
|----------|----------------------------------------|
| \(n\)    | 33                                     |
| \(l\)    | 6                                      |
| \(d_{ig}\) | Randomly generated on \([5,20]\) (kilometer) |
| \(T_k\)  | Randomly generated on \([2,4]\) (yuan/km) |
| \(C_k\)  | Randomly generated on \([80,100]\) (yuan/ton/hour) |
| \(q_i\)  | Randomly generated on \([5,15]\) (hundred pieces, of which each piece weighs 6 kg) |
| \(Q_k\)  | Randomly generated on \([0.5, 1, 1.5, 2]\) (ton) |
| \(v_k\)  | Randomly generated on \([60,80]\) (km/hour) |

The parameters of ABC: NP=50, limit=100, Maxcycle=400.

4.2. Results and Analysis
Take a certain run to generate a calculation example as an example to analyze the experimental results. The running results of a calculation example are shown in Table 2. In the iterative search process of this example, the Pareto solution to its frontier convergence process is shown in Figure 1. From Table 2 and Figure 1, it is observed that the designed algorithm can solve the model and provide ideal distribution scheme.
5. Conclusions

To optimize the distribution path of cold chain distribution, a mathematical model with minimum transportation cost and cold cost as the optimization objectives is established first. Then an ABC algorithm to solve the multi-objective model is designed. Finally, the model and algorithm are verified with an experimental example generated by combining relevant literature example and random method.

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