Research on Cold Chain Site Selection Layout for Multiple Distribution Centers Considering Construction Quantity

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Abstract. To enhance dairy product distribution efficiency and reduce damage during transportation, this study addresses losses in the logistics chain from production centers to distribution centers and demand points. By considering distribution center number, location, and capacity, the optimal locations are determined using the elbow method and allocated based on demand. A model for optimizing multiple dairy distribution centers is developed to minimize total cost. Improvements to the adaptive genetic algorithm, including adaptive crossover and mutation probabilities, enhance algorithm efficiency and quality. The optimal distribution center locations are identified based on real-world conditions, with a case study in Jinan, Shandong Province validating the model's effectiveness and practicality.

Keywords: cold chain transportation; third level distribution network; multiple distribution center site selection; improved adaptive genetic algorithm

1 INTRODUCTION

With the continuous improvement of residents' health awareness, people's demand for the nutrition and taste of dairy products has also greatly increased. This not only provides new growth opportunities for the development of China's dairy industry, but also puts forward higher requirements for the quality, freshness, and other aspects of the dairy industry [1]. Considering the charac-teristics of easy corrosion and freshness in the transportation of dairy products, the current distribution model can no longer meet the requirements of consumers for fast delivery of dairy products. The distribution center is a key node and important infrastructure in the logistics system network, playing a pivotal role in the planning of the entire logistics system network [2].

In the context of selecting locations for cold chain distribution centers, Hu LL et al. [3] improved the adaptive immune algorithm and designed an adaptive penalty mechanism to address the location allocation issue for multiple cold chain logistics centers. Zhao SA et al. [4] considered the requirements of carbon emission cost and minimum

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freshness, constructed a dual-level planning site selection model, and utilized a two-stage heuristic algorithm to determine the optimal solution. Wang CL [5] focused on fresh food logistics, constructing a multi-objective two-level logistics distribution network model and solving it. Ma ZJ [6] utilized a genetic algorithm to solve the location model of agricultural pre-cooling stations.

Regarding the selection of locations for multiple distribution centers, Li B [7] addressed the problem of synchronous pickup and delivery of fresh agricultural products. Wang Y [8] resolved the location planning issue for multiple distribution centers by conducting cluster analysis on alternative distribution centers. Wei J [9] Wei J et al. applied innovative methods to establish a multi delivery location model for fresh agricultural products.

In summary, the cold chain site selection layout plays an important role in the overall network. A reasonable site selection layout can reduce operational risks, minimize logistics interruptions and losses caused by unexpected events or emergencies, and ensure the quality and safety of cold chain products.

This study combines cold chain logistics features and focuses on reducing losses in the initial phase of dairy product distribution. It utilizes the penalty cost function suggested by Fujiware et al. [10] to develop a location model for dairy distribution centers with the primary goal of cost minimization. Through the use of an enhanced adaptive genetic algorithm to solve the model and comparing it with traditional genetic algorithms, the findings show that the improved genetic algorithm proves to be effective.

2 PROBLEM DESCRIPTION

The multi-distribution center location problem in the dairy cold chain, studied in this article, is based on the traditional multi-distribution center location problem, considering the special requirements of cold chain transportation, which involve keeping items transported at low temperatures to ensure their quality and safety. Simultaneously, a three-level supply chain was also taken into account, encompassing transportation from manufacturers to transit distribution centers and then to demand points. The model constructed in this article includes transportation costs from traditional distribution centers to demand points, fixed construction costs, as well as storage costs for corresponding fresh products, time-related losses during transportation, and transportation costs from production centers to alternative points. The intuitive three-level multi-distribution center location problem diagram is depicted in Figure 1.

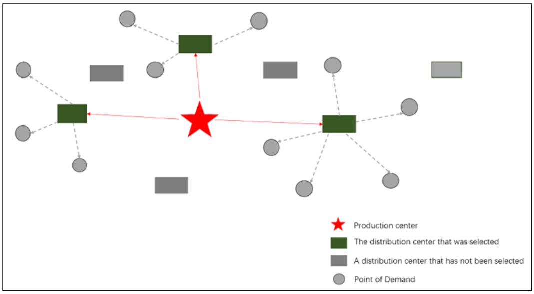

Fig. 1. Location problem diagram for three-level multiple distribution centers

3 MODEL BUILDING

3.1 Model Assumptions

Based on the characteristics of dairy product distribution, this article makes the following assumptions:

① The number and location of alternative distribution centers are known, and only a fixed number of required distribution centers can be selected from the given location points during the site selection process.

② During transportation, consider the cost of dairy product loss during the delivery process, which is related to the delivery time.

③ The maximum inventory level of each distribution center is fixed, and the demand level of each demand point varies within the normal range.

④ The vehicle always maintains a constant speed during transportation, and only considers straight transportation from point to point during transportation.

After proposing the hypothesis, define the variables and parameters in the model, as shown in Table 1:

Table 1. Symbol Description

symbol	definition
L	The set of candidate points i
N	The set of demand points j
O	The point where the production center is located
y_i	A variable of 0-1 indicates the establishment of a distribution center in alternative location i . 0 is the opposite, $i \in L$
x_{ij}	The 0-1 variable, where 1 represents the candidate location i responsible for service demand point j , and 0 represents the opposite, $i \in L, j \in N$
f_i	Represents the transportation distance from production center O to distribution center i , $i \in L$
d_{ij}	Represents the transportation distance from alternative location i to demand point j , $i \in L, j \in N$
p_1	Represents the unit transportation cost from the production center to the distribution center
p_2	Represents the unit transportation cost from the secondary distribution center to the demand point

c_i	The storage cost per unit product in alternative location i, $i \in L$
G	Indicates the number of alternative distribution centers required to be established
U_i	Represents the fixed construction cost of alternative site i, $i \in L$
Q_i	Indicates the maximum storage capacity of alternative site i
B_j	Represents the demand for demand j, $j \in N$
α	Coefficient 1 for calculating dairy product losses
β	Coefficient 2 for calculating dairy product losses
v	The driving speed of vehicles during the delivery process

3.2 Mathematical Model

Based The total cost of optimizing the milk distribution center location in this study comprises four components: transportation cost C_1, storage cost C_2, dairy product loss cost C_3, and fixed construction cost C_4 of the distribution center. Transportation costs include costs from the production center to the distribution center and from the distribution center to the demand point. Storage costs vary based on different site locations. The loss cost of dairy products is calculated using an exponential penalty cost function proposed by Fujiware et al., considering losses between production centers, distribution centers, and demand points. The location selection model with total cost as the objective is represented by the following equation based on the above description.

$$
\begin{aligned}
MinC &= C_1 + C_2 + C_3 + C_4 \\
&= \sum_{i=1}^{L}\sum_{j=1}^{N} x_{ij}B_j f_i + p_2\sum_{i=1}^{L}\sum_{j=1}^{N} x_{ij}d_{ij}B_j + \sum_{i=1}^{L}\sum_{j=1}^{N} x_{ij}B_j c_i + \sum_{i=1}^{L}\sum_{j=1}^{N} x_{ij}B_j\alpha\left(e^{\beta\frac{d_{ij}}{v}} - 1\right) + \sum_{i=1}^{L} y_i U_i
\end{aligned}
\tag{1}
$$

4 SOLVING ALGORITHM

4.1 Establishment of Site Selection Model

In the k-means algorithm, the number and position of initial centroids have strong subjectivity, which can affect the calculation results. The elbow method, also known as the elbow method [11-13], is a commonly used method in k-means algorithms to determine the number of optimal clustering centers. The core indicator is the sum of the squared errors (SSE), which is the clustering error of all samples. A smaller SSE indicates a smaller distance within the cluster, indicating better clustering performance. Conversely, a larger SSE indicates less than ideal clustering performance.

$$
SSE = \sum_{i=1}^{k}\sum_{p\in c_i} |p - m_i|^2 \tag{2}
$$

As the number of clusters K increases, sample partitioning becomes more refined, the degree of aggregation of each cluster also increases, and SSE gradually decreases. When the K value is less than the true number of clusters, an increase in K will increase the clustering degree of each group, and therefore the decrease in K is also significant; But when the K value reaches the true number of clusters, the degree of aggregation obtained by increasing K will sharply decrease. Finally, the highest K value is found by finding the turning point of the sum of squares within the cluster. The elbow method indicator measurement image is shown in Figure 2. When K=3, the image forms a clear inflection point. Before this point, the image decreases significantly, while after this point, the image decreases slightly. Therefore, it is the optimal number of clusters. At this point, the clustering effect is the best, and this can be used as the result output.

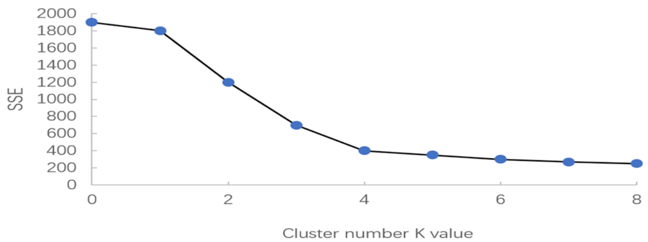

Fig. 2. Sum of squared errors indicator

4.2 Solution of Adaptive Genetic Algorithm Model

The algorithm process is shown in Figure 3:

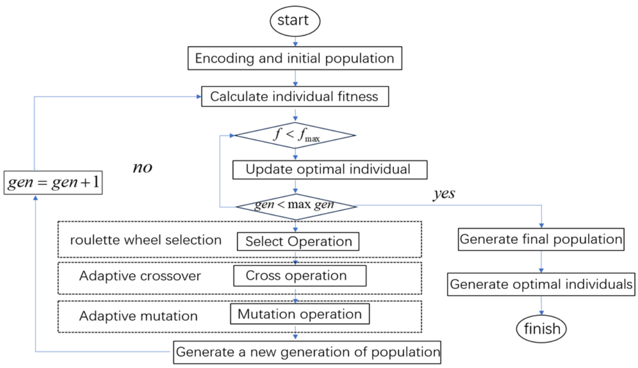

Fig. 3. Genetic algorithm flowchart

Step 1: Chromosome coding and population initialization

Encode each possible solution of the problem into the form of chromosomes or individuals, and unify the expression of all individuals.

Step 2: Calculate the fitness function value

With the goal of minimizing costs, choose the fitness function as the reciprocal of the total system cost. The larger the fitness function, the higher the probability of individuals being selected, and vice versa.

$$f(x)=\frac{1}{F(x)} \tag{3}$$

Step 3: Select operator

Using the traditional roulette wheel method, the size of the fitness function is mapped to the probability of being selected, where the higher the fitness, the greater the chance of being selected. The calculation formula is as follows:

$$P_i=\frac{f(x_i)}{\sum_{i=1}^{n} f(x_i)} \tag{4}$$

In the formula: P_i represents the probability of an individual being selected, f represents the fitness function value of the individual, x_i represents the individual in the population.

Step 4: Adaptive crossover operator

Adopting a two-point crossover approach for crossover operations, when achieving local optima, using a higher crossover probability to eliminate weaker individuals; When the fitness is higher than the average fitness, a lower crossover probability is used to preserve excellent individuals. The calculation formula is as follows:

$$P_c=\begin{cases}\dfrac{K_1\left(f_{\max}-f^{'}\right)}{f_{\max}-f_{avg}} & f^{'}\geq f_{avg}\\ K_2 & f^{'}<f_{avg}\end{cases} \tag{5}$$

Step 5: Adaptive mutation operator

Using single point mutation for individual mutation operations. Randomly generate a natural number, denoted as k_1, and then mutate the gene at position k_1 in the individual. By adjusting the value of the fitness function, the mutation probability can be appropriately adjusted, that is, when f is closer to f_{avg}, P_m should be made larger, which can maintain the diversity of the population. The formula is as follows:

$$P_m=\begin{cases}\dfrac{K_3\left(f_{\max}-f\right)}{f_{\max}-f_{avg}} & f\geq f_{avg}\\ K_4 & f<f_{avg}\end{cases} \tag{6}$$

P_m represents the adaptive crossover probability; K_3 and K_4 are constants with intervals of (0,1)

Step 6: Determine the fitness function value

Repeat steps three, four, five, and six until a new population is formed.

Step 7: Termination Conditions

If the maximum number of iterations is reached, the algorithm ends; otherwise, proceed to step three.

5 INSTANCE SOLVING

5.1 Solving K-means Clustering

Through the information statistics of demand points, alternative power distribution centers, and production centers, the layout map of each point can be obtained, including 1 production headquarters, 10 alternative power distribution centers, and 26 demand points. Under the premise of cost control, the construction quantity of distribution centers is set to [2,10], and the construction quality of distribution centers is calculated within this range. The solution shows that when k=3, it is the optimal number of clusters.

5.2 Adaptive Genetic Algorithm Site Selection Optimization

Solve through programming software, and when the optimal value remains unchanged for 100 consecutive generations or the population chromosomes are completely consistent, end the calculation and output the result. After performing the calculations, good results were obtained, verifying the effectiveness of the model and algorithm. Among them, B_4, B_9, and B_{10} were selected as the company's dairy product distribution centers. The specific coordinates, longitude and latitude of the selected distribution centers, and the optimal distribution plan from the distribution center to the demand point are shown in Table 2. Among them, the average total cost is 2199257.2 RMB, the fixed cost of site selection is 470000 RMB, and the storage cost of the distribution center is 11156 RMB. The total transportation cost is 1574607.3 RMB, of which the transportation cost from the production center to the distribution center is 129191.8 RMB, and the transportation cost from the secondary distribution point to the demand point is 1445415.5 RMB. The total cost of dairy product loss is 143494.0 RMB, of which the cost of dairy product loss from the supply point to the secondary distribution point is 100821.3 RMB, and the cost of dairy product loss from the secondary distribution point to the demand point is 42672.7 RMB.

Table 2. Solution results

number	longitude	latitude	Maximum capacity of distribution center	Demand points served by distribution centers	Delivery Load (kg)	Loading rate%
Distribution Center 4	117.2	36.76	41000	6、10、12、13、15、17、25	29790	0.73
Distribution Center 9	117.3	36.81	30000	1、2、3、4、5、7、8、9、11、14、16、19、20、21、22、23、24、26	27670	0.92
Distribution Center 10	117.3	36.74	45000	18	28430	0.63

5.3 Analysis of Calculation Results

Through the improvement strategy of the site selection model and the encoding of chromosomes to the calculation of adaptive mutation probability, it effectively solves the problems of premature convergence and local optima in traditional genetic algorithms, significantly enhances spatial search ability, and improves the solving ability and efficiency of the algorithm model.

5.4 Innovation and Application of Algorithms

Compared to fixed probabilities, our algorithm can adjust the crossover and mutation probabilities in real-time based on the current state of the optimization process. This dynamic adaptability enables the algorithm to better cope with the characteristics and difficulties of different problems, thereby exploring more intelligently in the search space, accelerating convergence, and finding better solutions.

By improving the dynamic adjustment of the crossover and mutation operators, they can automatically change with fitness, provide the optimal crossover and mutation probability relative to a certain solution, accelerate the elimination speed of inferior solutions, maintain the diversity of the population, thereby improving the convergence speed of the algorithm and increasing its ability to find the optimal solution.

6 CONCLUSIONS

This article establishes a model for optimizing the location of distribution centers, introduces adaptive crossover and mutation probabilities, and uses an improved genetic algorithm to determine the final distribution center location. Its goal is to minimize the total cost and solve the layout problem of distribution centers. Finally, the effectiveness of the model and algorithm was verified through numerical examples.

By optimizing the location layout, enterprises can improve the efficiency and quality of cold chain logistics services, enhance competitiveness, and occupy a larger market share. Studying the layout of cold chain site selection can help promote the development and progress of the cold chain logistics industry, promote the formulation and implementation of industry standards, and improve the overall industry level.

REFERENCES:

1. Li Jilu, Zhang Xiao, Zhu Jie. Research on Distribution Center Location Problem Based on Adaptive Immune Algorithm [J]. China Storage and Transportation, 2019 (08): 141-144. DOI: 10.16301/j.cnki.cn12-1204/f.2019.08.059
2. Xu Xinliang, Li Cuixia, Xu Jiaqi. The Current Situation, Evolution, and Development Trends of the Whole Dairy Industry Chain in China [J]. China Dairy Industry, 2022, 50 (08): 42-47. DOI: 10.19827/j.issn1001-2230. August 8, 2022
3. Hu Lili, Xia Yangkun. Location allocation and adaptive immune algorithm for multi cold chain logistics centers [J]. Mathematical Practice and Understanding, 2018,48 (16): 31-39

4. Zhao Shi'an, Qu Chiwen. Improved cuckoo algorithm for solving logistics distribution center location problem [J]. Mathematical Practice and Understanding, 2017,47 (03): 206-213
5. Wang Chenglin, Zheng Ying, Huangfu Yilong, et al. Research on the Location and Path Optimization Problem of Fresh Food Logistics Distribution Network [J]. Mathematical Practice and Understanding, 2020, 50 (10): 33-43
6. Ma Zujun, Wang Yiran. Optimization of pre cooling station layout considering the "first one kilometer" loss of fresh agricultural products [J/OL]. Chinese Management Science: 1-11 [2023-09-15] DOI: 10.16381/j.cnki.issn1003-207x.2021.2618
7. Li Bing, Dang Jiajun. Site selection and path optimization for synchronous pickup and delivery of fresh agricultural products under multiple distribution centers [J]. Journal of Intelligent Systems, 2020,15 (01): 50-58 DOI: 10.11992/tis.201905042
8. Wang Yong, Huang Siqi, Liu Yong, et al. Optimization of logistics multi distribution center location based on K-means clustering method [J]. Highway Transportation Technology, 2020,37 (01): 141-148 DOI: 10. 3969 /j. issn. 1002－0268. 2020. 01. 017
9. Wei Jie, Wang Jiaxin. FCM-ISA algorithm and application for continuous site selection of multiple distribution centers for fresh agricultural products [J]. Operations Research and Management, 2019,28 (11): 85-90 DOI: 10.12005 /orms. 2019. 0252
10. Fujiwara O, Perera U L J S R EOQ models for continuously deteriorating products using linear and exponential penalty costs [J] European Journal of Operational Research, 1993, 70 (1): 104-114. DOI: 10.1016/0377-2217 (93) 90235-F
11. Wang Jianren, Ma Xin, Duan Ganglong. Improved K-means clustering k-value selection algorithm [J]. Computer Engineering and Applications, 2019,55 (08): 27-33 DOI： 10.3778/j.issn.1002-8331.1810-0075
12. Chen Yu, Tian Bojin, Peng Yunzhu et al. Joint Elbow Method and Expectation Maximization Gaussian Mixture Clustering Customer Clustering Algorithm for Power Systems [J]. Computer Applications, 2020,40 (11): 3217-3223 DOI： 10. 11772/j. issn. 1001-9081. 2020050672
13. Ni Weihong, Chen Tai. Site selection of emergency logistics distribution centers based on clustering centroid method [J]. Journal of Nanjing University of Technology (Natural Science Edition), 2021,43 (02): 255-263 DOI: 10. 3969 /j. issn. 1671－7627. 2021. 02. 017