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A multi-objective optimization model for the location of cold chain logistics distribution center based on trust domain optimization algorithm

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Abstract. Cold chain transportation refers to a logistics method that transports fresh, perishable, and perishable items from the place of production, processing or warehouse to the place of consumption under certain temperature conditions. As consumers have higher and higher requirements for food safety and quality, the cold chain logistics industry has also developed rapidly. However, the high cost of cold chain logistics, the difficulty of technology, the difficulty of ensuring service quality and other problems have also arisen, and how to optimize cold chain transportation has become a hot issue in the cold chain logistics industry. Cold chain transportation optimization refers to the premise of ensuring the quality and safety of goods, through reasonable transportation paths, transportation methods, temperature control and other measures, to minimize the cost of cold chain transportation, improve efficiency and service quality. In order to achieve the optimization of cold chain transportation, it is necessary to establish a reliable cold chain logistics distribution center to ensure the safety and quality of goods during transportation. In order to solve the problem of location selection of cold chain logistics distribution center, this paper first defines the service reliability and calculation method of cold chain distribution center. Then, the location model of the cold chain logistics distribution center and the trust domain optimization algorithm model were established. The model aims to minimize the total cost, while considering multiple factors such as transportation distance, temperature control, facility construction, etc., to ensure the reliability and operational efficiency of the cold chain logistics distribution center. Finally, this paper introduces an example for calculation to prove the feasibility and universality of the model in the location problem of cold chain logistics distribution center. Through the calculation of examples, it can be seen that the model can effectively reduce the cost of cold chain transportation and improve the service quality and efficiency of cold chain logistics distribution center. In summary, this paper proposes a reliable location model and trust domain optimization algorithm model for cold chain logistics distribution centers to solve the challenges faced by the cold chain logistics industry. This model can provide guidance for cold chain logistics companies to gain a greater advantage in a highly competitive market.

Keywords: Cold chain transportation, Trust domains, Site selection of the center.

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1. Introduction

Cold chain transportation refers to a logistics method that transports fresh, perishable, and perishable items from the place of production, processing or warehouse to the place of consumption under certain temperature conditions [1]. Cold chain transportation optimization refers to the premise of ensuring the quality and safety of goods, through reasonable transportation paths, transportation methods, temperature control and other measures, to minimize the cost of cold chain transportation, improve efficiency and service quality [2]. Consumers are demanding more and more from food safety and quality [3]. With the improvement of people's living standards and the enhancement of health awareness, consumers have higher and higher requirements for the safety and quality of food [4]. Cold chain transportation can ensure the quality and safety of food during transportation, reduce food loss and waste, and improve consumer trust and satisfaction; Cold chain transportation is costly and inefficient [5]. The cost of cold chain transportation mainly includes the cost of transportation, storage, packaging, manpower, etc., and the efficiency of cold chain transportation is also affected by many factors such as temperature control and transportation path [6]. Therefore, how to reduce costs and improve efficiency by optimizing cold chain transportation solutions has become an important issue for enterprises and governments [7]. Cold chain transportation involves a wide range of fields. Cold chain transportation not only involves the transportation of daily necessities such as food and medicine, but also involves the transportation of high-end products such as biological products and chemicals. The optimization of cold chain transportation is of great significance to ensure the country's economic development and people's quality of life.

At present, linear programming algorithms and various other artificial intelligence algorithms have been widely used in cold chain transportation optimization. For example, linear programming algorithms can optimize the path, temperature control, and transportation mode of cold chain transportation by establishing mathematical models [8]. Neural network algorithms can learn from historical data to predict future demand and transportation needs to optimize cold chain transportation solutions [9]. Genetic algorithms can optimize the scheme of cold chain transportation by simulating the evolutionary process in nature. Deep learning algorithms can improve the efficiency and safety of cold chain transportation by learning large amounts of data [10].

Based on the above research basis, this paper selects the trust threshold optimization algorithm for the optimization task of cold chain logistics, and compares it with the traditional linear programming algorithm, which provides a certain research basis for subsequent research.

2. Cold chain distribution center service reliability and calculation method

In cold chain logistics, the service reliability of the distribution center is a very important indicator, which is used to measure the service level of the logistics system. The service reliability of a distribution center refers to the logical combination of the reliability of all related logistics operations within the distribution center. Here, we assume that the reliability of all other logistics operations is 1, so the reliability of the service is determined only by the distribution process. Under certain conditions, assuming that the time specified by the customer is i, the probability that the product will be delivered to the customer is P_{ij}. This probability can be used to measure the service reliability of the distribution center, and it can also be used to evaluate the service level of the entire cold chain logistics system. If the P_{ij} is higher, it means that the service reliability of the distribution center is higher, and the service level of the entire cold chain logistics system is also higher. Therefore, improving the service reliability of distribution centers is an important direction for the optimization of cold chain logistics. Rule:

$$P_{\mathrm{ij}} = p\left(T_{ij} \le t_j\right) = p\left(s_{ij}/V_{ij} \le t_j\right) = p\left(V_{ij} \ge s_{ij}/t_j\right) = 1 - FV_{ij}\left(s_{ij}/t_j\right) \quad (1)$$

T_{ij} refers to the time it takes for a shipment to be delivered from the distribution center i to customer j; TJ refers to the delivery time requested by the customer; S_{ij} refers to the distance between the distribution center i and customer j; V_{ij} refers to the velocity distribution function of the vehicle from the distribution center i to the customer j.

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The formula for calculating the reliability of a distribution center for multiple customer services introduced by equation (1) is:

$$P_s = \frac{\sum_{i\in M}\sum_{j\in N} d_j P_{ij}}{\sum_{j\in N} d_j} = \frac{\sum_{i\in M}\sum_{j\in M} d_j[1-FV_{ij}(s_{ij}/t_{ij})]}{\sum_{j\in N} d_j} \quad (2)$$

Pi refers to the service reliability of the distribution center system; dj refers to the demand of customer j; pij refers to the reliability of the distribution center i to provide services to customer j.

3. Location model of cold chain logistics distribution center

3.1. Hypothetical conditions

This model is designed to establish a location model for a cold chain logistics distribution center, which involves multiple distribution centers and multiple demand points, using frozen or refrigerated trucks as a means of transportation to deliver a single type of fresh product. The customer demand and geographical location are known, and several addresses are selected from the alternative addresses for the construction of distribution centers, so that the total cost of delivering goods to customers in these distribution centers is minimized, and the service reliability of the whole system is maximized. While taking into account the associated costs, it is assumed that the total cost of the system does not take into account the storage costs of the warehouse, and that the delivery temperature of the products can be maintained during transportation, so it can be assumed that the spoilage rate of the delivered fresh products is constant without considering other influencing factors.

3.2. Conceptual model

Decision variables:Xij refers to the volume of transportation from distribution center i to customer j;This mathematical model is to meet the minimum service reliability value P0 preset by the enterprise, and to maximize the service reliability of the logistics distribution center system, while ensuring that the total cost of the system is minimized. The total cost of the system includes fixed costs, transportation costs from the distribution center to the point of demand, damage costs, and processing and packaging costs. In this model, it is assumed that the spoilage rate of the perishable products distributed is constant, so no other influencing factors need to be considered. In order to achieve the optimal solution, it is necessary to select several addresses from the alternative addresses for the construction of distribution centers, using frozen or refrigerated trucks as a means of transportation to distribute a single type of fresh product. Customer demand and geographic location are known, taking into account the associated costs, but the total system cost does not take into account the storage costs of the warehouse. The following mathematical models can be built:

$$\min U = \left[\sum_{i=1}^{m} F_i + \sum_{i=1}^{m}\sum_{j=1}^{n} h_{ij}x_{ij}s_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n} px_{ij}\left(1-e^{-\theta s_{ij}/v_{ij}}\right) + \sum_{j=1}^{n}\sum_{i=1}^{m} g_i x_{ij}\right]Z_{ij} \quad (3)$$

$$P_s = \frac{\sum_{i\in M}\sum_{j\in N} d_j[1-FV_{ij}(s_{ij}/t_j)]}{\sum_{j\in N} d_j} \geq P_0 \quad (4)$$

$$\sum_{i=1}^{m} Z_i \leq q \quad (5)$$

$$\sum_{j=1}^{n} x_{ij} \leq a_i, i = 1,2,\ldots m \quad (6)$$

$$\sum_{i=1}^{m} x_{ij} \geq d_j, j = 1,2\ldots n \quad (7)$$

Equations (3) and (4) are objective functions, which represent the minimum total logistics cost and the maximum reliability of logistics services, respectively. Equation (5) indicates that the number of distribution centers to be built shall not exceed Q; Equation (6) indicates that the total amount of products distributed by the distribution center to customers shall not exceed its own capacity, and AI indicates the capacity of the distribution center i; Equation (7) indicates that the total amount of distribution from distribution center i to demand point j is not less than its demand.

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4. Rely on domain optimization algorithms

4.1. Principle of Reliance Domain Algorithm

The trust domain algorithm is an optimization algorithm used to solve unconstrained nonlinear optimization problems. The principle is to construct a trust domain within the neighborhood of the current point, that is, a feasible region, and then find a feasible step in this area, so that the objective function can be improved within this step. The core idea of the algorithm is to gradually approximate the global optimal solution by adjusting the step size and search direction under the premise of ensuring the feasibility of the current solution.

Specifically, the trust domain algorithm first calculates the gradient of the objective function at the current point and the Haysom matrix, and then determines the next search direction and step by solving a trust domain subproblem. The goal of this subproblem is to find a feasible step size within the trust domain, so that the objective function can be improved within that step, and the step size is not outside the range of the trust domain. If a feasible step is found, the position of the current point is updated, and the gradient and Haysom matrix are recalculated to proceed to the next iteration. If no feasible step size is found, reduce the size of the trust domain and re-resolve the trust domain subproblem until a viable step size is found or the trust domain is reduced to a certain extent.

The advantage of the trust domain algorithm is that it can quickly approximate the global optimal solution under the premise of ensuring the feasibility of the solution, and it also has good performance for non-smooth or highly nonlinear objective functions. However, the disadvantage of the algorithm is that it needs to solve the sub-problem of the trust domain, which requires a large amount of computation, and the size of the trust domain needs to be adjusted, and the convergence of the algorithm may not be guaranteed.

The trust domain algorithm is a kind of nonlinear optimization algorithm, which has better global convergence than the linear programming algorithm, can deal with nonlinear problems, non-smooth problems and constraints, and is insensitive to the initial point. Therefore, the trust domain algorithm is more flexible and practical in practical applications.

4.2. Comparison of Reliance Domain Algorithm and Linear Programming Algorithm

The trust domain algorithm can handle nonlinear problems. Linear programming algorithms can only deal with linear problems, while nonlinear problems often exist in practical problems. The trust domain algorithm can still find the global optimal solution when the objective function is nonlinear. This is because the trust domain algorithm uses second-order information to perform a second-order Taylor expansion of the objective function, so as to describe the curvature information of the objective function more accurately. The trust domain algorithm can handle non-smooth problems. A non-smooth problem is when the objective function is underivable or discontinuous at certain points. Linear programming algorithms can only deal with continuously derivable objective functions, while trust domain algorithms can handle some non-smooth problems. The trust domain algorithm solves the sub-problem in a sub-problem manner, and gradually approximates the global optimal solution by solving the sub-problem. The trust domain algorithm can handle constraints. Constraints are unavoidable in practical problems, linear programming algorithms can only deal with linear constraints, while trust domain algorithms can deal with nonlinear constraints. The trust domain algorithm uses the penalty function or the Lagrangian multiplier method to deal with the constraints, which makes the solution process more flexible.

The trust domain algorithm is not sensitive to the initial point. The selection of the initial point has a great influence on the solution result, and the trust domain algorithm is not sensitive to the selection of the initial point. This is because the trust domain algorithm adopts a local quadratic model, which can estimate the gradient and Haysom matrix of the objective function through the quasi-Newtonian method, so as to describe the curvature information of the objective function more accurately.

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5. Case Study

The issue related to the establishment of a logistics distribution center system between four alternative cold chain distribution center addresses and six customers. Enterprises hope to establish up to 3 cold chain logistics distribution centers under the premise that the service reliability of the distribution center system is maximized, and the total cost is minimized. The products delivered are seafood products sold in supermarkets, which need to be transported at a temperature of -5℃, and the price is 18 yuan per piece. The average driving speed of the vehicle is 30km/h, and the unit transportation cost is 0.3 yuan/km. The distance from the specific distribution center to the customer, the customer's demand, the correlation coefficient, the facility cost of the alternative distribution center, the transfer fee and the capacity are shown in the table. By building a mathematical model, it is possible to determine the optimal distribution center location and distribution volume to meet the needs of the enterprise.

Table 1. The distance from the distribution center to the customer.

	C1	C2	C3	C4	C5	C6
W1	8	20	17	34	27	15
W2	26	15	24	20	58	31
W3	12	24	35	13	46	28
W4	15	16	13	37	24	26

Table 2. The distance from the distribution center to the customer.

client	C1	C2	C3	C4	C5	C6
demand d(kg)	20000	15000	20000	10000	10000	10000

According to the multi-objective optimization model of cold chain logistics distribution center site selection based on trust domain optimization algorithm, the results are as follows:

The minimum cost is 1741158 yuan, and the demand of customer 1 is provided by the distribution center 1 for 10,000kg and the distribution center 4 for 10,000kg; The demand of customer 2 is provided by the distribution center 2 15000kg; The demand of customer 3 is provided by the distribution center 4 20000kg; The demand of customer 4 is provided by the distribution center 2 10000kg; The demand of customer 5 is provided by the distribution center 4 10000kg; The demand of customer 6 is provided by distribution center 1 with 20000kg and distribution center 2 with 10000kg.

6. Conclusion

With consumers' increasing requirements for food safety and quality, the cold chain logistics industry has developed rapidly. Cold chain transportation refers to a logistics method that transports fresh, perishable, and perishable items from the place of production, processing or warehouse to the place of consumption under certain temperature conditions. In this process, it is very important to ensure the quality and safety of goods, so it is necessary to minimize the cost of cold chain transportation and improve efficiency and service quality through reasonable transportation paths, transportation methods, temperature control and other measures. This is the goal of cold chain transport optimization.

In order to achieve the optimization of cold chain transportation, it is necessary to establish a reliable cold chain logistics distribution center to ensure the safety and quality of goods during transportation. However, how to select a site to establish a cold chain logistics distribution center is a very important issue. In order to solve this problem, this paper first defines the service reliability and calculation method of cold chain distribution center. Then, the location model of the cold chain logistics distribution center and the trust domain optimization algorithm model were established.

The model aims to minimize the total cost, while considering multiple factors such as transportation distance, temperature control, facility construction, etc., to ensure the reliability and operational efficiency of the cold chain logistics distribution center. In this model, we need to consider many factors, including the type and quantity of goods, transportation distance, transportation mode, temperature

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control, facility construction, and so on. We need to consider these factors comprehensively according to the actual situation in order to come up with the best location plan for the cold chain logistics distribution center.

Finally, this paper introduces an example for calculation to prove the feasibility and universality of the model in the location problem of cold chain logistics distribution center. Through the calculation of examples, it can be seen that the model can effectively reduce the cost of cold chain transportation and improve the service quality and efficiency of cold chain logistics distribution center. This model can not only be applied to the location of the cold chain logistics distribution center, but also can be applied to the location of other fields, and has a very wide application prospect.

In conclusion, this paper introduces in detail the concept of cold chain transportation and its optimization methods, as well as the solution to the location problem of cold chain logistics distribution centers. This model can help us better optimize cold chain transportation, improve the service quality and efficiency of cold chain logistics distribution centers, and provide consumers with safer and high-quality food.

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References

[1] Zhang Zhongjing, Wang Jiaying, Chen Zhicheng. China Storage and Transportation, 2023(10): 57-58.DOI:10.16301/j.cnki.cn12-1204/f.2023.10.115.

[2] Sun Peiru, Chen Zijun. Logistics Science and Technology, 2023,46(14): 143-145+149. DOI:10.13714/j.cnki.1002-3100.2023.14.039.

[3] Wang Qinchai. Logistics Engineering and Management,2021,43(06):45-47+56.[4] Jiang Mingzhu. Research on the optimization strategy of cold chain logistics efficiency in China[J].Journal of Changchun College of Finance,2022(06):78-83.)

[4] Sun Peiru, Chen Zijun. Logistics Science and Technology, 2023,46(14): 143-145+149. DOI:10.13714/j.cnki.1002-3100.2023.14.039.

[5] Yan Qiuhan. Agricultural Equipment Technology,2022,48(02):57-60.)

[6] Yang Ruoyu, Ruan Xiaohua, Lin Peiqi. China Storage and Transportation,2021(12):140-141.DOI:10.16301/j.cnki.cn12-1204/f.2021.12.078.

[7] Wang Minhao. Research on supply chain optimization of e-commerce of fresh agricultural products[D].Zhejiang Ocean University,2022.DOI:10.27747/d.cnki.gzjhy.2021.000012.

[8] Yongkang X ,Zhenfeng Z ,Jianbo X , et al. Renewable energy time series regulation strategy considering grid flexible load and N-1 faults[J]. Energy,2023,284.

[9] S M R ,Svetlana S ,Janez K , et al. Time resolved study of temperature sensing using GdO:Er,Yb: deep learning approach[J]. Physica Scripta,2023,98(11).

[10] Lv Chengyao, Shao Kenan, Zhang Shuaishuai, et al. Computer Technology and Development,2020,30(11):168-173.)