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THE LOCATION OF COLD CHAIN LOGISTICS FOR AGRICULTURAL PRODUCTS FOR THE"FIRST KILOMETRE"

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Abstract: With the accelerated development of China's agricultural modernisation, the importance of cold chain logistics for agricultural products has become increasingly prominent. However, problems such as insufficient cold chain coverage and lack of pre-cooling links have led to high spoilage rates and high logistics costs for fresh agricultural products. Taking Jiangsu Province as an example, this study constructs a two-stage cold chain logistics and distribution centre site selection model that takes economic, environmental and social factors into account. In the first stage, this study selects 12 indicators in four dimensions, namely, economic development, traffic congestion, total logistics demand, and green and low-carbon level, and uses the entropy weight method to quantitatively assess the logistics level of 13 cities in Jiangsu Province. By calculating the logistics level score of each city, the spatial economic distance between cities is defined, and the K-means clustering algorithm is combined to divide Jiangsu Province into regions. The clustering results show that the clustering method based on spatial economic distance can more scientifically reflect the economic connection and logistics demand among cities, which provides an important basis for the subsequent site selection decision. In the second stage, the study uses the centre of gravity method to select the optimal distribution centre location within each clustering region. The centre of gravity method determines the optimal location of the distribution centre by calculating the weighted average location of each demand point within the region with the objective of minimising transport costs. Ultimately, by comparing the two methods based on spatial economic distance clustering and traditional geographic distance clustering, the results show that the clustering method based on spatial economic distance significantly reduces the transport cost. The total transport cost is reduced from $16,356.33 to $14,156.00, which is about 13.45%. This result not only verifies the validity and practicability of the constructed model, but also provides a scientific basis for the location of cold chain logistics distribution centre in Jiangsu Province, which helps to improve the operational efficiency and economic benefits of cold chain logistics.
Keywords: Cold chain logistics; Site selection model; Entropy weight method; K-means clustering; Centre of gravity method

1 INTRODUCTION

With the acceleration of China's agricultural modernisation process, the production, circulation and consumption patterns of agricultural products have undergone significant changes. As a key link in guaranteeing the quality of agricultural products, reducing losses and enhancing market competitiveness, cold chain logistics for agricultural products has become an indispensable part of the modern agricultural industrial system. In recent years, the state attaches great importance to the development of cold chain logistics as an important hand in promoting rural revitalisation and high-quality development of agriculture. 2020, the Ministry of Agriculture and Rural Development issued the "Implementation Opinions on Accelerating the Construction of Agricultural Products Warehousing and Freshness Preservation Cold Chain Facilities", which explicitly puts forward that we should focus on the main production areas of fresh and live agricultural products and poverty-stricken regions, accelerate the construction of warehousing and freshness preservation cold chain facilities, and solve the "first kilometre" problem of agricultural products going out of villages and entering cities. "The No.1 Document of the Central Government in 2024 further emphasised the need to optimise the construction of cold chain logistics system for agricultural products, accelerate the layout and construction of backbone cold chain logistics bases and public cold chain logistics facilities in county areas, and promote the deep integration of cold chain logistics with modern agriculture and food processing.
Cold chain logistics of agricultural products refers to the maintenance of a suitable low-temperature environment at all times during the whole process of production, processing, transport, storage and marketing, so as to guarantee the quality and safety of agricultural products. At present, some progress has been made in the infrastructure construction of cold chain logistics, and the pre-cooling and cold storage functions of cold storage and the use of refrigerated trucks in the transport process can effectively prolong the freshness period of agricultural products and reduce losses [1,2]. However, the degree of standardisation and marketisation of cold chain logistics still needs to be improved. Relevant studies have pointed out that the current cold chain logistics exists problems such as high logistics costs and serious losses, and put forward countermeasures such as modernisation of hardware and facilities, standardisation of management, and resource intensification. With the continuous development of the Internet of Things, blockchain and

other new technologies, scholars have begun to explore their application in cold chain logistics, optimize the layout of the cold chain network through the model, and provide a scientific basis for the construction of infrastructure [3]. Aiming at the current situation and problems of the cold chain logistics of special agricultural products, some studies have also proposed optimisation strategies based on IoT technology, including cost management, supervision and control, and the cultivation of third-party enterprises, in order to improve the quality and efficiency of services [4]. In addition, there are also studies that analyse the development opportunities and challenges of cold chain logistics from the perspective of rural revitalization strategy, and put forward development paths such as strengthening top-level design, optimizing layout, and innovation drive [5].

The site selection of cold chain logistics distribution centre is the core link of optimizing the network layout, which is crucial for reducing logistics costs, improving distribution efficiency and guaranteeing the quality of fresh produce products. Early researches mainly focused on the basic siting model, with the goal of minimising transport costs, using traditional methods such as the centre of gravity method and linear programming, which are applicable to the siting of a single distribution centre. With the development of the logistics industry, research has gradually shifted to multi-objective optimisation, taking into account multiple objectives such as cost, service quality and distribution efficiency [6]. In recent years, the research pays more attention to the comprehensive consideration of economic, environmental and social factors [7], and from the perspective of green logistics, the improved algorithm solves the siting problem considering the time window, carbon emission and cargo damage cost [8], and constructs the siting model with integrated carbon emission and freshness, which is solved by using multiple optimisation algorithms [9-11].

In summary, the cold chain logistics of agricultural products in China is facing challenges such as high loss, high cost, insufficient infrastructure and lagging standardisation. Existing research focuses on infrastructure construction, distribution centre location and technology application, and is shifting from single-objective optimization to multi-objective optimization, with the introduction of algorithms and models to enhance decision-making science. New technologies such as the Internet of Things (IoT) provide new ideas for industry development. Future research needs to comprehensively consider economic, environmental and social factors to promote the sustainable development of cold chain logistics. This study focuses on systematically analysing the key factors of agricultural cold chain logistics site selection, constructing a scientific site selection model and verifying its application. It provides a theoretical basis for the governmental departments to formulate the layout planning of cold chain logistics facilities, and provides cold chain logistics enterprises with a scientific decision-making method for site selection, so as to promote the efficient development of cold chain logistics of agricultural products.

2 A TWO-STAGE COLD CHAIN LOGISTICS AND DISTRIBUTION CENTRE SITE SELECTION MODEL BASED ON K-MEANS CLUSTERING AND CENTRE OF GRAVITY APPROACH

Based on the existing research, this study takes 13 cities in Jiangsu Province as examples, selects 12 indicators from four dimensions of economic development status, traffic congestion degree, total logistics demand and green low-carbon level, uses entropy weighting method to carry out the calculation of the weight of each indicator, constructs the spatial economic distance and combines with the K-means clustering algorithm and centre of gravity method to construct the two-phase siting model, which takes into account the reasonableness of the region delineation and the site selection scientific, providing a new solution for the cold chain logistics distribution centre site selection problem [12].

2.1 Calculation of Spatial Economic Distance

2.1.1 Selection of logistics level score indicators

The logistics level score was calculated based on 12 indicators for each city and used to redefine the distance between the 13 cities. The logistics level score we used mainly considered four dimensions: economic development, traffic congestion, total logistics demand, and green and low-carbon level. Specifically, the green and low-carbon level was measured by total energy consumption, CO2emissions, and carbon intensity [13]; and the economic development was measured by the per capita disposable income of the urban resident population, total investment in fixed assets, and growth rate of the tertiary industry; Vehicle density (motor vehicle ownership divided by urban construction area), population density (permanent urban population divided by urban construction area), and road mileage are used to measure the level of traffic congestion; permanent urban population, freight volume, and area of land used for logistics warehousing are used to measure the demand for logistics, and the relevant data are obtained from the China Statistical Yearbook.

2.1.2 Entropy weighting method to determine indicator weights

This paper adopts the entropy weight method to quantitatively measure the logistics level score indicators, and the calculation steps of the entropy weight method are mainly as follows:

(1) Data normalisation. The indicators have different units of measurement, so they need to be normalised, and the specific normalisation methods are as follows. Taking into account the need for logarithmic operations on the data in the subsequent calculations, a non-negative translation is carried out in advance, with a translation of 0.001 units:

Positive indicators:

$$X'_{\theta\,ij} = \frac{x_{\theta\,ij} - x_{min}}{x_{max} - x_{min}} + 0.001 \tag{1}$$

Negative indicators:

$$X'_{\theta ij} = \frac{x_{max} - x_{\theta ij}}{x_{max} - x_{min}} + 0.001 \tag{2}$$

where $x_{\theta ij}$ is the value of the original indicator j for the i evaluation object in the year θ ,x_{max} ,x_{min} are the maximum and minimum values of the indicator, i =1,2,..., n , j =1,2,..., n , θ =1,2,..., n . $X'_{\theta ij}$ are the new values after normalisation and non-negative leveling. In this paper, three indicators, namely total energy consumption, CO2emission and carbon intensity, are negatively normalised, while the rest are positively normalised.

(2) Calculate the weight of the i evaluator under the j indicator in the year θ for that indicator:

$$Y_{\theta ij} = \frac{X'_{\theta ij}}{\sum_{\theta=1}^{r} \sum_{i=1}^{n} X'_{\theta ij}} \tag{3}$$

(3) Calculate the information entropy for the j th indicator:

$$S_j = -k \sum_{\theta=1}^{r} \sum_{i=1}^{n} (Y_{\theta ij} \ln (Y_{\theta ij})) \tag{4}$$

included among these $k = \frac{1}{\ln rn}$

(4) Calculate the coefficient of variation:

$$E_j = 1 - S_j \tag{5}$$

(5) Determine the weights, which reflect the importance of the indicator, and evaluate the importance of the indicator in direct proportion to the value of the weights. Calculate the weight of the indicator j :

$$W_j = \frac{E_j}{\sum_{j=1}^{m} E_j} \tag{6}$$

The results of calculating the weight coefficients of the 12 indicators using the entropy weighting method are shown in Table 1:

Table 1 Entropy Weighting Method of Logistics Level Score Indicators

dimension	norm	weights
Economic development	Per capita disposable income of the urban resident population	0.0855
	Total investment in fixed assets	0.1015
	Tertiary growth rate	0.0724
Level of traffic congestion	Vehicle density	0.1107
	population density	0.1132
	Number of road miles	0.0632
Total logistics demand	Municipal resident population	0.0538
	volume of freight	0.0356
	Land area for logistics and warehousing	0.0626
Green and low-carbon levels	Total energy consumption	0.1254
	Carbon dioxide emissions	0.0852
	carbon intensity	0.0909

2.1.3 Calculation of spatial economic distance

Based on the normalised data of the 12 indicators of the 13 cities and the weighting coefficients of each indicator, the logistics level score of each city is calculated Z_i with the following formula:

$$Z_i = \sum_{j=1}^{n} Y_{ij} W_j \tag{7}$$

After deriving the logistics level score, the improved distance formula is as follows:

$$D(X_i, X_j) = \frac{D_{ij}^2}{(Zi\ Zj)^u} \tag{8}$$

$D(X_i, X_j)$ measures the spatial economic distance between two cities, influenced by two types of distance factors: spatial distance factor and economic distance factor. D_{ij}^2 indicates the spatial distance factor between two cities. Z_iZ_j denotes the logistics economic distance factor between two cities. Where Z_i ,Z_j represent the logistics level scores of city i and city j respectively. u represents the degree of influence of the logistics economic distance factor in the measurement of distance between two cities.The larger the value of u ,the greater the impact of the logistics economic distance factor.When u is 0,the distance formula is equivalent to the Euclidean distance.In this paper,we assume that the logistics economic distance factor $u = 0.1$,which best scientifically balances the influence of economic gravity and distance[14].

2.2 Regional Division of Jiangsu Province based on K-means Clustering

Based on the calculated spatial economic distance between the 13 cities, clustering was performed using the K-means algorithm. The Euclidean distance is used as a measure of the similarity between the data objects, and the similarity is inversely proportional to the distance between the data objects, the greater the similarity, the smaller the distance. The algorithm needs to pre-specify the number of initial clusters k and k initial clustering centres, according to the similarity between the data objects and the clustering centres, the position of the clustering centres is continuously updated, and the sum of squares of errors (SSE) of the class clusters is continuously reduced, when the SSE is no longer changing or the objective function is converging, the clustering is finished, and the final result is obtained.

The Euclidean distance between a data object and a clustering centre in space is calculated as.

$$d(x, C_i) = \sqrt{\sum_{j=1}^{m} \left(x_j - C_{ij}\right)^2} \tag{9}$$

where, x is the data object,C_i is the i th clustering centre,m is the dimension of the data object, ,$x_j C_{ij}$ is the j th attribute value of x and C_i .

The sum of squared errors SSE for the entire dataset is calculated as.

$$SSE = \sum_{i=1}^{k} \sum_{x \in C_i} |d(x, C_i)|^2 \tag{10}$$

Before performing K-means clustering, based on the relationship between the number of clusters k and the error squared and SSE, the elbow method was used to select the k value corresponding to the elbow point as the optimal number of clusters based on the trend of SSE at different k values [15].

In order to make a comparison, clustering was performed based on the spatial economic distance and the actual geographic distance calculated from the latitude and longitude coordinates of the 13 cities, respectively, and the optimal number of clusters based on the spatial economic distance was determined to be 3 based on the elbow method first, while the optimal number of clusters based on the actual geographic distance for clustering was 2. The results of the clustering are shown in Table 2 and Table 3.

Table 2 Spatial Economic Distance Clustering

Region	Cities covered
Region I	Nanjing, Suzhou, Huai'an, Yancheng
Region II	Wuxi City, Xuzhou City, Nantong City, Yangzhou City, Zhenjiang City, Taizhou City
Region III	Lianyungang City, Suqian City, Changzhou City

Table 3 Geographic Clustering

Region	Cities covered
Region I	Nanjing, Suzhou City, Wuxi City, Changzhou City, Nantong City, Yancheng City, Yangzhou City, Zhenjiang City, Taizhou City
Region II	Xuzhou, Lianyungang, Huai'an, Suqian

2.3 Selection of Optimal Distribution Centre Locations within each Clustered Area Based on the Centre of Gravity Method

Since the clustering algorithm part of the integrated consideration of both spatial and non-spatial factors for the division of the region and site selection, so this study to minimize the transportation cost as the sole basis for decision-making, first of all, according to the actual situation to determine the demand point of the coordinates of$j(x_i, y_i)(i, j = 1,2 \ldots, n)$, set the coordinates of the logistics centre P for (x_0, y_0) , which can be obtained as follows.

$$F = \sum_{j=1}^{n} c_j \tag{11}$$

$$c_j = f_j w_j d_j \tag{12}$$

$$d_j = \sqrt{(x_0 - x_j)^2 + (y_0 - y_j)^2} \tag{13}$$

where F is the total transport and distribution cost from centre P to each demand point:c_j is the cost from P to a single pointj :f_j is the unit transport and distribution cost from P to pointj ;w_j is the distribution volume from P to pointj ;d_j is the straight line distance between logistics centre P and pointj .

Bringing equation (12) into equation (11) yields.

$$F = \sum_{j=1}^{n} f_j w_j d_j \tag{14}$$

virtuous$\frac{\partial F}{\partial x_0} = \frac{\sum_{j=1}^{n} f_j w_j (x_0 - x_j)}{d_j} = 0$, $\frac{\partial F}{\partial y_0} = \frac{\sum_{j=1}^{n} f_j w_j (y_0 - y_j)}{d_j} = 0$

Equations (15) and (16).

$$x_0 = \frac{\sum_{j=1}^{n} f_j w_j \frac{x_j}{d_j}}{\sum_{j=1}^{n} f_j \frac{w_j}{d_j}} \tag{15}$$

$$y_0 = \frac{\sum_{j=1}^{n} f_j w_j \frac{y_j}{d_j}}{\sum_{j=1}^{n} f_j \frac{w_j}{d_j}} \tag{16}$$

At this point, the obtained $P(x_0, y_0)$ is the extreme point of the total distribution costF expression: if it is not the optimal solution, then continue to iterate, the iteration formula is as follows.

$$x^{(q+1)} = \frac{\frac{\sum_{i \in I} f_i w_i x_i}{\left[\left(x^{(q+1)} - x_i\right)^2 + \left(y^{(q)} - y_i\right)^2\right]^{1/2}}}{\frac{\sum_{i \in I} f_i w_i}{\left[\left(x^{(q+1)} - x_i\right)^2 + \left(y^{(q)} - y_i\right)^2\right]^{1/2}}} \tag{17}$$

$$y^{(q+1)} = \frac{\frac{\sum_{i \in I} f_i w_i y_i}{\left[\left(x^{(q+1)} - x_i\right)^2 + \left(y^{(q)} - y_i\right)^2\right]^{1/2}}}{\frac{\sum_{i \in I} f_i w_i}{\left[\left(x^{(q+1)} - x_i\right)^2 + \left(y^{(q)} - y_i\right)^2\right]^{1/2}}} \tag{18}$$

In the above two equations,q is the number of iterations,i is the demand point number, andI is the cluster class where the demand point number is located. When the iteration ofF no longer changes, the iteration stops. At this time,F obtains the minimum value, and the corresponding solution is the optimal solution, i.e., the centre of gravity of logistics centre P site selection and construction.

2.4 Analysis of Model Results

On the basis of using the clustering algorithm to determine each distribution area, each city in the divided area is taken as a logistics demand point, and the specific situation is shown in Figure 1. The per capita disposable income of each point is taken as the demand for logistics resources, and the centre of gravity method is used to make corrections to the cold chain logistics centre.

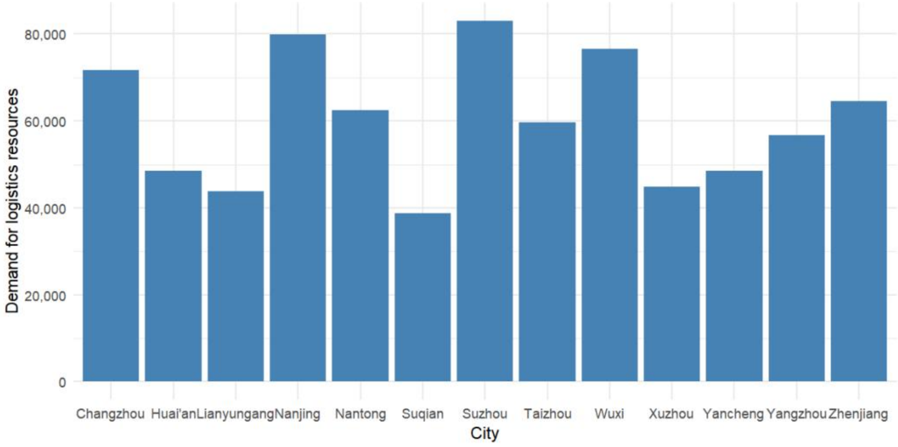

Figure 1 Demand for Logistics Resources by City

Not taking into account the changes in freight rates in each region of Jiangsu Province, assuming that the unit freight rate is RMB 1/kg*km, and taking into account that the establishment of a cold chain logistics centre requires supporting infrastructure, and it cannot be arbitrarily established in a location outside of the city, the logistics centre will be set up in the city closest to the centre of gravity.

Calculate the transport costs and site selection cities in Jiangsu Province under the 2 modelling methods, and the results are shown in Table 4 and Table 5.

Table 4 Results of Spatial Economic Distance Clustering Centre of Gravity Method

Region	City of centre of gravity	Transport costs
Region I	Taizhou	8829.00
Region II	Yangzhou	4330.67
Region III	Suqian	996.33

Table 5 Results of Geographic Clustering Centre of Gravity Method

Region	City of centre of gravity	Transport costs
Region I	Changzhou	14779.33
Region II	Suqian	1577.00

According to the data in the table, the model with clustering based on spatial economic distance and combined with the centre of gravity method for site selection has a total transport cost of $14,156.00, compared to the model with clustering based on geographic distances calculated directly from the latitude and longitude coordinates of the 13 cities, which has a total transport cost of $16,356.33. This indicates a significant reduction in the total transport cost from $16,356.33 to $14,156.00, which is about 13.45 per cent, after taking into account the economics. This result fully proves the effective improvement of the cold chain logistics site selection model in this study in the three aspects of indicator selection, the improvement of distance formula driven by the economicity factor, and the application of the centre of gravity method based on the clustering results. In addition, by comparing the two clustering methods, the clustering method based on spatial economic distance is more reasonable in terms of regional division, and can more accurately reflect the economic linkages and logistics demand among cities.

In summary, the two-stage model proposed in this study is not only innovative in theory, but also shows high practical value in practical application. By comprehensively considering economic, environmental and social factors, the model is able to more scientifically determine the location of cold chain logistics and distribution centres, effectively reduce the transportation cost and improve the logistics efficiency, thus providing a strong support for the sustainable development of cold chain logistics of agricultural products.

3 CONCLUSION

This study focuses on the siting of cold chain logistics and distribution centres for agricultural products in Jiangsu Province, aiming to construct a two-stage siting model that integrates economic, environmental and social factors in order to optimise the layout of distribution centres and improve the efficiency and sustainability of cold chain logistics. In the first stage of the study, this study uses the entropy weight method to quantitatively assess the logistics level of each city in Jiangsu Province. By calculating the logistics level scores of each city, this study provides important data support for the subsequent regional division and distribution centre location. Subsequently, the study further combines the K-means clustering algorithm to divide Jiangsu Province into regions based on spatial economic distance.In the second stage, this study uses the centre of gravity method to select the optimal distribution centre location within each region, and by calculating the weighted average location of each demand point within the region, the optimal location of the distribution centre can be effectively determined so as to minimize the transportation cost.

The research results show that the clustering method based on spatial economic distance can divide the area more scientifically and significantly reduce the transport cost. By optimizing the site layout of the distribution centre, the total transport cost is reduced from 16356.33 yuan to 14156.00 yuan, which is about 13.45% lower. This result not only verifies the validity and practicability of the constructed model, but also provides a scientific basis for the location of cold chain logistics distribution centres in Jiangsu Province, which helps to improve the operational efficiency and economic benefits of cold chain logistics.

In the future, intelligent optimisation algorithms such as machine learning can be further introduced to construct a dynamic siting model to adapt to the dynamic changes in demand and improve the optimisation accuracy. In addition, the scope of the study can be expanded from Jiangsu Province to other regions or more application scenarios to explore the applicability and effectiveness of the model under different geographic, economic and policy conditions, so as to provide a broader and more practical scientific basis for the location decision-making in the cold chain logistics industry.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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