Research on Location Optimization of Logistics Center Based on Center of Gravity Method: A Case Study of Jilin Province

Chenghang Su *

College of Civil Engineering, Fuzhou University, Fuzhou, 350108, China

*** Corresponding author Email:** 1249662541@qq.com

Abstract: With the rapid development of the global economy, logistics plays an increasingly important role in modern society. As the core node of the logistics system, logistics center is responsible for the distribution, transfer and distribution of goods. The scientific and rational location of the logistics center will directly affect the efficiency and cost of logistics transportation. In this paper, Jilin Province, a key agricultural producing area in China, is selected as the research object. By collecting certain historical data information, regression analysis method and moving average method are used to predict the grain output of each city, and the average value of the predicted values obtained by the two methods is used as the final forecast value. The initial site selection of grain logistics center in Jilin Province is calculated by using the center of gravity, and the new site selection after iteration is obtained by using the center of gravity. Finally, the location of the final grain logistics center is determined by considering the factors such as geographical location, traffic accessibility and usable area around. This study can provide some reference value for the optimization of logistics center location.

Keywords: Grain Logistics; Regression Analysis; Moving Average Method; Center of Gravity Method; Site Selection Optimization.

1. Introduction

With the rapid growth of the global economy and the acceleration of urbanization, logistics has become increasingly important in modern society. As the core node of the logistics system, logistics centers are responsible for the distribution, transfer, and allocation of goods. The scientific and rational placement of these centers directly impacts the efficiency and cost of logistics transportation. In China, with the ongoing advancement of the "Belt and Road" Initiative, the strategic layout of logistics centers has become a crucial factor in promoting economic growth.

China has always been a major agricultural country. Jilin Province, as a major agricultural production base, holds significant importance for grain transportation. However, China's grain logistics system still has the problems of slow response of grain logistics market and high cost of grain logistics [1]. The challenge of how to scientifically and rationally locate and construct grain logistics centers to improve logistics efficiency and reduce costs is a pressing issue. Employing scientific methods and technological means for site selection can not only advance grain logistics development in Jilin Province but also provide valuable insights for the progress of the national logistics industry.

Research on the location of logistics centers both domestically and internationally has yielded significant achievements. Xu [2] studied the location of agricultural product logistics centers in Liaoning Province using the Analytic Hierarchy Process (AHP). Zhang et al. [3] established a location model for grain post-production service centers based on two-stage stochastic programming and solved it using the Benders decomposition algorithm. Zhang [4] applied the Analytic Hierarchy Process to investigate the location of grain logistics centers in Benxi County. Wang et al.[5] studied the location problem of grain drying center by using the homodifferential ranking model. Liu et al. [6] explored optimization of logistics center locations by applying mathematical models such as the center of gravity method and the weighted factor comparison method. Xu et al. [7] and Li et al. [8], along with their respective teams, used decision models based on neural networks to study the location of logistics centers.

This paper takes Jilin Province as the research object, and studies the problem of the location of grain logistics center in Jilin Province. Regression analysis and moving average prediction method were used to predict grain output, and the initial location of the initial logistics center was selected in combination with the center of gravity method. Then the location coordinates of the new logistics center were determined iteratively. Finally, the final location of the grain logistics center was determined by comprehensively considering factors such as geographical location, transportation convenience and space size.

2. Data Processing

The latitude and longitude information for the central areas of various cities in Jilin Province was obtained from the Autonavi Open platform. These coordinates were then converted into plane coordinates using the Web Mercator projection through a coordinate conversion tool, as shown in Table 1.

The grain output of each city in Jilin Province from 2014 to 2022, along with the population data of each city in Jilin Province in 2023(as shown in Table 2 and Table 3), were selected and processed based on certain assumptions.

Table 1. Latitude, longitude and plane coordinates of Jilin Province

City	Longitude	Latitude	X-Coordinate	Y-Coordinate
Changchun City	125.32	43.82	13952166.42	5409016.935
Siping City	124.35	43.17	13844150.26	5309660.954
Songyuan City	124.82	45.13	13896470.46	5612706.360
Baicheng City	122.83	45.62	13674909.26	5690049.300
Jilin City	126.55	43.83	14088999.44	5410530.187
Yanji City	129.50	42.88	14417525.47	5265666.850
Tonghua City	125.93	41.73	14019983.68	5093068.522
Baishan City	126.42	41.93	14074551.40	5122892.450
Liaoyuan City	125.13	42.88	13930990.00	5265684.345

Table 2. Grain production by cities in Jilin Province, 2014-2022 (unit: 10,000 tons)

City	2014	2015	2016	2017	2018	2019	2020	2021	2022
Changchun City	789.745	873.226	871.16	839.007	867.96	845.962	875.426	908.156	912.122
Siping City	570.912	576.911	608.897	662.225	686.011	663.703	730.851	721.052	713.964
Songyuan City	518.661	510.107	546.059	566.046	537.182	539.271	561.979	589.754	580.711
Baicheng City	176.962	246.655	243.167	270.042	293.484	275.497	269.042	291.162	326.847
Jilin City	373.387	371.276	377.853	456.179	475.066	470.5	488.32	544.57	515.951
Yanji City	98.059	118.646	124.256	122.801	138.522	154.565	153.454	167.797	184.506
Tonghua City	162.286	192.627	210.492	204.737	213.092	222.424	266.431	289.396	320.337
Baishan City	41.209	43.787	44.798	44.564	47.186	50.175	50.364	50.864	54.186
Liaoyuan City	157.653	213.892	252.277	284.274	271.064	279.608	285.974	295.995	312.582

Table 3. Population by city of Jilin Province in 2023 (unit: ten thousand people)

City	Changchun City	Siping City	Songyuan City	Baicheng City	Jilin City	Yanji City	Tonghua City	Baishan City	Liaoyuan City
Population in 2023	805.29	380.14	324.94	235.37	464.95	79.61	253.66	156.62	151.9

3. Forecast of Grain Output and Grain Transportation Demand

3.1. Introduction to Prediction Model

Regression analysis is based on a large number of observational data, using statistical methods to establish the function expression of the regression relationship between the dependent variable and the independent variable (that is, regression equation), and using the regression equation for analysis. It is usually divided into linear regression and nonlinear regression. In this paper, unitary linear regression in linear regression is used to forecast grain yield.

The equation of linear regression in one variable is as follows:

$$\hat{y} = \hat{b}x + \hat{a} \quad (1)$$

Where $\hat{a}$ and $\hat{b}$ are obtained by the least square method, the formula is as follows:

$$\hat{b} = \frac{\sum_{i=1}^{n} x_i y_i - n\bar{x}\bar{y}}{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2} \quad (2)$$

$$\hat{a} = \bar{y} - b\bar{x} \quad (3)$$

In this paper, x is the year, and y is the grain production of a city in year x (unit: 10,000 tons).

Moving average method is a forecasting method that uses a group of recent actual data to forecast the future one or several periods of data, which can be divided into simple moving average and weighted moving average. This paper adopts simple moving average.

The simple moving average formula is as follows:

$$Ft = (A_{t-1} + A_{t-2} + A_{t-3} + \cdots + A_{t-n})/n \quad (4)$$

Where: Ft is the predicted value of the next period, A_{t-1}, A_{t-2}, A_{t-3}, ..., A_{t-n} is the actual value of the previous period, and n is the number of periods of the moving average.

$$E_{ij} = \frac{\widehat{A_{ij}} - A_i}{A_i} * 100\% \quad (5)$$

$$\overline{E_{ij}} = \frac{E_{ij}}{q-n} \quad (6)$$

Where: $\widehat{A_{ij}}$ represents the predicted value, A_i represents the actual value, q is a parameter or count, the specific meaning needs to be determined based on the actual situation.

The grain output of each city in Jilin Province in 2023 was predicted by regression analysis method and moving average method respectively, and the average value of the predicted grain output of each city using the two methods was obtained as the expected grain output of each city in Jilin Province in 2023.

3.2. Prediction of Grain Production in 2023 by Regression Analysis

Create a scatter plot in Excel showing the relationship between year x and grain production y (unit:10,000 tons). Perform a regression analysis in Excel to fit the data and obtain the corresponding simple linear regression equation, as shown in Table 4. Substitute x=2023 into this equation to obtain the predicted grain production values for each city in Jilin Province for the year 2023 through regression analysis, as shown in Table 5.

3.3. Prediction of Grain Production in 2023 by Moving Average Method

For the same city, take n= 2,3,4, ...,8. The average relative error corresponding to the simple moving average method was observed respectively, and the 2023 grain output forecast value corresponding to the n value of the minimum average relative error was taken as the 2023 grain output forecast value of the city by the moving average method. Can be obtained:

Table 4. Unary linear regression equation corresponding to year x and grain yield y

City	Linear regression equation of one variable
Changchun City	y = 20.834x - 41383
Siping City	y = 20.834x - 41383
Songyuan City	y = 8.2034x - 16005
Baicheng City	y = 13.171x - 26313
Jilin City	y = 22.09x - 44125
Yanji City	y = 9.7234x - 19481
Tonghua City	y = 17.535x - 35154
Baishan City	y = 1.498x - 2975.6
Liaoyuan City	y = 15.479x - 30976

Table 5. Grain output of each city in Jilin Province in 2023 predicted by regression analysis (unit: 10,000 tons)

City	Changchun City	Siping City	Songyuan City	Baicheng City	Jilin City	Yanji City	Tonghua City	Baishan City	Liaoyuan City
Grain Output in 2023	915.57	763.56	590.994	331.73	563.02	188.906	318.99	54.949	338.87

Table 6. Grain output of each city in Jilin Province in 2023 predicted by moving average method (unit: 10,000 tons)

City	Changchun City	Siping City	Songyuan City	Baicheng City	Jilin City	Yanji City	Tonghua City	Baishan City	Liaoyuan City
Grain Output in 2023	898.568	717.508	554.906	291.206	530.261	176.152	304.867	52.525	304.288

3.4. Forecast the Grain Transportation Demand of Each City in Jilin Province in 2023

The average value of predicted grain output of each city using the two methods was obtained, which was used as the expected grain output of each city in Jilin Province in 2023.

Table 7. Projected grain output by cities in Jilin Province in 2023 (unit: 10,000 tons)

City	Changchun City	Siping City	Songyuan City	Baicheng City	Jilin City	Yanji City	Tonghua City	Baishan City	Liaoyuan City
Grain Output in 2023	907.069	740.534	579.461	311.468	546.64	182.529	311.928	53.737	321.579

For any city, subtract the projected grain production of the city in 2023 from the city's population and annual per capita grain consumption (assumed to be 550 kg, i.e. $5.5 * 10^{-5}$ (10000 tons)) to obtain the estimated grain transportation demand of the city in 2023 (in absolute value), denoted as w_j.

Table 8. Expected grain transportation demand of each city in Jilin Province in 2023 (unit: 10,000 tons)

City	Changchun City	Siping City	Songyuan City	Baicheng City	Jilin City	Yanji City	Tonghua City	Baishan City	Liaoyuan City
w_j	464.1595	531.457	400.744	182.015	290.918	138.7435	172.415	32.404	238.034

4. Location Analysis of Grain Logistics Center in Jilin Province

4.1. Model Establishment

Assume there are nnn nodes distributed within a specific area, each with a resource quantity or demand $W_j (j = 1,2,\cdots,n)$, and plane coordinates $(x_j, y_j)(j = 1,2,\cdots,n)$. The coordinates of the logistics center to be established are (x, y), and the transportation cost rate from each node to the logistics center is $C_j (j = 1,2,\cdots,n)$.

According to the methods of finding the center of gravity of a body system in a plane are:

$$\begin{cases} x * \sum_{j=1}^{n} C_j W_j = \sum_{j=1}^{n} C_j W_j x_j \\ y * \sum_{j=1}^{n} C_j W_j = \sum_{j=1}^{n} C_j W_j y_j \end{cases} \quad (7)$$

It can be deduced that the center of gravity method formula is as follows:

$$\begin{cases} x = \sum_{j=1}^{n} C_j W_j x_j / \sum_{j=1}^{n} C_j W_j \\ y = \sum_{j=1}^{n} C_j W_j y_j / \sum_{j=1}^{n} C_j W_j \end{cases} \quad (8)$$

Where C_j is the transportation cost rate, assumed to be 0.55 yuan/(ton·kilometer).

By substituting the relevant data, the initial coordinates of the grain logistics center (x_0, y_0) can be determined. The formula for calculating the total transportation cost is:

To minimize the total cost F, the first partial derivatives must be zero, resulting in the following formulas:

$$F = \sum_{j=1}^{n} C_j W_j [(x - x_j)^2 + (y - y_j)^2]^{1/2} \quad (9)$$

To minimize the total cost FFF, the first partial derivatives must be zero, resulting in the following equations:

$$\begin{cases} \frac{\partial F}{\partial x} = \sum_{j=1}^{n} C_j W_j (x - x_j)/[(x - x_j)^2 + (y - y_j)^2]^{1/2} = 0 \\ \frac{\partial F}{\partial y} = \sum_{j=1}^{n} C_j W_j (y - y_j)/[(x - x_j)^2 + (y - y_j)^2]^{1/2} = 0 \end{cases} \tag{10}$$

Therefore, the following equations can be derived:

$$\begin{cases} x = \frac{\sum_{j=1}^{n} C_j W_j x_j/[(x-x_j)^2+(y-y_j)^2]^{1/2}}{\sum_{j=1}^{n} C_j W_j/[(x-x_j)^2+(y-y_j)^2]^{1/2}} \\ y = \frac{\sum_{j=1}^{n} C_j W_j y_j/[(x-x_j)^2+(y-y_j)^2]^{1/2}}{\sum_{j=1}^{n} C_j W_j/[(x-x_j)^2+(y-y_j)^2]^{1/2}} \end{cases} \tag{11}$$

Substituting the initial solution (x_0, y_0)obtained from the first step of the barycentric method into the right side of the above equations yields new coordinates (x, y), denoted as (x_1, y_1). Similarly, substituting (x_1, y_1) into the right side of the equations yields new coordinates (x, y), denoted as (x_2, y_2). This iterative process continues, eventually (x, y) will converge to a specific coordinate. When (x_n, y_n)=(x_{n+1}, y_{n+1}) within a certain precision and (x, y) shows a converging trend, it can be considered that the optimal coordinates for the logistics center location have been found within that precision.

4.2. Model Solving

By substituting the relevant data, the initial solution (x_0, y_0) is (13945964.6214,5393783.0075), with the corresponding latitude and longitude coordinates being (125.27736859,43.7289941).

The iterative process is executed using a computer program, which halts when the accuracy reaches 0.0001. After 76 iterations, a new location (13952153.2740, 5409011. 9795) for the grain logistics center is determined, and its coordinates are converted to longitude and latitude (125.3329616, 43.828119), as shown in Figure 1.

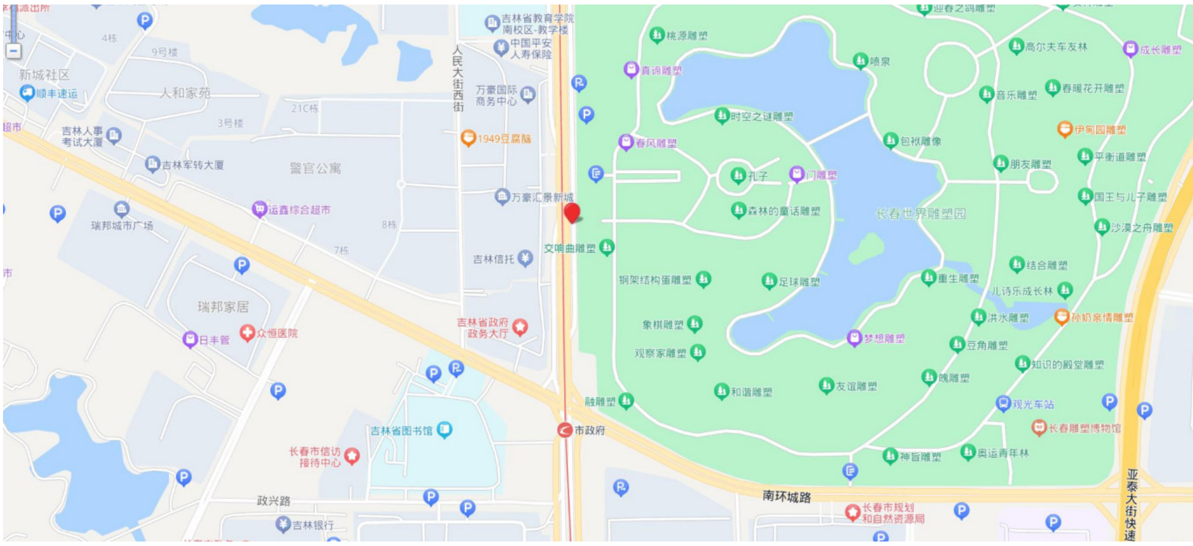

Figure 1. Location diagram of the site selection point

5. Location Optimization

For the location of a grain logistics center, the position obtained through the barycentric method iteration often requires further inspection, verification, and optimization. Food logistics centers need to be strategically located to meet their specific needs.

In addition, it is necessary to comprehensively consider various other factors in the location of food logistics centers, such as:

(1) Geographical location and transportation convenience: An ideal geographical location should be near the grain production area to facilitate grain acquisition and storage. It should also be close to major transportation arteries to ease the transportation of grain.

(2) Soil conditions: The site should have good engineering geological conditions, avoiding areas prone to hazards like debris flows and landslides. The soil should be solid and reliable, not prone to settling or collapsing.

(3) Hydrological conditions: Food distribution centers need to be located away from flood-prone river basins and areas with groundwater overflows, avoiding threats such as floods and tides.

(4) Land area: The location should have sufficient space for warehousing, loading, unloading, and other logistics activities to meet both current operational needs and future development of the food logistics center.

Taking the above factors into consideration, this paper analyzes and investigates the surrounding location of the site obtained after the iteration of the center of gravity method to find a new location suitable for the grain logistics center, as shown in Figures 2 and 3.

6. Conclusion

This paper uses regression analysis and moving average methods to predict grain production in various cities in Jilin Province. It calculates the grain transport volume for each prefecture-level city in Jilin Province based on the transport volume, location coordinates of each city, and the grain transport rates in Jilin Province. The center of gravity method is then used for site selection of the grain logistics center. Finally, the optimal site selection plan is determined through comprehensive consideration.

Figure 2. New site location diagram

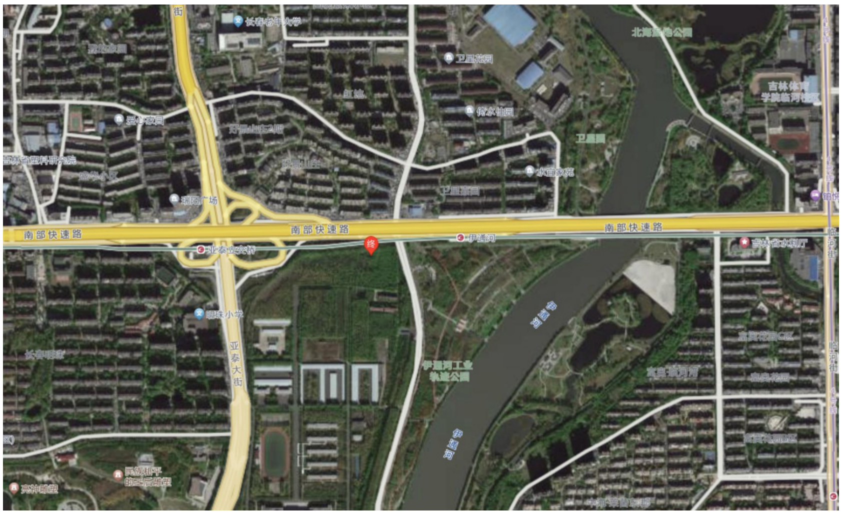

Figure 3. Satellite diagram of the new site location

However, it is important to note that the site selection for a grain logistics center is a complex systemic project in a real-world environment, often requiring consideration of many more factors and variables. Additionally, some data in this paper were assumed due to difficulties in obtaining accurate data, which may result in certain deviations from reality. The method used in this paper can provide a practical solution for logistics center location problems that do not require extremely high precision and fast location. For logistics center site selections requiring higher accuracy, establishing complex optimization models with more parameters may be considered.

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