Study on Location of Emergency Logistics Center Based on Improved TOPSIS, Shannon Entropy and Coordinated Development Degree Model

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Abstract: In order to select the emergency logistics center scientifically and rationally, a comprehensive evaluation method combining the improved technique for order preference similarity to the ideal solution (TOPSIS) method, Shannon entropy, and coordinated development degree model (CDDM) is proposed. The improved TOPSIS method is used to calculate the relative proximity of alternatives to the ideal solution, the inhomogeneity of indicators is evaluated by Shannon entropy, and the CDDM is used to assess the relationship between the relative proximity and inhomogeneity of the alternatives. On this basis, the evaluation index system of the emergency logistics center is constructed from four dimensions: emergency demand and supply conditions, economic development level, logistics development level, and communication development degree, and the feasibility and effectiveness of the method are verified by taking the Jiaodong Peninsula as an example.

Keywords: Location, Coordinated development degree model (CDDM), Technique for order preference similarity to ideal solution (TOPSIS) method, Shannon entropy.

1 INTRODUCTION

In recent years, emergencies have been occurring in China, such as the SARS epidemic in 2003, the Wenchuan earthquake in 2008, and a series of other disasters. the outbreak of the new crown epidemic in 2020, which continues today, has caused serious losses to the economic development of the affected areas and poses a huge challenge to global health governance. When emergencies come, emergency relief materials should be transported quickly from emergency logistics centers to the affected areas with the principle of maximizing time efficiency and minimizing the casualty rate and economic loss rate. Therefore, reasonable evaluation and selection of emergency logistics centers can reduce transportation and distribution costs, improve the response speed of emergency logistics systems, and protect people's needs.

Emergency logistics is different from general logistics activities, and it is necessary to establish an emergency logistics center in order to meet the needs of emergency supplies in emergency situations. For the establishment of the site selection index system, [4] considered environmental, economic and technical factors; [10] started from four aspects affecting the site

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selection: economic, technical, social, and environmental; [5] determined the appropriate landfill site from morphological, environmental and socio-economic factors; for the construction of the model, [1] considered the typhoon scenario [6] considered location, cost, and service factors to establish a multi-attribute decision model; in terms of evaluation methods, [3] used Grey Relationship Analysis (GRA) and Analytic Hierarchy Process (AHP) to solve the site selection problem of new public hospitals. As TOPSIS method has scientific and practicality. [2] proposed an uncertain multi-criteria decision-making method for the site selection problem and used the TOPSIS method to rank the site selection options; (Pham et al. 2017) used the fuzzy method and a hybrid method with TOPSIS to select an emergency logistics center to meet the needs of the people and rescue teams affected by the earthquake.

In summary, most studies construct evaluation index systems from three aspects: environment, economy, and technology, while this paper considers four aspects: emergency supply and demand conditions, economic development, logistics development, and communication development. This paper introduces gray correlation analysis into the TOPSIS method to make up for the defect that the TOPSIS method only calculates the relative distance and ignores the development trend between factors, thus not accurately reflect the actual situation, and calculates the gray correlation between each alternative address and positive and negative ideal solutions to construct the relative proximity. Meanwhile, the Shannon entropy method is introduced to evaluate the inhomogeneity among object indicators. [8] Since this paper considers relative proximity and inhomogeneity as important factors affecting the selection of logistics centers, the coordinated development degree model (CDDM) is introduced simultaneously to evaluate the relationship between them. [9] The method proposed in this study integrates multiple indicator systems and the inhomogeneity among indicators to comprehensively evaluate emergency logistics centers to determine the final location.

2 EMERGENCY LOGISTICS CENTER EVALUATION INDEX SYSTEM

When an emergency occurs, the distribution of emergency materials in the affected area has high timeliness, which requires the emergency logistics center to make emergency preparations and emergency response to ensure the timely supply of materials. In this paper, the evaluation index system of the emergency logistics center is constructed from the following four aspects, as shown in Table 1.

Table 1: Evaluation index system of emergency logistics center

Level 1 Indicators	Level 2 Indicators	Sybols	Indicator Description
Emergency needs and supply conditions	Population	X1	Represents the emergency level of demand as well as the level of supply
	Number of medical and health institutions	X2	
	Number of employees in the transportation industry	X3	
Economic Developmen t Level	Total GDP	X4	Reflects the level of economic and social development
	GDP per capita	X5	
	Total value of imports and exports	X6	
Logistics development	Road mileage	X7	Represents the degree of urban road development and freight
	Total road freight	X8	

level	Road freight turnover rate	X9	capacity
Degree of communication development	Number of cell phones	X10	Reflects the timeliness of information dissemination in the event of an emergency
	Number of Internet users	X11	

2.1 Calculation of Indicator Weights

At present, the most common methods for determining index weights are subjective weight evaluation method and objective weight evaluation method. In this study, the two methods, entropy weight method and AHP, are combined to determine the index weights from both objective and subjective aspects, and the specific steps are as follows.

Step 1: Construct the original data consisting of *n* alternatives and m indicators to build the initial decision matrix *X*.

$$X = \begin{bmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{nm} \end{bmatrix} \tag{1}$$

Step 2: Normalize *X* to obtain the decision matrix *A*.

$$A = \begin{bmatrix} A_{11} & \cdots & A_{1m} \\ \vdots & \ddots & \vdots \\ A_{n1} & \cdots & A_{nm} \end{bmatrix} \tag{2}$$

Step 3: Calculate the weight of the *j* indicator P_{ij}.

$$\mathrm{P}_{ij} = \mathrm{A}_{ij} \Big/ \sum_{i=1}^{n} \mathrm{A}_{ij} \quad 1 \le j \le m \tag{3}$$

Step 4: Calculate the deviation of the *j* indicator g_j.

$$e_j = -\frac{1}{ln(n)} \sum_{i=1}^{n} P_{ij} ln P_{ij} \tag{4}$$

$$g_j = 1 - e_j \tag{5}$$

Step 6: The entropy weighting index is u_j.

$$u_j = g_j \Big/ \sum_{j=1}^{m} g_j \tag{6}$$

Step 7: Calculate the subjective weights using hierarchical analysis. (Halil et al. 2016) The detailed steps of the AHP method are listed in the literature.

Step 8: Calculate final weights ω_j.

In order to make the weight distribution of each indicator more reasonable, a distance function is introduced to combine the subjective weights and objective weights, and the distance function is as follows.

$$D\left(\lambda_j, u_j\right) = \sqrt{\frac{\sum_{j=1}^{m}\left(\lambda_j - u_j\right)^2}{2}} \tag{7}$$

The coefficients of the subjective and objective weight assignments are α 、β， and the sum is 1,which is calculated by Equation (8).

$$D\left(\lambda_j, u_j\right)^2 = \left(\alpha - \beta\right)^2 \tag{8}$$

$$\omega_j = \alpha\lambda_j + \beta u_j \tag{9}$$

The combined weight of the *j* indicator ω_j.

$$\omega_j = \alpha\lambda_j + \beta u_j \tag{10}$$

3 COMPREHENSIVE EVALUATION METHOD STEPS

3.1 Calculating Relative Closeness Based on Improved TOPSIS

Combining the gray correlation analysis with the TOPSIS method, the greater the gray correlation between the alternative and the positive ideal solution, the closer the alternative is to the ideal solution, and vice versa. The calculation procedure of the improved TOPSIS method is as follows.

Step 1: Normalize the raw data to obtain the decision matrix *A*.

$$A_{ij} = \frac{X_{ij}}{\max\limits_{i} X_{ij}} \quad 1 \le j \le m \tag{11}$$

Step 2: Determine the weight vector using the entropy and AHP methods.

Step 3: Combining the weights with the decision matrix *A* to obtain the weighted decision matrix *D*.

$$D_{ij} = A_{ij} * \omega_j, 1 \le i \le n, 1 \le j \le m \tag{12}$$

Step 4: Use equations (13) and (14) to calculate the positive ideal solution D^+ ,negative ideal solution D^-.

$$D^+ = \left\{ D_1^+, D_2^+, D_3^+ \ldots D_m^+ \right\} \tag{13}$$

$$D^- = \left\{ D_1^-, D_2^-, D_3^- \ldots D_m^- \right\} \tag{14}$$

Where: $D_j^+ = \max_i \mathrm{D}_{ij}, 1 \le i \le n, 1 \le j \le m$

$D_j^- = \min_i \mathrm{D}_{ij}, 1 \le i \le n, 1 \le j \le m$

Step 5: Calculate the gray correlation between the emergency logistics center alternative and the ideal solution r_{ij}^+, r_{ij}^-.

$$r_{ij}^+ = \frac{\min_i \min_j \left| D_j^+ - D_{ij} \right| + \rho \max_i \max_j \left| D_j^+ - D_{ij} \right|}{\left| D_j^+ - D_{ij} \right| + \rho \max_i \max_j \left| D_j^+ - D_{ij} \right|} \tag{15}$$

$$r_{ij}^- = \frac{\min_i \min_j \left| D_j^- - D_{ij} \right| + \rho \max_i \max_j \left| D_j^- - D_{ij} \right|}{\left| D_j^- - D_{ij} \right| + \rho \max_i \max_j \left| D_j^- - D_{ij} \right|} \tag{16}$$

Where ρ is the discriminant coefficient, generally taken as 0.5. to obtain the gray correlation matrix R^+, R^-.

$$R^+ = \begin{bmatrix} r_{11}^+ & \cdots & r_{1m}^+ \\ \vdots & \ddots & \vdots \\ r_{n1}^+ & \cdots & r_{nm}^+ \end{bmatrix} \tag{17}$$

$$R^- = \begin{bmatrix} r_{11}^- & \cdots & r_{1m}^- \\ \vdots & \ddots & \vdots \\ r_{n1}^- & \cdots & r_{nm}^- \end{bmatrix} \tag{18}$$

Step 6: According to equation (15)(16), the gray correlation between the emergency center alternative and the positive and negative ideal solutions is calculated C_i^+, C_i^-.

$$C_i^+ = \frac{1}{m}\sum_{j=1}^{m} r_{ij}^+, \qquad 1 \le i \le n \tag{19}$$

$$C_i^- = \frac{1}{m}\sum_{j=1}^{m} r_{ij}^-, \qquad 1 \le i \le n \tag{20}$$

Step 7: Calculate the relative closeness of the gray correlation for each acute logistics center alternative α_i .

$$\alpha_i = \frac{C_i^+}{C_i^+ + C_i^-}, \qquad 1 \le i \le n \tag{21}$$

3.2 Unneven Evaluation Based on Shannon Entropy Method

The solution obtained by the improved TOPSIS method does not take into account the inhomogeneity of the evaluation indexes, and the inhomogeneity of each index will also affect the selection of the final emergency logistics center. In this paper, the Shannon entropy method is introduced for uneven evaluation, and the smaller the Shannon entropy is, the smaller the reliability of the program is, and vice versa. The evaluation calculation process is as follows.

$$\beta_i = -\frac{1}{ln(m)}\sum_{j=1}^{m} P_{ij} lnP_{ij}, (i = 1, 2, 3, \ldots, n) \tag{22}$$

$$P_{ij} = C_{ij} \Big/ \sum\nolimits_{j=1}^{m} C_{ij} \tag{23}$$

where β_i is the entropy of the evaluation object, *m* is the number of indicators, and *n* is the number of evaluation objects.

3.3 Comprehensive Evaluation Based on CDDM

Based on the above relative closeness and inhomogeneity evaluation results, the coordinated development degree model was used for comprehensive evaluation. The calculation process is as follows.

Step 1: The results of relative closeness and inhomogeneity evaluation are normalized to obtain γ_i, δ_i .

$$\gamma_i = \alpha_i / \alpha_{max} \tag{24}$$

$$\delta_i = \beta_i / \beta_{max} \tag{25}$$

Step 2: The relationship between relative proximity and inhomogeneity is quantified using the coordinated development measure, which is calculated as follows.

$$H_i = \left(\frac{\gamma_i * \delta_i}{\left(\frac{\gamma_i + \delta_i}{2} \right)^2} \right)^2 \tag{26}$$

$$M_i = \sqrt{H_i m} \tag{27}$$

Where: H_i is the degree of coordination of the ith emergency center; *m* is the number of comprehensive evaluation indicators of the system; M_i is the degree of coordinated development of the *i* emergency center.

Step 3: Determine the best emergency center location.

$$\text{Optimal location} = \text{Max}\{M_i\},\ i = 1, 2 \cdots n \tag{28}$$

4 CASE STUDY

Shandong Province is a northern temperate semi-humid monsoon climate, often hit by land and sea and other natural disasters frequently, especially the Jiaodong Peninsula because it is located in the Yellow Sea, the Bohai Sea zone, typhoon-induced rainstorms, and high winds and other derivative disasters are very easy to occur. Since the outbreak of the new crown, the epidemic in the Jiaodong Peninsula region has been successive, and the situation of foreign epidemics is serious. To prevent the importation of epidemics and emergencies, it is necessary to establish an emergency logistics center in the Jiaodong Peninsula region. Therefore, this study conducts a comprehensive evaluation of five alternative cities in the Jiaodong Peninsula region (Qingdao, Yantai, Weihai, Weifang, and Rizhao) to select the best emergency logistics center.

4.1 Computational Analysis

The original data of each index were obtained from the Statistical Yearbook of Shandong Province and the China Logistics Statistical Yearbook. The research subjects are five cities, namely Qingdao, Yantai, Weihai, Weifang, and Rizhao, and the study period is 2016-2020. To ensure the accuracy of the results, the index values are taken as the average of 5 years. The calculation and analysis process is as follows.

(1) The decision matrix constructed from the original data is normalized to obtain the normalization matrix A, as shown in Table 2.

Table 2: Standardized data for each indicator in the Jiaodong Peninsula

Indicator Name	Qingdao	Yantai	Weihai	Weifang	Rizhao
Population	1.00	0.70	0.29	0.93	0.29
Number of medical and health institutions	1.00	0.70	0.30	0.96	0.29

Number of employees in the transportation industry	1.00	0.41	0.18	0.20	0.31
Total GDP	1.00	0.63	0.24	0.47	0.16
GDP per capita	1.00	0.89	0.84	0.50	0.55
Total value of imports and exports	1.00	0.56	0.18	0.30	0.17
Road mileage	0.52	0.68	0.25	1.00	0.35
Total road freight	1.00	0.68	0.24	0.98	0.29
Road freight turnover rate	1.00	0.64	0.28	0.96	0.31
Number of cell phones	1.00	0.67	0.30	0.82	0.25
Number of Internet users	1.00	0.65	0.31	0.71	0.23

(2) For the decision matrix A, the objective weights of each evaluation index are derived according to equations (1) to (6) using the entropy weighting method, as shown in Table 3.

Table 3: Objective weights of each index after calculation by entropy weighting method

X	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
u_j	0.079	0.079	0.143	0.117	0.023	0.152	0.072	0.094	0.08	0.081	0.08

(3) Seven experts in the field of emergency management were invited to determine the subjective weights based on their own familiarity with the relevant theories in the field, and the results are shown in Table 4.

Table 4: Subjective weights of each index after AHP calculation

X	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
λ_j	0.058	0.192	0.106	0.118	0.026	0.068	0.039	0.103	0.18	0.074	0.037

(4) The distance function equation (7) is introduced, and the equations (8) and (9) are used to determine the coefficients of subjective and objective weights, respectively, and finally the combined weights are determined by equation (10), as shown in Table 5.

Table 5: Weight of each indicator combination

X	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
ω_j	0.067	0.143	0.12	0.118	0.025	0.104	0.053	0.099	0.136	0.077	0.056

(5) Weighted After the decision matrix D.

$$D = \begin{bmatrix} 0.07 & 0.14 & 0.12 & 0.12 & 0.02 & 0.10 & 0.03 & 0.10 & 0.14 & 0.08 & 0.06 \\ 0.05 & 0.10 & 0.05 & 0.07 & 0.02 & 0.06 & 0.04 & 0.07 & 0.09 & 0.05 & 0.04 \\ 0.02 & 0.04 & 0.02 & 0.03 & 0.02 & 0.02 & 0.01 & 0.02 & 0.04 & 0.02 & 0.02 \\ 0.06 & 0.14 & 0.02 & 0.06 & 0.01 & 0.03 & 0.05 & 0.10 & 0.13 & 0.06 & 0.04 \\ 0.02 & 0.04 & 0.04 & 0.02 & 0.01 & 0.02 & 0.02 & 0.03 & 0.04 & 0.02 & 0.01 \end{bmatrix}$$

(6) Positive and negative ideal solutions and gray correlation.

Positive and negative ideal soutions D^{+}, D^{-}:

$$D^{+} = \begin{Bmatrix} 0.07, 0.14, 0.12, 0.12, 0.02, \\ 0.10, 0.05, 0.10, 0.14, 0.08, 0.06 \end{Bmatrix}$$

$$D^{-} = \begin{Bmatrix} 0.02, 0.04, 0.02, 0.02, 0.01, \\ 0.02, 0.01, 0.02, 0.04, 0.02, 0.01 \end{Bmatrix}$$

Gray association C_i^{+}, C_i^{-}:

$$C_i^{+} = \{0.972, 0.630, 0.459, 0.730, 0.452\}$$

$$C_i^{-} = \{0.502, 0.626, 0.963, 0.643, 0.952\}$$

(7) Calculate the relative closeness of the gray association for each emergency center as.

$$\alpha_i = \{0.660, 0.502, 0.323, 0.532, 0.322\}$$

(8) The Shannon entropy of each candidate solution is calculated according to equation (22)(23), and the results are shown below.

$$\beta_i = \{0.954, 0.968, 0.976, 0.924, 0.964\}$$

(9) According to equation (24) (25), the data of relative closeness and Shannon entropy are normalized to calculate the degree of coordinated development of emergency centers as.

$$M_i = \{3.605, 3.543, 3.191, 3.582, 3.192\}$$

The larger *M* is, the better the corresponding emergency center is, and according to equation (28), the best emergency logistics center is Qingdao city.

5 CONCLUSIONS

This paper also considers four dimensions of emergency demand and supply conditions, economic development level, logistics development level, and communication development degree to establish the evaluation index system and adopts a comprehensive evaluation method combining the improved TOPSIS method, Shannon entropy, and coordinated development degree, and the results show that Qingdao is the best emergency logistics center in Jiaodong region. In the improved comprehensive evaluation method, the entropy method, which considers the objective attributes of the data, is combined with the AHP method, which considers the subjective characteristics of the data, to finally determine the index weights with more reasonableness. The improved TOPSIS method is used to solve the relative closeness and the inhomogeneity of each index based on Shannon entropy so that the evaluation results are closer to the actual situation. Finally, the relationship between the relative proximity and inhomogeneity of emergency logistics centers is studied by the coordinated development degree model, and a more objective and accurate site selection result is obtained, which provides a theoretical basis for the selection of emergency logistics centers. In fact, Qingdao has a good foundation in terms of economic development level, business environment, and communication development degree, which indicates that the evaluation model proposed in this paper is in line with reality and can effectively solve the emergency logistics center selection problem.

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