Evaluation of Logistics Emergency Response Capacity under Geological Disasters Based on Entropy Weight TOPSIS Gray Correlation Method-Taking Liaoning Province as an Example

Guoqing Wu*, YanbinWang

School of Business and Management, Liaoning Technical University, Huludao, Liaoning, 125100, China

*15936729283@163.com

Abstract. In recent years, the frequency and intensity of geological disasters in China have increased, causing significant losses to the safety of people's lives and economic property. A scientific evaluation of logistics emergency response capability is a necessary measure in dealing with geological natural disasters, effectively safeguarding the safety of people's lives and property and reducing the social burden. This paper focuses on geological disasters and takes Liaoning Province as the research subject, establishing an index system from five aspects: logistics infrastructure, transportation capacity, information systems, material storage, human resources, and emergency logistics potential. It employs a multi-criteria decision analysis method that combines the entropy weight method, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and grey relational analysis to conduct a comprehensive evaluation of emergency logistics in Liaoning Province. Based on the grey relational grade of calculated indicators, 18 indicators were ranked, revealing that the mobile phone penetration rate and the length of highways have a significant impact on emergency logistics, both exceeding 0.9. Indicators with a grey relational grade above 0.8 were selected for further analysis. Through TOPSIS, the closeness degree of emergency logistics in Liaoning Province from 2011 to 2020 was calculated, showing an overall upward trend over the past decade. The evaluation results demonstrate that the entropy-weighted TOPSIS-grey relational method can be an effective approach for evaluating emergency logistics capabilities.

Keywords: Liaoning Province; Emergency Logistics; Geological Disasters; TOPSIS; Grey Relational Analysis; Entropy Weight Method

1 INTRODUCTION

Geological disasters frequently occur globally, and China is among the countries most affected by natural disasters, leading to significant property damage and loss of life.

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Geological disasters have become a critical factor constraining the sustained, stable, and coordinated development of China's national economy[2].

Based on existing research, some scholars have introduced measures and reserve models for dealing with geological disasters. Zeng Wangjun [1] started from the application of big data in the supply of emergency material reserves, reviewed the current logistics situation of emergency material supply with big data, and proposed ideas and specific measures for the integrated development of big data and emergency material supply. Li Shuyu et al. [2] analyzed the current status and characteristics of China's emergency material reserves, discussed the shortcomings in the legal system, management mechanism, logistics, and information sharing in the management of emergency material reserves for major sudden events in recent years, and proposed measures such as perfecting the legal system for emergency material support, formulating emergency material reserve management plans, improving the efficiency of emergency material mobilization, and establishing an emergency material information platform. The goal is to effectively enhance China's emergency management capabilities by improving the emergency material management system [2].

Addressing geological disasters quickly and effectively is a pressing issue. The reserve and distribution of emergency supplies are crucial for mitigating the impact of disasters and are the focus of this paper [1]. This study employs an entropy weight-TOPSIS-grey relational analysis method to establish a multi-criteria evaluation system [3], as shown in Table 1, and conducts a grey relational analysis on 18 indicators of emergency logistics. Considering the rationality and objectivity of the evaluation, this paper selects indicators with a grey relational value greater than 0.8. Using TOPSIS, the Euclidean distances to the positive and negative ideal solutions are calculated, and the relative closeness is determined to evaluate the emergency logistics capabilities of Liaoning Province from 2011 to 2020, aiming to provide a reference for the field.

Table 1. Emergency logistics evaluation index system

Target layer	Criterion layer	Indicator layer
Logistics emergency capability	Logistics infrastructure	Railway freight volume (10000 tons)
		Highway freight volume (10000 tons)
	Transportation capacity	Railway operating mileage (kilometers)
		Highway route mileage (kilometers)
		National Highway Route Mileage (Kilometers)
		Provincial Highway Route Mileage (Kilometers)
		Highway density (kilometers/100 square kilometers)
		Number of newly registered civilian vehicles - vehicles
	information system	Total Postal and Telecommunications Business (100 million yuan)
		Internet penetration rate (%)
		Mobile phone penetration rate (unit/100 people)
	Material storage	Emergency material reserves (10000 tons)
		Emergency material procurement volume (10000 tons)
	Human Resources and Emergency Logistics Potential	R&D expenditure (100 million yuan)
		R&D as a percentage of GDP
		Number of R&D personnel(10000people)
		Number of regular university students - graduate students (person)
		Number of patent applications authorized (pieces)

2 RESEARCH METHOD

2.1 Entropy Weighting Method

Construct the original matrix, determine whether there are negative numbers in the input matrix, and if so, re-normalize to non-negative intervals (later calculation of the probabilistic equation needs to ensure that each element is non-negative) Now there are n objects to be evaluated and m evaluation indicators (which have been positively normalized) [4] The attribute value of the i object with respect to the j indicator, xij(i=1,2,3.... .n; j=1,2,3... .m) construct the normalized raw matrix as follows.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{1}$$

Data normalization is performed to create a standardized decision matrix, as the indicators studied in this paper vary in magnitude and dimension. The matrix resulting from this normalization process is denoted as Z, with each element within Z satisfying Equation (2).

$$Z_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{n} x_{ij}^2} \tag{2}$$

Evaluate the Z matrix to ascertain the presence of any negative numbers. If negative numbers are found, apply Equation (3) to normalize the X matrix once more, resulting in the Z matrix.

$$Z_{ij} = \frac{x_{ij} - \min\{x_{1j}, x_{2j}, \ldots, x_{nj}\}}{\max\{x_{1j}, x_{2j}, \ldots, x_{nj}\} - \min\{x_{1j}, x_{2j}, \ldots, x_{nj}\}} \tag{3}$$

Calculate the weight of the j indicator as shown P_{ij} in Equation (4) and the information entropy of the indicator e_j as Equation (5).

$$P_{ij} = Z_{ij} \Big/ \sum_{i=1}^{n} Z_{ij} \tag{4}$$

$$e_j = -\frac{1}{In(n)} \sum_{i=1}^{n} P_{ij} In(P_{ij}) \quad (j = 1, 2, \cdots, m) \tag{5}$$

The definition of the information utility value is $d_j = 1 - e_j$, implying that a higher information utility value corresponds to a greater amount of information. By normalizing the information utility values, we can obtain the entropy weight for each indicator, as illustrated in Equation (6) below.

$$\omega_j = d_j \Big/ \sum_{j=1}^{m} d_j \quad (j = 1, 2, \cdots, m) \tag{6}$$

2.2 Gray Correlation Analysis

During the grey relational analysis, the emergency logistics data column is set as 'reference sequence', and the columns representing factors affecting emergency logistics are set as 'comparison sequences', denoted as i = 1，2， ···， m，k= 1，2，···， n ,and X0 ={x0 (1)，x0 (2)，···，x0 (n)}，Xi ={xi (1)，xi (2)，···，xi (n)} respectively. To eliminate differences in units and meanings among various influencing factors, this study applies the initial value method for dimensionless processing of the data columns related to influencing factors [5].

$$X_i(k)=\frac{x_i(k)-x_i(k)_{\min}}{x_i(k)_{\max}-x_i(k)_{\min}} \tag{7}$$

Then, calculate the sequence difference X0(k) between emergency logistics Xi(k) and each influencing factor 'xxxΔ_i(k), the maximum difference Δ max at two levels, and the minimum difference Δ min at two levels.

$$\Delta_i(k)=\left|X_0(k)-X_i(k)\right| \tag{8}$$

$$\Delta_{\max}=\max_i \max_k \left|X_0(K)-X_i(k)\right| \tag{9}$$

$$\Delta_{\min}=\min_i \min_k \left|X_0(k)-X_i(k)\right| \tag{10}$$

Calculate the grey relational coefficient ξi (k) between the influencing factors, where ρ represents the resolution coefficient, which is typically set to 0.5 [7].

$$\xi_i(k)=\frac{\Delta_{\min}+\rho\Delta_{\max}}{\Delta_i(k)+\rho\Delta_{\max}},\rho\in(0,1) \tag{11}$$

Calculate the correlation degree Xi (k) of influencing factor X0 (k) to emergency logistics γi.

$$\gamma_i=\frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \tag{12}$$

2.3 TOPSIS Method

The TOPSIS method identifies the ideal solution by constructing a weighted normalized matrix. This is achieved by multiplying the normalized matrix with the weightsω_j, as shown in the formula below, resulting in the weighted normalized matrix Y,and define a positive ideal solution as(14),define the negative ideal solution as(15).

$$Y=(\mathrm{x}_{\mathrm{ij}})_{\mathrm{m\times n}}=\left[\omega_{\mathrm{j}}\times \mathrm{z}_{\mathrm{ij}}\right]_{\mathrm{m\times n}} \tag{13}$$

$$Y^+=(Y_1^+,Y_2^+,\cdots,Y_m^+)=\left\{\max y_{ij}\mid i=1,2,\cdots,n\right\}(0\le i\le n) \tag{14}$$

$$Y^-=(Y_1^-,Y_2^-,\cdots,Y_m^-)=\left\{\min y_{ij}\mid i=1,2,\cdots,n\right\}(0\le i\le n) \tag{15}$$

Define the distance of the $i(i = 1,2, \cdots, n)$ evaluation object to the maximum value as.

$$D_i^+ = \sqrt{\sum_{j=1}^{m}(Y_j^+ - y_{ij})^2} \tag{16}$$

Define the distance of the $i(i = 1,2, \cdots, n)$evaluation object to the minimum value as.

$$D_i^- = \sqrt{\sum_{j=1}^{m}(Y_j^- - y_{ij})^2} \tag{17}$$

Calculate the relative closeness S_i, which represents the score of each evaluation object, using the following formula.

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-}(i = 1,2,\cdots,n) \tag{18}$$

Based on the calculation results of the formula, the emergency logistics capabilities of Liaoning Province from 2011 to 2020 are ranked according to the size of S_i. A larger S_i indicates that the emergency logistics capability for that year is closer to the positive ideal solution, implying stronger emergency logistics capabilities; conversely, a smaller S_i indicates that the emergency logistics capability is closer to the negative ideal solution, signifying weaker emergency logistics capabilities.

3 EMPIRICAL ANALYSIS

To comprehensively and scientifically reflect the information of the indicators, this paper selects relevant data from Liaoning Province for the years 2011-2020. All data used in this paper are sourced from the National Bureau of Statistics and the National Statistical Yearbook. Considering the absence of some data for certain indicators, this study has employed interpolation techniques to fill in the missing data.

3.1 Indicator Weights and Gray Correlation Calculation

Indicator weights and gray correlation are calculated according to Equation (6) and Equation (12), respectively, as shown in Table 2 below.

Table 2. Emergency logistics indicators, weights, and grey correlation degree

evaluating indicator		weight	Grey correlation degree	Relevance ranking
dimension	index			
Logistics infrastructure	Railway freight volume (10000 tons)	0.032700299	0.788487735	9
	Highway freight volume (kilometers)	0.090685871	0.562760373	16

Transportation capacity	Railway operating mileage (kilometers)	0.018907188	0.879250601	4
	Highway route mileage (kilometers)	0.019744593	0.91912822	2
	National Highway Route Mileage (Kilometers)	0.035767318	0.782299664	10
	Provincial Highway Route Mileage (Kilometers)	0.026602216	0.848204685	6
	Highway density (kilometers/100 square kilometers)	0.126065575	0.534081027	17
	Number of newly registered civilian vehicles - vehicles	0.043861828	0.698163989	11
information system	Total Postal and Telecommunications Business (100 million yuan)	0.080648978	0.515366472	18
	Internet penetration rate (%)	0.018079733	0.894344356	3
	Mobile phone penetration rate (unit/100 people)	0.012754012	0.925459114	1
Human Resources and Emergency Logistics Potential	R&D expenditure (100 million yuan)	0.053550137	0.650016886	15
	The proportion of R&D expenditure to GDP (%)	0.026676714	0.804101923	8
	Number of R&D personnel (10000 people)	0.067153833	0.674640457	13
	Number of regular university students - graduate students (person)	0.048094900	0.663138758	14
	Number of patent applications authorized (pieces)	0.038923134	0.684568415	12
Material reserves	Emergency material reserves (10000 tons)	0.068451921	0.846542872	7
	Emergency material procurement volume (10000 tons)	0.583875101	0.856920141	5

By weighting the grey relational coefficients obtained from the analysis, the final correlation degrees are determined. These correlation degrees are then used to rank the 18 evaluation objects, with values ranging from 0 to 1. A higher value indicates a stronger correlation with emergency logistics capabilities, meaning a higher evaluation. According to the grey relational degrees of various evaluation indicators presented in Table 2, factors such as the mileage of highways (0.9191) and the mobile phone penetration rate (0.9255) have significant impacts on emergency logistics, with grey relational values both exceeding 0.9. In line with corroborative literature [6], this study selects influencing factors with a correlation degree greater than 0.8 as the main influencing factors.

3.2 TOPSIS Sorting

Calculate the positive ideal solution and negative ideal solution according to formulas (14) - (15), as shown in Table 3.

Table 3. Positive and negative ideal solutions for emergency logistics indicators

evaluating indicator		Positive ideal solution	Negative ideal solution
dimension	index		
Transportation capacity	Railway operating mileage (kilometers)	0.032700299	0
	Highway route mileage (kilometers)	0.019744593	0
	Provincial Highway Route Mileage (Kilometers)	0.026602216	0
information system	Internet penetration rate (%)	0.018079733	0
	Mobile phone penetration rate (unit/100 people)	0.012754012	0
Human Resources and Emergency Logistics Potential	The proportion of R&D expenditure to GDP (%)	0.026676714	0
Material reserves	Emergency material reserves (10000 tons)	0.038214861	0
	Emergency material procurement volume (10000 tons)	0.018327586	0

Based on Equations (16) to (17), calculate the Euclidean distances to the positive and negative ideal solutions, respectively. Then, using Equation (18), calculate the relative closeness as shown in Table 4.

Table 4. Euclidean distance and relative closeness of positive and negative ideal solutions

Year	Euclidean distance of positive ideal solution	Euclidean distance of negative ideal solution	Relative closeness
2011	0.1944	0.0986	0.3366
2012	0.1923	0.1084	0.3606
2013	0.1873	0.1162	0.3830
2014	0.1869	0.1205	0.3919
2015	0.1838	0.1144	0.3835
2016	0.1807	0.1227	0.4043
2017	0.1726	0.1328	0.4348
2018	0.1625	0.1426	0.4674
2019	0.1571	0.1408	0.4727
2020	0.1509	0.1583	0.5119

Based on the calculations, the relative closeness of emergency logistics in Liaoning Province from 2011 to 2020 is depicted in Figure 1. The logistics emergency capabilities in Liaoning Province showed an overall upward trend from 2011 to 2020. From 2011 to 2015, the growth rate of emergency logistics capabilities was slower, with an average annual increase of 0.1, and there was a certain degree of decline in 2015. From 2015 to 2020, a rapid upward trend was observed, with an average annual growth rate of 0.2. This further illustrates the increasing emphasis on the construction of emergency logistics in China.

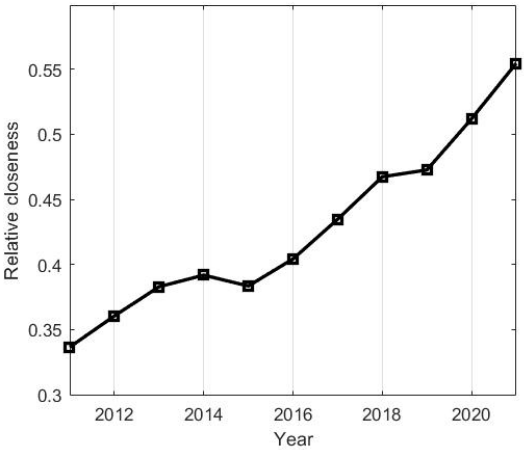

Fig. 1. Relative closeness of emergency logistics in Liaoning Province（2011-2020）

4 CONCLUSION

This paper employs an entropy weight-TOPSIS-grey relational comprehensive evaluation model, which objectively assigns weights to various indicators, calculates the grey relational degrees of the indicators, selects those with strong correlation for calculating the Euclidean distances to the positive and negative ideal solutions, and computes the relative closeness to evaluate the emergency logistics capabilities in Liaoning Province. The evaluation results are precise and can serve as an effective method for evaluating emergency logistics.

By calculating the grey relational degrees of various indicators, it was found that the mileage of highways (0.9191) and the mobile phone penetration rate (0.9255) have a strong correlation with emergency logistics. The emergency logistics capabilities in Liaoning Province exhibited an overall upward trend from 2011 to 2020. The growth rate of emergency logistics capabilities was slower between 2011 and 2015, but showed a rapid upward trend from 2015 to 2020.

In light of the current situation of geological disasters in our country, these disasters pose a significant threat to the safety of people's property. Conducting a comprehensive evaluation study on the logistics emergency capabilities under geological disasters can provide an effective reference for practical disaster response efforts. This is conducive to reducing the economic losses caused by geological disasters, ensuring the safety of people's lives and property, and offering a robust guarantee for the social and economic recovery after disasters.

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