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Evaluation of Beijing's Emergency Logistics Capacity in Response to Natural Disasters

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Abstract: China's vast geography and climatic diversity make it highly susceptible to natural disasters, leading to significant economic and human losses. The 2008 Wenchuan earthquake, the 2010 Yushu earthquake, and the 2017 Jiuzhaigou earthquake have highlighted the urgent need for improved emergency logistics capabilities. As China's capital, Beijing's ability to respond effectively to such disasters is of national and international interest. This study evaluates Beijing's emergency logistics capacity by establishing a scientific assessment framework covering pre-disaster, during-disaster, and post-disaster phases. The study aims to identify strengths, weaknesses, and optimization strategies for Beijing's emergency logistics system.

Keywords: *Emergency Logistics, Natural Disasters, Beijing, Disaster Management, Logistics Resilience*

I. INTRODUCTION

China's geographical and climatic complexity makes it prone to frequent natural disasters, leading to economic losses and human casualties. In recent decades, major disasters such as earthquakes and public health crises have underscored the importance of efficient emergency logistics. As the capital of China, Beijing's emergency management is critical for national security and urban resilience. This study evaluates Beijing's emergency logistics capacity through a comprehensive framework covering logistics resilience, adaptability, recovery capacity, and sustainability.

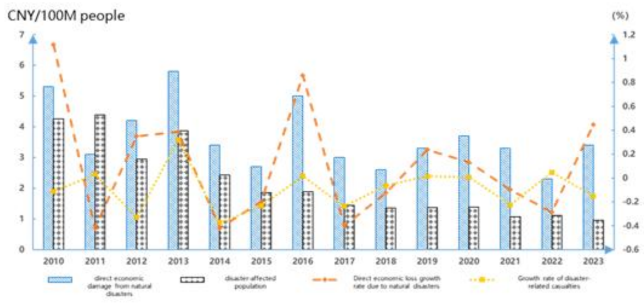

Figure 1: Economic Losses and Affected Population Caused by Natural Disasters in China (2010–2023)

The data indicate that natural disasters often lead to severe economic losses and casualties, causing long-term impacts on infrastructure, economic development, and social stability in affected areas.

As the capital of China, Beijing's emergency management capacity in response to natural disasters is not only critical for the city itself but also attracts nationwide and global attention. Therefore, enhancing Beijing's emergency logistics capabilities is crucial for ensuring the timely supply of materials, evacuation of personnel, and post-disaster recovery efforts.This study focuses on evaluating the emergency logistics capability of Beijing in response to natural disasters, aiming to establish a scientifically sound assessment framework. Based on emergency logistics theories and considering Beijing's geographical and disaster characteristics, the study analyzes three phases: pre-disaster, during-disaster, and post-disaster, with an emphasis on logistics resilience, adaptability, recovery capacity, and sustainability.

Objectives of the Study

1. Construct an assessment framework for Beijing's emergency logistics capacity, focusing on key indicators such as material reserves, logistics network efficiency, and information technology support.
2. Evaluate the current state of Beijing's emergency logistics system, identifying strengths and weaknesses.
3. Propose strategies to optimize Beijing's emergency logistics system to enhance response speed and recovery efficiency.

II. LITERATURE REVIEW

A. Urban Logistics Evaluation

Since the 1980s, urban logistics evaluation research has continuously evolved. Early studies primarily focused on infrastructure development and economic impacts. In recent years, with advancements in smart logistics and urban management, research has shifted towards logistics network optimization, sustainable logistics, and urban logistics resilience.

Some studies have applied quantitative methods such as Data Envelopment Analysis (DEA) and Analytic Hierarchy Process (AHP) to assess urban logistics efficiency, while others have explored government policy interventions in urban logistics. However, most existing studies focus on commercial logistics and routine distribution, with limited research on emergency logistics in the context of natural disasters.

B. Emergency Logistics Evaluation

As a critical component of disaster management, the assessment of emergency logistics capacity has become a key area of international research. W. Nick Carter first introduced the concept of emergency logistics in the "Handbook of Disaster Emergency Management," emphasizing the importance of rapid material deployment. In recent years, scholars have employed methods such as AHP, entropy weighting, and fuzzy comprehensive evaluation to develop various emergency logistics assessment models.

However, current research still faces the following challenges:

Incomplete Indicator Systems: Existing assessment frameworks often focus on specific aspects, such as resource allocation or emergency response, lacking a comprehensive evaluation framework.

Limited Resilience Perspective: The recovery, adaptability, and sustainability of logistics systems are often overlooked in evaluations.

Data Source Limitations: Many studies rely on historical data and lack dynamic simulation analyses.

C. Logistics Resilience Evaluation

In recent years, resilience theory has been increasingly incorporated into emergency logistics research, emphasizing a system's ability to adapt and recover from disruptions. Studies suggest that a resilient logistics system should possess rapid response capabilities, resource allocation efficiency, information-sharing mechanisms, and post-disaster recovery strategies. However, research on logistics resilience in China remains limited, particularly in the context of empirical analyses of urban emergency management systems.

III. INDICATOR SELECTION

A. Primary and Secondary Indicators

Primary Indicator	Secondary Indicator
Preparation	A1: Backup capacity of the power system
	A2: Urban resilience planning enhancement program
	A3: Household emergency supply reserves
	A4: Freight turnover in Beijing (10,000 ton-km)
	A5: Total road mileage in Beijing (km)
	A6: Permanent population
	A7: Government trust index/Number of administrative regulatory documents in Beijing
	A8: Beijing ecological environment quality index/Green coverage rate
	A9: Number of people affected by natural disasters in Beijing/Urban safety hazards
	A10: Coverage rate of early warning and monitoring information in Beijing
	A11: Number of emergency response plans
	A12: Number of administrative regulatory documents in Beijing/Urban recovery plans
	A13: Population density/Pollution congestion
Prevention	B1: Comprehensive urban risk assessment
	B2: Risk control level
	B3: Available general warehouse rental area in Beijing (10,000 square meters)
	B4: Number of emergency rescue teams in Beijing
	B5: Number of hospital beds per 1,000 permanent residents
	B6: Construction of comprehensive urban emergency information management platform
	B7: Shelter area (10,000 square meters)
Response	C1: Average police dispatch time (organization and mobilization capacity)
	C2: Promotion of safety technology
	C3: Degree of information database construction (communication, networks)
	C4: Emergency fund reserve capacity
	C5: Residents' ability to restore daily life (social insurance coverage rate)
	C6: Number of trucks (10,000 vehicles)
	C7: Response time for material transportation/City material transport time
	C8: Number of postal service packages (10,000 items)/Household emergency supply reserves
	C9: Foreign investment in transportation, warehousing, and postal industries (US$10,000)/International cooperation
Recovery	D1: Infrastructure repair capacity
	D2: Material distribution capacity
	D3: Degree of emergency plan drills
	D4: Implementation of publicity and training programs
	D5: Experience summary
	D6: Legal protection
	D7: Production recovery capacity (GDP in 100 million yuan)/Post-disaster work capacity
	D8: Population education level (number of college graduates in 10,000 people)

B. Qualitative Indicator Screening

The Transitive Closure Method is applied to effectively extract critical information from a vast amount of uncertain data. This method is particularly suitable for multidimensional data analysis, ensuring logical consistency in clustering, and is based on a well-established theoretical foundation. Given the nature of emergency logistics capacity indicators in major emergencies, this study employs the transitive closure method to perform fuzzy clustering analysis on qualitative indicators, thereby identifying key evaluation indicators.

(1) Establishing the Original Scoring Matrix

Under the context of natural disasters, emergency logistics capability assessment indicators are divided into pre-disaster, during-disaster, and post-disaster phases. To evaluate these indicators, expert scoring was conducted by inviting 106 participants from the fields of logistics and supply chain management, including undergraduate students (30.2%), master's students (59.4%), and Ph.D. students (10.4%). Each tertiary indicator was assessed based on four key evaluation dimensions: scientific validity, purposefulness, feasibility, and applicability.

The original scoring matrix was constructed using the results of 15 selected questionnaire responses. Table 4.1 presents the distribution of scores assigned by the participants.

Table 4.1: Expert Scoring Statistics

Indicator	Scientificity			Purposefulness			Feasibility			Applicability		
	Reasonable	Moderate	Unreasonable	Reasonable	Moderate	Unreasonable	Reasonable	Moderate	Unreasonable	Reasonable	Moderate	Unreasonable
A1	6	8	1	5	9	1	7	7	1	10	4	1
A2	8	6	1	7	6	2	11	4	0	10	5	0
A3	5	7	3	7	7	1	6	7	3	9	5	1
A4	9	5	1	3	9	3	3	8	4	12	2	1
A5	7	6	2	5	6	4	7	7	1	5	5	5

This process ensures that the evaluation of emergency logistics capacity indicators is scientifically rigorous and comprehensively assessed by experts in the field. The next steps involve refining the fuzzy similarity matrix and conducting further statistical analysis to determine the most relevant indicators for evaluation.

(2) Constructing the Fuzzy Similarity Matrix (R)

After establishing the original scoring matrix, the next step involves standardizing the raw data to eliminate the influence of different indicator scales. A commonly used normalization method is Max Normalization:

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

The cosine similarity method is then applied to construct the fuzzy similarity matrix R, which represents the fuzzy similarity relationships among different indicators:

$$r_{ij} = \frac{\sum_{k=1}^{S} a_{ik} a_{jk}}{\sqrt{\sum_{k=1}^{S} a_{ik}^2 a_{jk}^2}}$$

$\boldsymbol{a_{ik}}$ and $\boldsymbol{a_{jk}}$ are the components of vectors and in the -th dimension, and represent the vector dimensions. Normalized Indicator Values:

Secondary Indicator	Scientific Validity	Purposefulness	Feasibility	Applicability
A1	35	34	36	39
A2	37	35	41	40
A3	32	36	35	38
A4	38	30	29	41
A5	35	31	36	30

$$R = \begin{bmatrix} 1.00 & 0.93 & 0.90 & 0.88 & 0.86 \\ 0.93 & 1.00 & 0.92 & 0.91 & 0.89 \\ 0.90 & 0.92 & 1.00 & 0.87 & 0.85 \\ 0.88 & 0.91 & 0.87 & 1.00 & 0.84 \\ 0.86 & 0.89 & 0.85 & 0.84 & 1.00 \end{bmatrix}$$

(3) To obtain the fuzzy equivalence matrix Rˆ,the square method (max-min composition method) is applied iteratively:
Compute R^2 =R ∘ R, where ∘ denotes Boolean multiplication (taking the minimum value element-wise).
Compare R^2 and R. If R^2=R then Rˆ is found. Otherwise, continue computing.
Iterate until $R^{2k} = R^{2k-1} \circ R^{2k-1}$ holds, at which point Rˆ is determined as the fuzzy equivalence matrix.

The computations were performed using Python's sk fuzzy library within the Anaconda environment. During the clustering analysis of the fuzzy equivalence matrix, adjusting the threshold allows different classifications to be observed, helping to capture the clustering characteristics of the elements. The value of can be chosen flexibly based on specific research needs.

(4) Evaluating the Validity and Reliability of the Indicator System

To verify the rationality of the indicators screened using the transitive closure method, statistical tests were conducted, including calculating the validity coefficient (α) and reliability coefficient (ρ).

Validity Coefficientα measures consistency in expert scoring. If αapproaches 1.0, the indicator system is highly valid.

Reliability Coefficient ρ assesses the stability of the indicator system across multiple evaluations.

Reliability Thresholds:

0.6 ≤ ρ < 0.7: Minimum acceptable reliability

0.7 ≤ ρ < 0.8: Good reliability

0.8 ≤ ρ < 0.9: Very good reliability

ρ ≥ 0.9: Excellent reliability

The statistical formulas used are:

$$\alpha = \sum_{i=1}^{n} \alpha_i / n$$

$$\alpha_i = \sum_{j=1}^{s} \sqrt{(y_i - x_{ij})^2} / sQ_i$$

$$yi = \sum_{j=1}^{s} x_{ij} / s$$

$$\rho = \sum_{j=1}^{s} \left[\frac{\sum_{i=1}^{n} (x_{ij} - \bar{x}_j)(yi - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_{ij} - \bar{x}_j)^2 (y_i - \bar{y})^2}} \right] / s$$

$$\bar{x}_j = \sum^{n} x_{ij} / n$$

$$\bar{y} = \sum^{n} y_i / n$$

The computed results show α =0.09907<1,ρ=0.808459>0.8 , indicating good validity and reliability of the screened indicators.

C. Qualitative Indicator Screening

To refine quantitative indicators, Principal Component Analysis (PCA) was employed. PCA is a widely used statistical method for dimensionality reduction, transforming multiple correlated indicators into a smaller number of independent principal components, while retaining most of the original information.

The data used in PCA was sourced from: Beijing Statistical Yearbook、Beijing Government Public Data、Beijing Emergency Management Bureau、Beijing Communications Administration、Ministry of Industry and Information Technology (MIIT)、covering the period 2018–2024.

The results of PCA analysis led to the following selected quantitative indicators:

Primary Indicator	Secondary Indicator	
Preparation:	A1	Beijing ecological environment quality index/Green coverage rate
	A2	Number of people affected by natural disasters in Beijing (individuals)/Urban safety hazards
	A3	Beijing early warning information/Monitoring and early warning coverage rate

	A4	Permanent population density/Population congestion
	A5	Resilient city planning improvement plan
	A6	Government trust level/Number of administrative normative documents in Beijing
	A7	Household emergency supplies reserve
Prevention:	B1	Number of emergency rescue teams in Beijing (persons)
	B2	Number of hospital beds per 1,000 permanent residents
	B3	Construction of comprehensive urban emergency information management platform
	B4	Construction of comprehensive urban emergency information management platform
	B5	Area of shelters (10,000 square meters)
	B6	Urban comprehensive risk assessment
Response:	C1	Foreign investment in transportation, warehousing, and postal services (10,000 USD)/ International cooperation situation
	C2	Average police response time (organization and mobilization capability)
	C3	Household life recovery capability (social insurance coverage rate)
Recovery:	D1	Level of education of the population (Number of university graduates in 10,000 persons)
	D2	Infrastructure restoration capability
	D3	Material distribution capability
	D4	Implementation of publicity and training
	D5	Experience summary

The quantitative indicators are:

Primary Indicator	Secondary Indicator	
(Preparation):	A1	Number of people affected by natural disasters in Beijing / Urban safety hazards
	A2	Number of emergency plans
	A3	Population density / Urban congestion
	A4	Government trust index / Number of regulatory documents in Beijing
(Prevention):	B1	Available general warehouse rental area in Beijing (10,000 square meters)
	B2	Number of emergency rescue teams in Beijing
	B3	Shelter area (10,000 square meters)
(Response):	C1	Response time for material transportation / City material transport time
	C2	Number of postal packages (10,000 items) / Household emergency supply reserves
	C3	Foreign investment in transportation, warehousing, and postal services (USD 10,000) / International cooperation
(Recovery):	D1	GDP recovery capacity (100 million yuan) / Post-disaster work capacity
	D2	Population education level (number of college graduates in 10,000 people)

IV. WEIGHT DETERMINATION

Selection of Tertiary Indicators as Evaluation Factors

Tertiary Indicator	Description
A1	Beijing Ecological Environment Quality Index / Green Coverage Rate
A2	Number of People Affected by Natural Disasters in Beijing / Urban Safety Hazards
A3	Coverage Rate of Early Warning and Monitoring Information in Beijing
A4	Permanent Population Density / Urban Congestion
A5	Urban Resilience Planning Enhancement Program

For simplicity, A1, A2, A3, A4, and A5 will be used to represent these indicators in the following sections.

A. Qualitative Indicator Weights (G1 Method)

(1): Rational Ordering Using the Entropy Weight Method

The Entropy Weight Method (EWM) is used to determine indicator weights based on information entropy. This method is particularly useful for multi-attribute decision analysis, especially when indicator weights cannot be determined subjectively.

Probability Calculation: For the indicator and the evaluation object, the normalized value is denoted asa_{ij}。

The probability p_{ij} of the j evaluation object under the indicator is computed as follows:

$$p_{ij} = \frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}$$

p_{ij}	Value 1	Value 2	Value 3	Value 4
A1	0.12	0.12	0.13	0.13
A2	0.13	0.13	0.14	0.14
A3	0.11	0.13	0.12	0.13
A4	0.13	0.11	0.1	0.14
A5	0.12	0.11	0.13	0.1

(2)Entropy Calculation: The entropy E_i for each indicator is computed as:

$$E_i = -k \sum_{j=1}^{n} p_{ij} \ln(p_{ij})$$

where k = 1/ln(n) ensures that entropy values range between 0 and 1. Here, n = 5, so k = 1/ln(5).

ej	0.80	0.79	0.80	0.82

(3) Calculation of Dispersion Coefficients: The dispersion coefficient D_i is given by:

$$D_i = 1 - E_i$$

D_i	0.20	0.21	0.20	0.18

(4) Final Weight Calculation:

$$w_i = \frac{D_i}{\sum_{l=1}^{m} D_i}$$

Weight	0.25	0.27	0.25	0.23

Where **m** represents the total number of indicators.

(5)Using the calculated weights, the comprehensive score for each evaluation object is determined as follows:

$$S_i = \sum_{i=1}^{m} w_i a_{ij}$$

where S_i represents the comprehensive score of the **j** evaluation object.

指标	得分
A1	2.91
A2	3.09
A3	2.85
A4	2.79
A5	2.67

(6):Determining Relative Importance Between Adjacent Attributes

To evaluate the relative importance between adjacent attributes $\hat{C_i}$and $\hat{C}_{i-1}$, we define the relative importance ratio $r_\beta = \frac{w_{\beta-1}}{w_\beta}$, β =n,n-1, ••• ,2 as:

r_β	意义
1.0	$\hat{C_i}$and$\hat{C}_{i-1}$,Equal importance
1.1	$\hat{C_i}$and$\hat{C}_{i-1}$,Between equal and slightly more important
1.2	$\hat{C_i}$ and $\hat{C}_{i-1}$,Slightly more important
1.3	$\hat{C_i}$ and $\hat{C}_{i-1}$,Between slightly and significantly more important
1.4	$\hat{C_i}$ and $\hat{C}_{i-1}$,Significantly more important
1.5	$\hat{C_i}$ and $\hat{C}_{i-1}$,Between significant and highly important
1.6	$\hat{C_i}$ and $\hat{C}_{i-1}$,Highly important
1.7	$\hat{C_i}$ and $\hat{C}_{i-1}$,Between highly and extremely important
1.8	$\hat{C_i}$ and $\hat{C}_{i-1}$,Extremely important

Based on the above, the indicator ranking and rational value assignments are as follows:

Indicator	Score	Ranking Assignment	
A1	2.91	X1>X2>X5>X3>X4	x1*>x2*>x3*>x4*>x5*
A2	3.09	r2	1.20
A3	2.85	r3	1.40
A4	2.79	r4	1.20
A5	2.67	r5	1.60

(7)Computing Weights for Each Attribute

Using the weight formulas:

$$w_j^J = (1 + \sum_{\beta=2}^{n} \prod_{j=\beta}^{n} r_j)^{-1}$$

$$w_{\beta-1} = w_\beta \; r_\beta$$

β =n,n-1, ••• ,2， $\sum_{j=1}^{n} w_j^J = 1$。

Attribute	$w_j^J = (1 + \sum_{\beta=2}^{n} \prod_{j=\beta}^{n} r_j)^{-1}$, $w_{\beta-1} = w_\beta \; r_\beta$	Normalized Weight
w1	3.60	0.11
w2	4.32	0.13
w3	6.05	0.18
w4	7.26	0.22
w5	11.61	0.35
和	32.84	

4.2 Quantitative Indicator Weights (Coefficient of Variation Method)

Indicator	Weight
A1	0.35
A2	0.22
A3	0.13
A4	0.11
A5	0.18

(1) Weight Assignment for Quantitative Indicators Using the Coefficient of Variation Method

Indicator	Description
A1	Number of People Affected by Natural Disasters in Beijing / Urban Safety Hazards
A2	Number of Emergency Plans
A3	Permanent Population Density / Urban Congestion
A4	Government Trust Index / Number of Regulatory Documents in Beijing

To simplify representation, A1, A2, A3, and A4 will be used to denote the selected indicators in subsequent sections.

(2) Indicator Normalization

The purpose of indicator normalization is to convert all indicators into positive indicators, ensuring consistency in evaluation. Positive indicators: Higher values indicate better performance (e.g., academic scores). Negative indicators:

Lower values indicate better performance (e.g., ranking positions). For positive indicators, the original data remains unchanged:

$$a_{ij}^{'} = a_{ij}$$

For negative indicators, the following transformation is applied:

$$x_{normalized} = 1 - \frac{|x - x_{best}|}{M}$$

x_{best} is the optimal value of the indicato

Mis the maximum deviation between x andx_{best}

After normalization, the data matrix is as follows:

指标	a_{ij}						
A1	0	0.034535	0.029371	0.514686	1	1	1
A2	0.2857143	0.071429	0.285714	0.285714	0.642857	1	1
A3	1	1	0.863636	0.727273	0.590909	1	1
A4	0.375	0.875	0.5	1	0.5	0	1

(3) Calculation of Coefficient of Variation

To determine the importance of each indicator, the coefficient of variation (CV) is used.

Mean Calculation:

$$A_j = \frac{1}{n}\sum_{i=1}^{n} r_{ij}$$

Standard Deviation Calculation:

$$\sigma_i = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(r_{ij} - A_j)^2}$$

Since standard deviation reflects the dispersion of indicator values, it is used to define the weight of each indicator.

Coefficient of Variation Calculation:

$$V_j = \frac{\sigma_i}{A_j}$$

Indicator	Standard Deviation	Coefficient of Variation
A1	180.67	353.40
A2	0.62	1.21
A3	52.82	59.81
A4	6.77	11.15

(4) Weight Calculation

The weight of each indicator is calculated as:

$$\boldsymbol{w_j^o} = \frac{V_j}{\sum_{j=1}^{n} V_j}$$

Indicator	Weight
A1	0.8304
A2	0.0028
A3	0.1405
A4	0.0262

Step 4: Combined Weighting

To integrate qualitative and quantitative weights, the additive synthesis method is used. This method combines different weight sources to form a final comprehensive weight.

The combined weight formula is:

$$w = (w_o + w_j)/2$$

w_o represents the weight from quantitative indicators. w_j represents the weight from qualitative indicators.If an indicator is only qualitative or quantitative, its corresponding weight is set to 0 in the combination process. This method ensures a balanced and objective weight assignment for all evaluation indicators, considering both subjective and objective factors.

V. EVALUATION USING THE FUZZY COMPROMISE DECISION METHOD

The fuzzy comprehensive evaluation method combines fuzzy mathematics and fuzzy statistics, applying the principles of fuzzy transformation and maximum membership degree to comprehensively evaluate the factors influencing a specific matter. The evaluation process follows these steps:

(1): Define the Evaluation Factor Set

The set of evaluation factors is defined as:

$U = (u_1，u_2，\cdots，u_m)$, where , $u_i(i = 1，2，\cdots，m)$represents an evaluation factor, and m is the number of factors.

The evaluation set V is defined as:

$V = \{v_1，v_2，\cdots，v_j，\cdots，v_n\}$, where , $v_j(j = 1，2，\cdots，n)$represents the set of evaluation grades. The evaluation levels used in this study are [Excellent, Good, Poor].

Construct the Membership Degree Matrix.

After conducting single-factor evaluations, the fuzzy vector$R_i$for the i evaluation factor concerning v_j is given by: where r_{ij} represents the degree to which u_i belongs to v_j, ensuring 0 <r_{ij}< 1.

If m elements are evaluated together, the result is an m × n membership matrix R, given as:

$$R = \begin{pmatrix} r_{11} \cdots r_{1n} \\ \cdots. \\ \cdots. \\ \cdots. \\ r_{m1} \cdots r_{mn} \end{pmatrix}$$

The membership matrix for the selected indicators in this study is:

Indicator	Excellent	Good	Poor
A1	0.37	0.47	0.16
A2	0.42	0.36	0.22
A3	0.40	0.45	0.14
A4	0.42	0.38	0.20
A5	0.39	0.44	0.17

(2) Determine the Weight Vector of Evaluation Factors

In the fuzzy comprehensive evaluation method, each evaluation factor $u_i(i = 1, 2, \cdots, m)$ is assigned a weight, forming the fuzzy evaluation vector A:$A[a_1, a_2, \cdots, a_m]^T$。Weights are assigned based on the analytic hierarchy process (AHP) and the combined weighting method. The calculated weights are:

Indicator	Weight
A1	0.30
A2	0.27
A3	0.25
A4	0.06
A5	0.12

(3)Comprehensive Evaluation Calculation the fuzzy comprehensive evaluation result is calculated as: $B = A \circ R$where "∘" represents the fuzzy composition operator. The final evaluation result B is given by:

$B = [b_1, b_2, \cdots, b_n]$, if :$\sum_{i=1}^{n} b_j \neq 1$, normalization is performed. The fuzzy evaluation can also be expressed as:

$$b_j \& = (a_1 \bullet r_{1j}) + (a_2 \bullet r_{2j}) + \cdots + (a_m \bullet r_{mj})$$

$$j = 1,2, \cdots, n$$

Indicator	$a_m \bullet r_{mj}$		
A1	0.11	0.14	0.05
A2	0.11	0.10	0.06
A3	0.10	0.11	0.04
A4	0.02	0.02	0.01
A5	0.05	0.05	0.02

The final comprehensive evaluation values for each indicator are:

Indicator	b_j
A1	0.30
A2	0.27
A3	0.25
A4	0.06
A5	0.12

(4) Fuzzy Compromise Decision-Making

Since fuzzy comprehensive evaluation relies on expert judgments, it may be subjective and less effective in distinguishing results in highly homogeneous regions. To enhance objectivity, the fuzzy compromise decision-making method is introduced.

The distance between the fuzzy evaluation value b_j and the positive ideal solution (M^+) and negative ideal solution (M^-) is calculated as follows:

$$s_j^+ = M_j^+ - b_j$$

$$s_j^- = b_j - M_j^-$$

where M^+ and M^- represent the maximum and minimum fuzzy evaluation values of each emergency logistics indicator at level j.

$$M_j^+ = b_1$$

$$M_j^- = b_4$$

$$s_j^+ = [0, 0.03, 0.05, 0.24, 0.18]^T$$

$$s_j^- = [0.24, 0.21, 0.19, 0.06, 0.06]^T$$

Calculate the Fuzzy Membership Degree

The membership degree μ_ij for fuzzy decision optimization is calculated as:

$$\mu_{ij} = \frac{s_{ij}^-}{s_{ij}^+ + s_{ij}^-}$$

The resulting membership values are:

$$\mu_{ij} = [1.00, 0.88, 0.78, 0.00, 0.25, 2.91]^T$$

CONCLUSION

This study constructs a systematic evaluation framework for Beijing's emergency logistics capacity in the context of natural disasters and validates it through multiple data analysis methods. The findings suggest that optimizing emergency logistics requires improving response speed, strengthening resource allocation capacity, and enhancing information-sharing mechanisms. Future research can incorporate dynamic modeling techniques to simulate emergency logistics operations under different disaster scenarios, further increasing the practical applicability of the study.

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附录 A 应急物流能力评估影响因素调查问卷

尊敬的各位专家：您好！我是北京物资学院物流学院的一名研究生，非常感谢您抽出时间给予本问卷的专业性指导及权威性答复！本问卷的目的是想通过专家咨询获取指标评分，进而评估影响应急物流能力的重要影响因素，以求在此基础上构建出一个较为科学完善和实用的评估指标体系。此问卷调查采用无记名方式，只供学术研究之用，对您不会产生任何影响，请您认真作答。请您对各个指标在科学性、目的性、可行性、适用性 4 个维度进行评估，根据您的知识经验，认为“合理”打 3 分、认为“较合理”打 2 分、认为“不合理”打 1 分。

指标	科学性	目的性	可行性	适用性
A1 电力系统事故备用容量				
A2 韧性城市规划提升计划				
A3 家庭应急物资储备				
A4 北京市货物周转量(万吨公里)				
A5 北京市境内道路总里程(公里)				
A6 政府信任度/北京市行政规范性文件数				
A7 北京市生态环境质量指数/绿化覆盖率				
A8 北京市自然灾害受灾人数(个人)/城市安全隐患				
A9 北京市预警信息/监测预警覆盖率				
A10 应急预案数				
A11 北京市行政规范性文件数/城市恢复计划				
A12 常驻人口密度/人口拥堵				
B1 城市综合风险评估				
B2 风险控制水平				
B3 北京市通用仓储可租面积(万平方米)				
B4 北京市应急救援队(人数)				
B5 每千常住人口医院床位数(张)				
B6 城市综合应急信息管理平台建设				
B7 避难场所面积(万平方米)				
C1 出警到场平均时间(组织、动员能力)				
C2 安全科技推广				
C3 信息数据库建设程度(通信、网络)				
C4 应急资金储备能力				
C5 居民生活恢复能力(社会保险覆盖率)				
C6 货车数量(万辆)				
C7 物资运输反应时间/城市物资运送时间				
C8 邮政业务包裹数(万件)/家庭应急物资储备				
C9 交通运输、仓储和邮政业外商投资额(万美元)/国际合作情况				
D1 基础设施修复能力				
D2 物资配送能力				
D3 应急预案演练程度				
D4 宣传培训开展情况				
D5 经验总结				
D6 法律保障				
D7 生产恢复能力(生产总值(亿元))/灾后工作能力				
D8 人群受教育水平(高校毕业生人数(万人)				