Research on Resilience Evaluation of Urban Emergency Logistics System

Zhikui Huang*, Lei Zhuang[a]

School of Economics and Management, Nanjing University of Technology, NanJing, 211816 China

[a]zhleiphd@njtech.edu.cn
*Corresponding author's e-mail: 2239913378@qq.com

Abstract. China has experienced frequent outbreaks of sudden events in recent years, which have had a great impact on the stable development of society. In today's environment, where China has implemented a strategy of coordinated regional development, and where population movements between regional cities have become more frequent, the negative impacts and scope of sudden-onset events can expand rapidly in a short period of time. The logistics system is necessary to support the operation of the city, can mitigate the impact of sudden events, reduce losses and quickly respond to ensure the normal operation of the city itself, so it is necessary to grasp the level of resilience of urban emergency logistics in the region. This paper summarizes and organizes a set of evaluation index system of urban emergency logistics system resilience, constructs an evaluation model based on the improved entropy value-TOPSIS method, introduces the coupled coordination model to evaluate the coordinated development status between urban emergency logistics subsystems, and finally launches the evaluation and analysis in Jiangsu Province as an example.

Keywords: emergency logistics, coupled coordination, system resilience, entropy-topsis

1 Introduction

With the frequent occurrence of major sudden events, more and more scholars and experts have begun to pay attention to the vulnerability of urban systems. The expanding size of the urban population and the increasing complexity of the road network are increasing the complexity of the operation and governance of the urban logistics system, and in the event of a sudden event the degree and scope of the harm suffered by the city will be more serious than in other regions. The resilience of a city's emergency logistics system is affected by a number of factors, and a city's level of economic development does not necessarily represent its level of emergency logistics. The outbreak of the epidemic in Shanghai in February 2022 brought great damage to the logistics system of Shanghai, and the emergency supplies from neighboring cities had the problem of difficult to enter and exit, exposing that there are still many

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deficiencies in China's urban emergency logistics, which is worthy of our deep thoughts. Therefore, this paper will evaluate the resilience of urban emergency logistics systems in China and provide recommendations for their development[1].

Currently, research on the evaluation of urban emergency logistics capabilities mainly focuses on evaluation indicator systems, evaluation models, and methods. Thomas (2002) emphasized that emergency logistics is crucial during unexpected events. Through reliability assessment algorithms, it can be divided into three distinct phases: deployment, maintenance, and reconfiguration[2]. According to the characteristics of emergency logistics, Huang Guoping uses the weights obtained by entropy weight method and chromatographic analysis method as game opponents to determine the best combined weights[3]. For determining the weights of evaluation indicators, Huang Hui et al. (2017) employed a combined weighting method using the Analytic Hierarchy Process (AHP) and the Entropy Weight Method[4]. Li Qin found that there are many problems in China's emergency logistics, such as the lack of overall thinking, the single goal of emergency logistics and the lack of supervision mechanism, and pointed out that the key point of the development of emergency logistics is the systematic cooperation between enterprises and the government [5].

2 Constructing Evaluation Indicator System

Deng Aimin pointed out that the chosen indicators need to be scientifically and logically selected; otherwise, it may affect the accuracy of the evaluation results[6]. Therefore, this paper divides the urban emergency logistics system into four subsystems: economic, logistics capacity, information processing, and medical resources. These four subsystems cooperate with each other to meet the city's demand for emergency logistics[7]. The four dimensions are further subdivided into multiple indicators as shown in the table 1[8].

Table 1. Evaluation index

Urban Emergency Logistics System Resilience	Emergency EconomicResilience	Regional GDP (billion yuan)
		Per Capita GDP (yuan)
		Logistics Industry Output Value (billion yuan)
		Proportion of Tertiary Industry in GDP
		Public Safety Fiscal Expenditure (billion yuan)
		Emergency Transportation Management Expenditure (billion yuan)
	Emergency Logistics Comprehensive Resilience	Total Length of Roads (kilometers)
		Number of Civil Vehicles (ten thousand vehicles)
		Freight Volume (ten thousand tons)
		Passenger Volume (ten thousand people)
		Number of Logistics Personnel (ten thousand people)
	Emergency Information Sharing Resilience	Number of Internet Broadband Access Users (ten thousand households)
		Total Telecommunication Business Volume (billion yuan)
		Telephone Penetration Rate (units/hundred people)
		Total Postal Business Volume (billion yuan)
	Emergency Medical System Resilience	Number of Medical and Health Institutions (units)
		Number of Emergency Rescue Medical Personnel (ten thousand people)
		Number of Hospital Beds (units)

3 Construction of Evaluation Model

3.1 Improved Entropy-TOPSISI Method

This paper employs the entropy method to determine the objective weights of evaluation indicators[9]. The combination of the entropy method and TOPSIS has the advantages of high credibility and strong adaptability. However, the traditional Entropy-TOPSIS method also has certain limitations, such as being cumbersome and difficult to calculate, requiring specialized software for implementation. Therefore, this paper optimizes the calculation process based on this method. The following are the operational steps of the optimized Entropy-TOPSIS method:

(1) Obtain the standardized matrix. $R = (r_{ij})_{mn}$

Positive indicators:

$$r'_{ij} = \frac{x_{ij} - \min\limits_{1 \le j \le n}(x_{ij})}{\max\limits_{1 \le j \le n}(x_{ij}) - \min\limits_{1 \le j \le n}(x_{ij})} \tag{1}$$

Negative indicators:

$$r'_{ij} = \frac{\max\limits_{1 \le j \le n}(x_{ij}) - x_{ij}}{\max\limits_{1 \le j \le n}(x_{ij}) - \min\limits_{1 \le j \le n}(x_{ij})}$$

(2) Ideal solutions for normalized matrices

$$r_j^* = \begin{cases} \max\limits_{1 \le i \le m}(r_{ij}), j \in J^+ \\ \min\limits_{1 \le i \le m}(r_{ij}), j \in J^- \end{cases}, j = 1,2,\cdots,n. \tag{2}$$

Where r_j^* is the desired value of indicator j, J^+ represents the set of benefit-based indicators, and J^- represents the set of cost-based indicators.

(3) Determination of indicator weights.

$$w_i = \frac{\mu_i}{\sum_{i=1}^{m} \mu_i} \tag{3}$$

$$\mu_i = \frac{1}{\sum_{j=1}^{n}((1-r_{ij})^2 + r_{ij}^2)} \tag{4}$$

(4) Calculate the distance between positive and negative ideal solutions.

$$\begin{aligned} d_j^+ &= \sqrt{\sum_{i=1}^{m} w_i (1 - r_{ij})^2}, i = 1,2,\cdots,m. \\ d_j^- &= \sqrt{\sum_{i=1}^{m} w_i^2 r_{ij}^2}, i = 1,2,\cdots,m. \end{aligned} \tag{5}$$

(5) Calculate the similarity fit.

$$C_j = \frac{d_j^-}{d_j^+ + d_j^-}, j = 1,2,\cdots,n. \tag{6}$$

3.2 Coupling Coordination Model

Currently, domestic evaluation methods for coupling effects mainly include the Grey Relational Analysis (GRA) model, System Dynamics, and the Coupling Coordination Model. Among them, the Coupling Coordination Model evaluates whether the research object is in a state of coordinated development[10]. Coupling degree represents the degree of mutual constraint between subsystems, indicating whether their interactions are positive or negative; coordination represents the relationships and interactions among multiple aspects. When a problem occurs in one aspect of the system, it will hinder the normal operation of other related subsystems.In this study, the urban emergency logistics system is divided into four parts: economy, logistics transportation, information sharing, and medical resources.

$$C=\left[\frac{\prod_{\mathrm{i}=1}^{\mathrm{n}}U_i}{\left(\frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}}U_i\right)^{\mathrm{n}}}\right]^{\frac{1}{\mathrm{n}}} \tag{7}$$

$$T=\sum_{\mathrm{i}=1}^{\mathrm{n}}\alpha_{\mathrm{i}}\times U_{\mathrm{i}} \qquad \sum_{\mathrm{i}=1}^{\mathrm{n}}\alpha_{\mathrm{i}}=1 \tag{8}$$

$$D=\sqrt{C\times T} \tag{9}$$

4 Evaluation of Urban Emergency Logistics Resilience in Jiangsu Province

4.1 Evaluation of Urban Emergency Logistics Resilience

The main data sources for this study are the "Jiangsu Statistical Yearbook" from 2013 to 2022 and the statistical yearbooks of various prefecture-level cities in Jiangsu. Based on the improved entropy-TOPSIS method described in Chapter 3, the resilience of the emergency logistics systems in various regions of Jiangsu Province over the past decade has been calculated. The results are presented in the table 2:

Table 2. Resilience Table of Various Cities in Jiangsu Province from 2013 to 2022

City	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Average	Rank
Nanjing	0.283241	0.294996	0.302991	0.30258	0.298076	0.308799	0.326042	0.324841	0.337853	0.330603	0.311002	2
Wuxi	0.177232	0.174952	0.174962	0.17902	0.168578	0.163548	0.161744	0.158725	0.177882	0.179086	0.171573	3
Xuzhou	0.171891	0.172045	0.173603	0.186449	0.17313	0.172911	0.167751	0.167192	0.159232	0.158919	0.170312	4
Changzhou	0.094032	0.095382	0.098248	0.10454	0.101719	0.099861	0.08771	0.090516	0.090401	0.091023	0.095343	7
Suzhou	0.421099	0.449931	0.454602	0.463138	0.45462	0.45529	0.433312	0.437743	0.432516	0.440598	0.444285	1
Nantong	0.121798	0.140639	0.139293	0.145386	0.14726	0.144166	0.137973	0.13476	0.134366	0.13507	0.138071	5
Lianyungang	0.060228	0.05209	0.053084	0.056608	0.056541	0.053704	0.056362	0.05687	0.050897	0.050305	0.054669	10
Huai'an	0.066052	0.052034	0.05455	0.059438	0.055712	0.054363	0.048786	0.050021	0.048613	0.048534	0.05381	12
Yancheng	0.101813	0.097222	0.098354	0.101354	0.102342	0.103624	0.106782	0.110236	0.107914	0.105268	0.103491	6
Yangzhou	0.063095	0.056933	0.058353	0.060431	0.064635	0.066927	0.062502	0.071641	0.062657	0.063913	0.063109	8
Zhenjiang	0.060471	0.05959	0.05924	0.062308	0.057084	0.051658	0.047554	0.052646	0.053682	0.051531	0.055576	9
Taizhou	0.053778	0.048356	0.050809	0.056723	0.057385	0.055547	0.055218	0.057061	0.055372	0.055022	0.054527	11
Suqian	0.062686	0.03907	0.037361	0.036769	0.037028	0.038202	0.04471	0.073364	0.045559	0.049041	0.046379	13

From the above table, it can be observed that the resilience level of emergency logistics systems in various cities of Jiangsu Province has steadily increased from 2013 to 2022. This indicates a positive development trend in the emergency logistics systems of cities in Jiangsu Province, with resilience levels continuously improving. The ability to withstand the impact of sudden events has gradually increased. However, the overall resilience level is not high and remains at a moderate level. Additionally, there are significant differences in resilience levels among cities, with Nanjing and Suzhou demonstrating notably higher resilience levels compared to other cities, and the gap is substantial.

4.2 Evaluation and Analysis of Coupling Coordination Degree

According to formula (3-7), calculates the subsystem coupling degree C values of each city from 2013 to 2022 as shown in the table 3.

Table 3. Subsystem Coupling Values for Various Cities

City	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Nanjing	0.969442	0.970287	0.965613	0.96421	0.956088	0.955127	0.952091	0.961369	0.967544	0.970481
Wuxi	0.952774	0.933523	0.934127	0.930484	0.946076	0.958617	0.974014	0.966993	0.97566	0.968273
Xuzhou	0.846534	0.843701	0.865757	0.90069	0.890612	0.905822	0.912881	0.945041	0.946129	0.959698
Changzhou	0.891283	0.890249	0.884226	0.883573	0.891686	0.893057	0.880232	0.881779	0.912824	0.909089
Suzhou	0.972146	0.969309	0.967592	0.967309	0.969326	0.973196	0.97679	0.97583	0.97942	0.97737
Nantong	0.980176	0.951464	0.955384	0.964211	0.959016	0.965608	0.972387	0.988649	0.994764	0.993781
Lianyungang	0.827152	0.825049	0.84801	0.834912	0.845552	0.850066	0.865681	0.926563	0.898641	0.901767
Huai'an	0.515458	0.752986	0.73023	0.755963	0.730768	0.7573	0.771604	0.913203	0.933271	0.927878
Yancheng	0.830214	0.850637	0.857336	0.878596	0.868104	0.875901	0.8671	0.916182	0.917893	0.922827
Yangzhou	0.968585	0.947644	0.940185	0.930277	0.905958	0.871514	0.853196	0.850046	0.87463	0.871848
Zhenjiang	0.313824	0.288586	0.286741	0.282095	0.29469	0.301221	0.237396	0.215925	0.281798	0.275987
Taizhou	0.94851	0.912756	0.90654	0.888863	0.861712	0.849471	0.866522	0.916387	0.928761	0.913971
Suqian	0.283728	0.361105	0.546489	0.587041	0.641383	0.745383	0.799478	0.770615	0.761642	0.87487

Overall, from 2013 to 2022, the coupling degree of the four subsystems in Jiangsu Province remains relatively high. Except for Suqian and Zhenjiang, which have relatively low coupling degrees, other cities are in the high coupling stage. Additionally, the fluctuations in values are small, confirming that the urban emergency logistics system is an internally highly coupled system with strong correlation.The coupling degree of Suqian has gradually increased from the antagonistic stage in 2013 to the high coupling stage in 2022. Meanwhile, Zhenjiang has remained in the antagonistic stage with a low coupling degree for a long time. Looking at the time series, the coupling degree of the 13 cities in Jiangsu Province is not static but mostly shows a trend of yearly increase.

Table 4. Coordination Values of Subsystems in Various Cities

City	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Nanjing	0.397507	0.392413	0.394938	0.404933	0.400252	0.405209	0.412656	0.415738	0.420136	0.418644
Wuxi	0.334945	0.322676	0.32296	0.331627	0.326266	0.324649	0.326145	0.321851	0.339162	0.338914
Xuzhou	0.306689	0.304819	0.31055	0.328698	0.316256	0.318667	0.316236	0.322165	0.315071	0.318002
Changzhou	0.245346	0.241549	0.242828	0.252313	0.24943	0.250288	0.236032	0.238206	0.241548	0.242952
Suzhou	0.454434	0.445292	0.44556	0.458763	0.457401	0.459011	0.45789	0.459808	0.460306	0.461156
Nantong	0.288894	0.300348	0.300467	0.310863	0.311466	0.309985	0.304948	0.305325	0.305308	0.306946
Lianyungang	0.180239	0.168832	0.174044	0.178211	0.178346	0.17532	0.182593	0.190593	0.176067	0.174451
Huai'an	0.142464	0.165129	0.166464	0.175309	0.167371	0.171544	0.161355	0.179731	0.177542	0.179193
Yancheng	0.231131	0.232724	0.23637	0.243892	0.243674	0.246299	0.249058	0.260491	0.258462	0.255236
Yangzhou	0.212977	0.203104	0.203252	0.204971	0.205029	0.20619	0.193496	0.20316	0.190616	0.197208
Zhenjiang	0.106452	0.096468	0.095051	0.096393	0.093977	0.090045	0.075107	0.072788	0.085689	0.083587
Taizhou	0.197308	0.185655	0.187514	0.194652	0.192092	0.189313	0.185377	0.193166	0.187962	0.189323
Suqian	0.093555	0.091333	0.109482	0.112976	0.118236	0.132727	0.152884	0.184926	0.145577	0.165098

From the table 4 above, it can be observed that the coordination among the emergency logistics subsystems in various cities of Jiangsu Province has generally been steadily improving. However, the coordination degree is still not high, with most cities ranging between 0.1 and 0.3, indicating a moderate or severe imbalance. Only Suzhou and Nanjing have reached around 0.5, indicating a barely coordinated state.From 2014 to 2021, the coordination values in each region have been increasing, indicating that the emergency logistics subsystems of each city are developing towards better coordination.

4.3 Scenario Simulation

To study the impact of a subsystem on the overall system resilience, each subsystem indicator value is increased by 10% sequentially. This is done to observe how changes in the subsystem affect the resilience of the emergency logistics system. Taking Nanjing as an example, The results are shown in Table 5 and Figure 1.

Table 5. Comparison Before and After Subsystem Value Increase

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Average	Increment
Initial	0.283241	0.294996	0.302991	0.30258	0.298076	0.308799	0.326042	0.324841	0.337853	0.330603	0.311002	——
U1	0.298278	0.311007	0.319309	0.318663	0.3141	0.324093	0.338917	0.337182	0.352301	0.346899	0.326075	4.85%
U2	0.300478	0.309479	0.317618	0.316929	0.312197	0.323277	0.340835	0.338936	0.353652	0.34511	0.325851	4.77%
U3	0.295833	0.30647	0.312398	0.311677	0.311249	0.321988	0.341196	0.335211	0.348716	0.341001	0.322574	3.72%
U4	0.292691	0.304256	0.312937	0.31181	0.307966	0.318272	0.334974	0.33317	0.346657	0.338422	0.320116	2.93%

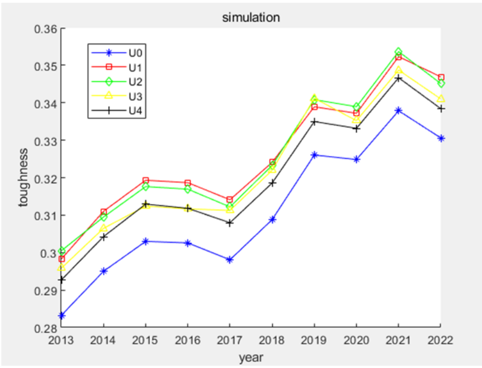

Fig. 1. Comparison of Resilience Value Increa

From the results, it can be observed that when the subsystem values are increased by 10%, the overall resilience values of the system are correspondingly improved. Particularly, the improvements in the economic and logistics capacity subsystems show the most significant impact on resilience values, with increments of 4.85% and 4.77% respectively. The improvements in the information sharing and medical resources subsystems are relatively weaker compared to the former two.Thus, it can be inferred that the economic foundation and logistics capacity are relatively important for the overall emergency logistics system in Nanjing. On the other hand, the information sharing and medical resources subsystems can be considered as potential bottlenecks in the system, representing areas for optimization. By continuously optimizing the indicators of these weaker subsystems, the resilience of the urban emergency logistics system can be further improved, making the entire system more stable and reliable.

5 Conclusion

This paper constructs a set of urban emergency logistics system toughness evaluation index system from four sub-systems, and constructs an evaluation model based on the improved entropy value topsis method, and introduces a coupled coordination model for further evaluation.This paper takes Jiangsu Province as an example, which has certain limitations, and the subsequent research can be specific to individual cities or regions, so that the research can be more accurate.

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