Vulnerability Evaluation of Port Logistics System and Identification of Contribution Factors Based on Entropy Power Method

Cuilian Liu[1*], Lingling Zhang [1], Chenchen Fang [1]

*Corresponding author: liu_cuilian@126.com

[1] College of Transportation Engineering, Dalian Maritime University, Da Lian, China

Abstract. In order to objectively evaluate the vulnerability of port logistics systems and identify the contributing factors, a vulnerability evaluation index system for port logistics systems is constructed using the framework of "exposure-sensitivity-adaptability". Taking Lianyungang port as an example, the vulnerability of its logistics system was quantitatively analyzed by combining the entropy weighting method and the linear weighting method, and the main contributing factors of vulnerability were identified using the contribution degree model. The results show that the vulnerability of the port logistics system of Lianyungang is fluctuating and decreasing, and at present it is moderately vulnerable, with the main contributing factors focusing on innovation and development capacity, infrastructure and equipment, logistics operation level.

Keywords: port logistics systems; vulnerability; entropy method; contribution factor identification.

1 Introduction

COVID-19 has had a short-term impact on China's economy and has seriously affected maritime logistics and supply chains. Although the full implementation of the latest epidemic prevention policy has minimized the impact of the epidemic on economic and social development, the impact of the epidemic still has an impact on the operation of the port logistics systems, with the port at its core. In this context, evaluating the vulnerability of the port logistics systems, identifying the influencing factors, and proposing anti-vulnerability strategies are important prerequisites for the efficient and safe operation of the port logistics systems.

Vulnerability [1] is the tendency of a system to be adversely affected, including the system's sensitivity or susceptibility to disturbance and its ability to adapt after being disturbed. The characteristic elements of vulnerability [2] consist of three factors: exposure, sensitivity, and adaptability. Based on the vulnerability theory [3], the vulnerability of the port logistics system is defined as the state in which the port logistics system loses all or part of its operational capacity due to the instability and sensitivity of its own system under external disturbance and perturbation, resulting in a decrease in the efficiency of the port logistics system. The internal characteristics of the port logistics system [4] are the direct cause of vulnerability, and external

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disturbances are the drivers of changes in the vulnerability of the system, which act by influencing the internal characteristics of the system to make changes in vulnerability, which are expressed through the exposure, sensitivity, and adaptability of the system.

The study of vulnerability theory in the field of port logistics systems is in its infancy and is not yet comprehensive. Xinhu Cao [5] used evidence-based reasoning algorithms and TOPSIS to assess the vulnerability of the Tianjin port. Based on the TEI@I "decomposition before integration" research framework, Lu Bo [6] used mutation theory to classify and integrate subsystems of complex port systems for vulnerability measurement. Jiang, MZ[7] combined fuzzy theory, evidence-based reasoning, and expected utility theory to establish a port vulnerability assessment system.

This study combines the results of previous research and constructs a vulnerability evaluation index system for port logistics systems using exposure, sensitivity, and adaptability as a framework. It combines the entropy weighting method and the linear weighting method to quantitatively evaluate the vulnerability of port logistics systems; introduces a factor contribution model to identify key factors affecting the vulnerability of port logistics systems; and finally, takes the Lianyungang port logistics system as an example to evaluate its vulnerability and identify key vulnerability-causing factors.

2 Research methodology

The use of the entropy weighting method to determine the weight of an indicator is less influenced by human factors, and the following are the steps to find the weight using the entropy weighting method:

Step1: The indicators were standardized using the extreme value method because of the non-uniformity of the data levels for each indicator. The formulas for the standardization of positive and negative indicator data are as follows:

$$x_{ij} = \left(X_{ij} - X_{min}\right)/(X_{max} - X_{min}) \tag{1}$$

$$x_{ij} = \left(X_{max} - X_{ij}\right)/(X_{max} - X_{min}) \tag{2}$$

Where x_{ij} is the standardised data, X_{ij} is the original data, X_{max} is the maximum value of the indicator data, X_{min} is the minimum value of the indicator data and $i = 1,2,\cdots,m; j = 1,2,\cdots,n$.

Step2: Calculating the entropy value e_j of an indicator and weights ω_j:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} P_{ij} \ln P_{ij} \tag{3}$$

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{4}$$

$$\omega_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \tag{5}$$

Based on the weights calculated by the entropy weighting method with standardized data, the vulnerability of the port logistics system is measured quantitatively using the linear weighting method with the following formula:

$$V = \frac{1}{3}(E + S + A) \tag{6}$$

Where V is the vulnerability index, E, S, A are the exposure, sensitivity and adaptability indices respectively, the 3 indices are obtained by the linear weighting method, and the criterion layer index is calculated as follows.

$$I = \omega_j \times X_{ij} \tag{7}$$

This paper explores the contributing factors affecting their vulnerability using a factor contribution model, calculated as follows.

$$L_i = \frac{x_{ij} \times \omega_j}{\sum_{i=1}^{m} x_{ij} \times \omega_j} \times 100\% \tag{8}$$

3 Evaluation indicator system construction

In this paper, the vulnerability evaluation indicators of port logistics system are divided into 3 systems, namely exposure, sensitivity and adaptability indicators. The factors affecting the vulnerability of the port logistics system are also taken into account to establish the indicator system, as shown in Table 1.

Table 1. Port logistics system vulnerability evaluation index system

Criterion layer B	Indicator layer X	Vulnerability characteristics
External disturbance B1	Zone foreign trade dependenceX1 Large-scale industrial value-added X2 Consumer Price Index X3	Exposure
Productive level B2	Port cargo throughput X4 Port container throughput X5 Net profit X6	
Infrastructure and equipment B3	Wharf length for productionX7 Number of berths of ten thousand tons X8 Loading & unloading machinery and equipment investment X9	
Operation level of port logistics system B4	Employees at the end of the year X10 The average berthing time of ships in port X11 Number of arrived ships X12	
Hinterland Economy B5	City GDP X13 Foreign trade or import/export volume X14 Total population X15 Retail sales of social consumer goods X16	Sensitivity

collector-distributor ability B6	Share of tertiary sector X17 Railway operating mileage X18 Highway mileage X19 Inland waterway mileage X20 GDP growth rate X21	
Potential for sustainable development B7	Port container throughput growth rate X22 Port cargo throughput growth rate X23 Growth rate of total retail sales of consumer goods X24 Annual profit growth rate of port enterprises X25	Adaptability
Innovation Development Capability B8	R&D expenditure X26 Number of logistics technology projects X27	

4 Example analysis

4.1 Vulnerability Assessment of Lianyungang Port Logistics System

The port of Lianyungang is one of the 11 international hub seaports in China, and it is of practical importance that the port of Lianyungang is selected as a case study for evaluation in this paper.

The data in this paper is obtained from the Port Annual Report 2015-2021 , Lianyungang Statistical Yearbook, and maritime statistics from the Lianyungang Maritime Bureau.

4.1.1 Indicator weights

Using the entropy weighting method to determine the indicator weights based on equations (1)-(5) and SPSS, the results are shown in Table 2.

Table 2. Lianyungang Port Logistics System Vulnerability Index Weights

Indicators	X1	X2	X3	X4	X5	X6	X7
Weights	0.043	0.029	0.025	0.031	0.060	0.039	0.039
Indicators	X8	X9	X10	X11	X12	X13	X14
Weights	0.036	0.067	0.024	0.043	0.083	0.028	0.041
Indicators	X15	X16	X17	X18	X19	X20	X21
Weights	0.036	0.021	0.038	0.014	0.014	0.014	0.028
Indicators	X22	X23	X24	X25	X26	X27	
Weights	0.018	0.029	0.017	0.021	0.025	0.097	

4.1.2 Classification of vulnerability

The vulnerability score was calculated according to equations (6)-(7). The vulnerability of the port logistics system is classified into five levels (I-V) using the natural interruption method[8]. The exposure, sensitivity and adaptability indices are also classified into five levels (1-5) using the equal spacing classification criteria, with the higher the index, the lower the vulnerability.

4.2 Vulnerability Analysis of Lianyungang Port Logistics System

The exposure, sensitivity, adaptability and vulnerability indices of the vulnerability of the port logistics system of Lianyungang from 2015-2021 are obtained from equations (6)-(7), and the results are shown in Table 3.

Table 3. Exposure, Sensitivity, Adaptability and Vulnerability Index and Rating of Lianyungang Port Logistics System

Year	Exposure		Sensitivity		Adaptability		Vulnerability	
	Index	Grade	Index	Grade	Index	Grade	Index	Grade
2015	0.004	2	0.002	1	0.003	1	0.003	I
2016	0.003	1	0.002	1	0.003	1	0.003	I
2017	0.003	1	0.003	1	0.003	1	0.003	I
2018	0.005	2	0.004	2	0.010	3	0.006	II
2019	0.005	2	0.006	2	0.005	2	0.005	II
2020	0.010	3	0.009	3	0.002	1	0.007	II
2021	0.011	3	0.011	3	0.009	3	0.010	III

(1) Exposure analysis. External disturbance-related indexes have a low weighting, which shows that external port disturbance factors have little impact on the vulnerability of the port logistics system, and Lianyungang port has the ability to resist external shock disturbances. Combined with Table 4, the change in the exposure index can be divided into two stages. 2015-2019 index is low. 2020 index grows more, because during the epidemic road logistics is not smooth, the port plays an advantage, such as 2021 Lianyungang port cargo throughput 277 million tons, year-on-year growth of 9.62%, of which the container completed 5.0349 million TEU, year-on-year growth of 4.80 per cent.

(2) Sensitivity analysis. Combined with Table 4, the changes in the sensitivity index can be divided into two stages. 2015-2017, the Lianyungang port logistics system index was low due to the weak economic base of the Lianyungang port hinterland, which did not provide sufficient support for the port logistics system. The index rose more in 2018 and steadily thereafter due to the increase in railway operation from 84 km to 204 km in 2018, which played an important role in the development of the Lianyungang port distribution system and the promotion of inland waterways; the continued rise of the index in 2019-2021 is due to the advantages of Lianyungang port after the epidemic, with the arrival of The number of vessels increased from 76,526 to 104,042, indicating that the frequency of vessels sailing in and out of the port increased, which has positive significance for the development of the port.

(3) Adaptability analysis. Combined with Table 4, the changes in the adaptability index can be divided into two phases. the changes in the adaptability index from 2015-2017 are small. In 2018 the index increased significantly, with the port further increasing its efforts in science and technology innovation and the number of science and technology projects in 2018. 2019-2020 the index continued to decline, and in 2021 it increased significantly, with the change being erratic due to the impact of the epidemic in 2020, when data for such indicators as the GDP growth rate decreased from 7.49% in 2019 to 2.56%, recovering to 13.74% in 2021.

(4) Vulnerability analysis. From the change in vulnerability index in Table 4, it can be divided into three stages. During the period 2015-2017, the vulnerability level of the port logistics system of Lianyungang was high, and from 2018-2020 it was high. The vulnerability of the port logistics system of Lianyungang became high in this period because in 2017 the government clarified "13th five-year" development planning of Lianyungang Port, which planned the development of Lianyungang Port in the next five years. The vulnerability level will be medium in 2021.

4.3 Factor contribution analysis

4.3.1 Analysis of factor contribution at the criterion level

From equation (8), the factor contribution of each criterion level of Lianyungang port logistics system from 2015-2021 was obtained, and the frequency and frequency of the occurrence of each criterion level indicator were integrated to filter out the top three indicators in terms of factor contribution size each year, as shown in Table 4.

Table 4. Key criterion layer index and their factor contributions

Year	Criterion layer index	Factor contribution (%)	Criterion layer index	Factor contribution (%)	Criterion layer index	Factor contribution (%)
2015	B4	8.45	B2	8.30	B1	4.38
2016	B3	8.00	B8	5.30	B7	4.92
2017	B1	5.36	B3	5.35	B7	4.26
2018	B8	16.56	B2	3.19	B1	3.11
2019	B4	6.07	B8	5.89	B2	4.56
2020	B3	9.49	B4	5.98	B2	4.01
2021	B8	6.89	B2	5.15	B4	5.14

According to the average factor contribution ranking of each criterion level indicator from the comprehensive screening, the main criterion level contribution indicators for the vulnerability of Lianyungang port logistics system are innovation and development capacity (8.66%), infrastructure and equipment (7.61%) and logistics operation level (6.41%).

4.3.2 Analysis of factor contribution at the indicator level

Solving for the factor contribution of the indicator layer and drawing a heat map of the vulnerability factor contribution of the Lianyungang port logistics system, see Figure 1.

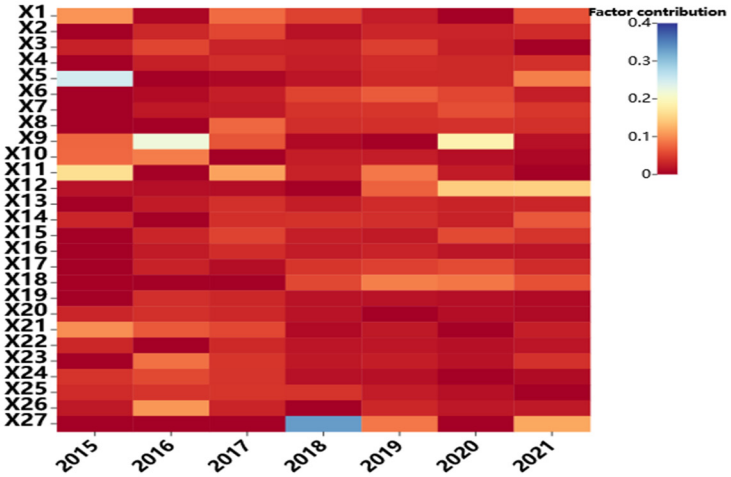

Fig. 1. Heat map of the contribution of vulnerability factors to the port logistics system of Lianyungang

As shown in Figure 1, the changes in the contribution of the indicators of Loading & unloading machinery and equipment investment, the number of logistics technology projects and container throughput are unstable. Therefore, more investment should be made in port handling equipment to further improve the efficiency of port operations; more investment should be made in research and development to increase the number of innovative science and technology projects in port logistics; the unstable change in the contribution of the factor of port container throughput indicates that the development of the port logistics system of Lianyungang is still constrained by external economic conditions, and should be actively constructed to enhance the container throughput by seizing the advantages of land-sea intermodal transport and two-way opening of Lianyungang port.

5 Conclusion

Based on the conclusion that the main contributing factors are concentrated in the areas of innovation and development capacity, infrastructure and equipment, and the level of logistics operations, the following three responses are proposed.

（1）Strengthen the innovation of port enterprises. Lianyungang Port should rely on the advantages of the construction of a science and technology demonstration port to promote scientific and technological innovation and transformation of results, with scientific and technological innovation and technology research and development as the breakthrough and process innovation as the main focus, to help the port move towards a safer and more efficient mode of operation.

（2）Do a good job in the construction of infrastructure and equipment for the port logistics system. Lianyungang Port should actively carry out the construction of berths and terminals to further explore the potential of berths, and at the same time co-ordinate the enhancement of the service guarantee capacity of the port infrastructure.

（3）Improve the operational capability of the port logistics system. Lianyungang Port should effectively summarise the operational experience of port logistics and effectively improve port services. Further optimise the port production operation process, strengthen the employment of key positions to supplement and continuously improve the service level of the port logistics system.

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