Study on the Vulnerability of Port Logistics System of Guangzhou Port Under the New Development Pattern

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Abstract. Under the new development pattern, it is necessary for the logistics industry to play its leading and linking role better. Port is an important window for domestic and foreign trade, and the sustainable and healthy development of its logistics system is particularly important. Vulnerability is an important indicator to evaluate the healthy development of the logistics system, and also an important guide to achieve sustainable development. With the new development pattern as the background, this paper constructs the evaluation index system of port logistics system combined with the theory of vulnerability, adopts the CRITIC-TOPSIS method to measure the overall development of port logistics system, identifies the main constraints combined with the obstacle degree model and puts forward specific suggestions. The results show that the vulnerability of Guangzhou port logistics system shows a fluctuating trend. From 2011 to 2020, the vulnerability index increases from 0.4870 to 0.5487, in which the sensitivity index increases and the resilience index decreases. The main obstacle factors gradually turn from port logistics operation and urban economic subsystem to logistics infrastructure, collection and distribution and port logistics support subsystem.

Keywords: New development pattern · Guangzhou Port · Port logistics system · Vulnerability · TOPSIS

1 Introduction

In 2020, China proposes to accelerate the construction of a new development pattern with the domestic circulation as the main body and the domestic and international circulation promoting each other, which puts forward higher requirements for the logistics industry, including port logistics. In the context of the new development pattern, the frequent movement of domestic and foreign goods and ships has increased the demand for port logistics services, and the environment in which the port logistics system is located has become increasingly complex. Based on the vulnerability theory, the key vulnerability factors of the port logistics system can be analysed and targeted suggestions can be made, which can provide reference for the sustainable and healthy development of the port logistics system and provide a solid guarantee for the construction of a new development pattern of domestic and international dual cycle.

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Table 1. Port Logistics System Vulnerability Evaluation Index System

Target level	Guideline level	Code	Indicator layer	Unit
Port Logistics System Vulnerability Evaluation Index System (A)	Infrastructure (B1)	C1	Terminal automation level	%
		C2	Quay length	Meter
		C3	Number of 10,000 ton berths	Individual
	Collection and distribution capacity (B2)	C4	Highway mileage	Kilometer
		C5	Railway operating mileage	Kilometer
		C6	Inland waterway mileage	Kilometer
	Port logistics operation (B3)	C7	Cargo throughput	Million tons
		C8	Container throughput	Million TEU
		C9	Foreign trade throughput	Million Tons
		C10	Number of container liner services	Individual
		C11	Loading and unloading efficiency	T/h
		C12	Number of arriving ships	Individual
	Urban Economy (B4)	C13	GDP	Billion
		C14	Proportion of tertiary industry	%
		C15	Total retail sales of consumer goods	Billion
		C16	Total export-import volume	USD Billion
		C17	Actually utilized foreign capital	USD Billion
	Port industries (B5)	C18	Investment in logistics infrastructure	Billion
		C19	industrial added value	Billion
		C20	Number of people engaged in logistics	Million

(*continued*)

Table 1. (*continued*)

Target level	Guideline level	Code	Indicator layer	Unit
	Port logistics support(B6)	C21	Number of university students per 10,000 population	Individual
		C22	Internet broadband access port	Million

2 Literature Review

In the context of vulnerability research, the term "vulnerability" first originated in the field of natural hazards and was initially focused on the potential impact of hazards. It has since been enriched to include a range of related concepts such as "risk", "exposure", "sensitivity", "adaptability" and "resilience". The field of application has been extended and the subject of research has expanded from a single aspect such as natural disasters and ecological environment to a complex coupled system such as social-ecological and human-environment, but the study of vulnerability in the field of port logistics is still in its initial stage. Zhang WX et al. [1] used hierarchical analysis to evaluate the vulnerability of the Tianjin port logistics system; Hsieh CH et al. [2] used fuzzy cognitive maps and sensitivity analysis models to quantitatively assess the vulnerability of four international ports from the perspective of infrastructure interdependence; Su DT et al. [3] used grey correlation analysis to explore the vulnerability of container hub ports vulnerability; Sierra JP et al. [4] investigated the impact of wave overflow on port vulnerability due to different scenarios of sea level rise in the context of climate change; Cao XH et al. [5] proposed a fast reaction-based port vulnerability assessment framework, and introduced fuzzy evidential reasoning methods and the fuzzy Technique for Order Preference by Similarity Ideal Solution (TOPSIS) in the framework.. Lu Bo et al. [6] studied the dynamic coupling relationship of internal and external control variables of port operation and used it to evaluate the vulnerability problem of the port (Table 1).

To sum up, most of the existing studies on port vulnerability are focused on port security and port operations, but there is less research on the vulnerability of port logistics systems and insufficient research on the drivers of vulnerability, and a scientific and complete theoretical system has not yet been formed for the construction of indicator systems. This paper constructs a vulnerability evaluation index system for the port logistics system in the context of the new development pattern and applies it to a case study, with the aim of solving existing problems, providing a reference for the sustainable development of the port logistics system and contributing to the development of the "double cycle" strategic system [7].

3 Indicator System Design Framework

3.1 Basic Ideas for Constructing an Indicator System

The port logistics system is an organic whole that covers the entire logistics operation process from supplier to demander [8], which has multiple functions and resources, but the use of these resources is usually not matched with the logistics demand of the domestic economy and society, and this phenomenon is even more obvious in the new development pattern. In order to better integrate into the new development pattern and address the existing shortcomings of the port logistics system, a study on the vulnerability of the port logistics system is needed. Based on the "double cycle" background, combined with the research object, the concept of port logistics system vulnerability is proposed, that is, the port logistics system in the face of internal and external environmental disturbance elements, the sensitivity of the system and its ability to cope with the interlock between the structure or function of the system is vulnerable to damage inherent properties of the system. Sensitivity refers to the degree of response of the system to internal and external disturbances; resilience refers to the strategic adjustments made by the system in the face of internal and external changes.

3.2 Analysis of Influencing Factors

The construction of the new development pattern requires port logistics to play its role as an internal and external link and continuously improve itself to achieve a balance between social demand and logistics supply. The port logistics system is analysed in terms of the requirements of the "double cycle" pattern for the logistics industry, and the following factors are derived.

Port logistics system influence factors consist of six parts: (1) Port logistics infrastructure. It is the basis for port logistics activities, and port logistics operations need to rely on port logistics infrastructure to complete, including the terminal automation level, quay length and the number of 10,000-ton berths. Among them, the number of berths will not only affect the port throughput capacity, but also have an impact on the situation of ships in port; (2) Collection and distribution capacity. It is used to measure the level of development of domestic and foreign trade transportation capacity, including high mileage, railway operating mileage and inland waterway mileage. The efficient connection of various modes of transportation can improve the response capability of the port logistics system; (3) Port logistics operation. This sub-system is the core of the port logistics system, which is expressed through indicators such as throughput, the number of container liner services, loading and unloading efficiency and the number of arriving ships. Among which the throughput and the number of arriving ships are used to measure the level of domestic and foreign trade demand, the number of container liner services is used to measure the two-way radiation capacity of the port, and the loading and unloading efficiency is used to measure the productivity of the port logistics system. (4) Urban economy. Logistics demand is derived from social and economic life, and the city's economy is a direct reflection of the level of social logistics demand in the region, including gross regional product (GDP), the proportion of tertiary industry in GDP, total retail sales of consumer goods, total export-import volume, and actually utilized foreign capital. GDP is used to measure the overall economic development of the city; the proportion of tertiary industry is used to measure the industrial structure of the city; the total retail sales of consumer goods is a reflection of the purchasing power of the society and reflects the scale of the consumer market; the total export-import volume is used to measure the development of domestic and foreign trade, which has a significant impact on the national economic cycle and the increase in trade volume will also increase the cargo throughput of the port; the actually utilized foreign capital reflects the level of foreign capital utilization in the port city, which can enhance the international trade level of the port city and promote the further development of port logistics; (5) The conditions of the port industry. The three indicators include the amount of infrastructure investment in the logistics industry, the value added of industries above the scale and the number of employees in the logistics industry at the end of the year. The amount of investment in logistics infrastructure measures the investment in logistics infrastructure in the port city; the value added of industry above the scale measures the total level and scale of industrial production; the port industry is a personnel-intensive industry [9], and the number of relevant employees needs to be measured; (6) Port logistics support. This includes indicators such as the number of university students per 10,000 people and the number of Internet broadband access ports. The increase in the level of education can provide high-quality talents for the development of the logistics industry, while the number of Internet access ports reflects the level of information technology development, and the increase in the level of information technology can improve the efficiency of port logistics operations.

4 CRITIC-TOPSIS Model

4.1 CRITIC Method for Calculating Weights

The CRITIC (Criteria Importance Though Intercrieria Correlation) method takes into account the differences and correlations between indicators, and scientifically evaluates the weights of each indicator in terms of comparative strength and conflict, and the results obtained are more objective and accurate [10]. The calculation steps are as follows:

$$y_j = \sum_{l=1}^{n}\left(1 - \frac{Cov(j,l)}{\sigma_j \sigma_l}\right)(j = 1, 2, \cdots, n) \tag{1}$$

$$G_j = \sigma_j y_j (j = 1, 2, \cdots, n) \tag{2}$$

$$W_j = \frac{G_j}{\sum_{j=1}^{n} G_j} \tag{3}$$

where G_j denotes the information content of the composite measure; σ_j denotes the comparative strength of each indicator; y_j denotes the conflict between indicators; and Cov(j,l) denotes the covariance of the evaluation data between indicator j and l.

4.2 TOPSIS Method for Calculating Vulnerability Indices

TOPSIS is a method for evaluating the relative merits of existing solutions [11]. The data of each indicator in the past years is used as a solution, and each solution in the past years is compared and analysed with the best value of each indicator in the past years, which makes the research more relevant to the real situation of the research subject.

$$Z^{+} = \left\{ \max_{1 \le i \le m} z_{ij} | i = 1, 2, \ldots, m \right\} = \left\{ z_1^{+}, z_2^{+}, \ldots, z_m^{+}, \right\} \tag{4}$$

$$Z^{-} = \left\{ \max_{1 \le i \le m} z_{ij} | i = 1, 2, \ldots, m \right\} = \left\{ z_1^{-}, z_2^{-}, \ldots, z_m^{-}, \right\} \tag{5}$$

$$D_j^{+} = \left(\sum_{i=1}^{m} \left(z_{ij} - z_i^{+} \right)^2 \right)^{-1} (i = 1, 2, \ldots, m) \tag{6}$$

$$D_j^{-} = \left(\sum_{i=1}^{m} \left(z_{ij} - z_i^{-} \right)^2 \right)^{-1} (i = 1, 2, \ldots, m) \tag{7}$$

$$C_i = \frac{D^{-}}{D^{-} + D^{+}}, (1 \le j \le n)(0 \le C_i \le 1) \tag{8}$$

where: Z^{+} denotes the positive ideal solution and Z^{-} denotes the negative ideal solution; D^{+} and D^{-} denote the distance of the evaluation vector to the positive ideal solution and the distance of the negative ideal solution for each year respectively; C_i denotes the combined vulnerability evaluation value.

4.3 The Barrier Model Calculates the Barrier Level for Each Indicator

$$d'_{ij} = 1 - x'_{ij} \tag{9}$$

$$A_{ij} = \frac{w_{ij} d'_{ij}}{\sum_{i=1}^{m} w_{ij} d'_{ij}} \times 100\% \tag{10}$$

$$U = \sum_{i=1}^{m} A_{ij} \tag{11}$$

where: A_{ij} denotes the barrier of a single indicator at the indicator level; w_{ij} denotes the contribution of the indicator to the overall target, here using the indicator weight value determined by the CRITIC method; d'_{ij} is the degree of deviation of the indicator, denoting the gap between the single indicator and the maximum target, set as the gap between the standardised value of the indicator and 1; x'_{ij} denotes the standardised value of the j^{th} indicator; and U denotes the barrier at the guideline level.

Table 2. Criteria for classifying sensitivity, resilience, vulnerability

Grade	Sensitivity	Resilience	Vulnerability
Low	[0,0.3901]	[0,0.3497]	[0,0.4993]
Medium	[0.3901,0.5242]	[0.3497,0.5404]	[0.4993,0.5207]
High	[0.5242,0.6583]	[0.5404,0.7311]	[0.4993,0.5241]
Higher	[0.6583,1]	[0.7311,1]	[0.5241,1]

5 Application of Vulnerability Assessment Models for Port Logistics Systems

5.1 Data Sources

The original data for all indicators in this study were obtained from the 2011–2021 *China Port Yearbook*, *China Logistics Yearbook*, *Guangzhou Yearbook*.

5.2 Vulnerability Grading

Using the mean-standard deviation classification statistic [12], the classes were classified and the criteria for classification are shown in Table 2.

5.3 Vulnerability, Sensitivity and Resilience Analysis of the Port Logistics System of Guangzhou Port

Based on Eqs. (4) to (8), the sensitivity, coping capacity and vulnerability indices of the port logistics system of Guangzhou Port from 2011 to 2020 are derived respectively, and their changing trends are shown in Fig. 1.

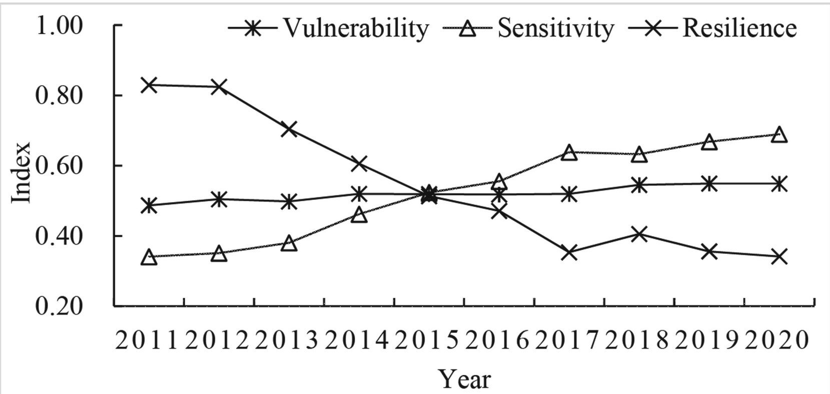

Fig. 1. Sensitivity, responsiveness, and vulnerability index

The overall vulnerability index shows a fluctuating trend, with the highest vulnerability index of 0.5490 in 2019 and the lowest vulnerability index of 0.4870 in 2011; the sensitivity index shows an increasing trend, from 0.3410 to 0.6894; the coping capacity index shows a decreasing trend, from 0.8295 to 0.3418. Of these, 2011 and 2013 are periods of low vulnerability; 2012 and 2014–2017 are periods of moderate vulnerability; and 2018–2020 are periods of high vulnerability. In order to further explore the main factors impeding the decline of the vulnerability of the Guangzhou port logistics system, a barrier degree model was used to calculate and analyse the key vulnerability-causing factors.

5.4 Port Logistics System Vulnerability Barrier Factor

In the selected sample years, the concentration of barrier factors varies from year to year, and due to the large number of indicators in the indicator layer, only the top 5 barrier factors and barrier degrees in the ten years are listed in this paper according to the size of the barrier degree, see Table 3. Gradually shifted to the infrastructure subsystem, consolidation and distribution capacity subsystem and logistics support subsystem.

During the period 2011–2016, the indicators are highway mileage C4, cargo throughput C7, container throughput C8, foreign trade throughput C9, total retail sales of consumer goods C15 and total export-import volume C16. Only highway mileage C4 is a coping capacity indicator, which makes the sensitivity indicator of Guangzhou port logistics system dominant. The reason for this is that during the 12th Five-Year Plan, Guangzhou City completed the third phase of the main project of Guangzhou Port Nansha Port Area, which has increased the port throughput capacity and container terminal throughput capacity, and as of 2016, its port cargo throughput reached 540 million tonnes and container throughput reached 18,849,700 international standard containers, ranking among the top in the world. At the same time, sea transportation is an important transportation channel for international trade goods, and with the development of sea trade the number of ships arriving at Guangzhou port has been increasing, which has also driven the growth of import and export trade volume to a certain extent. The increasing volume of cargo trade has put forward higher requirements for the construction of the port's collection and distribution system, but the construction process of its collection and distribution facilities, especially highway mileage, has been relatively slow, thus making the barrier of highway mileage C4 increase year by year. During this period, the barrier degree of total retail sales of social consumer goods indicator has also been at a high level, which is the main barrier factor for the reduction of the vulnerability of the port logistics system of Guangzhou Port. The new development pattern has put forward higher requirements on the scale of consumption in China, the domestic consumption market has become increasingly prominent in the process of economic development, and the increase in the level of consumption of residents can in turn drive the development and improvement of the port logistics supply system.

From 2017 to 2020, the main obstacle factors of the port logistics system of Guangzhou Port change, as reflected in the indicator level of C2 for quay length, C5 for railway operating mileage, C6 for inland waterway mileage, C12 for the number of arriving ships, and C22 for internet broadband access port, of which the number of arriving ships is a sensitive indicator and the remaining four indicators are all coping

Table 3. Top five barrier factors by year

Year	1		2		3		4		5	
	Indicator	Percent (%)	Indicator	Percent (%)	Indicator	Percent (%)	Indicator	Percent (%)	Indicator	Percent (%)
2011	$C7$	18.68	$C8$	18.35	$C16$	16.69	$C15$	16.55	$C9$	16.07
2012	$C7$	18.88	$C8$	18.23	$C16$	16.66	$C15$	15.30	$C9$	12.55
2013	$C7$	14.96	$C8$	14.91	$C16$	14.10	$C15$	11.74	$C9$	9.95
2014	$C8$	12.94	$C7$	12.55	$C15$	9.79	$C4$	9.23	$C16$	8.60
2015	$C4$	12.37	$C8$	10.47	$C7$	10.09	$C19$	8.10	$C9$	7.79
2016	$C4$	12.24	$C16$	8.26	$C8$	7.84	$C7$	7.60	$C2$	6.81
2017	$C4$	11.02	$C6$	9.91	$C12$	6.77	$C2$	6.38	$C22$	5.65
2018	$C6$	9.87	$C12$	9.60	$C5$	8.85	$C11$	7.67	$C22$	6.38
2019	$C6$	9.67	$C12$	9.32	$C5$	8.71	$C22$	7.32	$C18$	7.12
2020	$C5$	8.63	$C6$	8.20	$C22$	7.36	$C19$	7.08	$C17$	6.73

capacity indicators, which indicates that during this period the Guangzhou Port logistics This indicates that the resilience indicators of the Guangzhou port logistics system dominated during this period. In recent years, the successful completion of various tasks such as the deep-water channel widening project of Guangzhou Port has led to an increase in the number of ships arriving at the port, which has ultimately led to an increase in port throughput year after year, and the steady growth in port throughput has put its collection and distribution system under tremendous pressure. The results of the study show that from 2018 to 2020, railway operating mileage and inland waterway mileage have been the main obstacle factors of the whole system and the obstacle degree is increasing year by year. From the current situation, the transport structure of the port logistics system of Guangzhou Port is unreasonable, with road transport still being the main mode of cargo consolidation and dredging, compared to railway transport, which accounts for the lowest percentage, with the current percentage of railway cargo consolidation accounting for about 1% and dredging cargo accounting for about 10%, and there is still much room for improvement compared to international ports. The barrier degree of the number of Internet access ports indicator is rising year by year, and the barrier degree of its indicator fluctuates between 5.65% and 7.36% from 2017 to 2020, which indicates that the information construction level of Guangzhou Port's logistics system is insufficient, and the interconnection of various business data of the port using the Internet can better realize information sharing and improve the operational efficiency of the whole port logistics system. In the long run, Guangzhou Port should speed up the pace of informatization construction.

6 Conclusions and Recommendations

The analysis of the calculation results of the barrier degree shows that the two factors have different influence on the vulnerability of the port logistics system in different periods, and the main barrier factors have changed accordingly, with the main barrier factors gradually shifting from sensitivity indicators to coping capacity indicators.

Combining the above-mentioned analysis of the causes of the vulnerability of the port logistics system of Guangzhou port and the results of the main obstacle factors, the following suggestions are made: First, the construction of infrastructure for the logistics industry should be strengthened. The construction of port logistics infrastructure can lay a solid foundation for the continuous improvement of the port logistics system, enhance the efficiency of port logistics operations, further improve its level of openness to the outside world, and make the port better serve the main body of the domestic general circulation and the new pattern of domestic and international double circulation; secondly, the construction process of port logistics collection and distribution facilities should be promoted. From data analysis, it can be seen that from 2014 to 2020, the obstacle degree of the consolidation and dredging subsystem is increasing year by year, which hinders the overall development process of the port logistics system. Therefore, Guangzhou Port should actively promote the construction of port-diversion railways, improve the level of connection between special railway lines and inland river ports, and at the same time actively promote the expansion and upgrading of inland waterways, so as to enhance the port's consolidation and dredging capacity by improving the conditions of railway and waterway transportation, and lay the foundation for the efficient circulation of production factors under the new development pattern; thirdly, the construction process of smart ports should be promoted. Research results show that the number of Internet access broadband indicator barrier degree is increasing year by year, and the barrier degree reaches 7.54% in 2020, leaping to become the third largest barrier factor of port logistics system vulnerability. In the long run, the smart port construction can improve the efficiency of port handling operations, which in turn can improve the operation level of the whole port logistics system. Fourth, the level of social consumption in port cities should be enhanced. The new development pattern has put forward higher requirements on the scale of consumption, and the domestic consumption market has become increasingly prominent in the process of economic development. The government should adopt a number of policy measures to meet residents' consumption needs, which will drive the development and improvement of the port logistics supply system.

References

1. Zhang WX, Xi TY and Zhang RF. (2011) A case research on vulnerability of logistics system in the Tianjin port. *Energy Procedia*, **5**:2059-64.
2. Hsieh CH. (2014) Disaster risk assessment of ports based on the perspective of vulnerability. *Natural Hazards*, **74(2)**:851-864.
3. Su DT, Hsieh CH, and Tai HH. (2016) Container hub-port vulnerability: Hong Kong, Kaohsiung and Xiamen. *Journal of Marine Engineering & Technology*, **15(1)**:19-30.
4. Sierra JP, Casanovas I, Moaao c, Metres M, and Sanchez-Arcilla A. (2016) Vulnerability of Catalan (NW Mediterranean) ports to wave overtopping due to different scenarios of sea level rise. *Regional Environmental Change*, **16(5)**:1-12
5. CAO XH, and Lam JSL. (2019) A fast reaction-based port vulnerability assessment against catastrophes: case of the Tianjin Port explosion. *Transportation Research Part A: Policy and Practice*, **128**:11-33.
6. Lu B, Wen YJ, Xing J, and Song DP. (2020) Competition and cooperation strategy of Bohai rim portunder the framework of TEI@I methodology. *Management Review*, **32(7)**:246-257.

7. Zhang NZ. (2022) Research on the coordinated development of port logistics system-taking Tianjin port as an example. *Logistics Sci-Tech*, **45(10)**:25-32.
8. Wu P. (2014) Study on development strategy and architecture of port logistics systems. *Logistics Technology*, **33(17)**:92-94.
9. Huang YF. (2020) Research on the high-quality development of logistics industry in China -Based on the analysis of logistics development in Guangdong-Hong Kong-Macao Greater Bay Area. *Price: Theory & Practice*, **(04)**:168–171.
10. Lv ZP, Wu M, Song ZH, Zhao T and Du G. (2020) Comprehensive evaluation of power quality on CRITIC-TOPSIS method. *Electric Machines and Control,* **24(01)**:137-144.
11. Gao S, Sun HH and Sun W. (2021) Vulnerability assessment and obstacle degree analysis of marine economic system based on entropy weight TOPSIS model. *Ecological Economy*, **37(10)**:77-83.
12. Zhao M, Qiu WH and Liu BS. (2010) Relative entropy evaluation method for multiple attribute decision making. *Control and Decision*, **25(07)**:1098–1100+1104.