The Coastal Port Resilience Evaluation Indicator System for Emergency Situations

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Abstract. Various emergencies and their range of derivative impacts can cause disruptions to normal production activities at coastal ports. This paper presents a simple research framework for analyzing the resilience of coastal ports based on the above emergencies. By building and weighting a corresponding indicator system in the context of sudden short-term events and sudden long-term events using the CRITIC method, it screens out some key indicators. Further analysis was also carried out using Barrier Degree Model, to analyze some key constraints on the resilience of coastal ports at different time periods.

Keywords: Coastal Port; Resilience; Emergency; CRITIC; Barrier Degree Model

1 Introduction

The emergencies faced by coastal ports studied in this paper refer to some events that occur suddenly during the production and operation of seaports in the broad sense of seaports and their vicinity, which can cause various potential threats to the normal production activities of seaports[1]. For example, adverse impacts on seaport staff, vessels, infrastructure, buildings, etc. People need to try to take certain measures in a timely manner to eliminate the negative impacts in order to quickly restore the normal production and operation of the seaport. For coastal port production and operation, the daily activities are mainly faced with two types of unexpected short-term events: natural disasters (severe weather) and accidental disasters[2]. On the other hand, large-scale public health emergencies have had a huge impact on the activities of human society as a whole, and coastal port operations have suffered greatly as a result.

1.1 Natural disasters (severe weather)

Influenced by the land and water environment, the normal operation of coastal ports may be interfered by natural disasters such as typhoons, tsunamis, earthquakes, snowstorms, etc., of which typhoon weather has the deepest and most frequent impact. China's large ports are mostly located in the eastern coastal areas, typhoon weather caused by the direct disaster is mainly gusty winds, heavy rain, storm surge, these bad weather on the port operation is very big. Specifically, typhoons can cause huge waves and tides, which pose a safety threat to port facilities, and also lead to drastic changes in tides and currents, which make the water level and seawater flow in the harbor affect the normal operation of ship operations. In addition, these disasters of typhoons are very likely to induce secondary disasters such as urban

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flooding, house collapse, flash floods and mudslides, which will have a serious impact on the lives of coastal port workers and lead to the inability of port work to be carried out normally.

1.2 Social security incidents

In this paper, the social security incidents mainly refer to accidents in production safety. It also includes cyber-attacks, terrorist attacks and workers' strikes, which are not common in China's coastal ports, thus they are not considered to the resilience analysis for the time being. There are several categories of production safety accidents according to the circumstances leading to the risk, and there are also co-existence and causal relationships between these categories. For example, non-compliant operations, such as over-stocking of hazardous containers in yards, unreasonable operation, such as yard box area setting does not meet the requirements, failure of important equipment, sunch as aging, damage and untimely maintenance of emergency equipment.

1.3 Large-scale public health emergencies

The impact of international public health emergencies is very wide and the virus spreads very quickly, and coastal ports, as important land and sea transportation hubs and international transportation hubs, encounter such events more frequently than inland. The main public health emergencies that are better known to China are the SARS epidemic in 2003 and the COVID-19 epidemic in late 2019 (hereinafter referred to as "COVID-19"). During COVID-19, many countries and cities enacted various policies restricting people's daily activities to prevent the spread of the virus, which largely affected people's daily commuting and working patterns, and the impact was even more widespread for densely populated cities with clear zoning. For example, many of the staff at the Guangzhou port reside in the Guangzhou municipal district or county, and their daily work involves taking longer shuttle buses or public transportation to reach the operations area or the terminal's business building; however, the COVID-19 have caused this process to be cut off frequently, resulting in serious impacts on the terminal's daily production.

In addition to staffing factors, the cancellation of hub port calls by many shipping lines had a huge impact on cargo delivery at coastal ports. Delayed resumption of work and decaying market demand had resulted in lower evacuation of bulk cargoes, etc. This, coupled with external traffic control, had resulted in land-based transshipment being restricted as well, with cargoes taking up more than the normal amount of time and space for stacking at the ports. Data from the China Association of Ports and Harbors reflects that during COVID-19, bulk cargo port stocks increased by more than 10% over the same period previously, posing a challenge to port stacking capacity. In addition, the detention of important emergency supplies such as imported reefer containers at ports had an impact on people's lives. The capital market was also very pessimistic about the expectations of the port and shipping industry, which declined considerably more than other industries in the transportation sector. This is because the inability to ship and transport will have a negative impact on partners upstream and downstream of the industry chain as well, resulting in serious default risks and losses, as well as being detrimental to the future development of the industry.

This paper presents a simple research framework shown in Figure 1 for analyzing the resilience of coastal ports based on the above emergencies. And we will give an example of analyzing Guangzhou port's resilience in the next two parts.

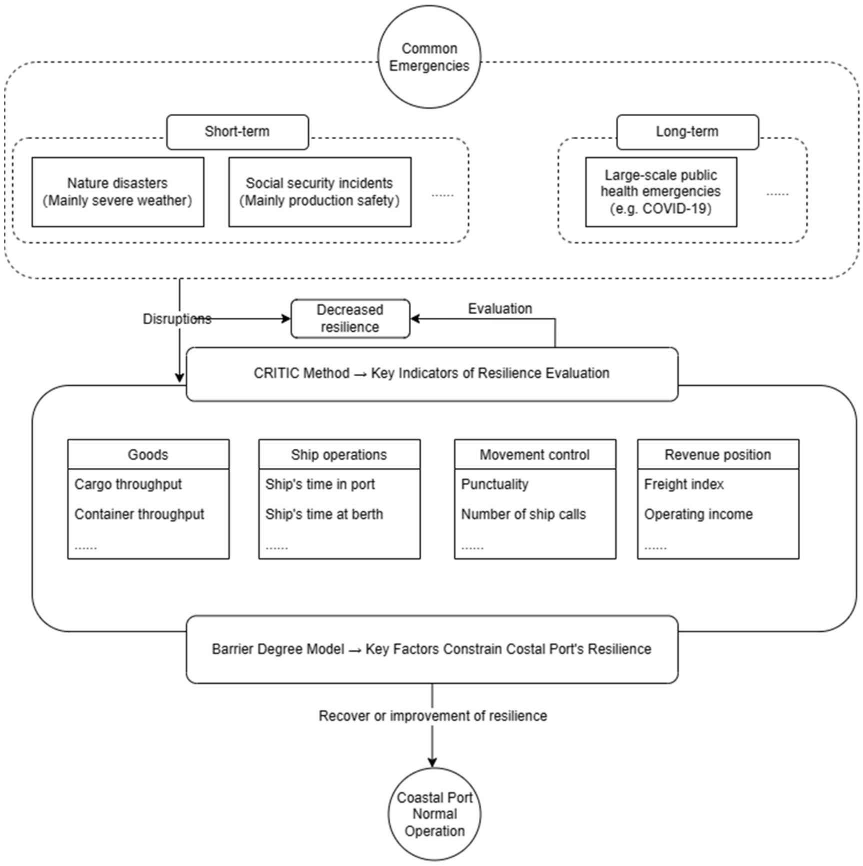

Fig. 1. A simple research framework architecture for analyzing the resilience of coastal ports.

2 Selection of indicators for coastal port resilience analysis

Based on Bruneau's research[3], this paper defines the resilience of a coastal port for emergencies as the ability of a coastal port to mitigate emergencies, encompassing the ability to contain the impacts of the disaster at the time of the emergency, the ability to recover after the disaster, and the sustainability to better respond to that type of emergency again in the future.

Considering the availability, usability, and quality of data, the indicator system for analyzing the resilience of coastal ports oriented to emergencies can be simplified into the structure shown in the table below. The indicators identified in this paper, based on the reference to the resilience research system in other fields, combine the statistical indicators and requirements of transportation and port reports and the actual situation of coastal port production. The data sources of the indicators referred to in this paper mainly come from the public port data of the Ministry of Transportation and Communications, the statistical analysis report of China Port Association and the actual data of Guangzhou port production, and the specific indicators and their corresponding sources are also indicated in table 1.

Table 1. Indicators for coastal port resilience analysis

Standardized layer	Indicator layer
Goods(A)	Cargo throughtput(A_1) Container throughput(A_2)
Ship operations(B)	Ship's time in port(B_1) Ship's time at berth(B_2)
Movement control(C)	Punctuality(C_1) Ship calls(C_2)
Revenue position(D)	Freight index(D_1) Operating income(D_2)

We provide a detailed explanation of the specific meaning of each indicator at the indicator level:

(1) Cargo throughput

For ports, cargo throughput refers to the total amount of cargo exported and imported into the port area by water transportation and loaded and unloaded in a year. Cargo throughput is the most important indicator to measure the scale and actual operation capacity of the port, and therefore, the calculation of cargo throughput is very strict and regulated by the state. The throughput indicator can be subdivided into cargo throughput, foreign trade cargo throughput, container throughput and so on. In the research on ports, there is a considerable part of modeling and forecasting analysis of port throughput. Sometimes, for various reasons, the statistical value of throughput does not necessarily correspond to the actual volume of operations, and in real-world scenarios, cargo throughput measured in daily units is not easily recorded by various statistics. In the case of daily toughness analysis, the sum of daily weights of cargo loaded and unloaded at the port can be used for estimation.

(2) Container throughput

Container throughput is a part of cargo throughput, which is now basically based on international standard containers, and the unit of measurement is usually TEU or tons. Container transportation revenue accounts for about half of the revenue of major coastal ports, and statistics on container throughput can better assess the situation and development trend of freight transportation in ports, and managers can also better assess the value of investment and potential revenue of ports accordingly.

(3) Ship's time in port

Ship operation is one of the most important activities in the port, and ship's time is one of the more important types of data in ship operation. Ship's time in port refers to the total length of time between the ship's arrival at the port's anchorage and its departure from the berth after berthing and completing the loading and unloading operations. Ship's time in port is closely related to the congestion of the port, and this indicator reflects the comprehensive efficiency of port facilities and equipment, pilotage, scheduling, loading and unloading, collection and evacuation, and customs clearance at ports.

(4) Ship's time at berth

Ship's time at berth refers to the total length of time from the time a ship arrives at a berth for loading and unloading operations to the time it completes the operations and leaves the berth. This indicator mainly reflects the efficiency of loading and unloading operations during the berthing period in the port, in addition, it is also related to the efficiency of the coordination and scheduling of the shipping agency and the port authority in the port. The time at berth emphasizes the efficiency of the loading and unloading operations more than the time in the port.

(5) Punctuality

After hundreds of years of development, the world's bulk goods, such as containers, crude oil, etc., in the transportation of various consumer areas, have their maritime transportation fixed routes. For example, the Western Europe route in the Persian Gulf is the main oil supply route in the oil-consuming areas of Western Europe, and is also one of the world's major international routes for crude oil, departing from the Persian Gulf, via the Indian Ocean - the Cape of Good Hope - call on South Africa (Durban or Cape Town) - the South Atlantic Ocean - Western Europe (Liverpool, Rotterdam). And shipping companies will follow these fixed routes to prepare the ship plan, which is convenient to dock with the ports on the route.

The maritime punctuality rate refers to the proportion of punctual vessel trips to the total number of vessel trips made by liners engaged in international or regional transportation on fixed routes, and between fixed ports in accordance with published schedules or in a regular manner during a statistical time period. The punctuality can reflect the safety and efficiency of fixed routes to a certain extent, and can promote the optimization of route selection decisions. The level of punctuality is not only related to the service quality of ports and shipping companies, but also to the operating costs of maritime transportation stakeholders. For ports, maritime punctuality can reflect both their hardware environment and management capability[4].

In this paper, the basis of calculating this indicator is the difference between the actual berthing time and the expected berthing time of the ship, and the deviation is counted as quasi-schedule within 24 hours, which is consistent with the calculation method of the quasi-schedule rate in the Global Liner Report released by Sea Intelligence, an authoritative Danish shipping consulting organization.

(6) Number of ship calls

Port of call refers to the port where a ship stops on its way from the port of departure to the port of destination, similar to the intermediate stop of a bus. The number of ship calls refers to the number of ships arriving at the port whose destination port is not the port, which can reflect to a certain extent the operational efficiency of the port, its operational capacity and the market's recognition of its comprehensive scheduling ability.

(7) Freight index

The freight index is an index that reflects the price of transportation and is known as the "barometer" of the shipping market. Freight indices are often used to measure changes in the cost of transporting various raw materials and the prosperity of commodity trade, and therefore, to a certain extent, they can reflect the revenue situation of ports and the future economic situation. This paper selects the Pearl River Shipping Freight Index in the statistical time period according to the region of Guangzhou port as an indicator of revenue, so as to reflect the shipping situation of Guangzhou port side by side.

(8) Operating income

Operating income is one of the core indicators of business activities, reflecting the scale of operation and profitability of the enterprise. The income of port enterprises is relatively single, and its main operating income is from the loading and unloading operations of terminals.

3 Weighting and screening of key indicators

3.1 Example data description

In the example analysis of the screening of key indicators of coastal port resilience, the data mainly come from the production and business management system of Guangzhou port, and a small number of indicators come from the statistical data released by China Port Statistical Yearbook and Pearl River Shipping Bureau, which are reliable in terms of data source and data quality. In order to facilitate a more intuitive presentation and comprehensive consideration of the changes in the indicators during the period when the above types of coastal ports are facing emergencies, the time scales of the data analyzed in the examples are mainly:

(1) Short-term: Seven days from May 20 to May 26, 2020, with the granularity of the collection of each indicator as day, of which a very heavy rainstorm occurred on May 22, with flooding in many parts of the city, and even casualties.

(2) Long-term: Six years from 2018 to 2023, with the granularity of the collection of each indicator as year, of which the end of 2019 to the end of 2022 is in the period of occurrence and recovery of COVID-19.

In this paper, we use the CRITIC method, Criteria Importance Though Intercrieria Correlation, to calculate the weight of indicators. This method takes into account the comparative strength of the indicators and the conflict between them to determine the weights[5]. The comparative strength of an indicator is generally expressed in terms of the standard deviation, which represents the fluctuation of the difference between the values of the indicators. The conflict between indicators is generally expressed as a correlation coefficient, which represents the conflict between indicator values.

After the comprehensive evaluation, this paper utilizes a handicap model to find the "major handicapping factors" for further study. The barrier degree model can more accurately measure the specific constraints affecting the level of sustainability. Among other things, the degree of obstacle reflects the degree of influence of each evaluation indicator on the level of sustainable development[6]. If the degree of obstacle of an evaluation indicator is large, it means that the indicator is an obstacle factor to the level of sustainable development, or resilience.

3.2 Short-term weighting

Since the time period includes weekends, the attendance of business people will affect the data entry, and in order to control the variables, this section does not calculate the revenue aspect of the indicator.

The results of the CRITIC method for objective weighting are shown in Table 2. The weights of the indicators A1 and A2 are both over 20%, substantially ahead of the other indicators, which suggests that the differences between A1 and A2 fluctuate more significantly and reflect more information. This also reflects the fact that in the context of sudden short-term events, cargo-level data of coastal ports are more suitable for resilience metrics. Therefore, it can be concluded that A1 (cargo throughput) is the key indicator for resilience evaluation of coastal ports oriented to sudden short-term events.

Table 2. Results of CRITIC for short-term

Indicator	Variability	Conflict	Information Quantity	Weight
A_1	0.008	5.586	0.044	3.549
A_2	0.015	4.197	0.062	4.982
B_1	0.027	4.934	0.134	10.789
B_2	0.014	5.305	0.073	5.865
C_1	0.071	10.017	0.709	57.129
C_2	0.028	4.464	0.126	10.189

The results of the Obstacle Degree Model are shown in Table 3. Indicators with high level of obstacles are B_1 and B_2, which are the main obstacle factors. This reflects that in the context of sudden short-term events, the resilience level of coastal ports is more affected by the ship operation situation. Therefore, it can be concluded that when oriented to sudden short-term events, coastal ports should improve the ship operation situation to enhance their resilience level.

Table 3. Results of Obstacle Degree for short-term

Date	A_1	A_2	B_1	B_2	C_1	C_2
5/20	0	0	0.2488	0.3573	0.1521	0.2416
5/21	0.2135	0.2206	0.2762	0.0049	0.1060	0.1785
5/22	0.1732	0.1378	0.2640	0	0.0982	0.3265
5/23	0.1713	0.1405	0.2700	0.3434	0	0.0745
5/24	0.3526	0.3013	0.0153	0.2014	0.0179	0.1112
5/25	0.0040	0.0148	0.5306	0.3562	0.0942	0
5/26	0.2951	0.2182	0	0.1670	0.0789	0.2406
Mean	0.173	0.148	0.229	0.204	0.078	0.167

3.3 Long-term weighting

The results of the CRITIC method for objective weighting are shown in Table 4. The weighting of the C1 metric is over 50%, substantially ahead of the other metrics, which suggests that the differential fluctuations in C1 are more pronounced and reflect more information. This also reflects the fact that in the context of sudden and prolonged events, the data at the dispatch level of coastal ports are more suitable for resilience metrics. Therefore, it can be concluded that C1 (punctuality) is a key indicator for the resilience evaluation of coastal ports oriented to sudden and prolonged events.

Table 4. Results of CRITIC for long-term

Indicator	Variability	Conflict	Information Quantity	Weight
A_1	0.008	5.586	0.044	3.549
A_2	0.015	4.197	0.062	4.982
B_1	0.027	4.934	0.134	10.789
B_2	0.014	5.305	0.073	5.865
C_1	0.071	10.017	0.709	57.129
C_2	0.019	4.249	0.082	6.628
D_1	0.003	3.86	0.011	0.869
D_2	0.028	4.464	0.126	10.189

The results of the Obstacle Degree Model are shown in Table 5. Indicators with high level of obstacles are C1 and C2, which are the main obstacle factors. This reflects the fact that the resilience level of coastal ports in the context of sudden long-term events is strongly influenced by the level and efficiency of dispatching. Therefore, it can be concluded that when oriented to sudden long-term events, coastal ports should improve the scheduling level and efficiency to enhance their resilience level.

Table 5. Results of Obstacle Degree for long-term

Year	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2
2017	0.0452	0.0622	0.0848	0.01803	0.6199	0.0397	0	0.1298
2018	0.0318	0.0620	0.0805	0.06624	0.6389	0	0.0028	0.1173
2019	0.0267	0.0249	0.0516	0.02046	0.7433	0.0559	0.0074	0.0693
2020	0.0273	0.0236	0.0323	0.01650	0.7365	0.1009	0.0106	0.0520
2021	0.1226	0.0419	0	0	0	0.6038	0.0799	0.1516
2022	0	0	0.3128	0.1700	0.4824	0.0141	0.0205	0
Mean	0.042	0.035	0.093	0.048	0.536	0.135	0.020	0.080

4 Conclusion

In the context of sudden short-term events such as severe weather, cargo throughput is the key indicator for the evaluation of coastal port resilience; in the context of sudden long-term events, punctuality is the key indicator for the evaluation of coastal port resilience. After constructing the coastal port resilience evaluation indexes and screening the key evaluation indexes, this paper provides a preliminary analysis of the resilience level. Coastal ports should act in terms of vessel operations in the event of sudden short-term events, and in terms of scheduling level and efficiency in the event of sudden long-term events. In the future, we can improve the research framework by adding more detailed indicators and use some predictive models to study further.

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