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Resilience Measurement and Enhancement Strategies for Meizhou Bay Port Enterprises

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Abstract: The measurement of resilience in port enterprises has seldom been studied and understood. To assist port enterprises in formulating scientifically sound resilience enhancement strategies, this paper aims to develop a resilience measurement framework. The entropy-weighted TOPSIS method is utilized to measure the resilience of Meizhou Bay Port, effectively extending the application of resilience theory in the port sector and providing a crucial reference for the resilience measurement of port enterprises. The results reveal that the resilience of Meizhou Bay Port decreased from 0.4049 in 2018 to 0.34013 in 2022, indicating a current low level of resilience that requires a series of measures to enhance. Analyzing different dimensions, absorptive capacity experienced the most significant decline at the onset of the pandemic and then stabilized; adaptive capacity decreased the most, falling below absorptive capacity by 2022; and recovery capacity remained the most stable, with the least decline. This reflects the vulnerability of absorptive and adaptive capacities under significant shocks, necessitating attention and improvement in daily port operations.

Keywords: port resilience; entropy-weighted TOPSIS method; Meizhou bay; measurement

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1. Introduction

In recent years, the frequency of uncertain public disasters and disturbances has increased globally, including natural disasters (such as earthquakes, floods, typhoons, and droughts), public health events (such as the COVID-19 pandemic), and extreme weather events triggered by climate change. The COVID-19 outbreak in 2019 is one of the most recent and profoundly impactful global public health emergencies. To curb the spread of the virus, many countries implemented strict epidemic prevention measures, including isolating port staff and reducing shifts and working hours, which led to decreased port operational efficiency, setbacks in port investment and expansion plans, and disruptions in port supply chains [1]. Some countries experienced a decrease in export capabilities due to port operation obstacles, leading to reduced trade surpluses and slowed economic growth. For countries dependent on imported resources, disruptions in port supply chains also meant resource shortages, potentially leading to price increases and even social instability [2]. Similar disturbances will continue to emerge in the future, highlighting the necessity of developing port resilience, which is the ability of enterprises to quickly recover after functional interruptions.

Ports are not only hubs of international trade and engines of regional economic development but also crucial nodes in the global supply chain and energy transportation [3]. They play a key role in driving economic globalization and promoting the development of the service industry. From this perspective, the resilience of port enterprises is of significant importance to both national and global economies. However, research on the measurement

of port enterprise resilience is still lacking. To more effectively propose strategies for enhancing the resilience of port enterprises, it is necessary to establish and validate a framework for assessing port resilience. In particular, this framework should be used to measure the resilience strength of port enterprises.

This paper aims to develop a framework to measure the resilience of port enterprises and verify its applicability. The factors affecting the resilience of port enterprises vary by region and using them solely for port resilience evaluation has limitations in reflecting port characteristics. Therefore, a review and analysis of the literature related to port resilience was conducted to determine the indicator system for measuring port resilience and to form a resilience measurement framework. The literature review revealed that current methods for assigning weights to indicators mainly include subjective and objective weighting methods. Subjective weighting, due to its strong subjectivity and poor objectivity, increases the burden on decision analysts and has significant limitations in application. Objective weighting methods include the entropy method, principal component analysis, deviation and mean square analysis, and multi-objective programming. Among these, the entropy method is the most mature, has low data dependency, does not require specific assumptions or statistical analysis of the data, only needs information on attributes and decision schemes for analysis, and has a relatively simple and easy-to-operate calculation process. The main methods for quantitatively measuring resilience include the MCDA model [4], grey relational analysis [5], factor analysis [6], data envelopment analysis (DEA) [7], and the rank-sum ratio method [8]. The MCDA model and grey relational analysis are highly subjective, and grey relational analysis has difficulties in determining optimal values for some indicators. Factor analysis and DEA have strict requirements on sample quality and indicator design, making them less applicable. The rank-sum ratio method is greatly influenced by extreme values and outliers in the ranking process, affecting the final measurement results. Considering the limited sample size of the research subjects and the data nature of the selected indicators, this paper chose the entropy-weighted TOPSIS method for measurement.

This paper uses the Meizhou Bay Port in China as a case study to comprehensively measure the resilience of the port based on the actual operations of enterprises within the Meizhou Bay Port jurisdiction. First, a resilience measurement indicator system for Meizhou Bay Port enterprises is constructed based on a literature review. Next, the resilience of Meizhou Bay Port is measured using the entropy-weighted TOPSIS method. Finally, specific pathways for enhancing resilience are proposed based on the measurement results.

2. Literature Review

2.1. Concepts of Business Resilience

The concept of resilience was first introduced by Holling in 1973, who defined it as the ability of a population or state to maintain constant variables after experiencing instability factors and disturbances [9]. Building on this, Meyer (1982) introduced resilience into the field of organizational management, marking the beginning of research into business resilience [10]. Since then, the concept of resilience has been applied in various fields, including ecology, psychology, sociology, education, architecture, business management, and economics. The definition of resilience varies by author and, while not identical, most include similar key terms such as disruption, disturbance, maintenance, and recovery. Zhang Jichang et al. (2021) believe that there are four main perspectives on defining resilience: trait, outcome, capability, and process [11]. The trait perspective views resilience as a stress response behavior of enterprises, which inevitably take corresponding measures when faced with difficulties. Zhao Kun et al. (2021) found that to avoid low resource protection factors during opportunity recognition and high situational stimulus factors, enterprises generate resilience characteristics through different strategies at various stages of product development [12]. The outcome perspective considers resilience as the result of enterprise behavior, the output of the enterprise's response to disturbance processes. Fan Bo and Nie Shuang (2017) demonstrated that enterprise resilience results from the interaction

between external environmental factors and the protective resources held by internal entities [13]. The capability perspective views resilience as the adaptability, recovery ability, and transformation capacity that enterprises exhibit in response to uncertainty, change, and shocks. Zheng Mingming et al. (2023) defined resilience as "the ability to quickly return to normal operations after a disruptive event" [14]. The process perspective considers resilience as the process of internal operation and management adjustments, adaptation, and improvements within an enterprise. Ainuddin and Routray (2012) showed that enterprise resilience is a process in which businesses use their resources through the interaction of situational stimulus factors (negative) and resource protection factors [15]. Kim et al. (2014) defined it as "a network-level attribute that enables it to withstand interruptions caused by electrical arc flashes" [16]. Compared to other definitions, this may be a heterogenous definition but still revolves around the "ability to withstand destruction." Kamalahmadi and Parast (2016) described resilience as "the adaptability of a supply chain that maintains the continuity of enterprise structure and function by reducing the likelihood of sudden disruptions" [17]. Shin and Park (2019) defined it as "the capacity to manage the consequences of inevitable events, allowing for the restoration of original operations or transition to a new, more desirable state after disruptions" [18]. Overall, business resilience refers to the ability to prepare for unexpected functional disruptions and to maintain or restore normal functions when disruptions occur, emphasizing the sustainability of functions without interruption.

2.2. Indicator System for Measuring Business Resilience

Although the concept of resilience was introduced early on, research on measuring business resilience is still in its developmental stage. Scholars have proposed various resilience measurement frameworks centered around financial performance, supply chain stability, organizational learning capability, leadership effectiveness, and crisis management abilities. Li Enji et al. (2022) measured business resilience using business performance indicators, including business revenue, return on assets, financial costs, and net profit margin [19]. Wang Gang and Zhao Xia (2023) derived empirical evidence of the impact of the COVID-19 pandemic from economic data and fluctuations in business financial data, analyzing the digital empowerment effect on agroforestry enterprises during crises [20]. While financial performance is crucial, it often overlooks non-financial indicators. Given the critical role of supply chains in modern enterprises, many scholars have developed tools to measure supply chain resilience, assessing aspects such as resilience, adaptability, and learning capacity to ensure that supply chains can quickly adjust and adapt to shocks [21]. Leadership also plays a key role in enterprise resilience, with studies showing that flexible and innovative leadership styles help to shape organizational culture, enhance employees' resilience awareness, and promote more proactive responses to challenges [22]. Scholars aim to comprehensively and systematically reflect all aspects of business resilience in their choice of resilience measurement indicators. Vugrin et al. (2011) built a resilience evaluation framework based on the "resilience triangle" theory, consisting of "absorptive capacity, adaptive capacity, and recovery capacity" [23]. Fu L. and Cao L. (2021) included employee resilience, management resilience, and employee coping styles in the model of organizational resilience impacts [24]. Li Xiaoxiang and Kong Mengqing (2023) used a combination of quick ratio, sedimented redundant resources, non-sedimented redundant resources, and return on net assets to comprehensively evaluate the impact of digital transformation on organizational resilience [25]. In addition to these, different index systems are developed based on varying scenarios, such as reverse mixed reform [26], technology and digitalization [27], and exploratory innovation [28]. The importance of resilience is increasingly recognized by domestic scholars. Resilience is not just the result of a single factor but the product of the interaction of multiple internal and external elements within an organization. Enterprises need to consider these factors comprehensively at multiple levels to develop an all-encompassing resilience strategy.

2.3. Port Resilience

Research on port resilience primarily focuses on three areas: risk management, frameworks for enhancing resilience, and resilience measurement. Resilience is closely linked to risk management, and there are many studies on port risk management. For example, Hui Shan Loh and Vinh Van Thai (2014) proposed a general guideline for addressing port disruptions based on risk management, business continuity management, and quality management, targeting operational deficiencies in ports [29]. Zheng Yeming and others (2022) categorized port resilience risk factors into internal and external causes, with internal factors including port planning, organization, and channel factors, and external factors encompassing environmental, human, and network factors [30]. Risk management focuses on establishing frameworks to enhance recovery capabilities. Wang Nanxi (2023) and others proposed a cyclical four-stage method to study port resilience, summarizing and categorizing the major disruptions currently affecting ports and suggesting strategies to improve preparedness and response capabilities [31]. Ding Min (2023) and others, from the perspective of port importance, proposed paths including strengthening regional collaborative cooperation, enhancing port supply capabilities, optimizing the collection and distribution structure, focusing on the construction of port storage and transportation facilities, strengthening technological innovation empowerment, and enhancing risk awareness [32]. Rice and Trepte (2012) conducted a survey of port operators to understand their experiences with port disruptions and their views on the necessary conditions for creating resilient ports, emphasizing the importance of establishing communication information systems and improving workforce flexibility [33]. S. Kim (2021) and others developed a framework for assessing port resilience based on the literature, which included a multi-level structure of nine factors: robustness, redundancy, visibility, flexibility, collaboration, agility, information sharing, response, and recovery [34]. Shaw and others (2017), through a multi-level case study of the UK port system and from the perspectives of suppliers and users, emphasized the participation of all stakeholders (including operators, shipping companies, and logistics companies) and the establishment of information sharing systems to reduce barriers of complexity, confidentiality, and political sensitivity [35]. Although these studies propose frameworks for enhancing port resilience, they remain somewhat abstract and the specific measures suggested are somewhat subjective without in-depth quantification. Therefore, measuring resilience is necessary. Hu Yanhua and others (2022) introduced safety resilience theory into the port field, proposing a port safety resilience triangle model consisting of disaster systems, disaster-bearing systems, and safety resilience management, and they assessed safety resilience using entropy-weighted theory based on normalized standards [36]. Lin W. S. and Liu W. (2023) divided port resilience into "physical–social–information" dimensions and used the CRITIC entropy method and TOPSIS method to build a resilience evaluation model for ports along the Maritime Silk Road, quantitatively analyzing the comprehensive resilience of 28 ports along the 21st-century Maritime Silk Road [37]. Omer and others (2011) developed a formula based on system dynamics to measure port resilience in terms of tonnage, time, and cost [38]. Kim and others (2023) analyzed the relationship between port security level, resilience, cargo operation performance, and sustainability performance based on structural equation modeling [39]. Gu Bingmei and Jiaguo Liu used a "ship–port–cargo" perspective, combining Hierarchical Holographic Modeling (HHM) with Fuzzy Cognitive Mapping (FCM), to study the impact of supply–demand balance and ship schedule reliability on port resilience [40]. Existing research has made significant contributions to understanding and measuring port resilience, but few papers delve into the concept of port resilience itself and mainly focus on the broader regional port landscape. There is a lack of micro-level analysis of corporate behavior. Therefore, this paper intends to measure the resilience of port enterprises—the "point" behavior—to explore business strategies of port enterprises in scenarios of frequent risks and disturbances.

3. Construction of the Indicator System, Methodology, and Data Sources

3.1. Construction of the Indicator System

Currently, there is no unified standard for constructing the dimensions of resilience measurement indicators for port enterprises. Scholars often build corresponding indicator dimensions based on actual conditions and their own research directions. This paper refers to the resilience triangle theory proposed by Vugrin and others and, combined with the literature review, sets the dimensions of resilience measurement indicators for port enterprises as absorptive capacity, adaptive capacity, and recovery capacity (see Table 1).

Table 1. Indicator system for measuring port resilience in Meizhou Bay.

Dimension	Indicators	Explanation of Indicators	Index Property	Source of Indicators
Absorptive capacity	Total territorial GDP	Gross economic product of a region	Forward	Lin, Liu [37]
	Port throughput	Volume transported into and out of a port area by waterways, roads, railways, pipelines, etc.	Forward	
	Unit consumption of 10,000 tonnes of throughput	Total energy consumption/cargo throughput	Negative	R. Yang et al. [41]
		Total amount of cargo transported and handled through terminals	Forward	Y. Zhu, M. Ming [42]
Adaptive capacity	Port cargo throughput	Proportion of the throughput of cargo types operated to that of the entire Meizhou Bay Port for such cargo types	Forward	Morris [43]
	Salary-to-output ratio	Employee remuneration payable/operating income	Moderation	W. Y. Li [44]
	Return on assets ratio	Total profit/total assets	Forward	Eunji Lee et al. [19]
	Labor productivity	Cargo throughput/total number of employees at the end of the period	Forward	W. Lin, Y. J. Geng [45]
Recovery capability	Port throughput capacity	Capacity of the port to handle cargo per unit of time	Forward	Mateos et al. [46]
	Number of port berths	Number of berths in the port available for ships to berth and load/unload cargoes	Forward	
	Total asset turnover	Operating income/average total assets	Forward	Y. B. Zhang et al. [47]
	Inventory turnover	Operating costs/average inventory balance	Forward	Z. X. Gao [48]

Port absorptive capacity is demonstrated by having access to public utility sources, effectively responding to unexpected demand fluctuations. This paper measures absorptive capacity through local GDP total, tonnage throughput per unit consumption, port collection and distribution volume, and port cargo throughput. Diversified growth in local GDP helps port enterprises to reduce risk, while ports with high collection and distribution volumes are typically better able to absorb market fluctuations. In the face of market demand fluctuations or increased economic uncertainty, port enterprises can maintain business operations more effectively by absorbing disturbances and improving operational efficiency [37]. Low unit consumption contributes to the sustainability of ports by reducing resource waste and improving energy efficiency. By implementing these measures, ports can lower their environmental impact, aligning with sustainable development goals [41]. High throughput helps ports to maintain competitiveness among global ports, as handling large volumes of cargo enhances their position in international trade and attracts more shipping companies and trade partners [42].

Port adaptability reflects actions generated over time due to ingenuity or additional efforts. This article measures it through market share rate, compensation-to-output ratio,

return on assets, and labor productivity. A larger market share brings about economies of scale, enabling companies to operate more efficiently, including cost effectiveness and resource utilization efficiency. This helps to enhance the financial resilience of companies, making them more capable of responding to market changes [43]. Under the high pressure of perturbations, a reasonable compensation-to-output ratio helps to maintain employee satisfaction. If employees feel that their compensation matches their contributions, the company can more easily maintain a positive work atmosphere, reduce employee turnover, increase loyalty, and improve adaptability [44]. The return on assets reflects the economic benefits achieved by the company during its operations, showcasing its ability to cope with external pressures [19]. When market demand fluctuates rapidly, companies with high productivity can more flexibly adjust their operational strategies and respond more quickly to customer needs [45].

Port resilience reflects a port's ability to quickly recover from significant disruptions that cause interruptions in port operations, requiring companies to take emergency measures to resume production as soon as possible. This article measures it through port throughput capacity, number of berths, total port assets, and inventory turnover rate. Port infrastructure is crucial for companies to respond to disturbances. Throughput capacity directly affects a port's ability to handle goods during disasters, emergencies, or other critical periods, while the number of berths concerns the port's potential for expansion and development [46]. Total asset turnover is a financial indicator that measures the efficiency of a company's total asset utilization over a certain period, which is essential for enhancing the economic resilience of port enterprises, making them more flexible and adaptive in the face of crises or market fluctuations [47]. A higher inventory turnover rate indicates that port companies are utilizing their funds more effectively, reducing capital occupation caused by inventory retention. This is significant for quickly adjusting fund and resource allocation during market demand fluctuations or external shocks [48].

3.2. Measurement Methods and Data Sources

3.2.1. Measurement Methods

The first step is to create a raw data matrix. A matrix of indicators is created by combining n measures from m port enterprises, $X = (x_{ij})_{m\times n}(i = 1, 2, 3\cdots m; j = 1, 2, 3\cdots n)$, where X represents the j indicator for the i enterprise.

The second step is to standardize the raw data. To eliminate the dimensional effects of the raw data, it is necessary to standardize the matrix constructed from the raw data, resulting in a dimensionless matrix, $V_{ij} = \{v_{ij}\}(i = 1, 2, 3\cdots m, j = 1, 2, 3\cdots n)$. Based on the different characteristics of the indicators, there are three processing formulas.

When the indicator is a growth-type indicator:

$$v_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}(i = 1, 2, 3\cdots, m; j = 1, 2, 3\cdots n) \quad (1)$$

When the indicator is an adverse-type indicator:

$$v_{ij} = \frac{\min(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}(i = 1, 2, 3\cdots, m; j = 1, 2, 3\cdots n) \quad (2)$$

When the indicator is a moderate-type indicator:

$$v_{ij} = \begin{cases} 1 - \frac{q_1 - x_{ij}}{\max(q_1 - \min(x_{ij}) - q_2)}, x_{ij} < q_1 \\ 1 - \frac{x_{ij} - q_2}{\max(q_1 - \min(x_{ij}) - q_2}, x_{ij} > q_2 \end{cases} \quad (3)$$

where x_{ij} is the original data, i = 1, 2, . . ., m (m is the number of port enterprises); j = 1, 2, . . ., n (n is the number of port business resilience measures), and $[q_1, q_2]$ is a reasonable fitness interval for the original data x_{ij}.

Translation of the coordinates when the result $V_{ij} < 0$ is calculated as follows:

$$v'_{ij} = v_{ij} + d, d = 0.0001 \tag{4}$$

The third step is to specify the weights of the indicators.

Firstly, it is necessary to calculate the weight of each sub-indicator in the upper level of indicators, as follows:

$$P_{ij} = \frac{v'_{ij}}{\sum_{i=1}^{m} v_{ij}} (i = 1, 2, \cdots, m; j = 1, 2, \cdots, n) \tag{5}$$

Secondly, the information entropy of each specific indicator is calculated as follows:

$$e_j = -\frac{\sum_{i=1}^{m} p_{ij} (\ln p_{ij})}{\ln m} \tag{6}$$

Finally, weights for specific indicators are calculated as follows:

$$W_j = \frac{1 - e_j}{\sum_{j=1}^{m} (1 - e_j)} (j = 1, 2, \cdots, n) \tag{7}$$

Step 4, the dimensionless matrix obtained in the second step is weighted to obtain matrix R:

$$R = \begin{pmatrix} R_{11} & \cdots & R_{1n} \\ \vdots & \vdots & \vdots \\ R_{m1} & \cdots & R_{mn} \end{pmatrix} = \begin{pmatrix} V_{11}W_1 & \cdots & V_{1n}W_1 \\ \vdots & \vdots & \vdots \\ V_{m1}W_m & \cdots & V_{mn}W_m \end{pmatrix} \tag{8}$$

Step 5, positive and negative ideal solutions are found:

$$R^+ = \{\max R_{i1}, \max R_{i2}, \max R_{i3}, \max R_{in}\} \tag{9}$$

$$R^- = \{\min R_{i1}, \min R_{i2}, \min R_{i3}, \min R_{in}\} \tag{10}$$

Step 6, the distance of each indicator from the positive and negative ideal solutions is calculated as follows:

$$D_i^+ = \sqrt{\sum_{i=1}^{m} (R_{ij} - R_j^+)^2} \tag{11}$$

$$D_i^- = \sqrt{\sum_{i=1}^{m} (R_{ij} - R_j^-)^2} \tag{12}$$

Step 7, a measurement score is derived, as follows:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{13}$$

C_i is a measure relative to the optimal solution and the value is between 0 and 1: a value closer to 1 means that the measure is closer to the optimal solution, indicating a higher level of resilience; on the contrary, a lower value means the measure is closer to the worst solution, and the lower the level of resilience of the enterprise. When the value is equal to 1, it indicates the highest level of resilience, and when the value is 0, it indicates that the firm is in a state of collapse and the system has suffered a huge shock.

3.2.2. Data Sources

This paper focuses on Meizhou Bay Port as the research area. Due to some enterprises starting production later, there is a lack of data support for horizontal comparisons by

year; some enterprises have been repeatedly acquired, resulting in a lack of continuity in data statistics. Therefore, following the principle of data availability, 15 port enterprises were selected as the subjects of this study. The time series data were mainly derived from five types of reports: enterprise port cargo classification transportation modalities, port cargo throughput, port energy consumption, business operation conditions, and corporate financial status.

4. Results and Analyses of Resilience Measures

4.1. Toughness Measurement Result

4.1.1. Calculate the Weight of Each Indicator

Following the steps outlined above, the weights for each dimension and indicator of resilience measurement for Meizhou Bay Port were calculated, as shown in Tables 2 and 3.

Table 2. Indicator weights for the three dimensions of port resilience in Meizhou Bay.

Dimension	2018	2019	2020	2021	2022
Absorptive capacity	0.28787	0.27003	0.25108	0.24826	0.27123
Adaptive capacity	0.31787	0.30553	0.27741	0.28123	0.25074
Recovery capability	0.39425	0.42444	0.47151	0.47052	0.47803

Table 3. Weights of resilience indicators for Meizhou Bay Port.

Indicators	2018	2019	2020	2021	2022
Total territorial GDP	0.06251	0.06448	0.06407	0.06524	0.06573
Port throughput	0.07800	0.07890	0.07056	0.07113	0.08284
Unit consumption of 10,000 tonnes of throughput	0.05357	0.03108	0.02821	0.02414	0.02717
Port cargo throughput	0.09380	0.09556	0.08824	0.08775	0.09548
Market share ratio	0.10614	0.10001	0.10793	0.10035	0.12210
Salary-to-output ratio	0.05019	0.05716	0.03186	0.02853	0.01951
Return on assets ratio	0.06009	0.03846	0.03989	0.03482	0.02525
Labor productivity	0.10145	0.10989	0.09774	0.11753	0.08388
Port throughput capacity	0.12150	0.09240	0.09361	0.09650	0.10532
Number of port berths	0.12011	0.13551	0.13727	0.15541	0.18081
Total asset turnover	0.07863	0.11364	0.16952	0.12604	0.11352
Inventory turnover	0.07402	0.08289	0.07111	0.09256	0.07838

4.1.2. Calculated Resilience Score

The raw data, made dimensionless and weighted, were calculated to obtain the overall resilience and the resilience measurements of each dimension for Meizhou Bay Port, as shown in Tables 4–8.

Table 4. Results of port overall resilience measurements in Meizhou Bay.

Time	2018	2019	2020	2021	2022
Overall Resilience	0.4049	0.36054	0.35035	0.34848	0.34013

Table 5. Results of resilience force in different dimensions at Meizhou Bay Port.

Time	2018	2019	2020	2021	2022
Absorptive capacity	0.12526	0.10587	0.10579	0.10650	0.11183
Adaptive capacity	0.13921	0.11968	0.10397	0.10379	0.09361
Recovery capability	0.14043	0.13498	0.14059	0.13819	0.13469

Table 6. Results of absorption capacity of Meizhou Bay Port.

Time	2018	2019	2020	2021	2022
Total territorial GDP	0.02832	0.02569	0.02607	0.02370	0.02647
Port throughput	0.03188	0.02991	0.03043	0.03395	0.03359
Unit consumption of 10,000 tonnes of throughput	0.03212	0.01707	0.01758	0.01838	0.01655
Port cargo throughput	0.03293	0.03320	0.03170	0.03048	0.03522

Table 7. Results of adaptive capacity of Meizhou Bay Port.

Time	2018	2019	2020	2021	2022
Market share ratio	0.03774	0.03388	0.03273	0.03046	0.03846
Salary-to-output ratio	0.03515	0.03185	0.02174	0.02046	0.01386
Return on assets ratio	0.03196	0.02194	0.02010	0.02086	0.01377
Labor productivity	0.03436	0.03202	0.02939	0.03202	0.02752

Table 8. Results of recovery capability of Meizhou Bay Port.

Time	2018	2019	2020	2021	2022
Port throughput capacity	0.03698	0.03061	0.03101	0.03024	0.03191
Number of port berths	0.03689	0.03879	0.03929	0.04013	0.04516
Total asset turnover	0.03429	0.03059	0.04302	0.03354	0.03164
Inventory turnover	0.03227	0.03498	0.02727	0.03428	0.02598

4.2. Analysis of Resilience Measurement Results

4.2.1. The Result Analysis of Index Weights

As shown in Figure 1, from the perspective of individual dimension weight coefficients, the weight value of the recovery capability dimension was greater than that of absorption capability and adaptive capability from 2018 to 2022, and the weight value showed an increasing trend year by year. Starting from 2019, the proportion of recovery capability began to exceed 40%, and from 2020, it exceeded 47%, which coincided with the timeline of the COVID-19 impact, further validating the accuracy of the indicators selected in this paper. Therefore, for port enterprises, when facing shocks, recovery capability had the greatest impact on the resilience of port enterprises. Port enterprises should regularly evaluate and plan four indicators in their daily operations: port throughput capacity, number of port berths, total asset turnover rate, and inventory turnover rate. Among the three dimensions, the lowest weight was absorption capability, with weights of only 25.1% and 24.8% during the most stringent pandemic control periods in 2020 and 2021, respectively. However, this does not mean that absorption capability should be ignored. For a company to develop, all aspects should be considered comprehensively; it is just that different strategies should be adopted in special periods.

4.2.2. Analysis of Global Toughness Measurement Results

As shown in Figure 2, from 2018 to 2022, the overall resilience of Meizhou Bay Port showed a declining trend, particularly in 2019, when the resilience score dropped sharply by 11%. This was mainly due to the impact of the COVID-19 pandemic, which had a significant short-term impact on China's economy during the initial outbreak and subsequently affected port production. The measurement results clearly showed that, within the dimensions of port resilience, while the recovery capability remained relatively stable, both the absorption capability and adaptive capability declined rapidly. In 2019, the scores for absorption capability and adaptive capability dropped by 15.5% and 14%, respectively. This both validated the scientific basis of the resilience triangle theory, which categorized enterprise resilience into absorption capability, adaptive capability, and recovery capability based on the magnitude of risk impact, and demonstrated the stability of the recovery

capability of Meizhou Bay Port enterprises. In the face of significant shocks, recovery capability serves as the last line of defense, enabling enterprises to rapidly restore port production through a series of remedial measures.

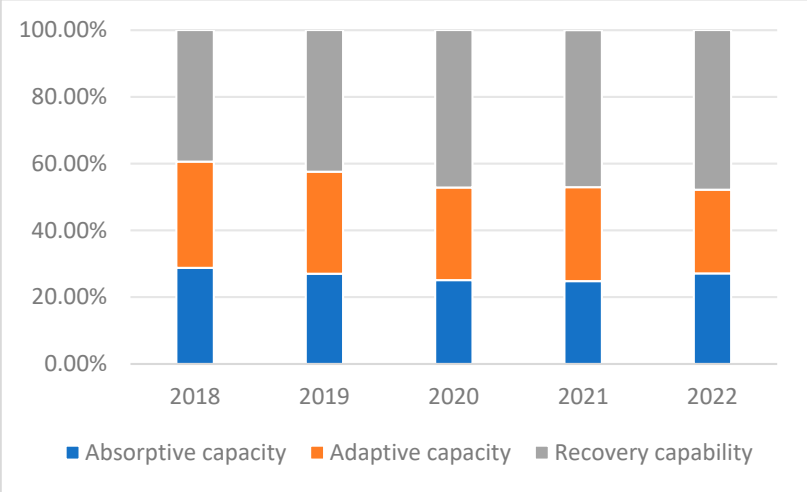


Figure 1. Port enterprise resilience dimension weights, 2018–2022.

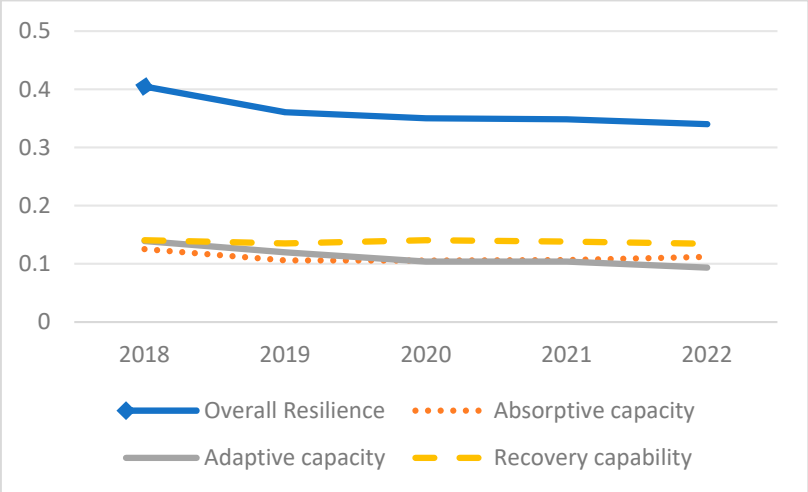


Figure 2. Results of the resilience measurement for port enterprises, 2018–2022.

4.2.3. Analysis of Three Dimensions Toughness Measurement Results

Dimensional analysis of absorption capacity

As shown in Figure 3, the indicators of the absorption capacity of port enterprises in Meizhou Bay exhibited a fluctuating trend, with a significant drop in most indicators in 2019. This aligned with the nature of absorption capacity, which is the first to fail when facing significant impacts, requiring enterprises to rely on other capabilities for recovery and adjustment to maintain normal operations. The local GDP score dropped sharply from 2018 to 2022, followed by repeated rises and falls, closely related to pandemic control policies. Cities would lock down and restrict movement, halting some industrial production whenever a case was detected, and would gradually recover after achieving "zero cases". This led to repeated stoppages and resumptions of operations for hinterland enterprises due to the uncertainty of case development.

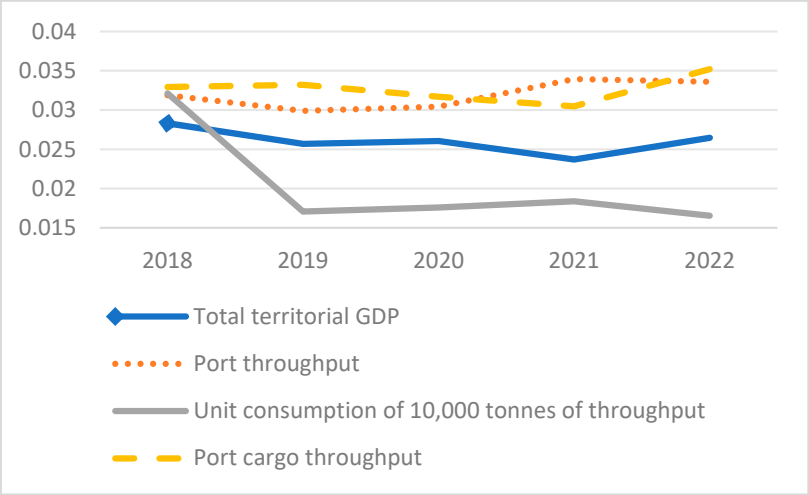


Figure 3. Absorptive capacity score, 2018–2022.

Similarly, the single consumption per ten thousand tons of throughput also saw a sharp decline from 2018 to 2019, a slight increase from 2019 to 2021, and a slight decrease again from 2021 to 2022. This phenomenon was mainly due to changes in port operations during the initial stages of pandemic control, causing operational inefficiencies such as reduced ship inspection efficiency, difficulties in workers clearing holds while wearing protective gear, and poor ship-to-shore communication, leading to increased port stay times and prolonged machinery idle times. The slight increase from 2019 to 2021 was mainly due to the gradual clarification of port control measures, which improved the efficiency of ship-to-shore operations. The slight decrease from 2021 to 2022 was primarily because of the comprehensive lifting of pandemic controls at the end of 2022, with port workers being infected, which temporarily reduced operational efficiency.

The scores for port collection and distribution volume and port cargo throughput remained relatively stable, with minor fluctuations, mainly due to the types of cargo handled by port enterprises in Meizhou Bay. These enterprises primarily deal with key livelihood materials such as coal, oil, natural gas, and grain. National macro policies have consistently emphasized maintaining smooth logistics for these essential materials, ensuring that port operations and production do not experience significant disruptions.

Dimensional analysis of adaptive capacity

Adaptive capacity has four indicators in total. As shown in Figure 4, except for market share rate, all other indicators were lower at the end of 2022 compared to the end of 2018. Among them, the market share rate score showed a significant decline from 2018 to 2021 but rapidly rebounded in 2022 to a level higher than that in 2018. This improvement was attributed to the country's emphasis on the industrial chain and supply chain, proposing the construction of material reserve bases. Certain materials such as coal and oil received increased attention and assurance in 2022.

The salary–output ratio score exhibited a noticeable downward trend, declining from 0.03515 in 2018 to 0.01386 in 2022, an average annual decrease of 13%. This was mainly due to epidemic control policies requiring port workers to implement shift work management, such as 7 + 7, 14 + 7 + 7, and N + 7, which increased labor costs for port enterprises.

The return on assets and the salary–output ratio scores showed consistent downward trends, primarily due to a series of control measures that increased operating costs for ports. Some countries implemented preferential control measures for daily necessities, causing price inversions in commodities such as natural gas, leading to less than ideal profit conditions for port enterprises.

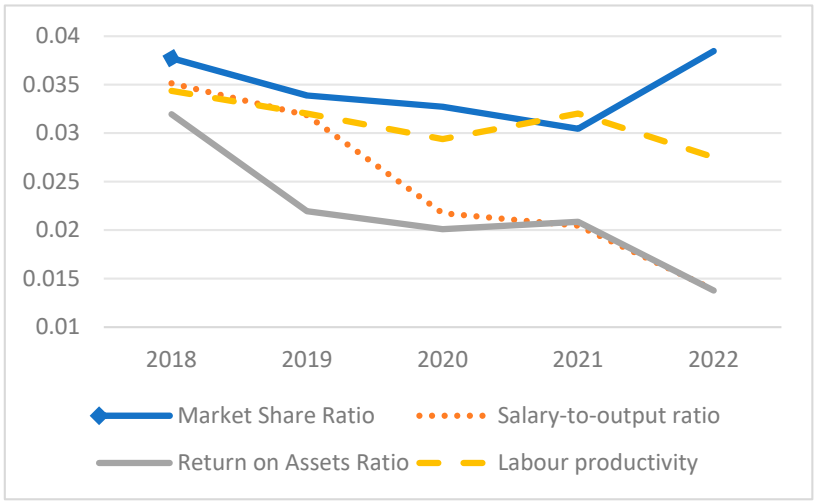


Figure 4. Adaptive capacity score, 2018–2022.

The labor productivity score remained relatively stable. Although the number of port workers increased, the increase in throughput of port cargo was even greater.

Dimensional analysis of recovery capability

From Figure 5, it is evident that the port throughput capacity score experienced a significant decline from 2018 to 2019 but then stabilized, with slight fluctuations thereafter, maintaining an overall range between 0.03 and 0.032. Port throughput capacity is closely related to berth quantity, classification, and operational efficiency, with fluctuations primarily due to changes in operational efficiency. The score for port berth quantity increased year by year, indicating that various port enterprises in the Meizhou Bay area had sufficient berths to effectively cope with shocks and risks, positively impacting port operational efficiency.

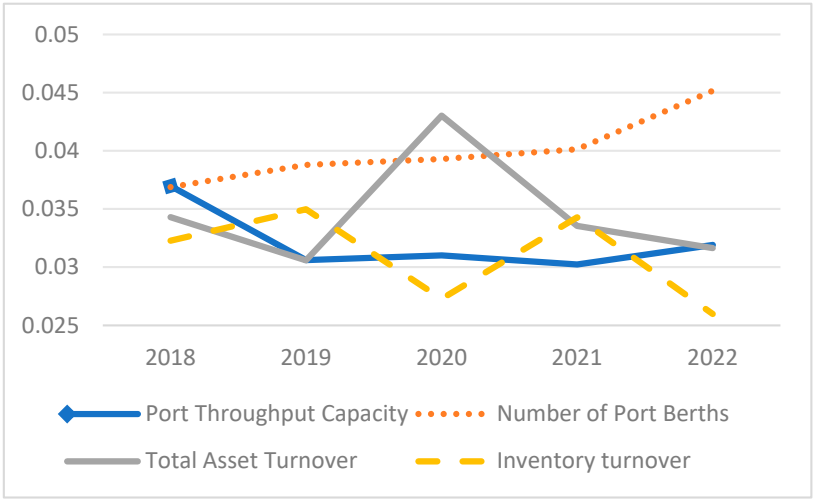


Figure 5. Recovery capability score, 2018–2022.

The total asset turnover rate showed considerable variability. There was a decline from 2018 to 2019, followed by a sharp increase in 2020, and rapid declines again in 2021 and 2022. From the raw data, this was due to enterprises expanding operations in mixed ore blending and bonded ship fueling. In 2020, various enterprises significantly increased their operating income. The subsequent rapid declines were mainly due to the increase in average total assets. From 2020 to 2022, port enterprises in the Meizhou Bay area collectively added six new berths.

Inventory turnover rate scores showed fluctuating trends. There were no significant fluctuations from 2018 to 2019, indicating strong risk resistance practices by enterprises in this regard. However, from 2019 to 2022, there was a jagged fluctuation pattern, primarily due to the establishment and operation of national material reserve bases, which introduced instability.

5. Resilience Enhancement Strategies for Port Enterprises

(1) Actively serve the landing and development of port-related industries. Fully leverage the leading role of ports to serve the construction of modern industries and the expansion of domestic demand, and establish a new pattern of integrated port-industry-city development. First, actively support the expansion of port-adjacent industries, such as petrochemical and energy industries, and power plants. Proactively connect with projects like Sinochem Phase III, Furefining's 1-million-ton ethylene project, the Xiuyu downstream propylene industry, and LNG cold energy bases to attract investments, and accelerate the construction of major port industry-supporting docks, guiding public docks to enhance the transportation quality of chemical products. Second, focus on enhancing the service functions of port-related industries, accelerate the construction of supporting public docks and waterways for port-related industries, and support industrial parks in strengthening, extending, and supplementing industrial chains.

(2) Continuously expand the hinterland reach of the port. First, facilitate internal economic circulation. Fully utilize the advantages of westward, eastward, southward, and northward connections to expand the hinterland toward land and sea and open up a major channel for land–sea and river–sea intermodal transport. Actively coordinate with railway departments to reduce fares and increase transport capacity, effectively turning transport distance advantages into freight cost advantages, reducing logistic costs for iron ore and coal customers within Jiangxi Province. Closely cooperate with cities connected by port railways, deepen roots in Jiangxi, look toward the two lakes, find complementary opportunities and suitable goods for ports, and promote the construction of inland and enclave ports, thus fostering bi-directional land-sea goods circulation. Leverage the advantages of bulk cargo hub ports, promote cooperation with ports along the Yangtze River, and vigorously develop water-to-water trans-shipment. Second, consolidate the international external circulation channel. Actively connect with the "Maritime Silk Road" initiative; strengthen exchanges and cooperation with countries along the Maritime Silk Road; expand import of bulk cargo such as crude oil, natural gas, and ore; promote export of refined oil goods; and create an important port for bulk cargo import and export in the "Maritime Silk Road" pioneer area.

(3) Fully promote the aggregation of port-related trade and logistics. Relying on the port's platform advantages of cargo flow, capital flow, and information flow aggregation, accelerate the cultivation and aggregation of trade logistics and value-added services to further transform and upgrade the port. First, leverage the aggregation advantages of logistics and shipping resources to promote the construction of a bulk cargo trading platform and establish trading centers for coal, ore, and chemicals. Encourage strong domestic and foreign port and shipping enterprises to invest in Meizhou Bay Port and develop port shipping businesses, enriching investment entities. Second, extend port service functions; support port enterprises in expanding logistics, commerce, information, and financial services based on loading, unloading, and warehousing services; develop bonded warehousing and delivery warehousing; carry out distribution, circulation processing, inventory management, and other value-added services; diversify operations; and enhance quality benefits and service levels. Third, improve and enhance container transport functions; coordinate and collaborate with dock enterprises, shipping enterprises, and container trucking enterprises and other related entities; promote the development of container shipping routes; and support the construction of the "Silk Road Sea Route."

(4) Actively enhance the quality of port transportation services. Compensate for deficiencies in cost reduction and efficiency enhancement; focus on customer needs; provide efficient, convenient, and reliable services; upgrade port loading and unloading facilities and equipment; improve loading and unloading efficiency and service levels; invest in modern equipment, automation technology, and environmentally friendly facilities to attract more ships and cargo; enhance customer satisfaction; retain existing customers; and attract new customers.

(5) Fully stimulate the enthusiasm of port workers for entrepreneurship. First, enhance the quality and skills of employees through investment in employee training and development, enhance employees' professional qualities and skill levels, help employees master the latest technology and management knowledge, and improve work efficiency and productivity. Second, establish incentive mechanisms, encourage employees to work actively and improve performance, establish reward systems, and reward employees who perform excellently to stimulate their motivation and enthusiasm for work. Third, optimize the organizational structure and processes, especially for state-owned enterprises, streamline decision-making processes, reduce management levels, optimize job division and cooperation mechanisms, enhance team execution efficiency, and reduce salary costs. Fourth, focus on employees' work environment and welfare benefits, enhance employees' job satisfaction and loyalty, provide good working conditions and benefits, foster employees' sense of belonging and responsibility, and increase their work motivation and productivity, thereby improving the wage–output ratio.

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