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INTEGRATION NEEDS AND CHALLENGES FOR GREEN AND SMART TRANSFORMATION OF PORT INDUSTRY BASED ON MULTI-SOURCE DATA

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This research explores the integration needs and challenges for achieving green and smart transformation in the port industry, leveraging multi-source data and geographic information technology. The study utilizes comprehensive data, including information from the National Enterprise Credit Information Publicity System, the National Catalogue Service for Geographic Information, and road network maps of Jiangsu Province in China. Geographical analysis methods, such as weighted kernel density estimation and standard deviation ellipse analysis, are employed to identify spatial distribution patterns and changes in the port and shipping service industry. The results indicate a spatial distribution pattern with weak expansion from the center along the "northwest-southeast" direction. Challenges such as decentralized management and competing interests hinder port integration for sustainable development. By understanding the spatial dynamics, policymakers can make informed decisions for a greener, smarter, and more efficient port sector.

1. INTRODUCTION

1.1. SMART AND GREEN TRANSFORMATION

China's Jiangsu province, with its extensive coastline, boasts a remarkable array of ports, including seven of China's major ports and five of its key maritime ports. In 2020, the province's ports impressively handled 2.97 billion tons of cargo, demonstrating steady year-on-year growth. Furthermore, foreign trade throughput reached 560 million tons, and container throughput registered 18.95 million TEU, contributing to Jiangsu's status as a leading port in China regarding cargo passing capacity, berths of 10,000-ton class and above, cargo throughput, and ports handling 100 million tons. Despite these remarkable achievements, the current operation of Jiangsu's ports predominantly occurs at the municipal level, leading to a lack of inter-regional connections that adversely affect comprehensive management and coordination [1].

The inefficiency of this development mode diverts local governments' attention away from optimizing port resource utilization efficiency and environmental governance, primarily focusing on short-term economic gains and political objectives [2]. Consequently, the industry faces low specialization and fierce homogeneous competition. For instance, most port enterprises in Jiangsu primarily load and unload dry or liquid bulk, lacking specialized wharves, resulting in underdeveloped port specialization [3]. Homogeneous competition further restricts the resource allocation capacity of port enterprises in Jiangsu, impeding their potential for further growth. Additionally, the utilization rate of coastal ports along the Yangtze River in Jiangsu remains below the national average, with only 60 % of the coastal resources developed and utilized and limited opportunities for developing deep-water coastal resources [4]. High costs and complexity further hinder coastal port development. Ineffective land resource protection and diversion for other purposes add to coastal ports' challenges, compounded by increasing constraints from marine environmental assessments. Ports with high-pollution products, such as steel and coal, like Suzhou Port, have long grappled with environmental supervision problems, highlighting the pressing need for sustainable and intelligent transformation.

To address these challenges and achieve sustainable development and coordination, Jiangsu province is actively reshaping port layout planning at both the provincial and municipal levels, introducing concepts like "smart port" and "green port" [5]. Establishing Jiangsu Port Group in 2017 marked a pivotal step, integrating major state-owned port assets and provincial port and shipping enterprises along the Yangtze River and coastal regions to establish a hierarchical port development pattern. Integration efforts aim to create intelligent and comprehensive management of ports in Jiangsu, with coastal port groups envisioned along the coast. The Layout Plan of Jiangsu Coastal Ports (2015-2030) emphasizes the integration of data, transformative improvements, optimized development, and enhanced modernization of ports. Riverside ports play a crucial role in fostering integrated transport systems, shaping industrial layouts, and contributing to sustainable urban development. On the other hand, coastal ports will focus on expediting basic equipment construction, facilitating larger scale, standardized, and centralized port area layouts.

Furthermore, Jiangsu province has released the Jiangsu Green Port construction three-year action plan (2018-2020) and other policy specifications to anchor sustainable development as the overarching integration goal. This plan aims to enhance long-term supervision mechanisms for port ecological and environmental protection, thereby promoting green transformation and upgrading of ports. The ultimate objective is achieving a green, circular, low-carbon, sustainable transportation system. Through comprehensive integration and transformative measures, Jiangsu's ports are gradually realizing environmentally friendly supervision of ship pollutants, water pollution, shore power facilities, a green environment, and efficient dust and oil and gas recovery management.

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1.2. MULTI-SOURCE DATA AND GEO-INFORMATIONAL PERSPECTIVE

The quest for sustainable and environmentally friendly practices in the industry has become a pressing global priority [6,7]. As ports play a vital role in facilitating international trade and economic growth, their environmental impact cannot be overlooked. Successfully integrating various factors is essential to achieving greener and more sustainable port operations. However, this endeavor has complexities, and understanding the challenges associated with green integration is paramount.

In recent years, there has been a growing realization that addressing the environmental challenges faced by ports requires a comprehensive approach that goes beyond traditional methods. There may need to be more than the conventional reliance on isolated data sources and single-dimensional analyses to unravel the intricacies of port operations and their environmental implications. Instead, harnessing the potential of multi-source data becomes pivotal in comprehending the multifaceted aspects of port sustainability.

Multi-source data refers to the amalgamation of diverse data sets from various origins, including but not limited to satellite imagery, remote sensing, geospatial data, and socioeconomic information. By leveraging the power of multi-source data, researchers and stakeholders gain access to a broader range of insights that would have been otherwise challenging to acquire through singular sources. This holistic approach provides a comprehensive understanding of the interactions between the port industry, the environment, and the surrounding communities.

The green integration of ports demands a deep understanding of several intertwined aspects, such as the utilization of coastal resources, the impact of port activities on marine ecosystems, and the socio-economic implications of sustainable practices. Multi-source data, with its capacity to provide diverse and complementary information, is instrumental in investigating these complexities.

Moreover, as port operations often span multiple administrative divisions, each with distinct policies and regulations, understanding the challenges of green integration requires a geographically focused perspective. Analyzing the data from a geographical standpoint offers unique insights into the spatial distribution of environmental impacts, resource utilization patterns, and the interconnectedness of different port facilities.

In this context, this research seeks to underscore the significance of employing multi-source data and geographical analysis to explore the difficulties and barriers faced during the green integration of ports in Jiangsu province, China. By integrating data from various sources and adopting a geographical lens, this study aims to comprehensively assess the challenges and potential solutions for achieving sustainable and intelligent port operations. The findings of this research endeavor can inform policymakers, port authorities, and stakeholders in their efforts to address the environmental impact of port activities and promote a greener and smarter port industry in Jiangsu province and beyond.

2. METHODOLOGY

2.1. GEOGRAPHICAL ANALYSIS METHODS

2.1.1. DATA COLLECTION

This paper divides the overall port shipping industry into the Shipping Service and Derivative Shipping Service industries. The data is obtained with Python from the National Enterprise Credit Information Publicity System (http://gsxt.amr.gd.gov.cn/), the National Catalogue Service for Geographic Information (www.webmap.cn), and the road network maps of each city in Jiangsu Province. Concerning the port & shipping industry classification in previous literature [3,8], we found the relevant enterprises in these data platforms by searching with keywords. We categorized these enterprises with the priority field described in the National Enterprise Credit Information Publicity System. items are introduced. This article collects 10640 enterprise data and categorized them with the time division of "Before 2000", "2001-2010" and "2011-2020" (Table 1).

Table 1

Classification, structure, and number of enterprises of port shipping industry in Jiangsu.

First Classification	Sub-Category	Enterprise Quantity		
		Before 2000	2001-2010	2011-2020
Overall Port Shipping Industry		2703	2496	5441
Shipping Service Industry	Storage; Loading and Unloading; Handling; Container Road Transport; Water Cargo Transport (Ocean, Coastal and Inland); Cargo Port; Multimodal Transport	664	1266	3683
Derivative Industry	International Shipping Agency; International Freight Forwarding Agency; Ship Inspection; Ship Repair and Building; Ship and Equipment Supply; Shipping and Ship Technology Development and Transfer	2039	1230	1758

2.1.2. WEIGHTED KERNEL DENSITY ESTIMATION

Kernel density estimation mainly estimates the density of point or line patterns using a moving window. Considering the spatial stability of each enterprise, different registered funds are weighted in the calculation to explore the evolution of different types of spatial distribution in the shipping service industry [9,10]. The kernel density is generally defined: let x_1,..., x_n be independent identically distributed samples drawn from the population with a distribution density function of f. it is estimated that f is the value at a certain point x. The Rosenblatt-Parzen kernel estimation is commonly used.

$$f_n(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x-x_i}{h}\right), \qquad (1)$$

where: k is the kernel function; h is the bandwidth, greater than 0, and its determination or selection has a great impact on the calculation result; $x - x_i$ is the distance between the estimated point and the sample x_i. ArcGIS10.8 calculates the weighted kernel density in this paper, and the weighted values for registered capital below 0.5 million yuan, 0.5-1 million yuan, 1-5 million yuan, and more than 5 million yuan are 1-4, respectively.

2.1.2. STANDARD DEVIATION ELLIPSE

To understand the structural characteristics of spatial geographic elements, we chose the standard deviation ellipse (SDE) method, first proposed by Lefever in 1926. The mean center, the median center, and the mode center were first studied. Centrality and aggregation are important spatial structural features that reflect industrial efficiency. Standard deviation ellipses are created to summarize the spatial characteristics of geographic features: central tendency, outliers, and direction trends (Zhang et al., 2023). Tools are available to visualize standard deviation ellipses in ArcGIS. Standard deviation ellipse (SDE) has become a classic algorithm for exploring the spatial distribution direction and spread of elements, which can help us understand the overall spatial structural characteristics of the shipping service industry in Jiangsu. Therefore, the present study used ArcGIS 10.8 software to operate the SDE to explore the spatial distribution direction and scope of the shipping service industry in Jiangsu. The calculation formula is as follows:

$$\tan \alpha = \frac{\left(\sum_{i=1}^{n} \bar{x}_i^2 - \sum_{i=1}^{n} \bar{y}_i^2\right) + \sqrt{\left(\sum_{i=1}^{n} \bar{x}_i^2 - \sum_{i=1}^{n} \bar{y}_i^2\right)^2 + 4\left(\sum_{i=1}^{n} \bar{x}_i \bar{y}_i\right)^2}}{2\sum_{i=1}^{n} x_i - y_i}, \quad (2)$$

$$\sigma_x = \sqrt{\frac{2\sum_{i=1}^{n} (\bar{x}_i \cos \alpha - \bar{y}_i \sin \alpha)^2}{n}},$$

$$\sigma_y = \sqrt{\frac{2\sum_{i=1}^{n} (\bar{x}_i \sin \alpha + \bar{y}_i \cos \alpha)^2}{n}},$$

where, $\bar{x}_i, \bar{y}_i$, is the difference between the mean center of different shipping service enterprises and the $x\,y$ coordinates. σ_x and σ_y is the standard deviation along the x-axis and y-axis, respectively.

3. RESULTS

3.1. UNDERSTAND SOLIDIFICATION WITH DENSITY MAPPING

3.1.1. YANGTZE RIVER DELTA

The Global Shipping Traffic Density database jointly established by the World Bank and IMF is used to draw the pictures in this paper. And as part of the IMF's World Seaborne Trade Monitoring System [12]. The dataset spans 2015-2020, with all observed ship movements and a resolution of 500m. It also contains data on various types of ships, including merchant ships, oil tankers, containers, and other types of ship density distribution data. This paper adopts the point density analysis tool in ArcGIS [13]. The shipping density of Jiangsu province and its adjacent regions is finally drawn by removing the background value of 0 and dividing the region with the natural breakpoint method. Figures 1 and 2 introduced the shipping density in the Yangtze River delta region and the weighted kernel density of the port shipping industry in Jiangsu. Secondary literature has found that the shipping density of ports in Shanghai, Ningbo, and Qingdao from 2015 to 2020 was significantly higher than that in Jiangsu. Reference [14] reveals that in the past 30 years, the port system in the Yangtze River Delta region has changed from centralized development to decentralized development, closely related to the evolution of the hub ports in the Yangtze River Delta. Since the 1980s, Shanghai port, as a hub port in the Yangtze River Delta region, has benefited from the scale effect, its continuous expansion of the port scale, and its radiation effect on the surrounding ports, which has been increasingly enhanced. From 1981 to 1999, the market share of Shanghai Port's cargo and container throughput accounted for more than 37 % and 70 %, respectively.

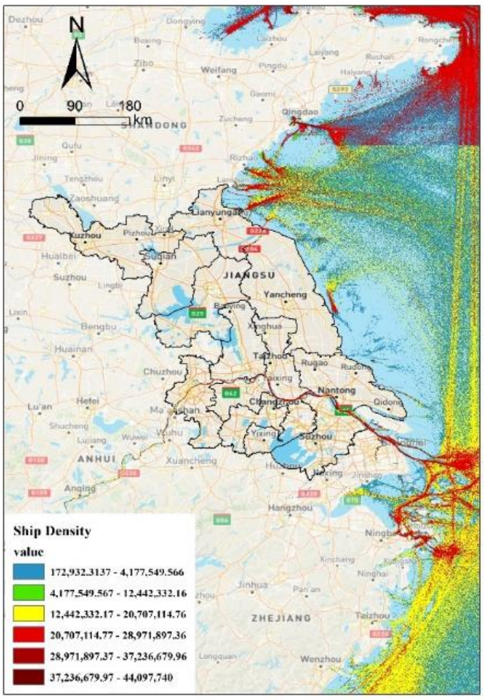


Fig. 1 – Jiangsu Shipping Density between 2015-2020.

During this period, Shanghai port, which had a large competitive advantage, has been leading the evolution of the port system in the Yangtze River Delta region. With the acceleration of economic development, Shanghai Port has gradually developed into a regional comprehensive logistics center. Still, a single port has obvious limitations in geography and logistics convenience, so Ningbo-Zhoushan Port has emerged as a new hub within the Yangtze River Delta. So far, although Suzhou Port in Jiangsu Province is considered to have great potential and outstanding coastal resources, it has yet to be a hub port like Shanghai and Ningbo. As shown in Fig. 1, the shipping density of relevant ports in Jiangsu is significantly lower than in Shanghai and Ningbo. Why does Jiangsu's shipping develop slowly? Past scholars attribute this current situation to the decentralized management of Jiangsu. Jiangsu is rich in water transport resources, especially inland rivers, and coastal resources, which led to the emergence of port trade in various cities and regions. Such a situation can be vividly observed in Fig. 1. The inland shipping density of Jiangsu can reach the range of 2070114.77-28971897.36, but only Lianyungang and Yancheng two coastal ports can reach this range to a certain extent. Local administrations consider their interests and carry out shipping competition in Jiangsu Province. The aggravation of vicious competition hinders realizing the potential for shipping in Jiangsu province. For this geopolitical and historical reason, local interests will be affected after the implementation of Jiangsu integration. Port integration in Jiangsu faces many conflicts, which will be analyzed in the following.

3.1.2. EVOLUTION IN JIANGSU

Based on the calculation results of the kernel density by type (Fig 2), the overall shape of the port and shipping service industry presents obvious spatial agglomeration characteristics. Before 2000, the overall port and shipping service industry was mainly concentrated in coastal and riverside cities, especially Yancheng City, Huai'an City, and other areas. The overall port and shipping enterprises in these

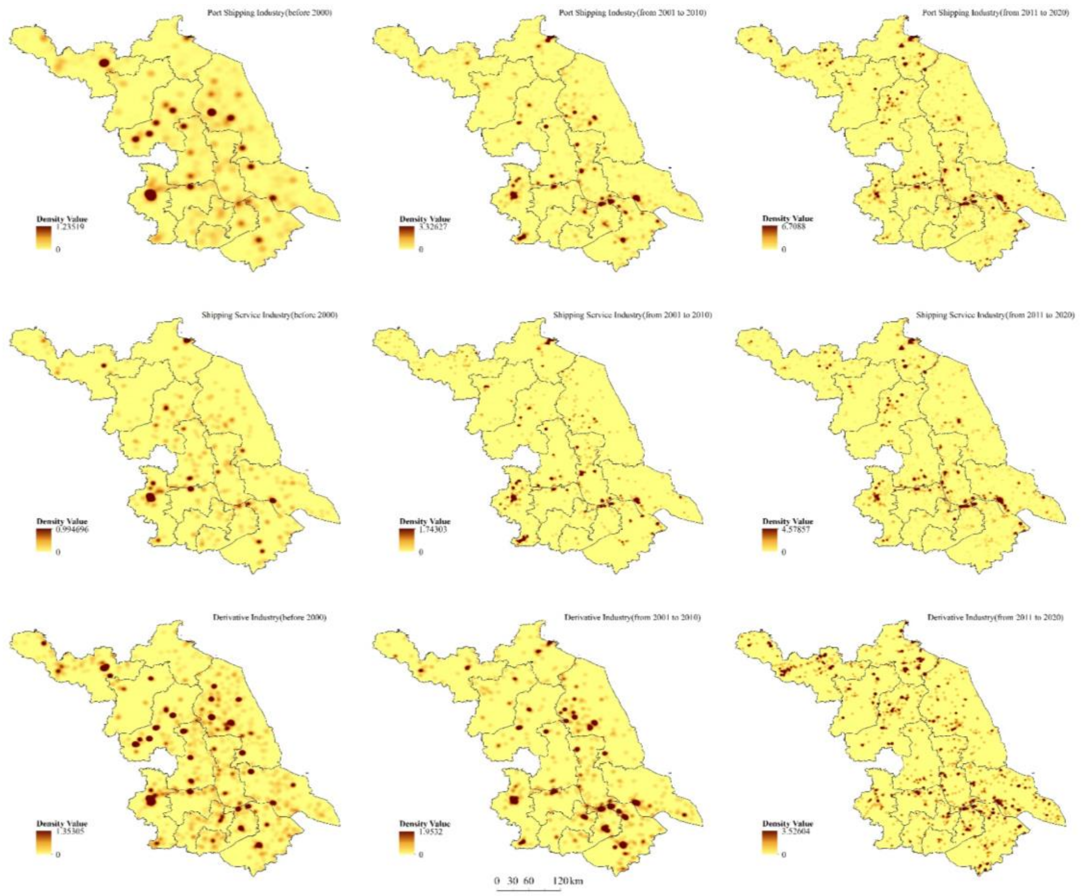


Fig. 2 – Distribution of weighted kernel density by type.

cities adjacent to the Yangtze River had the most obvious clustering characteristics. In contrast, the overall port and shipping enterprises in the cities in the central and southern regions were less concentrated. From 2001 to 2010, the overall port and shipping service industry gradually spread to the surrounding areas from the main concentrating areas of Jiangsu Province, and the central and southern coastal cities began to see the clustering of the industry. In the second half of 2009, the coastal development in Jiangsu was listed as a national strategy to build a modern seaport. Introducing this policy is a breakthrough in following the national strategy of coastal development in Jiangsu. Therefore, from 2011 to 2020, the overall concentration of the port and shipping service industry became less obvious, and the overall density of port and shipping enterprises in all cities increased significantly. The shipping and derivative service industries had a large degree of freedom in space selection and were less restricted by physical logistics. Before 2000, the shipping service industry was mainly concentrated in Nanjing, Zhenjiang, Yangzhou, and other areas distributed along the Yangtze River and has gradually spread to coastal areas in recent years. Most derivative port and shipping services are high-end industries in the value chain, evolving from single-core to multi-core.

In 2000, a circular development centered on the Bund-Lujiazui was formed. By 2020, the areas mentioned above had continued to expand, forming new concentration areas in coastal cities Lianyungang and Nantong and would continue to spread to the surrounding areas. These two types of high-density regions have high spatial stability. In 2013, China put forward "the Belt and Road" strategy. In particular, the “Belt and Road” International Cooperation Summit Forum was held in Beijing in May 2017, and a series of achievements were obtained. More and more relevant enterprises are gathering in coastal areas to adapt to the competition and development trend in port and shipping logistics. Although the intensity of industries is constantly expanding, these all occur in fixed multi-point areas.

3.2. STANDARD DEVIATION ELLIPSE ANALYSIS

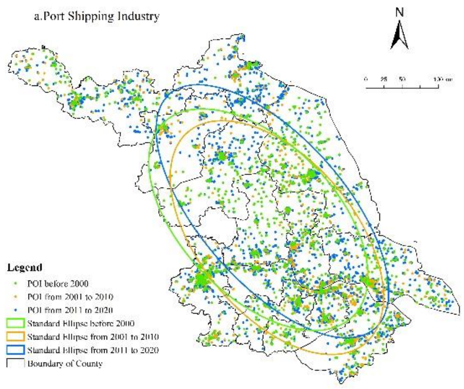
Table 2 and Figure 3 show the analysis results of the standard deviation ellipse of Jiangsu's port and shipping service industry. Overall, the distribution pattern of the port and shipping service industry in Jiangsu shows a weak spatial distribution trend of expansion from the center, and the central axis is generally on the line that connects Yangzhou to Taizhou. The rotation angle q of the standard deviation ellipse is about 146.69°. The center points of the ellipse are located at the junction of Jiangdu District, Gaoyou City, and Xinghua City, the three Yangzhou city districts, from the distribution center's perspective.

Table 2

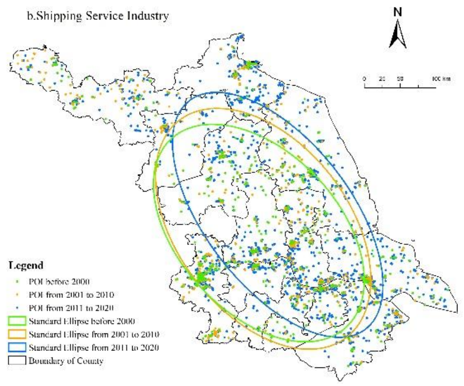
Standard Deviation Ellipse Parameters

a. Overall Port Shipping Industry	**Longitude of Center Point**	**Latitude o f Center Point**	**Semi-Major Axis Length**	**Semi-Mino Axis Length**	**Rotation Angle**
Before 2000(includin g 2000)	119.466946	32.812621	207932.785	114297.318	145.03602
Year 2001–2010	119.696877	32.589648	213977.183	113814.309	148.80715
Year 2011–2020	119.641317	32.918594	240868.511	107309.311	146.22712
b. Shipping Service Industry	**Longitude of Center Point**	**Latitude of Center Point**	**Semi-Major Axis Length**	**Semi-Mino Axis Length**	**Rotation Angle**
Before 2000(includin g 2000)	119.479899	32.623443	199728.165	119078.394	147.42916

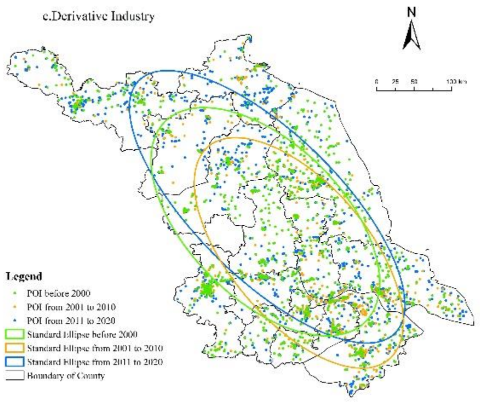
Year 2001-2010	119.533763	32.677594	216008.782	125489.707	152.02698
Year 2011-2020	119.716222	32.853337	227019.025	106957.817	149.81805
c. Derivative Industry	**Longitude of Center Point**	**Latitude o f Center Point**	**Semi-Major Axis Length**	**Semi-Mino Axis Length**	**Rotation Angle**
Before 2000(includin g 2000)	119.462728	32.874227	209659.795	111914.739	143.95622
Year 2001-2010	119.864765	32.499129	208435.446	97835.265	147.08769
Year 2011-2020	119.484391	33.055309	265531.215	104290.023	141.4696



(a) Overall port shipping Industry (2000, 2010, 2020).



(a) Shipping service industry (2000, 2010, 2020)



(b) Derivative industry (2000, 2010, 2020)

Fig. 3 – Distribution pattern and standard deviation ellipse in Jiangsu by type.

From 2000 to 2010, the center points of the ellipse continuously moved in the southeast direction, and from 2010 to 2020, they continued to move in the northeast direction. Judging from the changes in the major and minor axes of the standard deviation ellipse, the major and minor axes of the standard deviation ellipse of the overall port and shipping service industry in Jiangsu Province show a certain degree of fluctuation, which indicates that the port and shipping service industry has a certain tendency of aggregation or diffusion throughout the province. Regarding different port and shipping service enterprises, the overall pattern of the shipping service industry presents a spatial pattern of "northwest-southeast", but the angle q is larger than that of the overall port and shipping service industry, which is about 149.76 °. Judging from the changes in the major and minor axes of the standard deviation ellipse, the difference between the major and minor axes of the ellipse is small, which indicates that the centripetal force of the shipping service industry is weak, and the directionality is not obvious. The overall pattern of the derivative port and shipping service industry also presents a "northwest-southeast" spatial pattern, with a rotation angle q of about 144.17 °. Judging from the changes of the major and minor axes of the standard deviation ellipse, the minor axis has no obvious changing trend. In contrast, the major axis shows an obvious increasing trend, especially after 2011, which indicates that the derivative service industry has an obvious diffusion trend along the major axis and also shows that the derivative service industry has a strong centripetal force and obvious directionality.

4. DISCUSSIONS

Given our findings on the widespread structural consolidation within Jiangsu Province's water transportation industry, it becomes evident that a comprehensive analysis of conflicts is a necessary next step. Due to this paper's scope and length limitations, we cannot delve into a detailed conflict analysis. However, our extensive spatial analysis has highlighted key areas for future exploration in this field. Essential to this future research are the identified stakeholders and their potential choices, pivotal in navigating the industry's transformation toward efficiency and sustainability. The stakeholders include three principal decision makers (DMs), each playing a significant role in the industry's structural consolidation and sustainable transformation. These are the Jiangsu Provincial Government (DM1), which oversees the implementation of national strategies and integration of port resources; local governments (DM2), representing the interests of stakeholders in port cities; and local port enterprises (DM3), engaged in operational activities. They each have various options concerning the integration of ports in Jiangsu, from administrative policies to economic cooperation strategies. This identification of decision makers and their choices serves as a crucial starting point for any future conflict analysis in the region, underscoring the significance of these entities in the context of the changing dynamics of Jiangsu's water transportation sector. The options available to each decision maker, central to understanding potential conflicts and synergies, are concisely outlined in Table 3.

Table 3

Decision makers and their options

DMs	Options
DM1 provincial government	A1, administration policy A2, economic policy A3, mixed policies
DM2 local government	B1, promote integration B2, not promote integration
DM3 port enterprise	C1, willing to integrate C2, unwilling to integrate

5. CONCLUSIONS

The port transformation and integration strategy in Jiangsu Province, aimed at fostering sustainable development and efficient management of the port sector, also highlights the need for future conflict analysis. While the strategy seeks to resolve issues of fragmented operations and intense competition at the municipal level, its challenges are multi-faceted. Integrating "smart port" and "green port" concepts is essential for optimizing port planning, data integration, and modernization of ports in Jiangsu.

However, the integration process is complicated by administrative boundaries, overlapping management roles, and conflicting interests among various stakeholders. These challenges necessitate effective coordination across regions and underscore the importance of conflict analysis in the future. Geographical analysis methods like weighted kernel density estimation provide insights into the spatial distribution of the port and shipping industry, indicating areas where improved coordination, resource optimization, and enhanced environmental governance are crucial.

Addressing these challenges is vital for unlocking the full potential of shipping and facilitating green, intelligent port operations [19,20]. Conflict analysis will be crucial in navigating administrative complexities and ensuring effective stakeholder collaboration [15]. The findings of this study not only offer valuable guidance for policymakers and stakeholders but emphasize the need for ongoing conflict analysis to address limitations and enhance the effectiveness of the port transformation and integration strategy in Jiangsu. Continued efforts in this direction will be critical for achieving a more efficient, sustainable, and environmentally friendly port sector [16–18].

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