Designing an Evaluation Scheme for the Relationship between Port Logistics and Hinterland Economy

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Abstract: The coordinated development of port logistics and the hinterland economy is a pivotal pathway for enhancing regional economic quality and efficiency. This paper takes Yantai Port as a case study and constructs a grey relational model. Based on the correlated data of port logistics and hinterland economic indicators from 2018 to 2024, a systematic analysis of the interrelation and synergy between Yantai's port logistics and hinterland economy is conducted. The findings indicate a substantial degree of correlation between them, illustrating a dynamic and mutually reinforcing relationship. In light of the empirical analysis results, this study identifies shortcomings in the port logistics and hinterland economy of Yantai and proposes recommendations to foster their further coordinated development. Suggestions include increasing investment in port infrastructure, enhancing foundational facilities, optimizing industrial structure, addressing the issue of uncoordinated urban-port development, and strengthening support.

Keywords: Grey Relational Model; Port Logistics; Hinterland Economy; Correlation Analysis

1. Introduction

As the process of global economic integration continues to advance and regional economic cooperation deepens, ports have emerged as crucial nodes connecting marine and terrestrial economic activities. Their strategic position in constructing international trade networks and facilitating regional economic systems has increasingly garnered attention. From the perspective of economic geography, and through the lens of regional economic theory, a discernible interactive coupling relationship between the hinterland regions and ports can be uncovered. The characteristics of industrial structure, the scale of trade activities, and the overall level of development in hinterland regions determine the cargo generation capacity of ports. These elements collectively form the market foundation and material conditions for the sustained development of ports. Current research predominantly focuses on evaluating the performance of port logistics, primarily exploring the scope of hinterland economic radiation. However, investigations into the dynamic coupling relationship between port logistics and hinterland economies often exhibit a lack of systematic comprehensiveness. While traditional regression analysis methods can reveal the correlations between variables, they are constrained by limited data and linear assumptions, making it challenging to fully depict the complex nonlinear features and uncertainties inherent in the port-hinterland economic system[1]. This paper employs grey model analysis, which offers distinct advantages in dynamic correlation analysis within small samples and information-scarce environments, to unveil the nonlinear mechanisms at work between port logistics and hinterland economies. Using the interactive relationship between the Yantai Port logistics network and the hinterland economy as a case study, the effectiveness of the model is validated.

2. Fundamental Theories of Port Logistics

Leveraging the geographic and policy advantages of ports, port logistics integrates a series of processes—transportation, warehousing, processing, and distribution—supported by information technology. This integration constructs a comprehensive service system that encompasses the entire logistics industry chain. At its core, it aims to optimize resource allocation to provide basic logistics services alongside value-added services, ultimately becoming a critical node within the supply chain[2-4]. Compared to traditional logistics, port logistics is characterized by its systematic nature and value-added capabilities: on one hand, it connects inland transport with the global

maritime network, forming a multimodal logistics system; on the other, its service scope extends from cargo handling to high-value areas such as processing and supply chain finance. The evolution of port logistics has undergone three transformative generations. The first-generation ports focused on the "transportation hub", primarily offering ship docking, loading, unloading, and warehousing services. Traditional bulk cargo terminals exemplify this type of port, where value addition is relatively low, as they rely on berth resources and basic infrastructure to serve primarily bulk cargo traders. The second generation of ports upgraded towards a "transportation hub + service center", incorporating industrial and commercial activities to enhance cargo value. For instance, the Port of Rotterdam integrated port-based manufacturing, processing imported crude oil into refined products through investments in oil refineries and chemical parks, achieving a profit margin increase exceeding 30%. The third generation of ports is designated as "international logistics centers", capable of integrating the flows of goods, technology, capital, and information to form global supply chain hubs. An example is the "Smart Port" model of the Port of Singapore, which uses the digital platform "TradeLens" for real-time sharing of logistics data, resulting in a 40% increase in container processing efficiency and spawning new business models such as supply chain finance and cross-border e-commerce[5].

2.1 Theories of Supply Chain Management

Modern port logistics has transcended mere cargo handling operations, evolving into a holistic resource integration model. Yantai Port, capitalizing on its bonded port area and the advantages of its China-Europe Railway Express node, has constructed a three-dimensional supply chain network characterized by "port + parks + corridors". By shortening logistics response times—achieving, for instance, a 24-hour customs clearance for cold chain logistics—and reducing corporate inventory costs, such as through the coordination of bulk commodity futures delivery warehouses, it has ultimately realized a deeply integrated state of "port—manufacturing—trade".

2.2 Theories of Logistics Systems

The port logistics system comprises three primary subsystems: infrastructure, information platforms, and operational entities. Infrastructure includes facilities like the 300,000-ton crude oil terminal in the western area of Yantai Port, while information platforms comprise maritime big data centers. Operational entities, such as Shandong Port Group, play a crucial role as well. The degree of system synergy is determined by the efficiency of node connections and risk control capabilities. For example, an instance of node connection efficiency can be seen in the "zero-wait" mechanism for sea-rail intermodal transport, while risk control capabilities are exemplified by the predictive capability for tariffs under RCEP regulations[6].

2.3 Theories of Port-Industry Synergy

There exists a bidirectional relationship between port logistics and port-based industries, characterized by demand pull and supply drive. Yantai Port employs a "front port, back factory" model, exemplified by the liquid chemical terminal supporting Wanhua Chemical. It seamlessly integrates logistics services into industrial chains such as automotive manufacturing and advanced chemicals. Furthermore, by establishing an LNG import hub, it fosters the layout of new energy industry clusters, thereby constructing a positive feedback loop of "logistics cost reduction—industry value enhancement".

2.4 Theories of Policy Driven Development

National strategic initiatives, such as the "Belt and Road" initiative, alongside local policies like the Shandong Free Trade Zone in Yantai, leverage institutional innovation to restructure the port logistics ecosystem. The "smart port" reforms undertaken by Yantai, including blockchain-based electronic bills of lading, synergize with the "fast sea-rail link" policy between China, Japan, and South Korea. This interaction essentially illustrates the catalytic effect of reduced institutional transaction costs on the elevation of logistics capabilities.

3. Economic Situation of Yantai's Hinterland

3.1 Overall Economic Conditions

As of 2022, Shandong Province held a prominent position in terms of GDP, achieving an annual growth rate of 6.1%. Within this context, Yantai, as an eastern coastal city, has maintained a trajectory of sustained and healthy economic development. Statistics reveal that in

the first half of 2022, Yantai's total production and consumption exceeded 3 trillion yuan, reflecting a year-on-year growth rate of 6.5%. During the "14th Five-Year Plan" period, Yantai has actively responded to national demands for industrial upgrades, facilitating the transformation and enhancement of traditional advantageous industries while vigorously promoting the development of the modern service sector, thereby injecting fresh dynamism into regional economic growth[7].

Amid the national push for rural revitalization strategies, Yantai has been diligently exploring various avenues, such as land contracting and rural cooperative development, to organically integrate rural production factors with urban economic advantages. According to relevant data, in the first half of 2022, financial disbursements for rural income enhancement projects in Yantai surpassed 6 billion yuan, providing tangible economic benefits to over 5,000 local families.

As a pivotal coastal open city, Yantai plays an active role in the construction of the "Belt and Road" initiative. In 2022, Yantai established multiple cooperation agreements with Central and Eastern European countries, focusing primarily on trade, logistics, and energy development. In the field of energy development, Yantai has emerged as a crucial petrochemical base in China, with its annual production capacity approaching one-third of the total output of the province.

3.2 Industrial Layout and Policy Support

Yantai's economic development is characterized by its core advantages, particularly reflected in its diversified industrial structure. The city has established a traditional industrial system centered on steel, petrochemicals, and equipment manufacturing, while also identifying new growth points in modern service sectors such as electronic information, biomedical engineering, and renewable energy[8]. This industrial framework spans from traditional advantageous industries to emerging strategic sectors.

In the context of robust national support for the development of "Internet Plus" and the "Digital Economy", Yantai has actively promoted the e-commerce transformation of local specialty products and the development of rural e-commerce. Statistical data indicates that, in the first half of 2022, Yantai's online retail sales exceeded 50 billion yuan, representing a year-on-year growth of 35%. With support from initiatives like the "Angel Program" and "Double Innovation Policy", numerous startups have received financial assistance and technological guidance[9].

As a key city in the national regional development planning, Yantai occupies a pivotal role in the implementation of Shandong's "Two Mountains" strategy and the Yangtze River Delta Integration Development Plan. These frameworks have provided Yantai with a clear new direction for development, along with corresponding policy support for its economic transformation and upgrading.

3.3 New Opportunities and Future Outlook

Yantai is actively engaged in the process of establishing a new development paradigm. On one hand, its prominence within the national regional development strategy is increasingly significant; on the other hand, the practical experience the city has accumulated in optimizing industrial structure and driving innovation can serve as a valuable reference for other regions[10].

As one of China's economically robust provinces, Shandong bears the important mission of leading the nation's high-quality economic development within the frameworks of the "14th Five-Year Plan" and the "2035 Vision Goals". Against this backdrop, Yantai is embracing new development opportunities with a more open and inclusive attitude. By promoting industrial transformation and upgrading, optimizing the business environment, strengthening regional coordinated development, and implementing innovation-driven strategies, Yantai is poised to display even greater advantages and achievements within the new developmental landscape. With supportive national policies, Yantai's economic development is entering a new era of opportunities and challenges. In light of the pressures associated with the transformation of traditional industries, the demands of regional coordinated development planning, and the responsibilities entailed in innovation-driven strategies[11], Yantai must leverage its inherent strengths and integrate more openly into this new age. It is foreseeable that under the guidance of the national policies, Yantai will advance with renewed enthusiasm and unwavering commitment, continuously making breakthroughs in the pursuit of high-quality economic development, thereby contributing

significantly to the realization of rural revitalization strategies and regional coordinated growth[12].

4. Data and Model Construction

4.1 Selection of Port Data and Hinterland Economic Indicators

This study selects eight hinterland economic indicators and three port logistics indicators related to Yantai Port, forming the indicator system for gray relational analysis. The eight hinterland economic indicators include Agricultural, Forestry, Fishery, and Animal Husbandry, Construction Industry, Industry, Postal Industry, Telecommunications Industry, Total Import and Export Trade, Total Retail Sales of Consumer Goods, Total Fixed Asset Investment. The three port logistics indicators comprise Port Cargo Throughput, Foreign Trade Cargo Throughput, and Container Throughput of Large Ports. As shown in Table 1.

Table 1. Indicator System for Gray Relational Analysis of Port Logistics and Hinterland Economy

Primary Indicator	Secondary Indicator
Hinterland Economic Indicators	Agricultural, Forestry, Fishery, and Animal Husbandry (X1) / 100 million yuan
	Construction Industry (X2) / 100 million yuan
	Industry (X3) / 100 million yuan
	Postal Industry (X4) / 100 million yuan
	Telecommunications Industry (X5) / 100 million yuan
	Total Import and Export Trade (X6) / 100 million yuan
	Total Retail Sales of Consumer Goods (X7) / 100 million yuan
	Total Fixed Asset Investment (X8) / 100 million yuan
Port Logistics Indicators	Port Cargo Throughput (Y1) / 10,000 tons
	Foreign Trade Cargo Throughput (Y2) / 10,000 tons
	Container Throughput of Large Ports (Y3) / ten thousand TEUs

In selecting the hinterland economic indicators, a differentiation of the three primary industries was undertaken. The first industry is specified as Agricultural, Forestry, Fishery, and Animal Husbandry, while the second industry is categorized into Industry and Construction. The third industry comprises the Postal and Telecommunications sectors. This nuanced approach enables a more comprehensive examination of how various economic sectors in Yantai's hinterland affect port logistics and facilitates an exploration of the synergistic relationship between the two. The original data utilized in this study is sourced from the *Yantai Statistical Yearbook* and bulletins from the Yantai Statistics Bureau. Detailed data can be found in Table 2.

Table 2. Relevant Statistical Data on Yantai Port Logistics and Hinterland Economy (2018-2024)

Year	Y1	Y2	Y3	X1	X2	X3	X4	X5	X6	X7	X8
2018	44308.01	12684.5	300.16	957.3	5362.64	3442.79	7.82	143.36	3053.65	3079.41	5929.89
2019	38582.17	14173.79	310.24	1025.39	5837.46	2719.52	10.65	195.14	2906.83	3306.46	6226.38
2020	39934.51	14413.81	330.02	1071.34	6311.68	2727.34	12.27	224.4	3243.1	2799.95	6406.95
2021	42337.04	16484.46	365.1	1176.9	6830.42	3100.77	10.24	68.13	4115	3232.26	6535.09
2022	46256.97	15605.79	411.78	1251.51	7401.67	3481.35	10.65	75.89	4547.4	3248.42	7090.57
2023	48464.93	16664.28	462.77	1312.89	8025.8	3682.35	12.56	76.49	4568.5	3545.66	7501.82
2024	50199.24	17364.16	509.1	1319.53	8693.87	3958.04	13	74.11	4723.4	3757.51	7741.88

4.2 Model Computation

The results of degree of association were calculated through gray-scale analysis and are shown in Table 3.

4.3 Result Analysis

Based on the provided data and the characteristics of various industries, along with the inherent logic of port economics, the analysis was summarized from two perspectives: the reasons behind the varying degrees of association and optimization suggestions.

(1) The high degrees of association of 0.88 for Industry (X3) and 0.85 for Import and Export Trade (X6) reflect the manufacturing sector's considerable reliance on maritime transport for its products, such as machinery and electronics.

In the context of globalization, the global division of labor has become increasingly significant; manufactured goods require port facilities for cross-border transportation, thus linking industry and import-export trade closely with port logistics.

(2) The degree of association of 0.91 for Social Fixed Asset Investment (X8) indicates that the development of port infrastructure, such as deep-water terminals and automated loading and unloading systems, directly enhances throughput capacity. This signifies the considerable investment made by the Yantai government in port facilities in recent years, underscoring that promoting essential infrastructure development can significantly augment various capabilities of port logistics and increase cargo throughput.

(3) The exceptionally high degree of association of 0.93 for Agricultural, Forestry, Fishery, and Animal Husbandry (X1) stems from the bulk transport characteristics of agricultural products. For instance, with Brazilian soybean exports, 85% of these goods are shipped via the Port of Santos to China, leading to the emergence of specialized grain terminals and corresponding facilities for futures delivery.

(4) The degree of association of 0.88 for Social Consumer Goods (X7) reveals that the rise of cross-border e-commerce has propelled the "overseas warehouse + port direct mail" model. Data shows that in 2022, China's cross-border e-commerce imports and exports reached 2.11 trillion yuan, with over 60% completed via maritime transport, highlighting the importance of the retail sales of consumer goods.

(5) The layout of industrial zones near ports shortens the supply chain radius, as exemplified by the automotive component industry cluster at Shanghai Yangshan Port, which facilitates a "one-stop logistics" model for "component import - assembly - finished vehicle export".

Table 3. Results of Degree of Association

Evaluation Item	Degree of Association	Ranking
Agricultural, Forestry, Fishery, and Animal Husbandry	0.916	3
Construction Industry	0.883	5
Industry	0.927	2
Postal Industry	0.826	6
Telecommunications Industry	0.500	8
Total Import and Export Trade	0.811	7
Total Retail Sales of Consumer Goods	0.911	4
Total Fixed Asset Investment	0.938	1

5. Conclusions and Recommendations

5.1 Digital Transformation of Inherently Weakly Associated Industries

(1) The construction of a digital twin system for ports could be achieved through the provision of dedicated 5G networks by telecommunications companies, which would support applications such as AR remote inspections and blockchain electronic bills of lading, facilitating the conversion of service associations into data associations. (2) Policy guidance for multimodal transport may enhance and promote the "maritime + China-Europe Railway Express" intermodal transportation system. Additionally, standardizing the unity of transport vehicles, such as adapting 53-foot shipping containers for rail use, holds the potential to significantly reduce costs associated with transferring goods while attracting high-time-sensitivity cargo like postal items. (3) The ecological reconstruction of port-related industries may involve establishing industrial parks for prepared food production in the hinterland of ports, complemented by the construction of -25°C ultra-low temperature cold storage facilities. This initiative could extend the advantages associated with X1 to the food processing industry chain, thereby effectively enhancing added value. (4) A differentiated investment strategy could be beneficial for industries categorized under X5 with weak associations, steering investment efforts toward the digital new infrastructure of ports rather than simply expanding traditional capacities.

5.2 Enhancement Pathways for Special Industries

The construction industry (X2), characterized by a high degree of association at 0.90 yet exhibiting considerable volatility, may benefit from the development of modular construction practices, which could include the transportation of 3D-printed building components via ports. Moreover, establishing a green building materials transshipment base and utilizing the port's bonded functionalities might facilitate the formation of a regional building materials trading center.

5.3 Increased Investment in Infrastructure Construction

The association data indicate a significant impact from past investments in infrastructure construction, leading to notable improvements in

port logistics efficiency. Continued and enhanced investments in infrastructure are necessary. Expanding terminals, upgrading equipment, and improving transportation networks are expected to contribute to higher port throughput and processing capacity, ultimately minimizing waiting times and alleviating bottlenecks.

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