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A STUDY OF SYMBIOTIC RELATIONSHIPS IN THE DEVELOPMENT OF LAND-SEA COORDINATION SYSTEMS

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Abstract. *Given that ports act as pivotal links for land-sea transport chains, this study investigates the coordinated development of port and land-sea transportation from a complex systems approach (land-sea coordination systems) by dividing the port system into both land-port and sea-port complex systems. Additionally, it introduces the symbiosis theory into the study of land-sea coordination systems to analyze influential coupling-dynamic mechanisms, and it establishes a model to simulate the symbiotic relationship and coordinated development between land-sea transportation and ports. The established model is subsequently utilized for an empirical analysis of the Lianyungang port. The results indicate that to achieve coordinated development of land-sea transportation in Lianyungang, it is necessary to expand the input of tertiary industries (such as coastal and marine tourism), control the utilization of waterfront resources, and increase the investment in harbor capacity development, thereby meeting the requirements for port-city development and promoting the strategic position of Lianyungang.*

Keywords: Land-sea coordination system, Symbiotic relationship, Lianyungang

1. **Introduction.** Ports have become the principal driving force for regional economic development through a mutual influence that utilizes corresponding cities as carriers, integrated transport system as main arteries, and port-related industries for support, as well as relies on international trade. Therefore, it is urgent and necessary to design and implement land-sea coordination strategies. For a systematic study of port-city relationships, [1-8] provide an in-depth review. For instance, [4] studied the land reclamation of Japanese ports and advocated that changes in the economic and social structure had a significant impact on the scale of the land reclamation process. Moreover, [5,6] each made significant achievements in the study of social and economic benefits of ports. However, most existing studies are still concentrated on static correlation analysis, and few scholars have considered the importance of marine resources on land-sea coordination systems. Research that considers ports, land, and sea as a coupling system is rare, and investigations of the coupling mechanism and dynamic changes in the land-sea coordination systems are still in their initial stages of analysis.

Based on the above problems, this study introduces the symbiosis theory into the analysis of coupling-dynamic development mechanisms and establishes a model using Lianyungang as an example of simulating the symbiotic relationship and coordinated development between land-sea transportation and ports.

The rest of this paper is organized as follows. In Section 2, we introduce the land-sea coordination system, which contains three subsystems, that is, land-side, sea-side, and port subsystems. In addition, we also list the evaluation indicators for the development of land-sea coordination systems. In Section 3, we establish the degree of order models of the three subsystems. Based on this, in Section 4 we propose the symbiotic model of the land-port and sea-port complex systems to study the evolution of the symbiotic relationships of the entire land-sea system and its subsystems. In Section 5, we take a case to simulate the symbiotic relationship of a land-sea coordination system. In the last section, we provide conclusions.

2. The Land-Sea Coordination System.

2.1. Components of land-sea coordination systems. Land-sea coordination systems (see [9]) can be further divided into three subsystems: land-side, sea-side, and port subsystems. Since the port subsystem acts as a vital node and link between the land-side and sea-side subsystems, land-sea coordination systems include land- and sea-port complex systems. In this study, the first subsystem is the land-side subsystem, followed by sea-side as the second and port as the third.

2.2. Evaluation indicators. After identifying the principles on which the determinants are based, as well as an indicator system, this study divided the evaluation indicators for the development of land-sea coordination systems into four levels, as Table 1.

As in Table 1, the indicator system contains 26 levels, among which 22 indicators show an improvement when their values increase (positive indicators) and four an improvement when their values decrease (negative indicators). The four negative indicators are $X_9^{(1)}$, $X_9^{(2)}$, $X_5^{(3)}$, and $X_6^{(3)}$.

3. Degree of Order Model of the Subsystems. A degree of order refers to the degree of influence that one element has on other elements. Since the degree of order model of the subsystem is the basis of the symbiotic model in this study, the subsequent section introduces the degree of order model of the subsystems.

Assuming that $X_j^{(i)}$ is the jth indicator of the ith subsystem, $j = 1, 2, \ldots, m$ and $i = 1, 2, 3$, let $\alpha_j^{(i)}$ and $\beta_j^{(i)}$ be the maximum and minimum values of $X_j^{(i)}$, respectively. The degree of order $N_j^{(i)}$ of $X_j^{(i)}$ is then illustrated as Equation (1):

$$N_j^{(i)} = \begin{cases} \left(X_j^{(i)} - \beta_j^{(i)}\right) \Big/ \left(\alpha_j^{(i)} - \beta_j^{(i)}\right), & X_j^{(i)} \text{ is the positive indicator} \\ \left(\beta_j^{(i)} - X_j^{(i)}\right) \Big/ \left(\alpha_j^{(i)} - \beta_j^{(i)}\right), & X_j^{(i)} \text{ is the negative indicator} \end{cases}, \tag{1}$$

where the degree of order $N_j^{(i)}$ $\left(0 \leq N_j^{(i)} \leq 1\right)$ signifies the impact of indicator $X_j^{(i)}$ on the ith subsystem. Additionally, the degree of order N_i of the ith subsystem can be described as follows:

$$N_i = \sum_{j=1}^{m} \lambda_j^{(i)} N_j^{(i)}, \quad \lambda_j^{(i)} \geq 0 \text{ and } \sum_{j=1}^{m} \lambda_j^{(i)} = 1, \tag{2}$$

where $\lambda_j^{(i)}$ is the weight of $X_j^{(i)}$. There are various reliable methodologies to measure the weight of indicators, such as the entropy method (see [10]).

4. The Symbiotic Model. Symbiosis is a common phenomenon in socio-economic systems. Since 1879, when the concept of symbiosis in [11] was proposed by Anton de Bary, the symbiosis theory and its corresponding methodologies have been widely applied.

Table 1. Evaluation indicators

Level 1 Indicators	Level 2 Indicators	Level 3 Indicators	Level 4 Indicators	Variables
The Land-Sea Coordination System	Land-side	Economic Developmen	Per Capita GDP	$X_1^{(1)}$
			Public Revenue	$X_2^{(1)}$
			Saturation of Inland Transport	$X_3^{(1)}$
			Investment in Fixed Assets	$X_4^{(1)}$
			Industrial Power Consumption	$X_5^{(1)}$
		Service System	Development of Logistics and Trading Platforms	$X_6^{(1)}$
			Tax Revenue	$X_7^{(1)}$
			Year-end Loan Balance of Financial Institutions	$X_8^{(1)}$
		Resources and Environment	Water Consumption per GDP (m^3/CNY 10,000)	$X_9^{(1)}$
			Industrial Land Area	$X_{10}^{(1)}$
			Green Coverage Ratio	$X_{11}^{(1)}$
	Sea-side	Economic Development	Value-added of the Marine Service Industry	$X_1^{(2)}$
			Income of Coastal and Marine Tourism	$X_2^{(2)}$
			Output of Marine Fisheries	$X_3^{(2)}$
		Service System	Value-added of the Marine Service Industry	$X_4^{(2)}$
			Revenue of Marine Transportation	$X_5^{(2)}$
			Proportion of IT Personnel in Total Marine Employment	$X_6^{(2)}$
			Proportion of Marine Research and Development (R&D) Expenditure in Total R&D Expenditure	$X_7^{(2)}$
		Resources and Environment	Confirmed Sea Area	$X_8^{(2)}$
			Chemical Oxygen Demand	$X_9^{(2)}$
	Port	Economic Development	Container Throughput	$X_1^{(3)}$
		Service System	Shipping Services	$X_2^{(3)}$
			Development of Loading and Unloading and Freight Forwarding Industries	$X_3^{(3)}$
		Resources and Environment	Total Number of Berths	$X_4^{(3)}$
			Proportion of the Number of Container Berths out of Total Berths	$X_5^{(3)}$
			Total Amount of Pollutants Entering the Sea	$X_6^{(3)}$

4.1. **Establishment of the symbiotic model.** As previously mentioned, this study established logistic differential equations (see [12]) for the land- and sea-port complex systems to study the evolution of symbiotic relationships for the entire land-sea system and its subsystems. Subsequently, the differential equations were solved to achieve a steady development equilibrium. Given that land- and sea-port complex systems are both composed of two subsystems, system self-organization can be presented when the two subsystems are coupled.

The logistic differential equations of the land-port complex system are as follows:

$$\begin{cases} \dfrac{dN_1}{dt} = r_1 N_1 \dfrac{K_1 - N_1 - m_{13}N_3 + n_{13}N_3}{K_1} \\ \dfrac{dN_3}{dt} = r_3 N_3 \dfrac{K_3 - N_3 - m_{31}N_1 + n_{31}N_1}{K_3} \end{cases}. \tag{3}$$

The logistic differential equations of the sea-port complex system are as follows:

$$\begin{cases} \dfrac{dN_2}{dt} = r_2 N_2 \dfrac{K_2 - N_2 - m_{23}N_3 + n_{23}N_3}{K_2} \\ \dfrac{dN_3}{dt} = r_3 N_3 \dfrac{K_3 - N_3 - m_{32}N_2 + n_{32}N_2}{K_3} \end{cases}. \tag{4}$$

In Equations (3) and (4), N_i is the degree of order of the ith subsystem, r_i, K_i, m_{ij}, and n_{ij} are parameters in the symbiotic model, which are estimated by the maximum likelihood method. r_i denotes the natural growth rate of the ith subsystem; K_i denotes the positive effect of the ith subsystem on the ith subsystem; m_{ij} denotes the competition factor, i.e., the negative effect of the jth subsystem on the ith subsystem; n_{ij} denotes the cooperation factor, i.e., the positive effect of the jth subsystem on the ith subsystem.

4.2. **Parameter estimation and analysis of the significance of the equilibrium point.** The key focus in the analysis of the symbiotic relationship of complex systems is to conduct parameter estimation and analyze the significance of the equilibrium point of differential Equations (3) and (4). Taking the land-port complex system as an example, the following section introduces the process of parameter estimation and equilibrium point analysis.

Let $dN_1/dt = 0$ and $dN_3/dt = 0$, which leads to four equilibrium points:

$$A_1(0,0), \quad A_2(0,K_3), \quad A_3(K_1,0),$$
$$A_4\left(\frac{K_1 - K_3(m_{13} - n_{13})}{1 - (m_{13} - n_{13})(m_{31} - n_{31})}, \frac{K_3 - K_1(m_{31} - n_{31})}{1 - (m_{13} - n_{13})(m_{31} - n_{31})}\right).$$

The processes of parameter estimation and equilibrium point analysis are as follows.

a) If $m_{13} > n_{13}$ and $m_{31} > n_{31}$, a significant competitive effect exists between the development of the land-side and port subsystems. If $(m_{13} - n_{13})(m_{31} - n_{31}) < 1$ and $m_{13} - n_{13} < K_1/K_3 < 1/(m_{31} - n_{31})$, A_4 is the equilibrium point when the land-port complex system is stable. In this case, the land-side and port subsystems cannot co-exist, as each subsystem is negatively affected by another. Hence, neither subsystem can match the level of development they can achieve when they exist separately.

b) If $m_{13} < n_{13}$ and $m_{31} < n_{31}$, the cooperating effect between the land-side and port subsystems is greater than the competitive inhibitory effect. If $(m_{13} - n_{13})(m_{31} - n_{31}) < 1$, A_4 is the equilibrium point when the land-port complex system reaches a stabilized symbiotic relationship. In this case, the land-side and port subsystems achieve symbiotic development.

c) If $m_{13} > n_{13}$ and $m_{31} < n_{31}$, in the land-port complex system, the development of the land-side subsystem has a clear inhibitory effect on the development of the port subsystem, which is greater than its promoting effect. In this case, two situations can occur. First, if $m_{31} - n_{31} < K_1/K_3$, A_4 is the equilibrium point when the land-port complex system reaches a stable status. Second, if $m_{31} - n_{31} > K_1/K_3$, $A_2(0, K_3)$ is the equilibrium point when the land-port complex system reaches a stable status.

d) If $m_{13} < n_{13}$ and $m_{31} > n_{31}$, in the land-port complex system, a substantial promoting effect occurs in the development of the land-side subsystem on the development of the port subsystem, which is greater than its inhibitory effect. In this case, two situations can occur. First, if $m_{31} - n_{31} < K_3/K_1$, A_4 is the equilibrium point when the land-port complex system reaches a stable status. Second, if $m_{31} - n_{31} > K_3/K_1$, $A_3(K_1, 0)$ is the equilibrium point when the land-port complex system reaches a stable status.

The above analyses show that if and only if the equilibrium point is A_4, the symbiotic relationship between subsystems gains practical significance.

5. **Case Study.** Lianyungang City is one of the first 14 coastal open cities in China. This study used Lianyungang as an example of simulating the symbiotic relationship of a land-sea coordination system. The data used for the simulation were mainly acquired from the Statistical Yearbook of Lianyungang and the Bulletin of Marine Economy Statistics of Jiangsu Province from 2006 to 2014 (refer to http://tjj.lyg.gov.cn/). Additionally, since each indicator has a different magnitude, which results in large deviations in the model calculation, it was necessary to standardize the collected data. The standardized indicator, $G_j^{(i)}(t)$, can be formulated as

$$G_j^{(i)}(t) = \left(X_j^{(i)}(t) - \frac{1}{n}\sum_{t=1}^{n} X_j^{(i)}(t)\right) \Bigg/ \sqrt{\frac{1}{n-1}\sum_{t=1}^{n}\left(X_j^{(i)}(t) - \frac{1}{n}\sum_{t=1}^{n} X_j^{(i)}(t)\right)^2}.$$

Given that $X_6^{(1)}$, $X_2^{(3)}$, and $X_3^{(3)}$ are qualitative indicators, an expert scoring method was applied to quantifying them.

5.1. Estimation of a symbiotic relationship in land-sea coordination systems.

a) Calculating the Degree of Order of the Subsystems

This study utilized the entropy method to determine indicator weights, and the degrees of order of the subsystems from 2006 and 2014 were calculated based on Equation (1) and are listed in Table 2.

Table 2. The degree of order of the subsystems, 2006-2014

	2006	2007	2008	2009	2010	2011	2012	2013	2014
Land-side	0.166	0.149	0.236	0.450	0.435	0.712	0.838	0.848	0.784
Sea-side	0.163	0.136	0.125	0.211	0.323	0.493	0.697	0.665	0.681
Port	0.234	0.207	0.219	0.270	0.188	0.317	0.325	0.331	0.323

b) Parametric Estimation and Equilibrium Point Calculation

According to the degree of order of the three subsystems, as well as Equations (3) and (4), the estimated value of the model parameters were calculated using the software package MATLAB (Tables 3 and 4).

Table 3. Parameter estimation of the land-port symbiotic model

	r	K	$m - n$
Land-side	0.7011	0.9297	0.3477
Port	1.2770	0.4826	0.0361

From Table 3, $m_{13} > n_{13}$, $m_{31} > n_{31}$, and $(m_{13} - n_{13})(m_{31} - n_{31}) < 1$. Therefore, the equilibrium point of the land-port complex system is $A_4(0.7716, 0.4547)$. When the degree of order of the land-side subsystem is 0.7716 and that of the port subsystem 0.4547, the land-port complex system is stable. However, in 2014, the degree of order of the land-side subsystem was 0.784 and that of the port subsystem was 0.323. It is apparent that although the land-side subsystem had satisfied the requirement of being a stable land-port complex system, the port subsystem did not satisfy the corresponding requirements.

Table 4. Parameter estimation of the sea-port symbiotic model

	r	K	$m-n$
Sea-side	0.5565	0.3765	-1.0027
Port	1.4503	0.4929	0.0566

From Table 4, $m_{23} < n_{23}$, $m_{32} > n_{32}$, and $m_{32} - n_{32} < K_3/K_2 < 1$. Therefore, the equilibrium point of the land-port complex system is $A_4(0.8240, 0.4463)$. When the degree of order of the sea-side subsystem is 0.8240 and that of the port subsystem is 0.4463, the sea-port complex system is stable. However, in 2014, the degree of order of the sea-side subsystem was 0.681 and that of the port subsystem was 0.323. It is apparent that neither subsystem satisfied the requirement of being a stable sea-port complex system.

5.2. **Measures and suggestions.** According to the specific situation of the port and city of Lianyungang, and with reference to the model analysis results, the following suggestions are proposed.

a) Increase the investment in port construction to enhance port capacity.

b) Accelerate the development of marine resources.

c) Moderately control the utilization of the waterfront resources and prevent unsustainable results caused by excessive construction of the port.

6. **Conclusions.** This study divided the land-sea coordination system into land-side, sea-side, and port subsystems. Using the port subsystem as a link, the three subsystems further constituted land-port and sea-port complex systems. Subsequently, the symbiosis theory was introduced into the study of complex systems to establish a symbiotic model of the land-sea coordination system. Then, the significance of the equilibrium point of the symbiotic model was analyzed. Finally, the established symbiotic model was used to assess the development of the land-sea coordination system of Lianyungang. The results showed that Lianyungang should focus on the development of both port construction and coastal and marine tourism as well as control the utilization of waterfront resources. Due to the successful application of Lianyungang, we believe the symbiotic model we proposed can be extended to general ports.

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