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An indicator system for evaluating the development of land-sea coordination systems: A case study of Lianyungang port

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ABSTRACT

The evaluation of the development of a land-sea coordination system, including how to measure success, remains a significant subject for exploration among researchers and practitioners. The main challenge in this subject is to establish a suitable indicator system. In this paper, we propose a novel approach to construct an indicator system to evaluate the development of a land-sea coordination system. We take Lianyungang port as a case study. A land-sea coordination system is considered as composed by three sub-systems, i.e., a land-side sub-system, a sea-side sub-system, and a port sub-system. Based on analysis of influential factors using questionnaires for the development of a land-sea coordination system, an initial indicator system is established. We apply structural equation modeling to screen the indicators from the initial indicator system. Finally, we analyze the reliability and validity of the screened indicator system. The results show that a total of 26 indicators are generated and grouped into three major categories: (1) economic development; (2) service system; (3) resources and environment, and the screened indicator system is of suitable feasibility to be applied to evaluate the development of the considered land-sea coordination system. Additionally, the results provide a scientific reference and decision-making basis for policy formulation and development evaluation of standard ports.

1. Introduction

As a primary connection point for land-sea transportation, ports play an important role in transportation networks (Andrade et al., 2016; Bebianno et al., 2015). With the acceleration of economic globalization, international industrial transfer activities have become more frequent, and industries have begun to cluster around ports (Yochum and Agarwal, 1998). As a complex conglomeration that consists of many components, such as corresponding cities, integrated transport systems, port-related industries, and international trade, ports have become the main driving force for regional economic development (Davis, 1983; Wang and Slack, 2000). Because of the combined influence of the large variety of external factors, the ecological environment of ports is extremely vulnerable (Borja et al., 2012; Shen et al., 2016). With the acceleration of development and utilization of ports, environmental problems of ports are extremely prominent, and environmental pollution and ecological destruction are very serious (Choi et al., 2015; Costanza, 2012; Cusson et al., 2015; Debeljak, 2002; Donohue et al., 2013; Fletcher et al., 2014; Petrosillo et al., 2009). Especially, the excessive exploitation and utilization of marine resources, the degradation of marine natural ecological functions, and the severe destruction of the marine environment have finally led to the slow development of the regional economy and the urgent and prominent environmental problems (Franzo et al., 2015; Fu et al., 2014; Han et al., 2011; Petrosillo et al., 2010; Tang et al., 2015; Uehara and Mineo, 2017). On this account, people should highly pay attention to the effective protection of ecological environment resources between land and sea areas of ports, which strengthens the overall development and coordinated management of land and sea areas of ports.

As a result of growingly economic and environmental pressures in the land and sea areas of ports, land-sea coordination is adopted as an approach for confronting the challenges, which is a significant output of

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the “China ocean agenda in the 21st century” (Xu et al., 2013; Yang et al., 2016). More precisely, land-sea coordination refers to the design, planning, and implementation of regional and social development, based on the coordinated equilibrium between land and sea (Zhang et al., 2003; Zhang et al., 2016; Zhao et al., 2016). It involves a comprehensive consideration of the characteristics of land-sea resources and the environment, a systematic examination of economic, ecological, and social functions of both land and sea, the carrying capacity of ecosystems, resources and the environment, and the dynamics and potential outputs of socio-economic systems. The purpose of land-sea coordination is to promote the harmonious, healthy, and rapid development of the regional economy and the effective protection of ecological environment resources of both land and sea. After more than two decades, hundreds of land-sea coordination initiatives, thousands of scientific papers, national and multinational reports, the question surrounding the achievement of land-sea coordination goals and objectives, including how to measure success, remain a significant subject for discussion among scholars and practitioners alike (Botero et al., 2016; Brambila and Flombaum, 2017; Nader et al., 2008; Peng et al., 2018; Shi et al., 2018; Tan et al., 2015; Tang et al., 2018). It is, therefore, an urgent and necessary task to design and implement land-sea coordination strategies.

Initial studies on land-sea coordination strategies predominantly focus on the selection criteria of port cities. With social and economic change, the breadth of research has been expanded, and significant progress has been achieved in empirical and quantitative studies (Álvarez-Romero et al., 2011; Grossmann, 2008; Jacobson et al., 2014; Turner et al., 1998) concerning spatial structure, development of transportation networks, and sustainable capacity of port cities. However, these investigations are based on establishing an indicator system of land-sea coordination. In other words, establishing an indicator system to evaluate the development of a land-sea coordination system is the primary concern for land-sea coordination researchers (Azar et al., 1996; Botero et al., 2016; Brambila and Flombaum, 2017; Cantasano and Pellicone, 2014; Jodha, 1990; Wackernagel et al., 1999).

The purpose of a indicator system is to provide a tool for guidance in coordination policies, including monitoring of measures and their results, and communication to the public at large (Ulanowicz et al., 1992). Indicators should provide hard, quantitative data to ensure a sound basis for both environmental and economic policy in the future (Mace et al., 2012). In fact, these indicators can continuously serve as an on-going protection against environmental complacency. Land-sea coordination strategies are based on environmental and biophysical baseline indices that effectively define comparative development potential and environmental constraints. It is widely believed that public institutions cannot develop a strategy for coordinated development without a quantitative knowledge of the state of the system (Zell and Hubbart, 2013). Therefore, land-sea coordination indicators can be used to develop regional economy and improve multiple-objective environmental decision-making under conditions of unknown variability (Vassallo et al., 2013). Conditions are very different in the different parts of any country, and the quality of life as well as the impacts produced on the environment depends on a variety of local factors of environmental, economic and cultural nature, and every action must cope with such local conditions, traditions, and attitudes (Vassallo et al., 2012).

Over the past two decades, researchers have made a series of achievements with respect to construction and application studies of indicator systems for land-sea coordination (Botero et al., 2016; Brambila and Flombaum, 2017; Jodha, 1990; Li et al., 2009; Nader et al., 2008; Shi et al., 2018; Siddig et al., 2016; Tan et al., 2015; Tan and Lu, 2015; Tang et al., 2018; Vassallo et al., 2016; Wackernagel et al., 1999; Zhang et al., 2012). From the previous work, we can conclude that approaches for constructing indicator systems are mostly divided into two categories: model-based approaches, and subject-based approaches.

On the one hand, model-based approaches are used to construct indicator systems, which are based on existing mathematical models, regardless of the modeling context. For instance, the Organisation for Economic Co-operation and Development and the United Nations Environment Program have jointly proposed the pressure-state-response (PSR) model (Li et al., 2009). Since the 1990s, indicator systems based on the PSR conceptual framework have gradually improved and matured (Li et al., 2009; Zhang et al., 2012). Jodha proposes a method to measure system coordination through the physical degradation of common property resources (CPRs) (Jodha, 1990). This approach suggests that if no degradation of CPRs is identified, then the system can be defined as ‘coordinated’. Wackernagel et al. propose the application of an Ecological Footprint method for the establishment of indicator systems (Wackernagel et al., 1999). The Ecological Footprint method assesses the impact of human beings on ecosystems by comparing the required natural resource consumption to maintain human survival and development, as well as by analyzing the size of bioproductive land required to absorb human waste, and the carrying capacity of population in any given area. Nader et al. propose a practical municipal level approach to produce the appropriate lists of environment and sustainable development indicators (Nader et al., 2008). A total of 110 indicators are generated and grouped into four major categories adopted by the national indicator system: (1) population and socio-economics; (2) economic activities; (3) environment; and (4) sustainable development activities and policies.

On the other hand, subject-based approaches are employed to construct indicator systems, which mostly consider classification criteria for indicators of different applied areas, and place excessive emphasis on the effectiveness of assessing land-sea coordination. For example, Tan et al. use multivariate and multimetric approaches to develop a benthic diatom-based index of biotic integrity for assessment of the aquatic environment in the upper Han River (China) (Tan et al., 2015). Siddig et al. assess how ecologists have selected, used, and evaluated the performance of the indicator species by focusing on the number of indicators used (one or more); common taxa employed; terminology, application, and rationale behind selection criteria; and performance assessment methods (Siddig et al., 2016). Botero et al. pay attention to overlapping spatial boundaries within the landward and marine areas and propose an indicator-based framework to measure the effectiveness of the individual planning instruments, as opposed to specific initiatives, in achieving management goals (Botero et al., 2016). Veríssimo et al. evaluate the suitability of thermodynamic-oriented indicators (Eco-Exergy and Specific Eco-Exergy) and trait-based indices as tools to capture potential ecological changes, comprehending their utility for addressing specific management objectives (Vassallo et al., 2016). Aiming to compare environmental indicator sets, Brambila et al. first propose a unified classification criteria for indicators using PSR and five subject categories. Then, they use these classification criteria to describe and compare 14 existing environmental indicator sets. Finally, they compare with environmental indicator sets based on their production characteristics and goals (Brambila and Flombaum, 2017). Tang et al. also propose a set of ecological indicators for coastal ecosystem health assessment using physical stressors such as total suspended matter, chemical stressors including nutrients and heavy metal pollutants, community structure metrics including species richness, diversity and evenness, and ecosystem level eco-exergy indicators (Tang et al., 2018). Recently, indicator systems based on levels of coordination of system development and the value of available resources are established (Azar et al., 1996; Bebianno et al., 2015; Berezina et al., 2017; Mairura et al., 2007; Piroddi et al., 2016; Song et al., 2017; Suzuki, 2003; Uehara and Mineo, 2017). This method is composed of systematic indicators and coordinative indicators. In this method, ‘System’ refers to a complex collection comprised of society, economy, and environmental resources.

From the literature review, it is apparent that indicator systems constructed by the previous studies place excessive emphasis on indicator data or take more consideration on subjective classification criteria. There remains a lack in studies which have been able to consider the more actual meaning of indicators, and the subjectivity that is involved in the analysis through various approaches and is conducted by different personnel.

The main contribution of this study is to propose a novelly comprehensive approach to construct an indicator system to evaluate the development of a land-sea coordination system. Lianyungang port is considered as a case study. A land-sea coordination system is considered as composed by three sub-systems, i.e., a land-side sub-system, a sea-side sub-system, and a port sub-system. We utilize questionnaires to analyze influential factors for the development of a land-sea coordination system. Based on the influential factors, an initial indicator system is established. We apply structural equation modeling to screen the indicators from the initial indicator system. Finally, we conduct reliability and validity analysis to assess the feasibility of the screened indicator system.

The rest of this paper is organized as follows. In Section 2, we introduce materials and methods for establishing an indicator system for evaluating the development of land-sea coordination systems, including the construction of a land-sea coordination system, questionnaires and the principle of the structural equation modeling. In Section 3, by considering Lianyungang port as a case study, we construct the indicator system for evaluating the development of land-sea coordination systems and verify its feasibility. In Section 4, this study is completed by offering some conclusions.

2. Methodology

2.1. An overview of the proposed approach

In this paper, we present a novel approach to construct an indicator system to evaluate the development of a land-sea coordination system, which combines many techniques, such as questionnaires, structural equation modeling, and reliability and validity analysis. We apply these techniques sequentially with each of which depends on the preceding one, forming a cascaded operation. An overview of the proposed approach is shown in Fig. 1.

In detail, we first establish a land-sea coordination system that consists of three sub-systems, i.e., a land-side sub-system, a sea-side sub-system, and a port sub-system. Based on analysis of influential

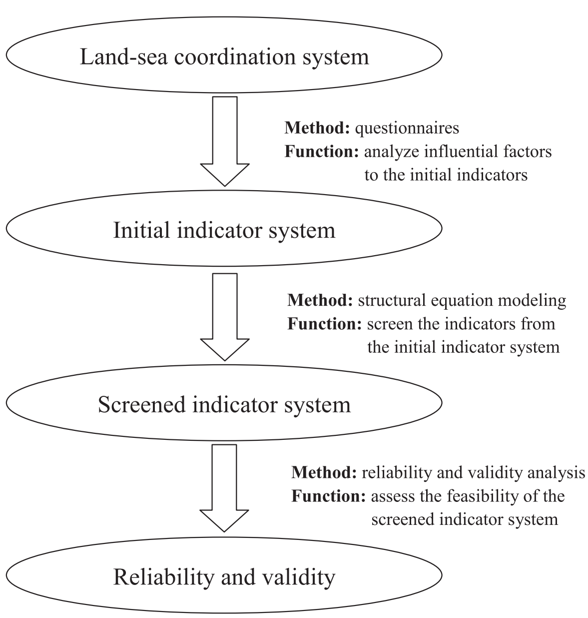

Fig. 1. An overview of the proposed approach.

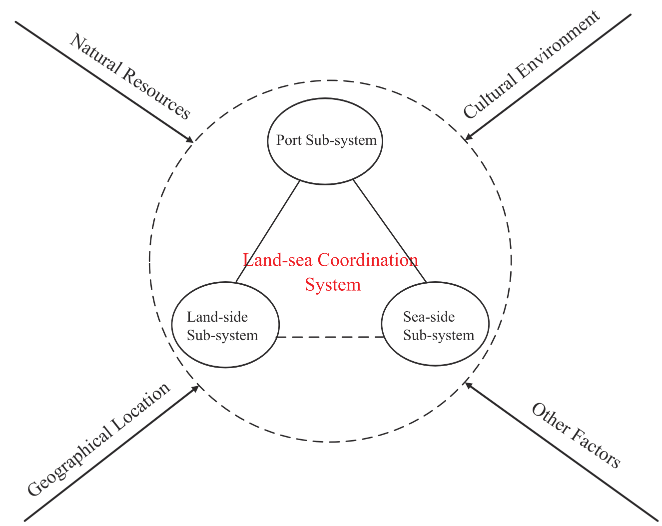

Fig. 2. Components of a land-sea coordination system.

factors using questionnaires for the development of the land-sea coordination system, an initial indicator system is first established. We apply structural equation modeling to screen the indicators from the initial indicator system. Finally, we analyze the reliability and validity of the screened indicator system.

2.2. Land-sea coordination system

As we know, besides both land and sea, port is also a significant component of land-sea coordination (Andrade et al., 2016; Bebianno et al., 2015). From a complex system perspective, in this paper, a land-sea coordination system has been considered to be composed of three sub-systems, i.e., a land-side sub-system, a sea-side sub-system, and a port sub-system. The land-side sub-system refers to the port city, the sea-side sub-system refers to the marine resources, and the port sub-system refers to the port. The components of a land-sea coordination system are illustrated in Fig. 2.

In Fig. 2, the external environment of a land-sea coordination system is composed of many factors, such as natural resources, cultural environment, geographical location and so on. Furthermore, it is obviously found that the land-side and sea-side sub-systems are considered as the core sub-systems, and the port sub-system is considered as the link.

2.3. Questionnaires

Based on analysis of the coordinated development of standard ports, it is obvious that regional economic development, service system development, and resource and environmental conditions play significant roles in the development of land-sea coordination systems (Botero et al., 2016; Brambila and Flombaum, 2017; Nader et al., 2008). The combined influence of these factors can determine the direction, scale, and progress of the coordinated development of ports (Brambila and Flombaum, 2017; Tan et al., 2015; Tang et al., 2018).

Questionnaires can be an effective means of measuring the behavior, attitudes, preferences, opinions, and intentions of relatively large numbers of subjects more cheaply and quickly than other methods (Mcdowell, 2006). In this paper, we adopt a questionnaire survey to evaluate the factors affecting the economic development, service system, and resources and environment of a land-sea coordination system, to define the main influential factors as a basis for an initial indicator system. In detail, three groups of people are defined as the target group for the questionnaire survey. The first group includes theoretical experts in economics, environmental protection, marine

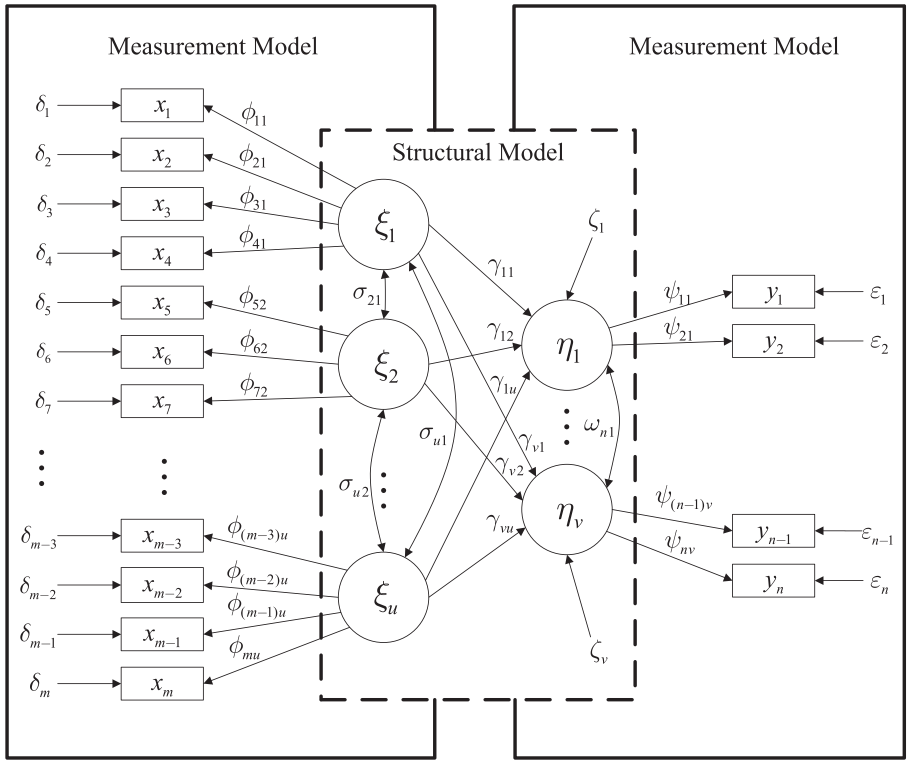

Fig. 3. Path diagram of the SEM.

science, and management science, the second is comprised of experts of harbors and shipping, and the third involves economic management personnel and government agencies.

2.4. Structural equation modeling

In a real land-sea coordination system, it is almost impossible that so many indicators are analyzed and applied to evaluate its development (Nader et al., 2008; Peng et al., 2018; Shi et al., 2018). It is often desirable to screen the initial indicators before further processing. The key process in the construction of an indicator system is accurate selection of indicators. In this paper, we apply structural equation modeling (SEM) to screen the initial indicators to construct the screened indicator system. Here, we briefly review the principle of SEM proposed in the literature (Anderson and Gerbing, 1988; Sadia et al., 2018; Washington et al., 2010).

An SEM is one of the methods for estimating latent variables and their effects on observed variables. It considers a simultaneous estimation of several equations of independent and dependent variables, which allows a multi-layered model to be assessed. It can deal with a large number of endogenous and exogenous observed variables simultaneously. The term “simultaneous equations” means that a set of equations can be specified by direct links between variables. SEM is commonly utilized to model latent variables. It is also specified as linear combinations of the observed variables. In general, an SEM is composed of both a measurement model and a structural model. The measurement model within the SEM incorporate estimates of measurement errors of exogenous variables and their intended latent variable. The structural model is concerned with how the model variables are related to one another. The structural component of the SEM is similar to a system of simultaneous equations. When the SEM includes the measurement model only, it is also known as a confirmatory factor model.

Formally speaking, the measurement model is used to describe the relationship between the observed indicators and the latent variables, which can be formulated by

$$\begin{cases} X = \Phi\xi + \delta \\ Y = \Psi\eta + \varepsilon \end{cases}, \tag{1}$$

where, $X = (x_1, x_2, \cdots, x_m)^T$ is a column vector composed of m exogenous indicators, and $\xi = (\xi_1, \xi_2, \cdots, \xi_u)^T$ is a column vector composed of u exogenous latent variables. $\Phi = (\phi_{ij})_{m\times u}$ is also known as the factor loading matrix of X on ξ, which describes the relationship between the exogenous indicators and exogenous latent variables. The closer the absolute value of ϕ_{ij} is to 1, the greater the correlation between x_i and ξ_j will be. $\delta = (\delta_1, \delta_2, \cdots, \delta_m)^T$, where $\delta_i \in [0, 1]$ for $i \in \{1, 2, \cdots, m\}$, is an m-dimensional error term. $Y = (y_1, y_2, \cdots, y_n)^T$ is a column vector composed of n endogenous indicators, and $\eta = (\eta_1, \eta_2, \cdots, \eta_v)^T$ is a column vector composed of v endogenous latent variables. $\Psi = (\psi_{ij})_{n\times v}$ is known as the factor loading matrix of Y on η, which describes the relationship between endogenous indicators and endogenous latent variables. The closer the absolute value of ψ_{ij} is to 1, the greater the correlation between y_i and η_j will be. $\varepsilon = (\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_n)^T$, where $\varepsilon_i \in [0, 1]$ for $i \in \{1, 2, \cdots, n\}$, is an n-dimensional error item.

The structural model is used to describe the relationship between exogenous latent variables and endogenous latent variables, which can be represented by

$$\eta = \Omega\eta + \Gamma\xi + \zeta,$$

where, the signifier of η and ξ is constructed in the same way as described in Eq. (1). $\Omega = (\omega_{ij})_{v\times v}$ describes the relationship between endogenous latent variables, where $\omega_{ij} = \omega_{ji}$. The closer the absolute value of ω_{ij} is to 1, the greater the correlation between ω_i and ω_j will be. $\Gamma = (\gamma_{ij})_{v\times u}$ is known as the factor loading matrix of η on ξ, which describes the influence of the exogenous latent variables on the endogenous latent variables. The closer the absolute value of γ_{ij} is to 1, the greater the correlation between η_i and ξ_j will be. $\zeta = (\zeta_1, \zeta_2, \cdots, \zeta_v)^T$ is a v-dimensional residual term.

In addition, we also denote that $\Sigma = (\sigma_{ij})_{u\times u}$ describes the relationship between exogenous latent variables, where $\sigma_{ij} = \sigma_{ji}$. The closer the absolute value of σ_{ij} is to 1, the greater the correlation between σ_i and σ_j will be. Hence, the path diagram of the SEM is shown in Fig. 3. The key

Table 1
The initial indicator system.

Level 1 Indicators	Level 2 Indicators	Level 3 Indicators	Level 4 Indicators	Variable
Land-sea Coordination	Land-side	Economic Development	Per Capita GDP	L_1
			Public Revenue	L_2
			Saturation of Inland Transport	L_3
			R&D Expenditure on Total GDP	L_4
			Investment in Fixed Assets	L_5
			Income from the Service Industry on Total GDP	L_6
			Industrial Power Consumption	L_7
		Service System	Development of Logistics and Trading Platforms	L_8
			Revenue of Land Transportation	L_9
			Tax Revenue	L_{10}
			Year-end Loan Balance from Financial Institutions	L_{11}
			Total Roadway Mileage	L_{12}
			Revenue of Leasing and Commercial Services	L_{13}
		Resources and Environment	Rate of Decline in Energy Consumption per Unit of GDP	L_{14}
			Water Consumption per GDP (m^3/CNY 10,000)	L_{15}
			Emissions of SO_2	L_{16}
			Number of Days with Good Air Quality	L_{17}
			Comprehensive Utilization of Industrial Solid Waste	L_{18}
			Total Land Area	L_{19}
			Industrial Land Area	L_{20}
			Green Coverage Ratio	L_{21}
	Sea-side	Economic Development	Value-added of Marine Service Industry	S_1
			Income of Marine Tourism	S_2
			Output of Marine Fisheries	S_3
		Service System	Added-Value from the Marine Service Industry	S_4
			Revenue from the Marine Transportation	S_5
			Proportion of IT Personnel to Total Marine Employment	S_6
			Proportion of Marine R&D Expenditure to Total R&D Expenditure	S_7
		Resources and Environment	Confirmed Sea Area	S_8
			Proportion of Marine Protected Areas to Total Sea Area	S_9
			Chemical Oxygen Demand	S_{10}
			Capacity of Seaward Channels in Tons	S_{11}
	Port	Economic Development	Total Foreign Trade (Import and Export)	P_1
			Saturation of Throughput Capacity	P_2
			Container Throughput	P_3
		Service System	Shipping Services	P_4
			Development of Loading & Unloading and Freight Forwarding Industries	P_5
		Resources and Environment	Length of Quay Line for Productive Use	P_6
			Total Number of Berths	P_7
			Proportion of the Number of Container Berths on Total Berths	P_8
			Total Amount of Pollutants Entering the Sea	P_9
			Compliance Rate of Marine Environmental Functional Area	P_{10}
			Emissions Rate of Industrial Wastewater in Harbor Area	P_{11}

process in the construction of the SEM is to estimate model parameters Φ, Σ, δ, Ψ, ε, Ω, Γ, and ζ. After estimation of model parameters, we should also investigate whether the SEM has a satisfactory degree of fit. Here, we adopt the following three indices, namely the comparative fit index (CFI), the root mean square error of approximation (RMSEA) and the adjusted goodness of fit index (AGFI), to evaluate the fit of the SEM.

- **CFI**: the value of CFI lies between 0 and 1; the closer the value is to 1, the better the overall fit of the model is.
- **RMSEA**: the smaller the value of RMSEA, the better the overall fit of the model is. It is generally believed that a RMSEA below 0.10 indicates a good fit, and that below 0.05 indicates a very good fit.
- **AGFI**: the value of AGFI lies between 0 and 1; the closer the value is to 1, the better the overall fit of the model is.

2.5. Reliability and validity analysis

As stated previously, we obtain the screened indicator system using the SEM. However, the feasibility of this system should be tested further. We assume that this system is a questionnaire, and thus reliability and validity of this system can be analyzed. Generally speaking, reliability and validity analysis are indispensable processes in questionnaire analysis, which serve as the criteria to test the quality of questionnaires (Carey and Seibert, 1993; Roberts et al., 2006). To ensure the feasibility of the questionnaire, it is important to conduct reliability and validity analysis.

Reliability refers to the degree of consistency in the results obtained when measuring the same thing repeatedly with the same indicator or measurement instrument. Internal reliability is the most commonly adopted measurement for reliability analysis. Hence, it is adopted in this study. The reliability coefficient usually lies between 0 and 1. The closer the coefficient is to 1, the better the reliability of the questionnaire will be.

Validity refers to the degree of accuracy of the measurement instrument. There is a wide range of validity analysis methods, and this study adopts criterion validity, as it is more commonly used. In addition, criterion validity can be divided into concurrent and predictive validity. Given that the criterion data of the concurrent validity can be easily obtained, whilst that of the predictive validity can only be obtained several weeks or even months following the research, the concurrent validity is applied to evaluate the indicator system.

3. Results analysis and discussion

3.1. Establishment of an initial indicator system using questionnaires

3.1.1. Analysis of influential factors

Based on the results of questionnaires, 31 major influential factors for the development of the land-sea coordination system are extracted, including 15 influential factors for the land-side sub-system, eight factors for the sea-side sub-system, and eight factors for the port sub-system. The detailed factors of each sub-system are described as follows.

The land-side sub-system is comprised of economic development, industrial development, the development of industrial parks, the development of tertiary industries, innovation capacity, the degree of investment in fixed assets, the scale of the inland transport system and logistics services, the construction of infrastructure, financial service conditions, tax policies, business services, the current resource conditions, resource consumption, environmental status, and pollutant discharge of the hinterland.

The sea-side sub-system includes marine economic development, development of tertiary industries, development of fisheries, the development of the marine public service, marine transportation, the current marine resource conditions, environmental conditions, and amount of pollutants entering the sea.

The port sub-system involves the degree of international trade, throughput capacity, cargo distribution capacity, reputation, management and service level, port resources, environmental conditions, and pollution control systems.

3.1.2. Initial indicator system

Based on the influential factors, this study designs the corresponding indicators and divides these indicators into four levels, see Table 1.

Table 1 shows that 43 indicators for evaluating the development of the land-sea coordination system are generated to form the initial indicator system, including 21 indicators for the land-side sub-system, 11 indicators for the sea-side sub-system, and 11 indicators for the port sub-system. In addition, there indicators are grouped into three major categories: (1) economic development; (2) service system; and (3) resources and environment. Especially, there are 18 indicators in reference to resources and environment, since resources and environment have always been regarded as an important support for the development of the regional economy. Moreover, we can find that all indicators related to ecological environment are negative, which bring in pressure on regional economic development. These indicators can remind people to protect the environment and provide a scientific reference and decision-making basis for environmental policy formulation.

3.2. Screening indicators using structural equation modeling

Previously, the establishment of an initial indicator system is mostly discussed. In this section, we use the SEM to screen the initial indicators. In order to obtain the suitably practical indicator system, we consider Lianyungang port as a case study. Based on it, the process of applying the SEM to screen the initial indicators is divided into four steps, i.e., data source and variable description, estimation of model parameters, evaluation of model fit and establishment of the screened indicator system.

3.2.1. Data source and variable description

Lianyungang port is one of the most famous ports driven by industries in China. The location of Lianyungang port in China is shown in Fig. 4. The figure is borrowed from the Planning Bureau of Lianyungang:http://layout.lyg.gov.cn/. As seen in Fig. 4, we can obviously find that Lianyungang port has a lot of location advantages richly endowed by nature. In this paper, we acquire the corresponding data of 43 initial indicators for Lianyungang port, from 2006 to 2014, to test the model. The data are mainly obtained from the Statistical Yearbook of Lianyungang, and the Bulletin of Marine Economy Statistics of Jiangsu Province, from 2006 to 2014. Notice that an expert scoring method is applied to quantify the qualitative indicators, such as L_8, P_4, and P_5.

In this paper, due to clear and simple logical relationship, the measurement model is adopted only. For simplicity and intuition, the notations and corresponding indicators of the exogenous latent variables in the SEM are presented in Table 2.

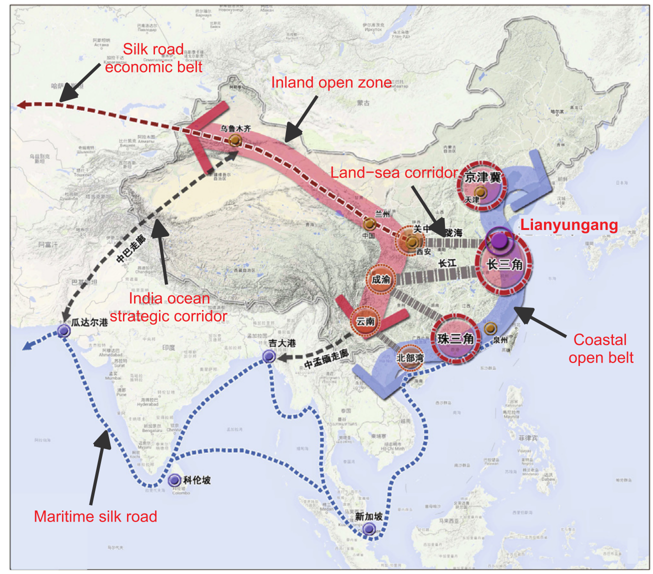

Fig. 4. Location map of Lianyungang port in China.

Table 2
Description of the exogenous latent variables.

Sub-system	Notation	Variable	Indicators Included
Land-side	ξ_1	Economic Development	$L_1 \sim L_7$
	ξ_2	Service System	$L_8 \sim L_{13}$
	ξ_3	Resources and Environment	$L_{14} \sim L_{21}$
Sea-side	ξ_4	Economic Development	$S_1 \sim S_3$
	ξ_5	Service System	$S_4 \sim S_7$
	ξ_6	Resources and Environment	$S_8 \sim S_{11}$
Port	ξ_7	Economic Development	$P_1 \sim P_3$
	ξ_8	Service System	$P_4 \sim P_5$
	ξ_9	Resources and Environment	$P_6 \sim P_{11}$

3.2.2. Estimation of model parameters

The software package AMOS 17.0 is utilized to estimate model parameters, making use of the maximum likelihood function. Moreover, we adopt standardized estimates for the parameters. With numerical computing, the path diagrams of the SEM with the corresponding variables for the land-side, the sea-side and the port sub-systems are illustrated in Figs. 5–7.

In Figs. 5–7, we can obtain the values of model parameters Φ, Σ, δ in Fig. 3. In particular, by taking Fig. 5 as an example, for $i \neq j$, $i \in \{1, 2, 3\}$ and $j \in \{1, 2, 3\}$, we find that arbitrary σ_{ij} in Σ is equal to 1, which indicates the high correlation between ξ_i and ξ_j. The similar conclusions can also be gained from Figs. 6 and 7.

3.2.3. Evaluation of model fit

After estimation of model parameters, we should also investigate whether the SEM has a satisfactory degree of fit. Here, CFI, RMSEA and AGFI are adopted to evaluate the fit of the SEM. The corresponding values of these indices are summarized in Table 3.

As shown in Table 3, the values of CFI are greater than or equal to 0.90, the values of RMSEA are below 0.10, and the values of AGFI are greater than 0.90. Therefore, the SEM has a satisfactory degree of fit and is successfully applied to evaluate the impact of the observed

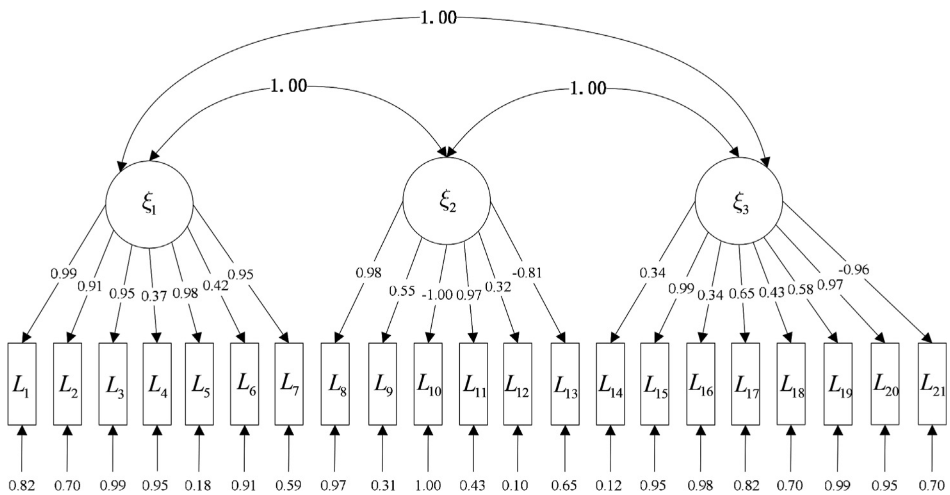

Fig. 5. Path diagram of the SEM for the land-side sub-system.

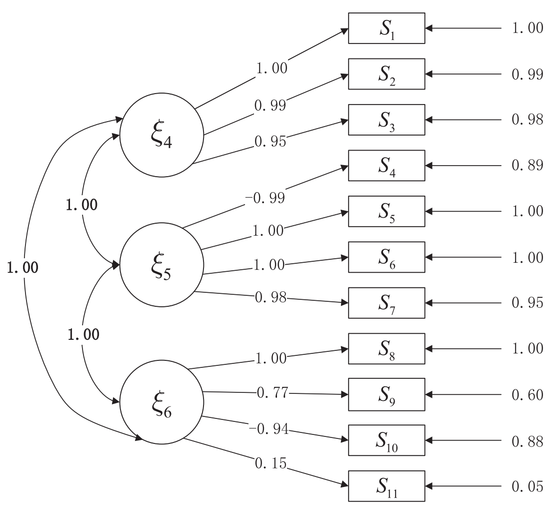

Fig. 6. Path diagram of the SEM for the sea-side sub-system.

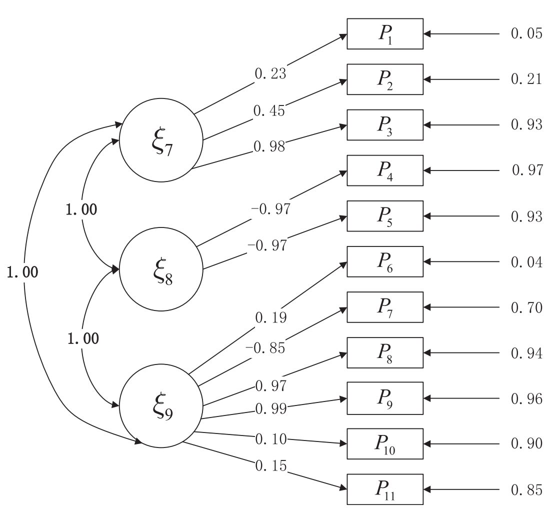

Fig. 7. Path diagram of the SEM for the port sub-system.

indicators on three sub-systems.

3.2.4. Establishment of the screened indicator system

In the former section, we can find that the SEM has a satisfactory degree of fit. Therefore, we can use it to screen the initial indicators

Table 3
Results of evaluating the fit of the SEM.

Sub-system	CFI	RMSEA	AGFI
Land-side	0.95	0.02	0.94
Sea-side	0.92	0.03	0.94
Port	0.90	0.07	0.93

based on all elements of Φ. In general, the acceptable threshold for the screening process is defined as $|\phi_{ij}| \geqslant 0.85$, i.e., indicators with $|\phi_{ij}| < 0.85$ are removed from the final list. After screening, 26 indicators are totally retained, thus forming the screened indicator system for the evaluation of the development of the land-sea coordination system, see Table 4.

3.3. Reliability and validity analysis of the screened indicator system

3.3.1. Reliability analysis

First, the screened indicator system is compiled into a questionnaire and Level 4 indicators are submitted to a panel of experts for an importance rating (from ‘0, not important at all’ to ‘1, very important’). Next, the total score of Level 4 indicators for each Level 3 indicator is equated to acquire the score of the corresponding Level 3 indicator. A similar method is applied to obtain the scores for Level 2 and Level 1 indicators. Then, the reliability coefficient of each indicator is computed accordingly. The software package SPSS (V19.0) is utilized for data processing. The results are shown in Table 5.

It can be seen from Table 5 that the internal consistency reliability coefficient of Level 1 and Level 2 indicators are both greater than 0.90, indicating that the reliability of the indicator system is relatively high.

3.3.2. Validity analysis

Here, we use the corresponding scores obtained in reliability analysis, of Level 1 and Level 2 indicators, to conduct validity analysis. First, Level 1 indicators are used as the criteria, and the corresponding scores of these indicators are used as the scores for the criterion. Next, a correlation analysis is conducted between Level 2 indicators and the criterion scores. Then, the correlation coefficient is utilized as the validity index for the constructed indicator system. The criterion validity analysis results, computed by SPSS, are shown in Table 6.

Notice that all coefficients are significantly correlated to 0.01 level (both sides). Table 6 shows that there is a significant, positive correlation between Level 1 and Level 2 indicators, suggesting that the indicator system has good criterion validity.

The results of reliability and validity analysis confirm that the

Table 4
The screened indicator system.

Level 1 Indicators	Level 2 Indicators	Level 3 Indicators	Level 4 Indicators	Variable
Land-sea Coordination	Land-side	Economic Development	Per Capita GDP	L_1
			Public Revenue	L_2
			Saturation of Inland Transport	L_3
			Investment in Fixed Assets	L_5
			Industrial Power Consumption	L_7
		Service System	Development of Logistics and Trading Platforms	L_8
			Tax Revenue	L_{10}
			Year-end Loan Balance from Financial Institutions	L_{11}
		Resources and Environment	Water Consumption per GDP (m^3/CNY 10,000)	L_{15}
			Industrial Land Area	L_{20}
			Green Coverage Ratio	L_{21}
	Sea-side	Economic Development	Value-added of Marine Service Industry	S_1
			Income of Marine Tourism	S_2
			Output of Marine Fisheries	S_3
		Service System	Added-Value from the Marine Service Industry	S_4
			Revenue from the Marine Transportation	S_5
			Proportion of IT Personnel to Total Marine Employment	S_6
			Proportion of Marine R&D Expenditure to Total R&D Expenditure	S_7
		Resources and Environment	Confirmed Sea Area	S_8
			Chemical Oxygen Demand	S_{10}
	Port	Economic Development	Container Throughput	P_3
		Service System	Shipping Services	P_4
			Development of Loading & Unloading and Freight Forwarding Industries	P_5
		Resources and Environment	Total Number of Berths	P_7
			Proportion of the Number of Container Berths on Total Berths	P_8
			Total Amount of Pollutants Entering the Sea	P_9

Table 5
Results of reliability analysis.

System	Land-side	Sea-side	Port	Land-sea Coordination
Reliability Coefficient	0.95	0.92	0.94	0.95

Table 6
Results of validity analysis.

	Land-side	Sea-side	Port
Land-sea Coordination	0.90	0.90	0.94

developed screened indicator system has satisfactory reliability and validity, and is suitable for evaluating the development of the land-sea coordination system of Lianyungang port, as well as for other standard ports.

4. Conclusions

In order to provide a tool for guidance in sustainability policies, including monitoring of measures and their results, and communication to the public at large, we propose a novel approach to establish an indicator system to evaluate the development of land-sea coordination systems. By taking Lianyungang port as a case study, we utilize questionnaires and the SEM to construct the indicator system. Finally, we analyze the reliability and validity of the indicator system to verify its feasibility and practicality. Conclusions reached are drawn as follows:

- Since all the indicators are quantified, the process of establishing the indicator system can be highly dependent on mathematical theory; thus the indicator system can be further analyzed and corresponding mathematical models for evaluating the development of land-sea coordination systems can be established.
- In fact, the establishment of the indicator system is a three-step process. The initial indicator system is firstly established through a questionnaire survey. Then, the initial indicators are screened using the SEM, so as to form the developed indicator system. Finally, the reliability and validity of the developed indicator system are analyzed.
- The developed indicator system is constructed based on more consideration on the actual meaning of the indicators, and the subjectivity involved in the analysis through various approaches. Thus, the indicator system has satisfactory reliability and validity, and is suitable for evaluating the development of the land-sea coordination system of Lianyungang port, as well as for other standard ports.

Because of taking Lianyungang port as a case, the indicator system established in this study has strong practicability. Therefore, this study provides a scientific reference and decision-making basis for policy formulation and development evaluation of standard ports. Due to the lack of the latest actual data of Lianyungang port, in the future research, the latest statistical data will be combined with the models for establishing the indicator system, so that the indicator system will be updated, which will greatly increase the timeliness of the indicator system.

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