Simulation research of port competitiveness based on system dynamics

Xie Yan[1]

School of Economics and Management, Jiangsu University of Science and Technology, Zhenjiang, Jiangsu, China

Abstract: It is an urgent problem for Chinese large and medium-sized ports to improve their competitiveness. With the method of system dynamics and the software Vensim-PLE, the simulation model of port competitiveness is constructed to explore the internal factors influencing mechanism and development trend of port competitiveness. By constructing causality diagram and system flow diagram, the paper analyzes the influence mechanism of related factors on port competitiveness. Taking Nanjing Port as the specific research object, it predicts the change trend of cargo throughput and other related variables and port competitiveness. Then it designs four simulation schemes to improve the port competitiveness of Nanjing Port ,and compares the improvement effects of different schemes . Finally, it puts forward some countermeasures and suggestions to improve port competitiveness.

1.Introduction

On March 12, 2021, the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Outline of 2035 Vision Goals were publicly released. It points out that we should speed up the building of China into a transportation power. As an important part of China's transportation power, ports play an irreplaceable special status and role. For port enterprises, how to improve their competitiveness, so as to achieve strategic goals has become an important practical problem that needs to be solved urgently.

At present, domestic and foreign scholars have extensively studied port competitiveness. These studies can be divided into two categories in terms of content. The first type is represented by scholars such as Kalgora[1], Chen Fuying [2], Lu Bo [3], Munim[4], Qin Fei [5], etc., used entropy weight -TOPSIS method, TEI@I method, AHP, principal component analysis, factor analysis, PLS-SEM, UTAGMS and other model methods, constructed different port competitiveness index system, evaluated the domestic and foreign ports, compared and analyzed the competitiveness of each port. The other is to analyze the competitiveness of a certain aspect of the port or a certain type of port. For example, Zhang Yuan [6] put forward the concept and evaluation index system of the competitiveness of the port by cargo category based on the characteristics of the production and operation of each cargo category of the port, and proved the different competitiveness of the same port for each cargo category through calculation examples. Wang Yu[7] evaluated the logistics competitiveness of Chinese coastal ports by comprehensive weighting method. Kavirathna[8] used generalized costing and discrete selection model to study the performance competitiveness of the Port of Colombo and analyzed the Port's operating performance. Based on the green concept, Aksoy.[9] studies how to increase the level of green competitiveness of Turkish ports by minimizing the negative effects of port operations as a major issue.

It can be seen from the above that existing researches on port competitiveness have made some achievements, but there are still some shortcomings. On the one hand, most researches on port competitiveness adopt the method of evaluation, and more focus on the results of port competition, failing to accurately identify the important factors to improve port competitiveness and their influence mechanism on port competitiveness. On the other hand, some scholars only pay attention to the performance of a certain aspect when studying port competitiveness, and do not comprehensively analyze the mechanism of port competitiveness improvement from a global perspective.

Port competitiveness system, as a dynamic complex system composed of multiple factors, has multiple interactive behaviors, showing nonlinear, procedural, feedback and other characteristics. In addition, due to the unavailability of some data, both qualitative and quantitative research methods have certain deficiencies. System dynamics is an effective method to analyze complex systems, which is based on the theory of system feedback control and combines qualitative and quantitative methods to study the dynamic behavior of system development[10]. Fu Haiwei, Liu Pei, Ridwan and other domestic and foreign scholars studied the dynamic relationship[11] between shipping service industry and ports, the resource integration dynamic mechanism of port

[1] Corresponding author：964254150@qq.com

collection and distribution system[12], the improvement mechanism[13] of port loading, unloading and handling efficiency and other related port issues by using the method of system dynamics. T Suheri choosed port, commercial shipping, marine protected area and commercial fishing as the key elements, whose interactions are modeled using system dynamics.[14]. Li X used the method of system dynamics to study the influence of port trade activities on the regional economic development of port hinterland[15]. These previous studies verify the applicability and effectiveness of system dynamics for studying port system. Based on this, this paper adopts the method of system dynamics to simulate and analyze the competitiveness of the port, which can make clear the relationship between the internal elements of the complex port system. And take the port of Nanjing as an example to conduct simulation operation, trying to open the port allocation related resources, improve the competitiveness of the port organization black box. In theory, this paper can provide new ideas for relevant port competitiveness research and enrich relevant theoretical research. In practice, it can provide reference opinions for port operators to formulate port development strategy and precise decision-making.

2.The construction of port competitiveness model

2.1.System flow diagram

Based on the competitiveness theory and system dynamics method, and referring to the research of Qiao Wenyi et al., [14],and combined with the relevant data of Nanjing Port studied in this paper. The boundary of the model system was Nanjing Port, the operation time range was 2011-2030, and the historical data span was 2011-2021. 2011 was taken as the simulation base year, and the simulation step length was 1 year.The data in the model are mainly from 《Nanjing Statistical Yearbook》,《China Port Statistical Yearbook》,major port websites and annual reports of the Port of Nanjing. Vensim-PLE software is used to construct the system flow diagram of port competitiveness, so as to visually represent the logical relationship between each influencing factor. The system flow diagram of port competitiveness is shown in Fig 1:

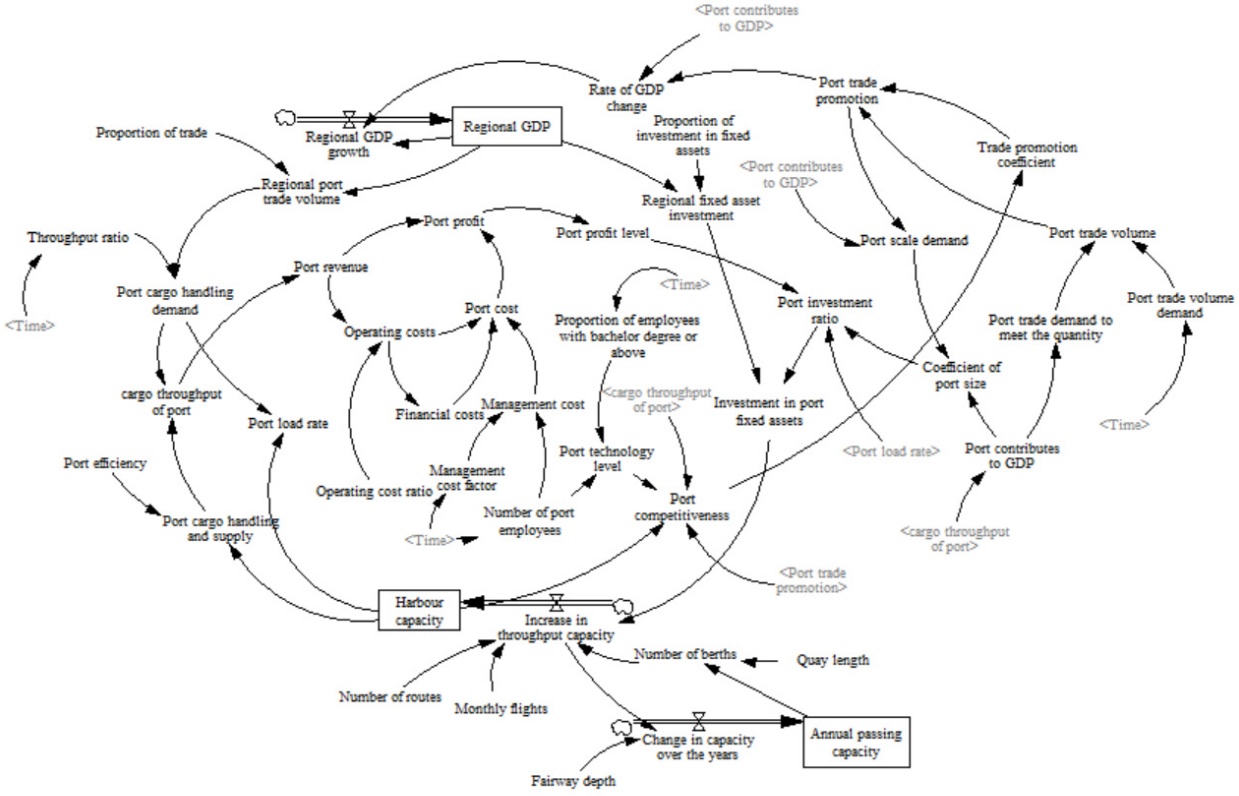


Fig. 1. System flow chart of port competitiveness

In Figure 1, annual passing capacity, harbour capacity, and regional GDP are state variables, indicating cumulative effect; increase in throughput capacity, increase in throughput capacity, and regional GDP growth are rate variables, reflecting the change speed of cumulative effect of state variables; others are auxiliary variables or constants. At the same time, the system flow chart shows the interrelationships of variables in more detail .For example, the competitiveness of a port is comprehensively considered by harbour capacity , port technology level ,cargo throughput of port and port trade promotion .Port handling capacity is determined by the number of routes, monthly flights and berths .Driven by port competitiveness as a whole, the system flow chart depicts the dynamic changes of regional GDP, port throughput, business revenue, trade volume and other factors to show the operation and mechanism of port

competitiveness system. annual transit capacity, port throughput capacity.

2.2.Historical value test of system dynamics model

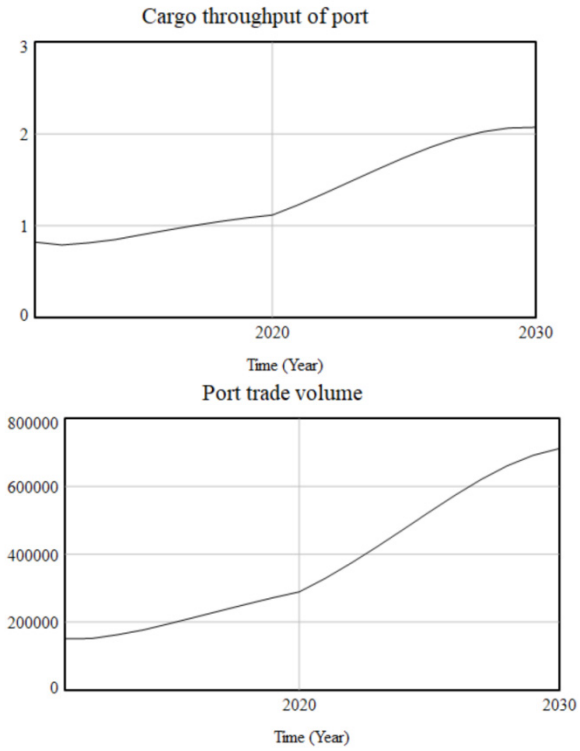
In this model, cargo throughput and regional GDP variables are selected for historical test, and the results are shown in the relative error of cargo throughput is within ±15%, the relative error of regional GDP is within ±10%, and the fitting degree of the model is within a reasonable range, which can be used as the basis for simulation and prediction.

Table 1 Test results of historical values of port competitiveness system dynamics model 2011-2021

	Cargo throughput /100 million tons			Regional GDP/ 100 million yuan		
	True value	Simulated value	Relative error	True value	Simulated value	Relative error
2011	0.840	0.818716	2.57%	5198.2	5198.2	0.00%
2012	0.852	0.787814	7.52%	6230.2	5856.47	6.00%
2013	0.857	0.81068	5.39%	7306.54	6594.32	9.75%
2014	0.895	0.845532	5.55%	8199.49	7418.52	9.52%
2015	0.922	0.898394	2.60%	8956.05	8336.44	6.92%
2016	1.009	0.950021	5.85%	10015.73	9354.41	6.60%
2017	1.062	0.999137	5.90%	10819.14	10478.6	3.15%
2018	1.041	1.04423	- 0.29%	11894	11714.3	1.51%
2019	1.062	1.08341	- 2.02%	13009.17	13063.7	- 0.42%
2020	1.038	1.11467	- 7.39%	14045.15	14528.2	- 3.44%
2021	1.076	1.22783	- 14.14%	16355.32	16107.4	1.52%

3.Model analysis

3.1. Analysis of simulation results



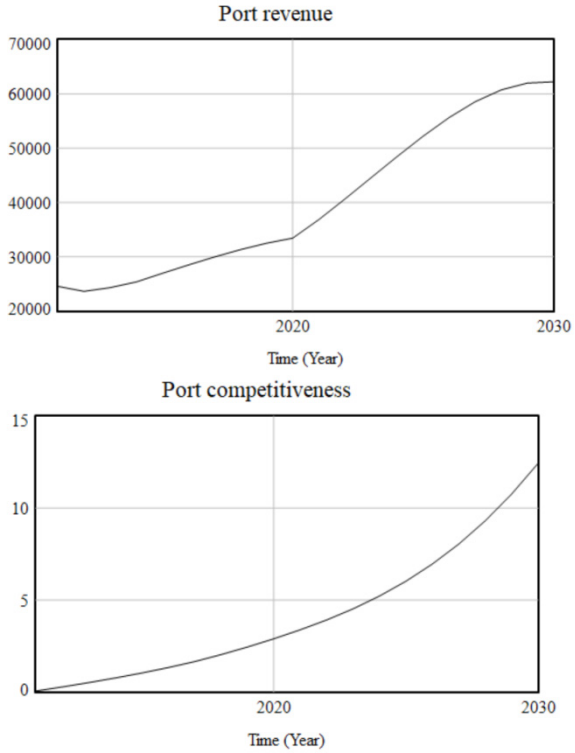


Fig 2. Simulation result of port competitiveness system

With the development of time and space, port competition becomes increasingly fierce, which is manifested in the changing trend of various related factors.From the above simulation results, it can be seen that from 2011 to 2030, the cargo throughput, port revenue and port trade volume of Nanjing Port all showed a stable growth trend of slow growth in the early stage and accelerated growth in the later stage.The simulation results show that it is expected that by 2030, the port cargo throughput will increase from

81 million tons in 2011 to 207 million tons, the port operating revenue will increase from 245.615 million yuan to 622.184 million yuan, and the port trade volume will increase from 150,623 million yuan to 7122.8 million yuan. It can be predicted that the Port of Nanjing will achieve stable and rapid development in the future.

During the observation period, the port competitiveness of Nanjing was low in the early stage, but increased at a fast speed in the later stage under the influence of various factors, and the upward trend gradually expanded. It shows that the investment and construction of the Port of Nanjing in the early stage will play a more important role in the later stage. The improvement of the competitiveness in the later stage is inseparable from the accumulation and application of various resources in the early stage. In the initial year of simulation, the initial value of port competitiveness of Nanjing Port is set as 0.05, and the port competitiveness level will reach 12.43 in 2030, which has achieved a breakthrough growth in 20 years. To explore the reasons, it is closely related to the economic development of the port hinterland, port investment, port technology level, port scale, port throughput and other factors.

3.2.Analysis of simulation scenarios

Four schemes are designed for the key factors affecting the competitiveness of ports, as follows:

Table 2. Port competitiveness simulation scheme table

Scheme name	Scheme description
Original scheme	The variables remained the same as the control group
Environmental enabler scheme	Other variables remain unchanged, and regional GDP increases by 50%
investment-driven scheme	Other variables remain unchanged, regional fixed asset investment increased by 50%, port fixed investment increased by 50%,
Cost control scheme	The remaining variables remain unchanged, the port operating cost is reduced by 50%, and the financial cost by 50%
Talent support Talent support	The remaining variables remain the same, the number of port employees increased by 50%, and the proportion of employees with a bachelor's degree or above increased by 50%

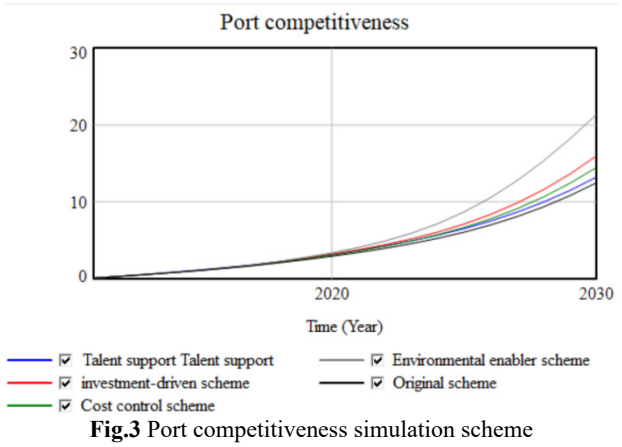


Fig.3 Port competitiveness simulation scheme

It can be seen from the figure above that compared with the original scheme, the port competitiveness of the four schemes designed has been improved in different degrees, indicating that there is room for improvement in the port under the current situation, and the methods to improve the port competitiveness can be considered from multiple aspects. As shown in the figure, in the early stage of simulation, the gap between each scheme and the original scheme is not obvious. With the passage of time, the adjustment factors gradually play a role, and the enhancement effect of the simulation scheme tends to be obvious. Among them, the schemes are ranked from largest to smallest in terms of port competitiveness enhancement effect, which are environmental promotion > investment drive > cost control > talent support. In the environmental promotion scheme, the port competitiveness is optimized from the original 12.43 to 21.31, indicating that the hinterland economic environment plays a core role in port competition. Different from the other three schemes, the environmental promotion scheme does not need a long time period to play its role, and the impact of hinterland economic conditions on port competitiveness is real-time. Investment drive, cost control and talent support all need to consider the delayed effect, which is also the most obvious reason for the environmental promotion effect. The other three schemes are not as effective as the environmental promotion schemes, but from the perspective of the port itself, these three schemes are feasible and efficient ways to improve the competitiveness. In the actual operation process of port enterprises, these four schemes can provide some management enlightenment and reference suggestions for operators.

4.Conclusion

Aiming at the urgent needs of the development of port competition, this paper establishes the system dynamics model of port competitiveness, studies the influence mechanism of relevant factors of port competitiveness, conducts simulation analysis with the data of Nanjing Port, simulates the evolution trend of port competitiveness in the future, and draws the following conclusions:

(1) Port competitiveness is a complex system whose system behavior is determined by the system structure and internal mechanism. The traditional linear, intuitive and simple method can not effectively reveal its internal self-organization rule, but the dynamic mechanism and changing trend of competitiveness can be revealed through system dynamics simulation.

(2) The model is basically accurate in the simulation of the development history of the Port of Nanjing from 2011 to 2021, and predicts that the port throughput, port trade volume and operating revenue of the port will increase year by year from 2022 to 2030, showing a good development trend. The port competitiveness of Nanjing Port increased steadily during the simulation period, and the future evolution trend is good.

(3) Four schemes designed according to the key factors, namely environmental support, investment driven, cost control and talent support, can more clearly simulate the

mechanism of port competitiveness improvement. Among them, the environmental promotion scheme plays the most obvious role in improving port competitiveness, while the other three schemes all play a role in improving port competitiveness.

References:

1. KALGORA B. Strategic Container Ports Competitiveness Analysis in West Africa Using Data Envelopment Analysis (DEA) Model [J]. Open Journal of Business Management, 2019, 07(2): 680-692.
2. Chen Fuying, ZHANG Jiantong. Evaluation and Comparative Study on the Competitiveness of Chinese Coastal Ports under the "Belt and Road" Strategy [J].Industrial Engineering and Management, 2021, 26(03): 1-7.
3. Lu Bo, Wen Yijing, Xing Jian.Research on competition and cooperation strategies of ports around Bohai Sea based on TEI@I methodology [J]. Management Review, 2020, 32(07): 246-257.
4. MUNIM Z H, DURU O, NG A K Y. Transhipment port's competitiveness forecasting using analytic network process modelling [J]. Transport Policy, 2022, 124: 70-82.
5. Qin Fei, Qu Linchi.Chain model of international competitiveness of Chinese port enterprises and policy implications [J]. Asia-pacific Economics, 2021, (04): 130-136.
6. Zhang Yuan, Huang Jun, Ding Wentao.Port Classification Competitiveness Evaluation Method based on Combination Weighting and TOPSIS method [J].Science Technology and Engineering, 2021, 21(28): 12294-12298.
7. Evaluation of port logistics competitiveness based on comprehensive weighting method. Journal of Shandong University of Science and Technology (Natural Science Edition), 2019, 38(05): 113-120.]
8. KAVIRATHNA C A, KAWASAKI T, HANAOKA S. Transshipment Hub Port Competitiveness of the Port of Colombo against the Major Southeast Asian Hub Ports* [J]. The Asian Journal of Shipping and Logistics, 2018, 34(2): 71-82.
9. AKSOY S, DURMUSOGLU Y. Improving competitiveness level of Turkish intermodal ports in the Frame of Green Port Concept: a case study [J]. Maritime Policy Management, 2020, 47(2): 203-220.
10. Wang Qifan.System Dynamics (2009 Revision) [M]. System Dynamics (2009 Revision), 2009.
11. Fu Haiwei.Impact of shipping service industry on port based on dynamic simulation [J]. Navigation of China, 2018, 41(01): 117-121+134.
12. Liu Pei, Mu Dong, Su Jie.Dynamic mechanism of resource integration in regional port collection and distribution system [J]. Journal of Systems Management, 2015, 24(03): 444-451+462.
13. RIDWAN A, NOCHE B. Model of the port performance metrics in ports by integration six sigma and system dynamics [J]. International Journal of Quality & Reliability Managemen, 2018, 35(1): 82-108.
14. Suheri T , Alexandri M B , Raharja S J , et al. Interaction between Marine Sectors using System Dynamics for Patimban Deep Sea Port as a Green Port: A Proposed Model[J]. IOP Conference Series Earth and Environmental Science, 2021, 799(1):012-021.
15. Li X , Zhang Y , Cao Y . Impact of Port Trade on Regional Economic Development Based on System Dynamics[J]. Journal of Coastal Research, 2020, 110(sp1).
16. Qiao Wenyi, Guan Weihua, Wang Xiaoge.Dynamics of port City Coupling System Based on Green Concept: A case study of Lianyungang City [J]. Journal of Nanjing Normal University (Natural Science Edition), 2018, 41(01): 140-148.