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Simulating Mechanism of Interaction Between Ports and Cities Based on System Dynamics: A Case of Dalian, China

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Abstract: Port-city system is a complex and integral system, and it can be simulated by system dynamic method, which is used to be employed to solve nonlinear problems. Based on the causality of the every element in the port-city system, the authors analyzed the feedback relation and logical relation among the system variables and system structure. A system-dynamic flow chart and correlation equations were put forward with VENSIM software, the quantitative relation was described, and the model was debugged. The development trend of the main influence factors in port-city system was simulated. By changing the parameters values of variables in the model, we studied the influence degree of each related factor. It is found that: 1) Foreign trade throughput of port play an important role in the development of export-oriented economy. 2) The development of primary industry and secondary industry affects most of the water transportation demand. With the constant increase of tertiary industry proportion in the industrial structure, the demand of national economy for water transportation decreases gradually. 3) Water transportation presents a kind of oversupply development situation, so port construction should properly slow down. 4) With the development of ports, its direct and indirect contribution to urban economy has been continuously increasing, but contribution rate will be continuously decreasing.

Keywords: port-city; system dynamics; Dalian; China

1 Introduction

Coastal port and city are interactive. Port is a special function of city, and city is the carrier of port development. With the acceleration of economic globalization, the international transfer of industries becomes more frequent, and industry agglomeration towards port is more obvious. As a result, the relationship between port and city is closer. The behavior pattern and characteristic of port-city system depend on its internal dynamic structure, so it is needed to study the internal dynamic structure and the interaction mechanism of main elements.

The study abroad on port-city interaction began in the 1960s (Pearson, 1964), and mostly focused on the theory analysis and static study on the effect of port on city. In the 1980s, Davis (1983) put forward the concept of indirect and induced port economic impact, and then, the US government agencies led by the US Maritime Administration (MARAD) and Bureau of Economic Analysis (BEA) started to study the measurement model of port economic impact, mainly concentrated on the calculation method of port economic impact on city, and have formed comparatively perfect software package. The study abroad on dynamic model about the impact of port on city mainly utilized the dynamic input-output method, which achieved some improvements in not only the impact of port on city in the time-point, but also the change of port economic development in the period.

The domestic studies on both qualitative analysis of port-city interaction and static model are relatively mature, however, the quantitative studies are still on the stage of development. After Ren and Ding (1994) proposed to employ the system dynamics to analyze the port system qualitatively, the studies on the index, calculation method and research ideas of socio-economic impact of port have been done (Zou, 1997; Chen and Shao, 1999; Song, 2001). The quantitative studies mainly focused on the impact of port on city. Yuan (2002)

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used input-output method to measure GDP pulled by Dalian port, and Liu (2004) analyzed the proportion in and the social impact of port economy on city economy. Generally, the previous researches mostly considered the unilateral impact of port on city using port-city static model, which are hard to reflect the dynamic change of the whole port-city interaction system.

System Dynamics (SD model for short) can reflect function of complex system structures and interactive relationship between dynamic actions, conduct dynamic simulating test of complex systems, investigate the changeable behavior and trend of complex systems affected by different strategy factors, and provide support to decision maker (Wang, 1995). With broad application of the SD in the fields of macro-economics, micro-economics, society and population, ecology and environment, technology and education, and so on, SD has shown superiority in the aspect of studying complex nonlinear system.

There are nonlinear relationship and complex causality between internal factors in port-city system. As a result, it is difficult to describe this system by using linear theories and methods. SD can achieve the simulation of system action through simulating internal system structure, which has special superiority in handling high-order and multi-loop nonlinear port-city system. Therefore, we chose port-city SD model, using VENSIM-PLE software to build model and carry out the construction, regulation and scenario analysis of port-city system dynamic simulation model. Based on the analysis on simulation results, we studied the action mode and interaction mechanism of port-city system, which will provide a scientific decision basis and sound method support for development of port and city in the future.

2 Study Area and Methods

2.1 Study area

Dalian is located in the eastern coast of Eurasia, the southern tip of the Liaodong Peninsula in Northeast China, west to the Huanghai (Yellow) Sea, east to the Bohai Sea, north to the Shandong Peninsula across the sea, and south to the three northeastern provinces and a vast hinterland of Inner Mongolia (Fig. 1). It is also in the important region of Northeast Asia Economic Zone and the Bohai Economic Rim. Adjacent to Japan, R O Korea, D P R Korea, and Far East Russia, as a maritime gateway of North China, East China and the world, it is an important port, trade, industry and tourist city.

In 2003, on the implementation of revitalizing the Northeast Old Industrial Base by the Central Committee and State Council of China, it is proposed that we should make full use of the conditions and advantages of the existing port in Northeast China, and build Dalian into an important international shipping center in Northeast China. This is a function orientation of Dalian, which provides Dalian with development opportunities. With its unique advantages of ports, developed facing-port industry, all-round opening-up and perfect modern services function, Dalian is accelerating the process of building an

Fig. 1 Location sketch of Dalian port-city

international shipping center.

2.2 Building port-city system dynamics model

2.2.1 Modeling process

According to the SD principle, we chose a port-city compound system as the modeling object. The port-city system dynamics (PCSD) model is built in 3 main steps as follows:

Step 1: Divide the port-city system into a port system and a city system, based on the causal feedback analysis, drew system flow charts respectively, and then built quantitative relation based on the system analysis.

Step 2: Put the original data of definitive parameters and policy variables into structure equation, and carry out the simulation calculating, then the values of variables and related change chart could be gotten.

Step 3: Through drawing the result curve chart, adjusting data, and repeatedly simulating experience, PCSD model could be attained.

The purpose of modeling is to describe the interaction relationship between port system and city system quantitatively (Fig. 2).

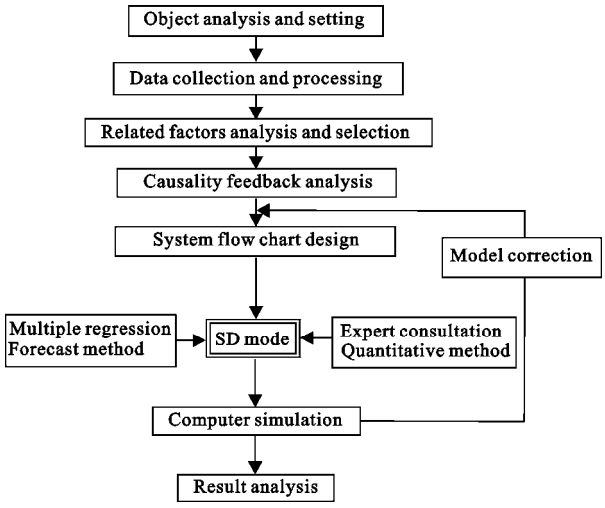

Fig. 2 Flow chart of system modeling

2.2.2 Causal feedback analysis

In the port-city simulation model, there are positive (+) and negative (–) feedback effects between various variables, which can avoid single-way simulation and manual intervention, therefore, the simulation result will be more scientific and objective. The chart below is causal feedback chart of port-city system, and here we just analyzed several main causal feedback loops (Fig. 3).

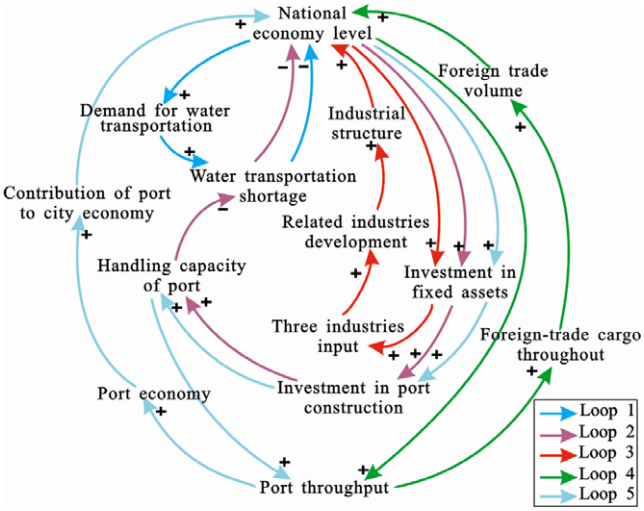

Fig. 3 Causal feedback chart of port-city system

Feedback loop 1: There is a negative feedback relationship between national economy development and the demand for water transportation. If national economy level improves, the demand for water transportation will increase, then there will be a gap in transportation which can not realize the due value, and the result is the decline of national economy level. The loop describes the stable and balanced relationship between national economy and the demand for water transportation through their interaction and self-control.

Feedback loop 2: There is a positive feedback relationship between national economy development and water transportation supply. If national economy level improves, the local government will increase relevant investment in fixed assets used for infrastructure, including the port construction. Therefore, the water transportation shortage will be eliminated, which will bring the unimpeded goods circulation, attain the profits quickly, and improve national economy. This loop indicates that the development of national economy will promote the increase of water transportation supply.

Feedback loop 3: There is a positive feedback relationship between industrial structure and national economy development. With extending of regional economic scale, fixed asset investment will continue to increase, the investment in the three major industries will be out of balance, and the industrial structure will be adjusted correspondingly. Then the adjustment of industrial structure will also react on national economy development.

Feedback loop 4: There is a positive feedback loop formed by foreign trade volume and national economy.

The port development can promote local export-oriented economy development, which will improve national economy, as well as the demand of port transportation.

Feedback loop 5: There is a positive feedback loop formed by port development and national economy. The increase of port throughput will promote the port economy, such as facing-port industry and port service industry. With the increasing of contribution rate of port to urban economy, the port development can improve the whole national economy, which can also promote the great demand of water transportation, and then, the port throughput will increase greatly.

2.2.3 System flow chart

The causality and feedback mechanism mentioned-above is mainly qualitative analysis about the interactive relationship between port and city. In order to objectively grasp and quantitatively analyze the internal mechanism of the port-city system, we establish the flow chart of system dynamic model (Fig. 4). Compared with the causal relationship chart, flow chart describes the cumulative effect to influence dynamic performance of feedback system, which was different from material flow and information chain (Wang, 1994). This study used VENSIM software to build system flow chart, which includes 6 state variables, 6 rate variables, 32 auxiliary variables and 9 constants. The state variables include GDP, increasing value of primary industry, increasing value of secondary industry, increasing value of tertiary industry, handling capacity of port, and total length of docks for production. These variables reflect the state of system, and they are the accumulation steps of the feedback loop. The rate variables of the flow chart include increasing amount of GDP, increasing amount of primary industry, increasing amount of secondary industry, increasing amount of tertiary industry, increasing amount of handling capacity of port and increasing amount of docks for production. Those variables change the state of the system, and reflect the change rate of state variables. In order to express the complex relationships between state variables and rate variables, a number of auxiliary variables are used in the flow chart, which make the system structure and the role of the elements more clearly. Constants of the flow chart are used to describe the parameters or coefficients of system, and their values remain unchanged. In order to further quantitatively describe the internal mechanism of the port-city system, this article gives system dynamics equations based on the inherent structural relationship of those variables. The study period in this model starts from 2000, ends in 2020, and the time step is 1a.

3 Simulation

3.1 Parameter

The VENSIM software is used to do computer simulation, which is a regression analysis approach, based on the behavior of systematical history, to determine the unknown parameter in the model. The parameter values used in this model mainly came from the data of *Dalian Statistical Yearbook* (National Bureau of Statistics of China, 2000–2008a) and the *Urban Statistical Yearbook of China* (National Bureau of Statistics of China, 2000–2008b).

3.2 Model verification

The dimension consistent of this model has been tested and verified by the VENSIM software, and by inputting the initial data and parameter, we can get the fundamental simulated result. According to the simulation result, the validity of the model can be judged through computing the deviation between simulation values and actual values of important parameters, and comparing with the change trend of both the values. Using the related data from 2000 to 2006 to validate PCSD model, we chose parts of city indicators and port indicators as the verifying variables, and the result was shown in Table 1. There is little difference between simulation values and actual values of important parameters, with the deviations below 5%, which indicates that the simulation model is effective.

4 Results and Analysis

By analyzing the logical relationship and system structure of the variables via the feedback relationship chart and each subsystem, we built the system dynamic equation, observed its quantitative relationship, fitted and ran as well. The system-dynamic model of port-city is used to get the simulation results by governing those control parameters, and then analyze the results.

4.1 Simulated impact of port on city economy

4.1.1 Foreign trade throughput

The simulation analyzes the impact of a port′s trading

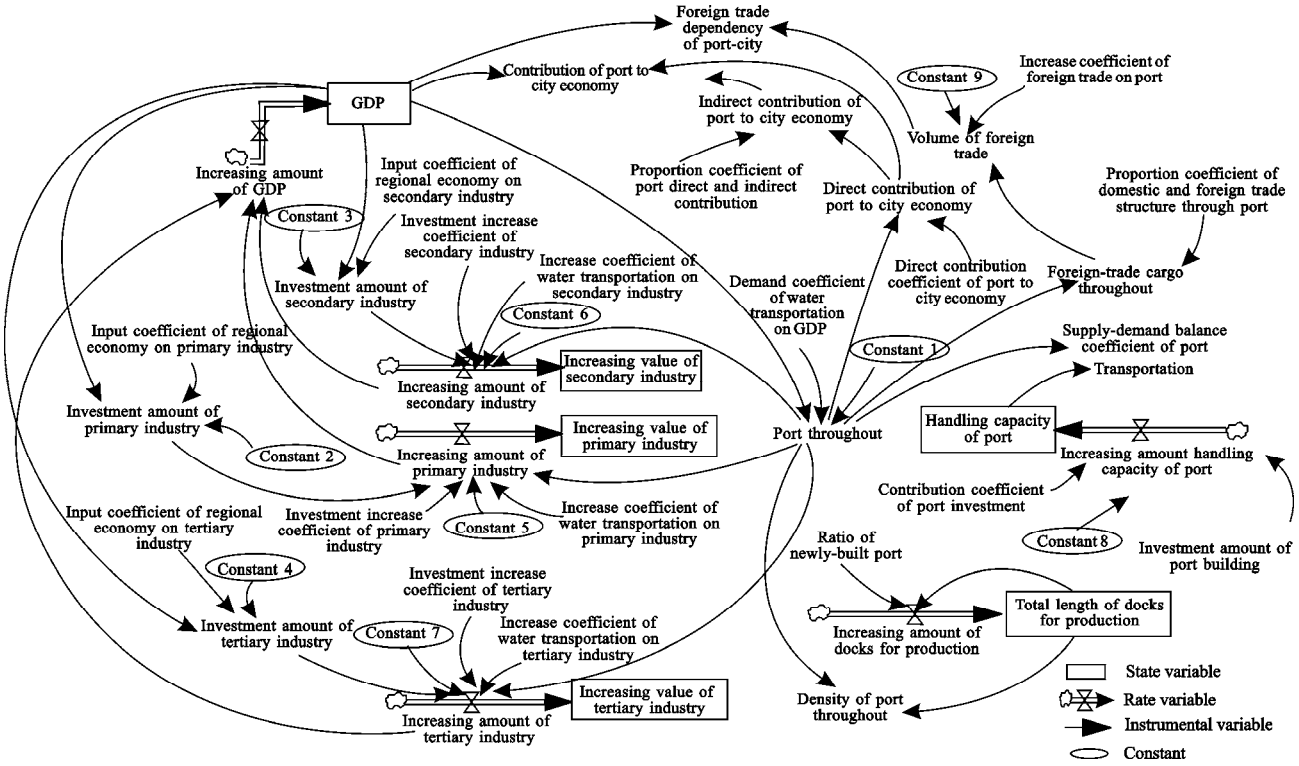

Fig. 4 SD simulation model of port-city system

Table 1 Relative deviation of simulated data and actual data

Item	Data	2000	2001	2002	2003	2004	2005	2006
GDP	Actual data ($\times10^9$ yuan (RMB))	1110.8	1235.60	1406.10	1634.20	1961.80	2152.20	2569.700
	Simulated data	1110.8	1263.18	1426.34	1601.06	1888.15	2088.47	2502.980
	Relative deviation (%)	0	2.2	1.4	–2.0	–3.8	–3.0	–2.6
Increase value of primary industry	Actual data ($\times10^9$ yuan)	105.4	110.88	118.30	133.080	160.74	171.01	205.390
	Simulated data ($\times10^9$ yuan)	105.4	109.00	115.33	128.587	156.98	162.72	198.060
	Relative deviation (%)	0	–1.7	–2.5	–3.4	–2.3	–4.9	–3.6
Increase value of secondary industry	Actual data ($\times10^9$ yuan)	517.2	581.74	660.90	775.47	937.74	1133.75	1195.78
	Simulated data ($\times10^9$ yuan)	517.2	593.65	677.26	768.52	897.98	1096.22	1153.87
	Relative deviation (%)	0	11.91	16.36	–6.95	–39.76	–37.53	–41.91
Increase value of tertiary industry	Actual data ($\times10^9$ yuan)	488.2	549.830	631.400	711.080	797.240	938.480	969.000
	Simulated data ($\times10^9$ yuan)	488.2	560.526	633.755	707.952	783.185	899.527	937.056
	Relative deviation (%)	0	1.9	0.4	–0.4	–1.8	–4.2	–3.3
Port throughput	Actual data ($\times10^6$ t)	0.9699	1.0519	1.1188	1.2601	1.4500	1.7100	2.0000
	Simulated data ($\times10^6$ t)	0.9322	1.0401	1.1556	1.2793	1.4118	1.6536	1.9055
	Relative deviation (%)	–0.039	–1.1	3.3	1.5	–2.6	–3.3	–4.7

structure change on the city system, by debugging the proportional coefficient between internal trade and foreign trade structure of a city system. Figures 5 and 6 are the simulation charts about the volume of foreign trade and foreign trade dependency of the city system. When the proportional coefficient increases by 0.5, that is the proportion coefficient of internal and foreign trade structure decreases from 1.91 (the actual value) to 1.41 (the simulated value), which will improve the portion of foreign trade throughput, as a result, the volume of for-

eign trade in Dalian will increase about 26.3%, and its dependence degree on foreign trade will increase from about 10% to 13%. The simulation results indicate that the port′s trading structure change has a great effect on the export-oriented economy of Dalian.

As the international freight exchange depends mainly on shipping, a port′s foreign trade throughput plays an important role on the foreign trade of the city the port belongs to. So, from some certain degree, it can be said that the foreign trade transport function of Dalian port makes a positive impact to export-oriented economy of Dalian.

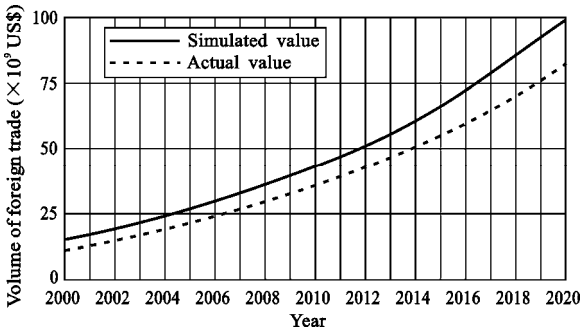

Fig. 5 Simulation of foreign trade volume change

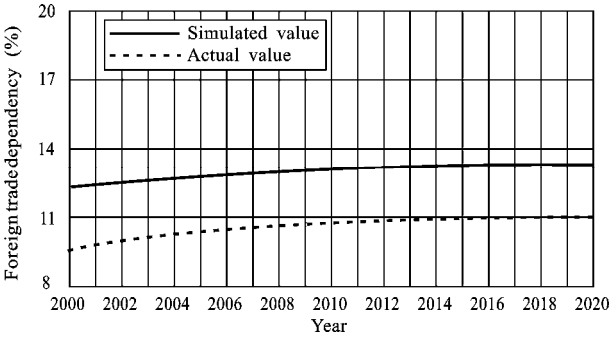

Fig. 6 Simulation of foreign trade dependency of city system

The raw material export is the main foreign trade activity in Dalian port, and the throughput of manufactured products is relatively low. It is closely related with the immature industry system of commercial, finance and other tertiary industries. Influenced by financial crisis, in the following period, the foreign trade throughput will decrease, which will inevitably affect the development of export-orientated economy.

4.1.2 Direct and indirect contribution

The direct contribution of port to urban economy is the initial or first-round impact of the port itself and its related industries on national economy and regional economy. The port and its related industries, as a part of national economy, just like other industries, can also increase city′s GDP and national and local tax revenue, and bring the employment opportunity. Meanwhile, as the most important infrastructure of the port-city, it can pull the development of city economy through the industrial relationship, thus make indirect contribution to city economy.

If the throughput increases 100×10^6 t in Dalian port, its direct contribution to Dalian City will be about 12×10^9 yuan, the indirect contribution about 60×10^9 yuan. From Figs. 7 and 8, it is found that the direct and indirect contribution of port to city economy will increase with the port development, while the contribution rate will decrease. The main reason is that city economy is going into the stage of multiple economies, and the pushing effect of port on city economy will decrease gradually.

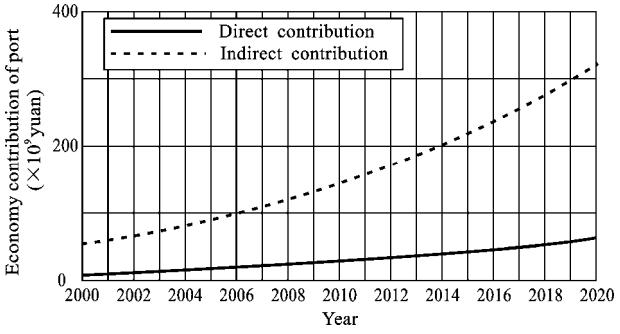

Fig. 7 Simulation of direct and indirect contribution of port

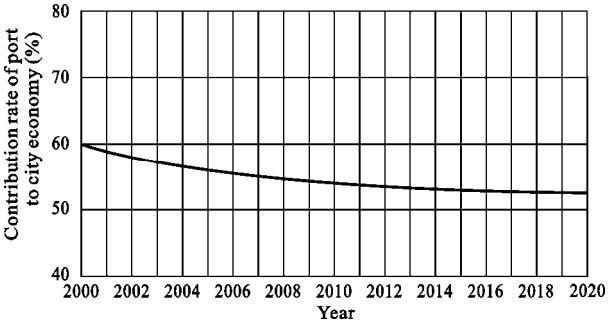

Fig. 8 Contribution rate simulation of port to city economy

4.2 Simulated demand for water transportation and construction scale of port

4.2.1 Demand for water transportation

The development of port is served for economic development of a city, and changes of the urban basic demand involving economic activities directly decide and affect the development of a port. So, port development has a

close relationship with the industry structure of a city. By adjusting the water transportation-demand factors of GDP, the relation of the industry structure and the demand for water transportation was simulated. Figure 9 shows simulated increasing values of the primary, secondary and tertiary industries. When demand coefficient for water transportation, the volume of shipped goods produced by GDP of 100×10^6 yuan, increased by 0.1%, the output value will increase 29.82% in the primary industry, 30.41% in the secondary industry and 0.96% in the tertiary industry. We can draw a conclusion that the relation between the primary industry and water transportation is relatively close, as well as that between the secondary industry and water transportation, while the tertiary industry needs water transportation less. It is mainly because that the demands for water transportation come from the primary and secondary industries mostly. Demand coefficient for water transportation has a direct relationship with the industry structure of a region. With the industry structure advancing of a region, the proportion of information, logistics industry and other tertiary industries will increase gradually, and the demand for water transportation decreases. At present, Dalian is in the stage of heavy chemical industry now, and demands for water transportation increase at a high speed. However, in the year 2040 or so, the economic development will enter a stage of advanced industry that dominated by the tertiary industry and the demands for water transportation will decrease gradually.

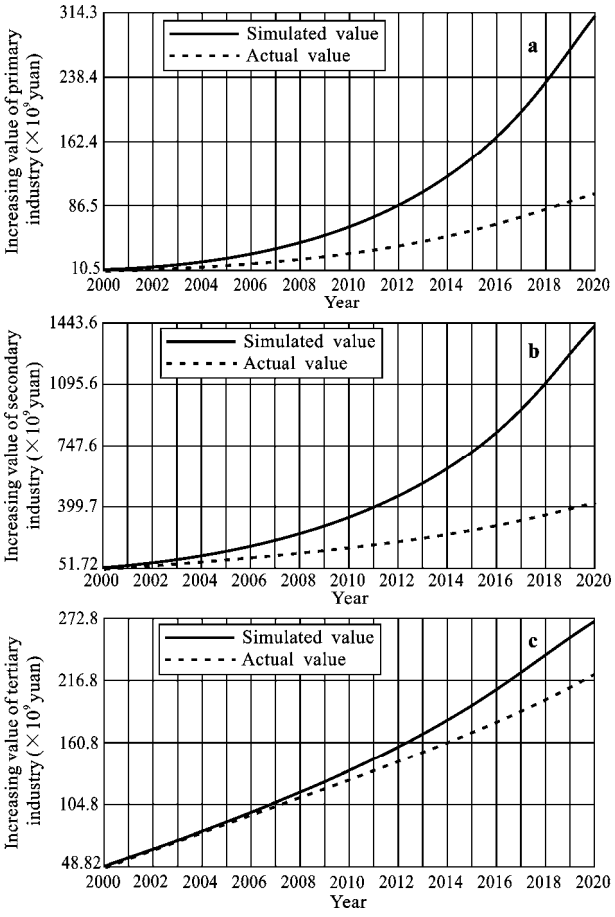

Fig. 9 Increasing value simulation of primary (a), secondary (b), and tertiary (c) industries

4.2.2 Port construction

Water transportation is the main mode of port-city to achieve the spatial transference of goods. If the water transportation can not meet the demand for economy development, it will block the economy development, such as the products backlog, the transportation jam and so on. However, if water transportation is developed blindly, it will bring the huge waste of resources because of the over-supply for water transportation.

According to simulated value and trend of the water transportation supply-demand balance coefficient (the ratio of handling capacity of port to port throughout) (Fig. 10), it can be attained that, before 2004, the demand for water transportation was over the supply, which restricted the development of city economy to some extent. From 2003 to 2006, with the strategy of building the important international shipping center of Northeast Asia, the port construction was soaring. While the infrastructure construction is a long-term engineering, the shortage of water transportation could not be mitigated rapidly. From 2006 to 2014, the water transportation supply-demand balance coefficient is basically over 1, which is on the stage of over-supply. With the adjusting of industry structure, the proportion of tertiary industry will increase. Under the influence from international finance crisis, this over-supply situation will aggravate gradually. The construction of infrastructure of a port belongs to a typical capital-intensive industry, the construction period and investment return period are all relatively long, and it will lead to a large waste or loss if not be planned carefully. So the construction of Dalian port should not enlarge construction scales blindly. It should slow down the speed of port construction, while consider the measures such as combining the technical progress, heightening the use efficiency to improve the water transportation supply ability, and avoid the waste of resources because of the excessive construction.

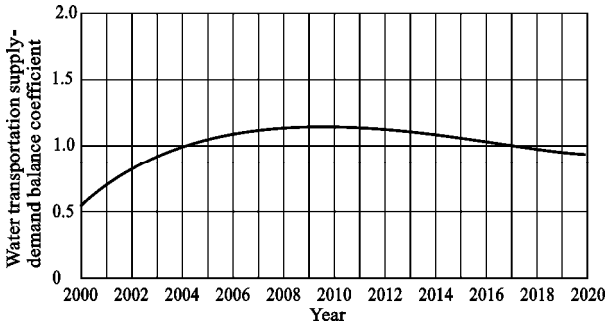

Fig. 10 Simulation of water transportation supply-demand balance coefficient

5 Conclusions

This paper used SD methods to simulate the action of port-city system, and verified the practicability and validity of the model through an empirical analysis of Dalian port-city system. Based on the analysis of the internal relationship between main influence factors and the influential effect, the following conclusions can be drawn: 1) the port plays a crucial role on urban economic development, but the port contribution to the urban economy will continue to decline with the diversification of the city; 2) with the development of industrial structure, the tertiary industry is rising, and the water transport demand for national economy will gradually reduce; 3) water transportation presents a kind of oversupply development situation, so port construction should properly slow down.

Under those conditions, the future development of Dalian should pay attention to the following points. 1) Ports as scarce resources have important strategic significance, so Dalian should care for the great effect of ports and it will be built into the important international shipping center of Northeast Asia. 2) According to the direction of industrial restructuring in Dalian, Dalian port should carry out functional orientation and strengthen the sense of service. 3) Making full use of Dalian port, we can promote the adjustment of industrial restructure, the development of export-oriented economy, and the interactive development between city and port. 4) Dalian City will enter the economic development stage of diversified economy, so we should promote the rapid development of the modern service industry, such as import and export trade, exhibition economy, modern logistics, international finance and so on. And 5) with the continuous adjustment of industrial structure, water demand will been moving toward a stable state. Therefore, we should avoid blind construction of port, and the production mode of port should be changed from extensive growth to intensive growth.

We defined model equations using the quantitative method combining with qualitative method, not the traditional method defining coefficient based on experience, and this method increased the accuracy of simulation result greatly. This modeling method of port-city system has universality, applicability and operability, which can be used for other port-city system. Aiming at different port cities, some parameters can be adjusted in this model, so it possesses universal properties, and can offer reference for other port cities.

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