IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received November 17, 2020, accepted December 23, 2020, date of publication January 12, 2021, date of current version January 26, 2021.
Digital Object Identifier 10.1109/ACCESS.2021.3051065

Sustainable Development of Port Economy Based on Intelligent System Dynamics

GUOYI XIU[1] AND ZEXU ZHAO[1,2]
[1]School of Economics and Management, Harbin University of Science and Technology, Harbin 150000, China
[2]School of Business, Hainan Tropical Ocean University, Sanya 572000, China
Corresponding author: Zexu Zhao (zhaozexu8899@126.com)

ABSTRACT With the development of economic globalization, international trade competition is increasingly intensified. As an important hub of waterway transportation, the sustainable economic development of ports has an important impact on the economic development of the entire country. Therefore, the research on the sustainable development of port economy has been paid more and more attention by everyone, but the current results are not ideal. This paper studies the sustainable development of port economies based on networked smart sensor technologies and system dynamics. First, according to the construction principles of the sustainable development index system, combined with the actual situation of the port economy, the evaluation index system layer of the sustainable development of the port economy is divided into four subsystems: population, environment, resources and economy. A system dynamics model for the sustainable development of the port economy will be constructed and its sensitivity will be analyzed. Then, the above system dynamics model is combined with the optimized K-means algorithm, and the K-means algorithm is used to quickly calculate the required data in the system dynamics model to form an intelligent system dynamics model for the sustainable development of port economy. Finally, this article takes a certain port economy sustainable development giant system as an example, and implements a sustainable development strategy based on the idea of the coordinated development of population, environment, resources and economy. Run the intelligent system dynamics model for the sustainable development of port economy constructed in this research to simulate the dynamics of each subsystem. Experimental results show that in the next 20 years, the total population, number of employed population and employment ratio of the port city will continue to increase. After 2025, the emissions of the Exhaust have been declining year by year, the total amount of resources has been continuously reduced, and the utilization rate of resources can be increased to 80.01%. The growth rate of GDP in 20 years is as high as 18.75%, the ratio of the secondary and tertiary industries has changed, and the tertiary industry has become the dominant one. Therefore, the sustainable development system dynamics model of the port economy based on intelligent algorithms and sensor technology can effectively predict the future economic trend, help adjust strategies and further promote the sustainable development of the port economy.

INDEX TERMS System dynamics, K-means clustering algorithm, port economy, sustainable development, subsystem.

I. INTRODUCTION

A. BACKGROUND SIGNIFICANCE

Port is a very important node related to international trade and logistics and an important support for regional export-oriented economy. It is one of the basic industries of the national economy and has an important impact on the development of trade and regional economy [1]. With the gradual deepening of the world financial crisis and the aggravation of the energy shortage crisis, the port economy must unswervingly move towards a sustainable development path, which is conducive to the efficient use of port resources, enhances the competitiveness of ports, and promotes the sustainable development of port cities. The system dynamics model is a laboratory of a large complex system of society and economy, which can realize scientific decision-making and

The associate editor coordinating the review of this manuscript and approving it for publication was Yanjiao Chen.

modernization of operation and management [2]. Therefore, the research on the sustainable development of port economy based on intelligent system dynamics is of great significance.

B. RELATED WORK

System dynamics models are widely used in the field of large-scale system research due to their unique capabilities, and their research results are also quite rich. Federico Barnabè based on the business case/service approach, discussed the maps, mathematical models and balanced scorecards developed based on the principles of system dynamics modeling [3]. Onat NC used the integrated dynamic LCSA model to analyze the environmental, economic and social life cycle impacts and life cycle costs of alternative vehicles in the United States, and developed a system dynamics model to simulate the US passenger transportation system and its interaction with the economy, environment and society [4]. Their research is of great significance, but the influencing factors considered in modeling are not comprehensive. The port city has a unique geographical location, and promoting the development of port economy is also the focus of researchers from various countries. Xiao Z used the method of system theory to establish a system framework for the sustainable development of port cities, and took Singapore as an example to conduct an empirical analysis to discuss the sustainability of the port system, urban system and port city policies [5]. Santos A MP uses the input-output analysis method to put forward a method of port economic impact assessment from the regional and national levels [6]. Their researches tend to be theoretical, lacking a large amount of data analysis and more intelligent and modern research methods.

C. INNOVATIVE POINTS IN THIS PAPER

In order to promote the sustainable development of the port economy, promote the optimization of the industrial structure, and improve the people's living standards, this paper conducts an in-depth study on the system dynamics model of the sustainable development of the port economy based on intelligent algorithms. The innovations of this paper are as follows: (1) Constructed a system dynamics model for sustainable development of port economy, which includes four subsystems of population, environment, resources and economy, and analyzed its sensitivity. (2) Combine the system dynamics model with the optimized K-means algorithm, use the K-means algorithm to quickly calculate the required data, and finally build an intelligent system dynamics model for the sustainable development of the port economy. (3) Taking a huge system of sustainable development of port economy as an example, run the model constructed in this research to simulate the dynamic trend of each subsystem. (4) Based on the analysis of this article, several suggestions on promoting the sustainable development of the port economy are put forward, such as strengthening the strategic understanding of the port layout, controlling the vicious competition situation of the port, optimizing the resource structure, and improving the service level.

II. INTELLIGENT SYSTEM DYNAMICS AND SUSTAINABLE DEVELOPMENT OF PORT ECONOMY

A. SYSTEM DYNAMICS MODEL

1) CHARACTERISTICS OF SYSTEM DYNAMICS

System dynamics analysis studies the information feedback system, which can correctly recognize and solve system problems, and can be used to analyze and study complex issues such as society, economy, ecology, and biology [7]. System dynamics believes that the dynamic structure and feedback mechanism within the system determine the behavior mode and characteristics of the system.

System dynamics has the following characteristics. First of all, system dynamics can be used to study and deal with highly nonlinear, high-order, multi-variable and multi-feedback system problems such as economy, society, ecology and biology. It is possible to comprehensively study complex multi-level and multi-sector large systems on the onlooker and macro level [8]. Second, when system dynamics solve problems, it uses a combination of qualitative and quantitative, systematic, analysis, synthesis and reasoning methods.

Third, system dynamics takes the open system as the research object, emphasizes the perspective of connection, development and movement, and believes that the behavior mode and characteristics of the system depend on the internal dynamic structure and feedback mechanism. Fourth, the system dynamics model is very standardized as a whole. Variables are classified according to the composition of the basic structure of the system. It is a laboratory for the actual system of economic society [9].

The system dynamics model is used to qualitatively and quantitatively analyze history, analyze the present, and study the future, which can realize scientific decision-making and modernization of operation and management. The problem-solving process is essentially an optimization process, and ultimately a better system function is obtained.

2) SYSTEM DYNAMICS MODEL STRUCTURE

The most basic structure of the system dynamics model is the feedback loop, which is a loop that couples the state, speed, and information of the system, corresponding to the unit, movement, and information of the system. The result of decision or action determines the change of state variables, and the generation of decision is divided into two types: self-regulation by information feedback and a special law of the system itself [10]. The former generally exists in the material world, while the latter exists in the non-biological world. The information at this time is not non-existent, but in a "potential" state.

The causal and interrelationship loop diagram is generally used in the initial stage of building a model. It is a non-technical and intuitive description of the model structure, which can allow some people who are not familiar with system dynamics to communicate and discuss [11]. Individual causal chains in the causal and interrelationship diagram can indicate whether their influence is positive or negative. The positive sign indicates that the variable pointed to by the arrow is positively correlated with the variable of the arrow source, while the negative sign indicates that the variable is negatively correlated. The polarity of the feedback loop in the graph of future de-top causality and interrelationship can be circled along the feedback loop to observe the cumulative effect of all the causal chains of the briber. If there are an even number of negative causal chains in the feedback loop, the polarity is positive; If there are an odd number of negative causal chains in the feedback loop, the polarity is negative.

System state variables can clearly represent the cumulative effect of the dynamic performance of the feedback system.In a feedback system, the accumulation link is called a state variable. System dynamics believes that the feedback system contains a continuous process similar to liquid flow and accumulation. The rate changes state variables over time. The state variable outputs the material, and the inventory is reduced. The information reflecting the warehouse situation sent from the warehouse to other parts of the system will not affect the state variable itself. In the flowchart, the material flow and the information chain are represented by solid and dashed arrows, respectively.

The hybrid diagram is used to describe the system structure. In the causality diagram, the state variables and speed are represented according to the symbols of the flowchart. It not only retains the simplicity of the causal and interrelationship loop diagram, but also clearly expresses important state variables and speeds. In this way, the mixed graph can be used more reliably to analyze and infer the dynamic characteristics of the feedback structure. Hybrid graphs can also make the actual dynamic causal relationships assumed by the model easier to understand, making it a step further to build equations that can be simulated by computers.

3) SYSTEM DYNAMICS MODELING STEPS

First of all, we must conduct a comprehensive analysis of the system to grasp the internal reasons and operating mechanism of the research object. In this step, it is necessary to understand the user's conception of the model system and the functions that the system should implement, and then conduct on-site inspections and collect relevant information and data. After obtaining the data, analyze the contradictions, variables and problems in the system, then divide the boundaries of the system, and clarify the values of exogenous variables, endogenous variables and input quantities. It is necessary to determine the reference mode of system behavior, graphically represent the main variables in the system, elicit related variables, and finally guess the trend of the problem.

Then analyze the system structure, classify the system information, analyze the feedback mechanism within the system and between subsystems. In this step, you need to first determine the sub-modules and levels of the system, and then analyze the variables and the relationship between the variables of the system, and determine the types of variables and the main variables [12]. Determine the feedback coupling relationship and the nature of the feedback between the loop and the loop, and analyze the possibility of the transfer of the main loop in the system over time.

Establish a mathematical standard model, determine parameters, and assign values to table functions. In order to discover system problems in time, modify and adjust the structure and parameters of the model, it is necessary to test run and debug the model until the simulation results reflect the real system. The built model needs to be tested and evaluated, and this operation can be dispersed in the construction process. Finally, the simulation is carried out to obtain the forecast trend result, which can be used as a basis for decision analysis.

B. K-MEANS CLUSTERING ALGORITHM

1) K-MEANS ALGORITHM FLOW

The K-means algorithm is suitable for cluster analysis of large-scale data, image and text processing data. Through iterative update, the sample set is divided according to the known number of clusters [13]. If the number of clusters is K, the sample set can be divided into K clusters, according to the similarity between samples in clusters than between samples. The effect of clustering will be better.

First, randomly select K initial cluster centers, divide them into clusters with the closest distance according to the distance between the remaining objects and each center, and then calculate the average value of each cluster and use it as the new cluster center [14]. In the iterative process, if different clustering centers appear twice in the neighborhood, you need to adjust all samples to modify the clustering centers before continuing the iteration; otherwise, the clustering is successful and the algorithm ends.

The cluster center is unchanged, which means that the criterion function has converged. The criterion function is shown in Formula 1:

$$G = \sum_{g=1}^{K} \sum_{x_g \in c_g} \left\| x_g - c_g \right\|^2 \tag{1}$$

Among them, c_g is the center of the g-th cluster, and x_g is the sample in the g-th cluster [15].

2) FEATURES OF K-MEANS ALGORITHM

The L-means algorithm has a two-stage iterative structure. The algorithm ends when all sample objects do not need to be re-divided. So the two most important points are dividing sample objects and updating cluster centers. The K-means algorithm has the advantages of simple thinking, fast calculation, good scalability and high efficiency, and its time complexity is close to linear [16].

However, the algorithm is very sensitive to the selection of initial clustering centers. If the selection is improper, invalid clustering effects may be produced, and different initial clustering centers will cause large differences in results and reduce stability. Moreover, the number of clusters generated by clustering needs to be given in advance. In specific applications, the number of clusters is difficult to predict, and it requires continuous experimentation to finally determine it.

Since the algorithm uses the average of all objects in each cluster as the center of the cluster, outlier data usually deviates from the center of the cluster. The calculation of the average will have a greater impact, the clustering center will deviate, and inaccurate clustering results will appear. In the K-means algorithm, usually the sum of squares function of the error is used as the benchmark function for clustering. The clustering problem is the problem of taking the extreme value of the objective function, which is an optimization problem [17]. One characteristic of the objective function is that because it is a non-convex function of the space state, there are usually only multiple local minimums and one global minimum. If the initial value of the algorithm is on the surface of a non-convex function, it may deviate from the search range of the global optimal solution. The iteration of the algorithm is performed along the search direction where the objective function value decreases, so the algorithm is easy to fall into a local optimal state.

3) CRITERIA AND EVALUATION OF CLUSTERING

Cluster analysis is an important technique in data mining and an unsupervised learning process. The clustering algorithm needs to satisfy the condition that the object dissimilarity in the cluster is weak and the dissimilarity between clusters is strong. The choice of clustering similarity measurement method needs to target specific clustering problems. There are many methods for measuring similarity between clusters, such as calculating the distance between centroids and calculating the average distance between all objects in one cluster and all objects in another cluster, calculate the distance between the center points, calculate the single connection distance or the full connection distance. The method of measuring similarity within a cluster is to calculate the distance between two objects, including Euclidean distance, Manhattan distance, oblique distance, Mahalanobis distance, and Ran's distance [18], [19].

The clustering criterion function is the criterion for determining the completion of clustering, as much as possible to gather objects belonging to the same cluster, and separate objects belonging to different clusters. There are generally two methods to determine the criterion function. One is the heuristic method, which relies on experience and subjective judgment. First, when a sample is allocated to a certain cluster, a threshold must be specified, and then the sample is allocated to a certain cluster according to the nearest neighbor measurement rule [20]. The second is the objective function method. The objective function shows the relationship between the sample and the cluster, and transforms the clustering problem into the problem of finding the optimal value of the objective function. Common indicators of objective function include error sum of squares criterion function, weighted average sum of squares criterion function, distance between classes and criterion.

The evaluation criteria for clustering include good scalability, which can handle larger and more complex data sets; usability and interpretability, and the clustering results must be valid and understandable. The ability to deal with data noise, reduce the influence of noise on data results, and discover the actual distribution of data; not too many input parameters; ability to handle multi-attribute data, etc.

C. SUSTAINABLE DEVELOPMENT OF PORT ECONOMY

1) REASONS FOR SUSTAINABLE DEVELOPMENT OF PORTS

As an important support for the regional export-oriented economy, ports have played a guiding role in the process of urbanization. The sustainable development of the port directly affects the urban regional positioning, resource allocation, and industrial structure layout [21]. The sustainable development of the port includes the establishment of the port city system, the formation of the urban transportation network, the overall planning of the port layout, the strengthening of port functions, the formation of regional coordination mechanisms, the strengthening of regional cooperation and the emphasis on environmental protection.

Sustainable development is an inevitable choice to keep the port competitive. Meanwhile, the ports of existing international shipping centers around the world are developing sustainable industrial policies, including multiple investment policies and sound land resource utilization policies, and promoting sustainable development through policy guidance. On the other hand, it is committed to improving the port's comprehensive transportation capacity and service level. In addition, it can also strengthen value-added services, port information structure, improve port functions, realize efficiency, safety, environmental protection and increase market competitiveness. Promote the economic development of surrounding areas through port construction and seek an interactive mode of mutual promotion and common development.

2) CHARACTERISTICS AND SIGNIFICANCE OF SUSTAINABLE PORT DEVELOPMENT

The four representative index systems for sustainable development are the research direction of ecology and the index system of "ecological services", the research direction of economics and the index system of "wealth evaluation", the direction of sociology and the index system of "human development", systematic research direction and "sustainability" indicator system [22].

Research on the sustainable development of ports can promptly discover the problems that exist in the development of ports, understand the law of development and its goals and connotations, and point out the direction of development [23]. Establishing a framework for sustainable port development can formulate strategies and countermeasures for port development. Studying the sustainable development theory of the port economy can provide theoretical guidance for the development of the port economy, optimize the resource allocation of the port, and then improve the operating environment for the development of the port economy.

3) NETWORKED SMART SENSORS

The networked intelligent sensor makes the sensor develop from single function and single detection to multi-function and multiple detection, from passive detection to active information processing, and from on-site measurement to remote real-time online measurement. Networked sensors can be connected to the networks of nearby people. There is no need for point-to-point connections between sensors and measurement and control machines. Therefore, the connection line is greatly simplified, investment is saved, maintenance becomes easy, and system expansion becomes easy.

The signal acquisition unit, data processing unit, and network interface unit are integrated to form a networked intelligent sensor. These three parts use different chips to form a composite chip or a single chip. The measured physical quantity of the sensor is converted into an electrical signal, and then converted into a digital signal through A/D. After the microprocessor processes the data, the result is transmitted back to the network, so that the data exchange with the network and the network interface module are completed [24], [25].

The microprocessor is the core of the networked intelligent sensor, which has the characteristics of small size, high reliability, low power consumption and strong anti-interference ability. Compared with traditional sensors, the biggest advantage of networked smart sensors is the high degree of freedom in information exchange. Not only can the detection setting value be flexibly set according to site requirements, but also a large amount of information can be continuously exchanged with the upper computer.

III. EXPERIMENTS ON ESTABLISHING SYSTEM DYNAMICS MODEL OF SUSTAINABLE DEVELOPMENT OF PORT ECONOMY

A. SYSTEM DYNAMICS MODEL OF SUSTAINABLE DEVELOPMENT OF PORT ECONOMY

1) CONSTRUCTING AN INDICATOR SYSTEM FOR SUSTAINABLE DEVELOPMENT OF PORT ECONOMY

According to the construction principles of sustainable development index system in Chapter 2, this article combines the actual situation of port economy and divides the evaluation index system of sustainable development of port economy into four subsystems: population, environment, resources and economy. Its structure is shown in Figure 1. The system established in this paper takes into account the structural characteristics of each subsystem and the correlation between the subsystems, and pays attention to the availability and quantification of indicators, so the system has a certain degree of objectivity and operability.

2) ESTABLISH SYSTEM DYNAMICS MODEL FOR SUSTAINABLE DEVELOPMENT OF PORT ECONOMY

The sustainable development system includes the four sub-systems of population, environment, resources and economy. Population is the driving force, the environment is the restriction, resources are the foundation, and the economy is the creation of conditions. They complement each other and form a huge and complex system. The coordinated development and degree of internal results and subsystems determines the level of sustainable development. Combined with the actual situation of the port economy, this paper establishes the overall causality diagram of the system, as shown in Figure 2:

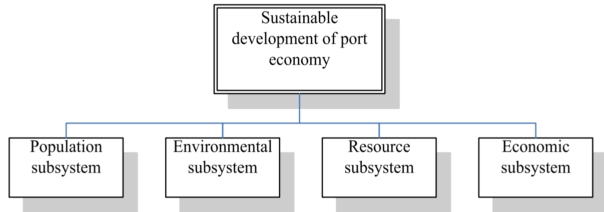

FIGURE 1. Evaluation index system for sustainable development of port economy.

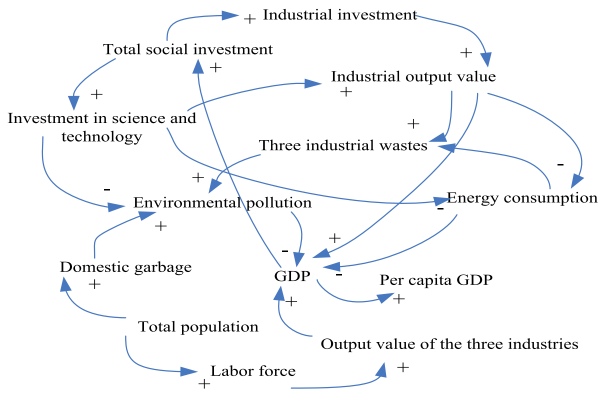

FIGURE 2. System overall causality diagram.

3) MODEL SENSITIVITY ANALYSIS

The complexity of system dynamics is reflected in the close connection of various relationships and parameters. Direct quantification of parameters will cause certain subjectivity and ambiguity. Therefore, sensitivity analysis is needed to test the influence of these uncertainties. The calculation process is shown in Formula 2:

$$m = \frac{(Yn' - Yn)/Yn}{(Xn' - Xn)/Xn} \tag{2}$$

B. K-MEANS CLUSTERING ALGORITHM OPTIMIZATION

The running speed of the traditional K-means algorithm is very low, and the execution process is relatively independent, so it needs to be optimized.

In the redistribution phase, based on the new cluster center, the data set will generate a new cluster set, and the point whose set changes during each iteration is called the "active point". When reallocating, only the "active point" is considered, and the cluster set to which it belongs can be changed without considering other data points, which can greatly reduce the number of calculations. Then use the closure of solving the cluster set to solve the "active point" at the edge of the cluster. The calculation process is shown in Formula 3:

$$\bar{Q} = \bigcup_{x \in Q} N \tag{3}$$

Among them, Q is the cluster set, x is the data point in the set, and N is the set of the data point itself and its neighbor nodes.

The closure-based K-means algorithm has one more pre-operation process than the traditional K-means algorithm, which is to calculate the neighbor nodes of the data concentration point. The process of the first iteration is the same. When the second step of the algorithm is performed, the closure-based K-means algorithm first performs closure operations on the K cluster set. In order to traverse the cluster closure, find the Euclidean distance between the data point in the closure and the cluster center.

Combine the aforementioned system dynamics model with the optimized K-means algorithm, and use the K-means algorithm to quickly calculate the required data in the system dynamics model to form an intelligent system dynamics model for the sustainable development of port economy.

C. SIMULATION SCHEME DESIGN

This article takes a huge system of sustainable development of port economy as an example, and implements sustainable development strategy based on the idea of coordinated development of population, environment, resources and economy.

First use networked smart sensors to collect relevant data information. Including the total population and employment of the port area in 2019, the emissions of three industrial wastes, total resources and resource utilization, GDP and the output value of the three major industries. Then run the intelligent system dynamics model of sustainable development of port economy constructed in this research to simulate the dynamics of each subsystem.

IV. DISCUSSION ON THE ROLE OF INTELLIGENT SYSTEM DYNAMICS IN STUDYING THE SUSTAINABLE DEVELOPMENT OF PORT ECONOMY

A. DYNAMIC SIMULATION RESULTS OF POPULATION AND ENVIRONMENT SUBSYSTEM

1) SIMULATION OF POPULATION SUBSYSTEM

The population subsystem of the model constructed by this research is used to simulate the change trend of the total population and the number of employed population in the port area. The results are recorded every 5 years for a total of 20 years, and the proportion of the employed population to the total population is calculated. The results are as follows:

TABLE 1. Simulation of total population and employed population.

Year	Total population	Employed population	Employment ratio %
2020	4392900	2549400	58.03
2025	4571200	2697800	59.02
2030	4595800	2810400	61.15
2035	4610200	2897800	62.86
2040	4622300	2911400	62.99

As shown in Table 1, in the next 20 years, the total population, number of employed population and employment ratio of the port area will continue to increase. However, it can be seen that the rate of increase in the total population of this city will gradually slow down after 2025, which indicates that when the people's living standards improve, the population growth rate will gradually decline, which is the same as the negative population growth in developed countries.

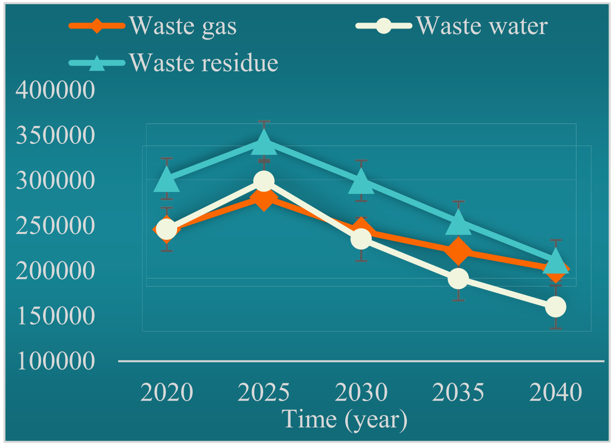

FIGURE 3. Trend of three wastes emissions.

2) ENVIRONMENTAL SUBSYSTEM

The environmental subsystem of the model constructed in this study is used to predict the change trend of the city's industrial three wastes emissions. The average value is calculated every 5 years and the change trend chart is drawn. The results are as follows:

As shown in Figure 3, the changes in the three industrial wastes between 2020 and 2025 are on the rise. Port area will inevitably cause environmental pollution when they develop industries and port transportation. However, over time, the thorough promotion of the concept of sustainable development, and the ongoing commitment to environmental governance will reduce the emissions of the three wastes year after year after 2025.This shows that as the economy develops, the concept of environmental protection is deeply rooted in the hearts of the people, and sustainable development is well implemented, environmental pollution will be improved.

B. DYNAMIC SIMULATION RESULTS OF RESOURCE AND ECONOMIC SUBSYSTEM

1) RESOURCE SUBSYSTEM

Using the resource subsystem in the model constructed in this study to simulate the total resource and utilization rate of the port area, the simulation results are as follows:

As shown in Figure 4, as time increases, resources continue to be consumed, and there is no possibility of regeneration after non-renewable resources are used. However, the regeneration speed of some renewable resources in a short period

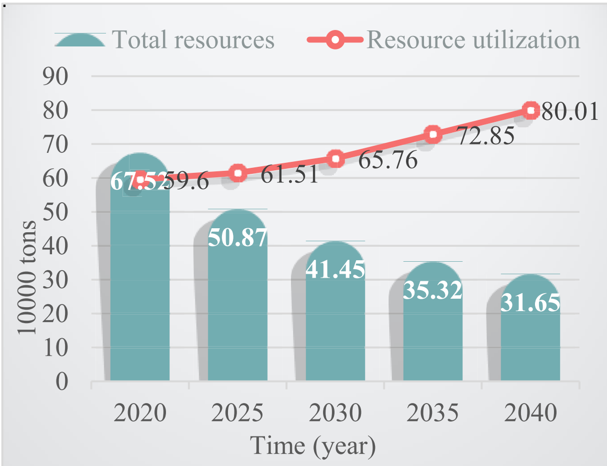

FIGURE 4. Trend of total resources and utilization rate.

TABLE 2. Trends in GDP and the proportion of output value of the three major industries.

Year	GDP (Billion Yuan)	Primary industry	Secondary industry	Tertiary industry
2020	8321.45	4.9%	49.1%	46%
2025	8656.31	4.8%	45.7%	49.5%
2030	9196.32	4.5%	42.2%	53.3%
2035	9511.47	4.5%	41.4%	54.1%
2040	9879.68	4.4%	38.7%	56.9%

of time is not as fast as the use speed, so the total amount of resources continues to decrease. However, with the advancement and development of science and technology, the utilization rate of resources has been continuously improved, which avoids many unnecessary waste of resources.

2) ECONOMIC SUBSYSTEM

Using the economic subsystem of the model constructed in this study to simulate the changing trend of the port city's GDP and the proportion of the output value of the three major industries, the results are as follows:

As shown in Table 2, the GDP of the port area has been increasing year by year, with a growth rate of 18.75% in 20 years, which shows that its economic level has been increasing year by year. Looking at the output value contribution ratio of the three major industries, the primary industry of port cities has never been able to occupy an excessively high proportion. Although the proportion has not changed much in the past 20 years, it has also shown a slow decline. The secondary industry initially occupied a dominant position. With the improvement of the economic level and the promotion of sustainable development, the proportion of the secondary industry's output value has dropped to 38.7% year by year. The rise of the tertiary industry initially rose from 46% to 56.9%, making a significant contribution to economic development.

In order to more intuitively show the changes in the proportion of the output value of the three industries, based on the data based on the forecast values of 2020, 2030 and 2040, draw a circle chart of the proportion of industries. The results are as follows:

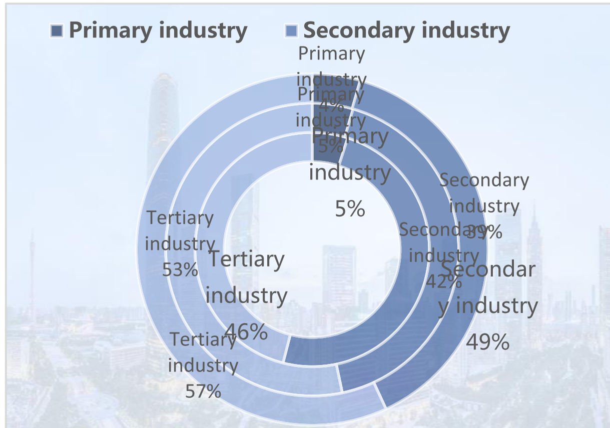

FIGURE 5. Trends in the proportion of output value of the three major industries.

As shown in Figure 5, the output value of the primary industry has not changed much, maintaining between 4-5%, with a slight decline. The proportion of the output value of the secondary industry has shown a sharp decline. Accordingly, the proportion of the tertiary industry has risen sharply, showing a trend of declining.

C. SUGGESTIONS FOR IMPROVING THE SUSTAINABLE DEVELOPMENT CAPACITY OF PORT ECONOMY

In order to improve the sustainable development of port economy, several suggestions are put forward based on the analysis of this article.

First, it is necessary to strengthen the strategic understanding of the port layout. When planning and development, it is necessary to fully consider the economic globalization process and the speed of national economic growth, energy supply sources and layout changes, national defense security and other factors.

Second, we must control port competition, avoid vicious competition, and create a strategic environment of cooperation and win-win for the sustainable development of the port economy. Because vicious competition will worsen the investment environment and affect economic development.

The third is to optimize the resource structure and seek sustainable development of conservation and environmental protection. By selecting the appropriate environmental management model and applying life cycle assessment techniques, it is possible to build conservation and environmental protection ports. In terms of resource structure, energy-saving materials can be used as much as possible to reduce energy consumption.

Finally, we must improve the service level, adhere to the people-oriented concept, and vigorously promote the port marketization process.

V. CONCLUSION

The system dynamics model is used to qualitatively and quantitatively analyze history, analyze the present, and study the future, which can realize scientific decision-making and modernization of operation and management. Combining system dynamics with optimized K-means algorithm and networked smart sensor technology, using K-means algorithm to quickly calculate the required data, the port economy composed of the four subsystems of population, environment, resources and economy can be The sustainable development of the intelligent system dynamics model can effectively predict the future direction of the subsystem, help adjust the development strategy, and further promote the sustainable development of the port economy.

In order to improve the sustainable development of port economy, several suggestions are put forward based on the analysis of this article. Strengthen the strategic understanding of the port layout; control the vicious competition situation of the port, and create a cooperative and win-win strategic environment for the sustainable development of the port economy. Optimize the resource structure, seek sustainable development of conservation and environmental protection; improve the service level, adhere to the people-oriented concept, and vigorously promote the port marketization process.

Due to the limited time and knowledge, this study did not conduct more performance tests when constructing the intelligent system dynamics model for the sustainable development of the port economy. The model may have certain problems and needs to be improved in the next study. In the final forecast stage, there may be omissions in the selection of data indicators for each subsystem, such as the trade ratio and transportation mode in the port economy.

REFERENCES

[1] J. Li and B. Jiang, "Cooperation in port economy and maritime logistics under the 'new normal,'" *Asian J. Shipping Logistics*, vol. 34, no. 3, pp. 189–190, Sep. 2018.

[2] J. W. Forrester, "Learning through system dynamics as preparation for the 21st century," *Syst. Dyn. Rev.*, vol. 32, nos. 3–4, pp. 187–203, Jul. 2016.

[3] F. Barnabè, "A 'system dynamics-based balanced scorecard' to support strategic decision making: Insights from a case study," *Int. J. Productiv. Perform. Manage.*, vol. 60, no. 5, pp. 446–473, Jun. 2011.

[4] N. C. Onat, M. Kucukvar, O. Tatari, and G. Egilmez, "Integration of system dynamics approach toward deepening and broadening the life cycle sustainability assessment framework: A case for electric vehicles," *Int. J. Life Cycle Assessment*, vol. 21, no. 7, pp. 1009–1034, Jul. 2016.

[5] Z. Xiao and J. S. L. Lam, "A systems framework for the sustainable development of a port city: A case study of Singapore's policies," *Res. Transp. Bus. Manage.*, vol. 22, pp. 255–262, Mar. 2017.

[6] A. M. P. Santos, R. Salvador, J. C. Q. Dias, and C. G. Soares, "Assessment of port economic impacts on regional economy with a case study on the port of lisbon," *Maritime Policy Manage.*, vol. 45, no. 5, pp. 684–698, Jul. 2018.

[7] E. Nabavi, K. A. Daniell, and H. Najafi, "Boundary matters: The potential of system dynamics to support sustainability?" *J. Cleaner Prod.*, vol. 140, pp. 312–323, Jan. 2017.

[8] A. Chapman and S. Darby, "Evaluating sustainable adaptation strategies for vulnerable mega-deltas using system dynamics modelling: Rice agriculture in the mekong Delta's an Giang province, Vietnam," *Sci. Total Environ.*, vol. 559, pp. 326–338, Jul. 2016.

[9] S. E. Orchard, L. C. Stringer, and C. H. Quinn, "Mangrove system dynamics in Southeast Asia: Linking livelihoods and ecosystem services in vietnam," *Regional Environ. Change*, vol. 16, no. 3, pp. 865–879, Mar. 2016.

[10] A. Sadeghi-Mobarakeh and H. Mohsenian-Rad, "Optimal bidding in performance-based regulation markets: An MPEC analysis with system dynamics," *IEEE Trans. Power Syst.*, vol. 32, no. 2, pp. 1282–1292, Mar. 2017.

[11] F. Cosenz, "Supporting start-up business model design through system dynamics modelling," *Manage. Decis.*, vol. 55, no. 1, pp. 57–80, Feb. 2017.

[12] X. Mao, V. L. Popov, J. Starcevic, and M. Popov, "Reduction of friction by normal oscillations. II. In-plane system dynamics," *Friction*, vol. 5, no. 2, pp. 194–206, Jun. 2017.

[13] C. Slamet, A. Rahman, and M. A. Ramdhani, "Clustering the Verses of the Holy Qur'an Using K-Means Algorithm," *Asian J. Inf. Technol.*, vol. 15, no. 24, pp. 5159–5162, 2016.

[14] S. Dalmiya, A. Dasgupta, and S. K. Datta, "Application of wavelet based K-means algorithm in mammogram segmentation," *Int. J. Comput. Appl.*, vol. 52, no. 15, pp. 15–19, Aug. 2012.

[15] J. Lei, T. Jiang, K. Wu, H. Du, G. Zhu, and Z. Wang, "Robust K-means algorithm with automatically splitting and merging clusters and its applications for surveillance data," *Multimedia Tools Appl.*, vol. 75, no. 19, pp. 12043–12059, Oct. 2016.

[16] J. Yang, Y. Ma, and X. Zhang, "An initialization method based on hybrid distance for k-means algorithm," *Neural Comput.*, vol. 29, no. 11, pp. 1–24, 2017.

[17] M. Ganesh, M. Naresh, and C. Arvind, "MRI brain image segmentation using enhanced adaptive fuzzy K-means algorithm," *Intell. Automat. Soft Comput.*, vol. 23, no. 2, pp. 325–330, 2017.

[18] C. S. Swapna, V. V. Kumar, and J. V. R. Murthy, "Improving efficiency of K-Means algorithm for large datasets," *Int. J. Rough Sets Data Anal.*, vol. 3, no. 2, pp. 1–9, Apr. 2016.

[19] R. Suryawanshi and S. Puthran, "A novel approach for data clustering using improved K-means algorithm," *Int. J. Comput. Appl.*, vol. 142, no. 12, pp. 13–18, May 2016.

[20] X. Xiao and L. Zhou, "Speech recognition adaptive clustering feature extraction algorithms based on the k-means algorithm and the normalized intra-class variance," *Qinghua Daxue Xuebao/J. Tsinghua Univ.*, vol. 57, no. 8, pp. 857–861, 2017.

[21] P. T.-W. Lee, Y. H. V. Lun, K.-H. Lai, and T. C. E. Cheng, "Maritime logistics and port connectivity in the globalised economy," *Transp. Res. E, Logistics Transp. Rev.*, vol. 95, pp. 323–325, Nov. 2016.

[22] A. Carpenter, R. Lozano, K. Sammalisto, and L. Astner, "Securing a port's future through circular economy: Experiences from the port of Gävle in contributing to sustainability," *Mar. Pollut. Bull.*, vol. 128, pp. 539–547, Mar. 2018.

[23] T. Mooney, "China port volumes grow amid slowing economy," *Fairplay*, vol. 389, no. 6910, pp. 28–29, 2017.

[24] F. Portella-Carbó and Ó. Dejuán, "Trade imbalances and fiscal policy in the eurozone: An analysis of economic interrelations with a global supermultiplier input-output model," *Cambridge J. Econ.*, vol. 43, no. 2, pp. 311–334, Mar. 2019.

[25] R. Karimpour, F. Ballini, and A. I. Ölcer, "Circular economy approach to facilitate the transition of the port cities into self-sustainable energy ports—A case study in copenhagen-Malmö port (CMP)," *WMU J. Maritime Affairs*, vol. 18, no. 2, pp. 225–247, Jun. 2019.

GUOYI XIU was born, in May 1959. He is currently a Professor with the School of Economics and Management, Harbin University of Science and Technology.

ZEXU ZHAO was born, in September 1986. He is currently pursuing the Ph.D. degree with the School of Economics and Management, Harbin University of Science and Technology. He is a Lecturer with the School of Business, Hainan Tropical Ocean University.