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Prediction of Port Container Throughput Based on Grey Prediction Model--A Case Study of Shanghai Port

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ABSTRACT. *The container throughput of a port is affected by many factors, and the relationship among them constitutes a complex non-linear system, but its changes also have inherent regularity. If we can correctly understand the changes and internal relations of these factors, grasp the regularity of these factors and select the appropriate model, we can predict the port throughput. At present, due to the rapid development of the hinterland economy of Shanghai Port, the changing macroeconomic policies and the market conditions at home and abroad, it is necessary to forecast the container throughput of Shanghai Port. In this paper, the grey prediction model is used to predict the container throughput of Shanghai Port reasonably.*

KEYWORDS: *Grey forecast, Container throughput, Shanghai port*

1. Introduction

Container transportation began in the middle and late 20th century. With the development of global economic integration, international trade is booming. Container transportation has become the best mode of transportation for international trade and has developed rapidly [1]. The container throughput of the world's ports continues to grow rapidly, and its throughput has become one of the important indicators of regional export-oriented economic development and port level. Since China's entry into WTO, the import and export volume of foreign trade has greatly increased [2]. With the sharp reduction of tariffs in China, the domestic market is further opened up, All kinds of non-tariff barriers will be gradually dismantled and the volume of foreign trade imports and exports will be greatly increased. Since most of China's foreign trade transportation is undertaken by water transport, this has greatly promoted the new round of development of the port, The development of port transport industry promotes the development of related services, brings new profit growth points to the port, and in turn further promotes the development of container transport. After years of development, China's container

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transport has made considerable progress, basically forming the layout of container ports with Bohai Bay (Dalian, Tianjin, Qingdao), Yangtze River Delta (Shanghai, Ningbo) and Pearl River Delta (Shenzhen, Guangzhou) as trunk ports [3]. With the construction of the main trunk line and the main channel of water transport, the main transport corridors connecting key ports have also been greatly improved. Combined with the construction of the main hub port of the port station, the construction of the container transport hub has also made certain progress.

Located at the forefront of the Yangtze River Delta, Shanghai Port is located in the middle of China's 18,000-kilometer continental coastline and at the mouth of the Yangtze River, the world famous port, located at the intersection of the east-west transportation channel of the Yangtze River and the north-south transportation channel of the sea, is the main hub port of China's coastal areas [4]. China is open to the outside world and participates in the important port of the international economic cycle. 99% of Shanghai's foreign trade materials go in and out through Shanghai Port, and the annual foreign trade throughput accounts for about 20% of the country's major coastal ports. As a world-famous port, Shanghai Port's container throughput ranked first in the world in 2013, and cargo throughput ranked second in the world, second only to Ningbo-Zhoushan Port [5]

2. Overview of Grey System

2.1 Brief Introduction of Grey System

Grey system theory was founded by Professor Deng Julong, a Chinese scholar. It is a new method to study the uncertainties of minority data and poor information. The grey system theory takes "small sample" and "poor information" uncertain systems with "partial information is known and partial information is unknown" as research objects. The grey system theory mainly extracts valuable information from the generation and development of some known information, and realizes the correct description and effective monitoring of the system's operational behavior and evolution law Grey system model has no special requirement and restriction on experimental observation data, so its application field is very wide [6].

2.2 Grey Prediction Model of Port Container Throughput

Port container transportation system as a subsystem of social economic system, The development level of throughput depends on the productivity distribution of the hinterland, the level of economic foreign trade development, the transportation network, the relevant ship capacity, port capacity and enterprise management level. Some of the information about these factors is known, but more is unknown, so the system has the essential features of the gray system. The grey forecast of port container throughput is to scientifically quantitatively predict the future state of the system by processing raw data and establishing a gray model to discover the law of

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system development [7]. Assuming the original sequence $X^{(0)}$ is Non-negative sequence:

$$X^{(0)} = (X_1^{(0)}, X_2^{(0)}, \dots., X_n^{(0)})$$

In this article, $X^{(0)}$ represents the container throughput of the port over the past n years, $X^{(0)}$ satisfies the condition of equal time interval.

Transform the original sequence $X^{(0)}$,generating first-order cumulative sequence $X^{(1)}$:

$$X^{(1)} = (X_1^{(1)}, X_2^{(1)}, \dots, X_n^{(1)})$$

In equation , $X_t^{(1)} = \sum_i^t X_i^0$.

$X_k^{(0)} + aZ_k^1 = b$ is a gray differential equation, Also known as GM(1,1)model.

In the above equation, a and b are the parameters to be estimated, Sequence $Z^{(1)} = (Z_1^{(1)}, Z_2^{(1)}, \dots, Z_n^{(1)})$ is a sequence generated by the mean of the adjacent elements of sequence $X^{(1)}$:

$$Z_k^{(1)} = \frac{X_{k-1}^{(1)} + X_k^{(1)}}{2}$$

Grey differential equation can be solved by least square method $X_k^{(0)} + aZ_k^{(1)} = b$ Estimates of parameters a and b, record separately as $\hat{a}$ and $\hat{b}$.

$$Y = \begin{pmatrix} X_2^{(0)} \\ X_3^{(0)} \\ \vdots \\ X_n^{(0)} \end{pmatrix} \quad B = \begin{pmatrix} -Z_2^{(1)} & 1 \\ -Z_3^{(1)} & 1 \\ \vdots & \vdots \\ -Z_n^{(1)} & 1 \end{pmatrix}$$

$$A = \begin{pmatrix} a \\ b \end{pmatrix}$$

$$X_k^{(0)} + aZ_k^{(1)} = b, \ Y=BA$$

The least square method is used to obtain the estimated value $\hat{A}$ of the parameter vector:

$$\hat{A} = \begin{pmatrix} \hat{a} \\ \hat{b} \end{pmatrix} = (B^T B)^{-1} B^T Y$$

According to the above marks, Generating differential equation $\frac{dx^{(1)}}{dt} + ax^{(1)} = b$ from sequence $X^{(1)}$, The formula is as follows:

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$$\begin{bmatrix} \hat{a} \\ \hat{b} \end{bmatrix} = (B^T B)^{-1} B^T Y$$

The solution (also called time response function) is:

$$X_{t+1}^{(1)} = \left(X_0^{(1)} - \frac{b}{a}\right).e^{-at} + \frac{b}{a}$$

Thus, The time response sequence of GM (1, 1) grey differential equation is:

$$\hat{X}_{k+1}^{(1)} = \left(X_0^{(1)} - \frac{b}{a}\right).e^{-ak} + \frac{b}{a}$$

k= 1,2,3.....n

If $X_0^{(1)}=X_1^{(0)}$, then we can get the following formula:

$$\hat{X}_{k+1}^{(1)} = \left(X_0^{(1)} - \frac{b}{a}\right).e^{-ak} + \frac{b}{a}$$

k=1,2,3.....n

Sequence $X^{(1)}$ is the first order cumulative sequence of $X^{(0)}$, sequence $X^{(0)}$ estimates can be obtained from the cumulative calculation of $\hat{X}_{k+1}^{(1)}$:

$$\hat{X}_{k+1}^{(1)} = \hat{X}_{k+1}^{(1)} - \hat{X}^{(1)}$$

k= 1,2,3.....n

3. Application of grey prediction model

3.1 Establishment of grey prediction model

Based on the forecasting model mentioned above, the container throughput of Shanghai Port is analyzed and modeled in this paper. The data of Shanghai Port from 2008 to 2018 are shown in Table 1.

Table 1 Container throughput of Shanghai Port in calendar years (unit: 10,000 TEU)

Particular year	2007	2008	2009	2010
throughput	2615.2	2800.6	2500.2	2906.9
Particular year	2011	2012	2013	2014
throughput	3173.9	3252.9	3377.3	3528.5
Particular year	2015	2016	2017	2018
throughput	3653.7	3713.3	4023.3	4201.0

The original sequence is obtained as follows:

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$X^{(0)}$ =(2615.2,2800.6,2500.2,2906.9,3173.9,3252.9,3377.3,3528.5,3653.7,3713.3, 4023.3, 4201.0)

The original sequence $X^{(0)}$ is transformed to produce the first order cumulative sequence $X^{(1)}$:

$X^{(1)}$ =(2615.2,5415.8,7916,10822.9,13996.8,17249.7,20627,24155.5,27809.2,31522.5,35545.8,39746.8)

According to the process of solving the estimated parameters of the model in the previous section, it can be concluded that:

$$Y=\begin{pmatrix} 2800.6 \\ 2500.2 \\ 2906.9 \\ M \\ 4201.0 \end{pmatrix} \quad B=\begin{pmatrix} -4015.5 & 1 \\ -6665.9 & 1 \\ -9369.45 & 1 \\ M & M \\ -39746.8 & 1 \end{pmatrix}$$

The results of parameter estimation are as follows:

$$\hat{A}=\begin{pmatrix} \hat{a} \\ \hat{b} \end{pmatrix}=(B^TB)^{-1}BY=\begin{pmatrix} -0.0451 \\ 2488.2 \end{pmatrix}$$

The results are substituted into the time response sequence of GM (1,1) model to obtain:

$$\hat{X}_{k+1}^{(-1)}=59371.731e^{0.0451k}-55170.731$$

This is the grey forecasting model of container throughput in Shanghai Port.

Because -a=0.0451<0.3, the model can be used for medium and long term prediction.

3.2 Residual test

According to the above model, the estimated value of the sequence can be obtained, and the estimated value of the original sequence can be obtained by the cumulative operation, as shown in Table 2.

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Table 2 Error Checklist

Particular year	Actual data	Model simulation data	residual	relative error (%)	accuracy (%)
2007	2615.2	2615.2	0.0	0.0	100.0
2008	2800.6	2666.0	131.8	4.7	95.3
2009	2500.2	2789.1	-291.0	11.6	88.4
2010	2906.9	2917.8	-12.3	0.4	99.6
2011	3173.9	3052.6	120.8	3.8	96.2
2012	3252.9	3193.5	59.7	1.8	98.2
2013	3377.3	3341.0	37.3	1.1	98.9
2014	3528.5	3495.3	35.7	1.0	99.0
2015	3653.7	3656.7	0.7	0.0	100.0
2016	3713.3	3825.5	-107.3	2.9	97.1
2017	4023.3	4002.2	27.5	0.7	99.3
2018	4201	4187.0	14.0	0.3	99.7

From the error checklist above, we can clearly see that the data residual in 2008 and 2009 is relatively large, which leads to relatively large errors and affects the accuracy. This is due to the outbreak of the global financial crisis in 2008-2009, which led to large fluctuations in data in 2008 and 2009. However, the average relative error of the model is 2.36%, which is far less than 10%. The average accuracy is 97.64%, more than 90%. Therefore, it is considered that the residual test is qualified and the model has high accuracy.

3.3 Model prediction results

Based on the above model, the container throughput of Shanghai Port from 2019 to 2021 is predicted, and the results are shown in Table 3.

Table 3 Prediction results of grey model for container throughput of Shanghai Port (unit: 10,000 TEU)

Particular year	2019	2020	2021	2022
throughput	4380.3	4582.6	4794.2	5015.6

As can be seen from the above table, the average annual growth rate of container throughput in Shanghai Port will reach 3.03% between 2019 and 2021. Compared with the average annual growth rate of 4.03% between 2007 and 2018, the difference of the average annual growth rate is only 1%, which is almost consistent. It can be seen that the prediction results are in line with the objective development trend and are basically credible.

4. Conclusion

In this paper, the grey forecasting model is used to predict the container throughput of Shanghai Port, and the accuracy is tested. The results show that the

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grey forecasting model can not only fit the historical data of container throughput of Shanghai Port, but also predict the future situation of container throughput of Shanghai Port. The author believes that when there are many uncertain factors affecting the prediction and the hinterland is too large, the application of grey prediction model to the prediction of port container throughput can still get more accurate results.

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