Prediction Study of Tianjin Port Throughput Based on GM (1, 1) Extended Model

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Abstract. Tianjin Port is the largest comprehensive main hub port and one of the main transshipment ports for energy and raw materials transportation in northern China. It has freight business with many countries. At the same time, Tianjin Port is the first port to carry out international maritime container transportation in China's coastal areas. Tianjin Port was built in the 1950s, and the container business has been started since 1973. In recent years, with the rapid development of large-scale, intensive and intelligent container ships in Tianjin Port, cargo throughput is an important indicator in the comprehensive evaluation of port development, which represents the development level of a port. At the same time, it also brings new tasks to the navigation guarantee work, in particular, it puts forward systematic requirements for port and wharf construction, navigation aids layout, navigation aids efficiency display and navigation aids base layout. The annual throughput of port cargo or container is one of the bases of world ports. As an output index, port enterprises, shipping companies, navigation guarantee departments and shipping economic analysis departments attach great importance to it. Therefore, the prediction of Tianjin Port cargo throughput can provide reference for Tianjin Port's next development planning, waterway use and navigation guarantee planning and layout, navigation aids setting, wharf construction, route mapping, etc. the article constructs of Tianjin Port. The average error is 0.29%, and the prediction accuracy is first class. This model can better predict the change trend of cargo for Tianjin Port, which is a better way to analyze the change trend for Tianjin port.

Key words: GM (1, 1) Extended Model, Cargo Throughput, Trend Prediction.

1. Introduction

Port throughput refers to the total cargo output, input into port area and loaded and unloaded in a period of time. Port throughput is an important index in comprehensive evaluation of port development, function and influence of port in the international and interregional water traffic chain, and also the measurement the quantitative reference basis for the construction and development of the
country, region and honesty [1]. As an output index, port enterprises, shipping companies, navigation guarantee departments and shipping economic analysis departments attach great importance to it. If we can accurately predict the port throughput, we can reasonably plan the port, so as to determine the development direction of the port, which has guiding significance for the construction of port facilities, production and operation management, and the harmonious development of logistics trade. The main channel of Tianjin Port is 47.5km long, which is a 300000 DWT deep-water channel [2-3]. The deepest depth of the channel has reached 22m. 250000 DWT ships can enter the port at any time, and 300000 DWT ships can enter the port by tide. As of 2016, Tianjin Port has 160 productive berths with a berth length of 37133m and a designed carrying capacity of 464 million tons, including 11.31 million TEU for containers, 329.43 million tons for bulk and general cargo, and 700000 vehicles. According to the approved Master Plan of Tianjin Port (2011-2030), Tianjin Port will form a spatial pattern of "one port with eight districts", that is, eight ports will be formed in Eastern/Northern/Southern/ Dagukou/ Gaoshaling/ Dagang/ Haihe and Beitang [4]. The north channel of Tianjin Port is the only channel for ships to berth at the Eastern and Northern ports of Tianjin port, which plays an extremely important role in the protection of container production and the operation of the free trade zone of Tianjin Port. To provide better service and support for the construction of Tianjin Port as a world-class port, especially to adapt to the construction of intelligent container terminal in Section C of Northern port area of Tianjin port, and to provide more high-quality and advanced navigation service for the construction and operation of intelligent terminal [5-6]. Based on the throughput prediction of Tianjin port, it is planned to upgrade the light buoy at the connection section of the north channel and the main channel, so that the ships in the water area can obtain the position and name information of the side signs of the channel in real time through AIS shipstation/radar/ECDIS and other marine navigation equipment connected with AIS signal, and more clearly identify the entry/exit and waypoint positions, In the complex traffic flow environment, it provides digital assistant means for bridge decision-making and ship handling [7]. By integrating entity AIS navigation aids, it realizes the digital perception of traditional visual navigation aids, improves the navigation aid efficiency of visual navigation aids under bad weather conditions, and ensures the safe navigation of ships and the safe production of ports.

2. Grey GM (1, 1) Extended Prediction Model

Extended prediction model is to establish Sui-se prediction model through a small amount of incomplete information, Grey system contains both known information and unknown information or uncertain information. It can weaken the randomness of the data and make it a more obvious characteristic law. The data of the past ten years show that the change rate of Tianjin Port's in and out throughput is close to the exponential curve, and the grey extended prediction applicability to simulate the exponential curve [8]. According to the grey theory, when some throughput data are obtained, the extended prediction model can be the relevant modeling method of grey theory. This paper uses the forecast model to simulate in the future.

3. Establishment of GM (1, 1) Throughput Expansion Prediction Model

Let the original number sequence of throughput \( X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)) \)

3.1. The Throughput Original Sequence is Buffered with Average Weakening.

\[
X^{(0)}D = (x^{(0)}(1)d, x^{(0)}(2)d, \ldots, x^{(0)}(n)d)
\]

Among:

\[
x^{(0)}(n)d = \frac{1}{n-k+1}[x^{(0)}(k) + x^{(0)}(k+1) + \ldots, x^{(0)}(n)], k = 1, 2, 3, \ldots
\]

3.2. The Throughput Sequence is Accumulated by 1-AGO Operator.

\[
X^{(1)}D = (x^{(1)}(1)d, x^{(1)}(2)d, \ldots, x^{(1)}(n)d)
\]
\[ X^{(1)}D(k) = \sum_{i=1}^{k} X^{(0)}(i), k = 1, 2, 3, \ldots, n \]  

3.3. Smooth Test is adopted for the Throughput \( X^{(1)}D \) Series.

\[ \rho(k) = \frac{X^{(0)}(0)}{\sum_{i=1}^{n} X^{(i)}} = 1, 2, 3, \ldots, n \]

If \( \frac{\rho(k+1)}{\rho(k)} < 1, k = 2, 3, \ldots, \), and if \( \rho(k) \in [0, 0.5], k = 3, 4 \), then the sequence of \( X^{(1)}D \) is quasi smooth.

3.4. The Exponential Law of Throughput \( X^{(1)}D \) Series is detected.

\[ \sigma(k) = \frac{x^{(1)}(k)}{x^{(1)}(k-1)}, k = 2, 3, \ldots, n \]

When \( \rho(k) \in [1, 1.5], k = 3, 4 \), the throughput \( X^{(1)}D \) series is a sequence with grey index law. If \( \sigma(k) \in [1, 1.5] \), then the GM (1, 1) model can be established for the throughput \( X^{(1)}D \) series.

3.5. Generating the Nearest Neighbor Mean Value of the Throughput \( X^{(1)}D \) Sequence.

\[ Z^{(1)}(1) = (z^{(1)}(1), z^{(1)}(2), \ldots, z^{(1)}(n)) \]

\[ z^{(1)}(k) = \frac{x^{(0)}(2) + x^{(0)}(k-1)}{2}, k = 2, 3, \ldots, n \]

\[ Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}, \quad B = \begin{bmatrix} 1 \\ -z^{(1)}(2) \\ -z^{(1)}(3) \\ \vdots \\ -z^{(1)}(n) \end{bmatrix} \]

3.6. The Least Square Estimation of Throughput Prediction Parameter Column \( \hat{a} = [a, b]^T \) is Performed.

\[ \hat{a} = (B^TB)^{-1}Y \]

3.7. Determine The Whitening Equation and Time Response Formula of GM (1, 1) Extended Throughput Model.

\[ \frac{dx^{(1)}}{dt} + ax^{(1)} = b \]

\[ x^{(0)}(k) = \beta - ax^{(1)}(k-1) \]

\[ \alpha = \frac{a}{1 + 0.5a}, \quad \beta = \frac{b}{1 + 0.5a} \]

3.8. Calculate the Analog Value of Throughput \( X(1) \) Sequence.

\[ \hat{X}^{(1)} = (\hat{x}^{(1)}(k1), \hat{x}^{(1)}(2), \hat{x}^{(1)}(3), \ldots, \hat{x}^{(1)}(n)) \]

3.9. Restore the Analog Value of Throughput \( X(0) \).
\[
\hat{X}^{(0)} = (X^{(0)}(k1), X^{(0)}(2), \ldots, X^{(0)}(n))
\]

3.10. Average Relative Error \( \Delta \) Test Of Throughput Model.

\[
\Delta_k = \frac{|x^{(0)}(k) - \hat{x}^{(0)}(k)|}{x^{(0)}(k)}
\]

\[
\Delta = \frac{1}{n-1}\sum^{n}_{k=1}\Delta_k
\]

| Table 1 | Reference table of throughput relative error accuracy test level |
|---------|---------------------------------------------------------------|
| Accuracy Level | Level 1 | Level 2 | Level 3 | Level 4 |
| Index Critical Value | 1% | 5% | 10% | 20% |

4. Taking Tianjin Port as an Example, the Throughput Prediction of Tianjin Port Based on GM (1,1) Extended Model (Living Example).

4.1. Establish the Original Time Series According to the Throughput Data of Tianjin Port From 2007 to 2013.

\[
X^{(0)} = (x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), x^{(0)}(4), x^{(0)}(5), x^{(0)}(6))
\]

\[
= (3.09, 3.56, 3.81, 4.13, 4.53, 4.77).
\]

According to the current situation of international shipping economy, the shipping economy may recover, so the AWBO operator is used to weaken the buffer of throughput series in order to be more in line with the actual situation [9-10].

\[
X^{(0)}D = (x^{(0)}(1)d, x^{(0)}(2)d, x^{(0)}(3)d, x^{(0)}(4)d, x^{(0)}(5)d, x^{(0)}(6)d)
\]

\[
= (3.98, 4.16, 4.31, 4.48, 4.65, 4.77).
\]

4.2. The Throughput Sequence is Accumulated by 1-AGO Operator.

\[
X^{(1)}D = (x^{(1)}(1)d, x^{(1)}(2)d, x^{(1)}(3)d, x^{(1)}(4)d, x^{(1)}(5)d, x^{(1)}(6)d)
\]

\[
= (3.98, 8.14, 12.45, 16.93, 21.58, 26.35).
\]

4.3. Smooth Test is Adopted for the \( X^{(1)}D \) Series.

\( \rho (3) \approx 0.53, \rho (4) \approx 0.36 < 0.5, \rho (5) \approx 0.27 < 0.5, \rho (6) \approx 0.22 < 0.5. \)

When \( k > 3 \), it basically satisfies the quasi smooth sequence.

4.4. The Exponential Law of Throughput \( X^{(1)}D \) Series is Detected.

4.5. Establish GM (1,1) Model for Throughput \( X^{(1)}D \) Series

\( \sigma (3) \approx 1.52, \sigma (4) \approx 1.36, \sigma (5) \approx 1.27, \sigma (6) \approx 1.22. \)

\( \sigma(k) \) [1,1.5] satisfies the quasi exponential law and can establish GM (1,1) model for throughput \( X^{(1)}D \) series.

4.6. Generating the Nearest Neighbor Mean Value of the \( X^{(1)}D \) Sequence.

\[
Z^{(1)} = (z^{(1)}(1), z^{(1)}(2), z^{(1)}(3), z^{(1)}(4), z^{(1)}(5))
\]

\[
= (6.06, 10.30, 14.69, 19.25, 23.96).
\]
\[
\begin{align*}
\mathbf{Y} &= \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ x^{(0)}(4) \\ x^{(0)}(5) \\ x^{(0)}(6) \end{bmatrix} = \begin{bmatrix} 4.16 \\ 4.31 \\ 4.48 \\ 4.65 \\ 4.77 \end{bmatrix}, \\
\mathbf{B} &= \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ -z^{(1)}(4) & 1 \\ -z^{(1)}(5) & 1 \end{bmatrix} = \begin{bmatrix} -6.06 & 1 \\ -10.3 & 1 \\ -14.69 & 1 \\ -19.25 & 1 \\ -23.96 & 1 \end{bmatrix}
\end{align*}
\]

4.7. The Least Square Estimation of Parameter Column \( \hat{\mathbf{A}} = [\mathbf{A}, \mathbf{B}]^T \) is Performed.

\[
\hat{\mathbf{a}} = (\mathbf{B}^T \mathbf{B})^{-1} \mathbf{B}^T \mathbf{Y} = \begin{bmatrix} -0.03482 \\ 3.9560937 \end{bmatrix}
\]

4.8. Determine the Whitening Equation and Time Response Formula of GM (1,1).

\[
\frac{dx^{(1)}}{dt} - 0.03482x^{(1)} = 3.9560937
\]

\[
\alpha = \frac{a}{1 + 0.5a} = -0.03544
\]

\[
\beta = \frac{b}{1 + 0.5a} = 4.02619
\]

\[
x^{(0)}(k) = 4.02619 - 0.03544x^{(1)}(k - 1)
\]

4.9. Calculate the Analog Value of \( X(1) \).

\[
\hat{x}^{(1)} = (\hat{x}^{(1)}(1), \hat{x}^{(1)}(2), \hat{x}^{(1)}(3), \hat{x}^{(1)}(4), \hat{x}^{(1)}(5), \hat{x}^{(1)}(6))
\]

\[
= (8.15, 12.47, 16.94, 21.57, 26.36, 26.36)
\]

4.10. Restore the Analog Value of \( X(0) \).

\[
\hat{x}^{(0)} = \left( \hat{x}^{(0)}(1), \hat{x}^{(0)}(2), \hat{x}^{(0)}(3), \hat{x}^{(0)}(4), \hat{x}^{(0)}(5), \hat{x}^{(0)}(6) \right) = (3.98, 4.17, 4.32, 4.47, 4.63, 4.79)
\]

4.11. Average Relative Error \( \Delta \) Test of the Model.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
Sequence & \( x^{(0)}(k) \) & \( \hat{x}^{(0)}(k) \) & \( \varepsilon(k) \) & \( \Delta_k \) \\
\hline
2 & 4.16 & 4.17 & 0.01 & 0.24\% \\
3 & 4.31 & 4.32 & 0.01 & 0.23\% \\
4 & 4.48 & 4.47 & 0.01 & 0.15\% \\
5 & 4.65 & 4.63 & 0.02 & 0.43\% \\
6 & 4.77 & 4.79 & 0.02 & 0.42\% \\
\hline
\end{tabular}
\caption{Average relative error \( \Delta \) test table}
\end{table}
\[ \Delta = \frac{1}{5} \sum_{k=2}^{5} \Delta_k = 0.29\% \]

The accuracy of relative error is level 1.

4.12. Tianjin port in 2021 will increase compared with that in 2020, and there will be a certain growth trend in the next few years.

5. Conclusion
To sum up, according to the prediction results of the throughput model, the average relative error of the model is 0.29%, and the prediction accuracy is first class. This model can relatively accurately reflect the changes of the cargo throughput of Tianjin port. According to the prediction results, the layout of the security facilities for the safe navigation of ships in Tianjin port is proposed. In particular, the use of double Beidou with AIS beacon will be more scientific and reasonable, which will contribute to the intensive and scientific allocation of navigation support resources, and promote the rationality and scientificity of port and wharf construction planning. However, cargo throughput is closely related to the development of global shipping economy, and there may be errors in the medium and long-term forecast. In order to be more accurate, we need to establish a metabolic model based on the latest data to make a more accurate forecast.

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