Forecasting Method for Lockage Freight Volume of Three Gorges Dam Area Based on Optimized Grey Buffer Operator

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ABSTRACT

In order to effectively predict the lockage freight volume of the Three Gorges Dam area, an improved grey prediction model for the lockage freight volume is proposed under the action of the optimized variable weight weakening buffer operator. By exploring the trend of the original data of freight volume, it is found that the original data sequence has the oscillation properties of "small sample" and "shock wave interference". The classical GM(1,1) model is difficult to simulate well for non-homogeneous exponential sequences and trend mutation sequences. So the method of constructing optimized variable weight weakening buffer operator is proposed by introducing accumulative transformation and translation transformation. On this basis, a new grey prediction model adapted to the lockage freight volume of the Three Gorges Dam area is established, and a case forecast is performed. By comparing and analyzing the prediction accuracy of the improved gray model and the traditional prediction model, it can be clearly seen that the improved gray model prediction accuracy of the optimized variable weight weakening buffer operator is significantly improved.

KEYWORDS

Waterway Transportation, Prediction Model, Gray Model, Buffer Operator, Three Gorges Ship Lock.

INTRODUCTION

Since the Three Gorges Project was built to store water, the Yangtze River Shipping has developed rapidly. According to the data analysis provided by the Yangtze River Navigation Administration of the Ministry of Transport, since the Three Gorges Project was opened to water in 2003, the average annual growth rate of the freight volume of the Three Gorges Dam has reached 11.6%. It exceeded 100 million tons for the first time in 2011 and reached 19 years in advance. In view of the design and passing capacity of the Three Gorges Ship Lock, the resulting Three Gorges Dam congestion has become regular and has become one of the bottlenecks restricting the rapid development of the Yangtze River Shipping. In the context of increasing demand for crossing gates and increasing
capacity gaps, the construction of new ship locks suitable for future shipping development has become an important breakthrough in solving the bottleneck of the Three Gorges Navigation. In order to cooperate with the construction of a new ship lock, it is necessary to analyze and predict the entire process of freight volume changes since the Three Gorges Dam area was opened to navigation. This provides a reference for assisting in formulating the passing capacity of the Three Gorges ship lock.

Most of the existing studies on the forecast of the lockage freight volume of the Three Gorges Dam area use regression analysis, elastic prediction, gray model, exponential smoothing, etc. And these studies are based on the sample of the freight volume of Gezhouba before the impoundment of the Three Gorges Project. However, the freight volume sample of Gezhouba is not really a sample to measure the lockage freight volume of the Three Gorges Dam area. The predictions made by these previous studies have drawbacks. In addition, the methods of these previous studies are mainly for the situation where the future development trend of the system is consistent with the development law formed by prior knowledge deduction. When faced with the system behavior data distorted by the shock wave interference of the system itself, the quantitative prediction results of the above method may be difficult to accept. In order to make the selected prediction samples more accurate and the prediction results more accurate, this paper selects the freight volume of the Three Gorges Project after the impoundment of the dam area as the sample, and carries out its prediction modeling under the condition of shock wave distortion.

The scatter plot of the lockage freight volume of the Three Gorges Dam area is illustrated in Figure 1. The freight volume is disturbed by two shock waves from Figure 1. These two shock waves are the implementation of ship type standardization policies and the limited capacity of ship locks. The freight volume sample constitutes a small sample oscillation sequence, which approximately satisfies a linear or exponential sequence, but it cannot be determined whether it is a homogeneous exponential sequence. Therefore, for

![Figure 1. The scatter plot of the lockage freight volume of the Three Gorges Dam area.](image-url)
the uncertainty of the "small sample" and "shock wave interference" of the freight volume at the Three Gorges Dam, it is most appropriate to use grey theory to establish a prediction model. Since the classic gray prediction model GM(1,1) is based on a nearly homogeneous exponential growth sequence, it is difficult to simulate well an approximate non-homogeneous exponential growth sequence. And its prediction accuracy is usually affected by the smoothness of the original sequence. The worse the smoothness, the less accurate the prediction. For the smoothness of the original sequence, most scholars increase the smoothness of the original sequence through mapping transformation to reduce the prediction error. But in fact, many original sequences not only show exponential growth, but also deviate from the original trend due to some shock wave (such as policy changes, natural disasters, wars, etc.) interference. The GM(1,1) model usually cannot predict the sudden change of the trend caused by shock wave interference, so Liu (1997) proposed to use the average strengthening and average weakening buffer operators to solve the predicted sudden change of trend. On the basis of Liu (1997)'s theory of buffer operator, some scholars later proposed a full-information variable weight buffer operator, a multivariable buffer operator, etc. Although these buffering operators can reduce the deviation caused by specific problems, the smoothness of the original data usually affects the degree of buffering of the operator, thereby affecting the accuracy of the prediction results. To solve this problem, this paper first introduces the cumulative translation transform to improve the smoothness of the original sequence; then on this basis, an optimized variable weight weakening buffer operator is constructed to weaken the local fluctuation components in the time series to obtain a new sequence; a new gray prediction model suitable for the forecast of the lockage freight volume of the Three Gorges Dam area is derived through the grey difference equation; finally, by comparing the prediction accuracy of the traditional prediction method and the improved prediction method, the effectiveness of the improved gray prediction model established after introducing the optimized variable weight weakening buffer operator is verified.

There are five sections in this study. The second section describes the changing trend of the lockage freight volume of the Three Gorges Dam area. Section 3 establishes an improved grey forecasting model of the lockage freight volume of the Three Gorges Dam area by constructing an optimized variable weight buffer operator. Section 4 presents empirical analysis and compares the results of traditional prediction methods and improved prediction method. Conclusions drawn from the analysis are discussed in the final section.

TREND ANALYSIS OF THE LOCKAGE FREIGHT VOLUME OF THE THREE GORGES DAM AREA

A time series was constructed using the lockage freight volume of the three gorges dam area since the Three Gorges Project in 2003 as a basic data (see Figure 1). The Three Gorges Ship Lock was in the trial navigation phase from 16 June 2003 to 8 July 2004, and was only officially opened after 8 July 2004. This time series uses the natural year (that is, January to December) as the sampling interval. This time series uses the natural year (that is, January to December) as the sampling interval. Therefore, in this paper, the freight volume from 2005 to 2018 is used as the sample basic data, and the sample data of the freight volume before 2005 is discarded.
Figure 1 indicates that the lockage freight volume is obviously not linear with the passage of time, and the scatter points are not the same curve. In the period from 2005 to 2018 after the official navigation, there have been three major fluctuations in the freight volume data. Firstly, the freight volume showed a rapid growth trend from 2005 to 2009. After 2009, there was a rapid increase, which can be derived from the comparison of the flatness of the broken line segment formed by scattered points; Secondly, the freight volume increased rapidly from 2009 to 2011 to reach its peak in 2011, and fell sharply after 2011; Thirdly, the freight volume reached a trough in 2012, and showed a rapid recovery from 2013 to 2018. From the comparative analysis of the influencing factors of freight volume, it is known that the key reason for these three large fluctuations comes from the shock wave composed of two intervention events. The first is that the formal implementation of the ship type standardization policy on 1 October 2009 has led to a rapid increase in the lockage freight volume thereafter; the second is that the lockage freight volume broke through the design capacity limit of the Three Gorges ship lock in 2011, which caused the freight volume to fall rapidly, and then resumed a rapid rise.

CONSTRUCTION OF AN IMPROVED GREY PREDICTION MODEL

Construction of Optimized Variable Weight Buffer Operator

Step 1. Construct the original sequence.

Assume that a non-negative raw sequence is \( X^{(0)} \), where \( X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)) \), and \( x^{(0)}(k) \geq 0, k = 1, 2, \ldots, n \); \( x^{(i)}(k) = \sum_{j=1}^{i} x^{(j)}(i), k = 1, 2, \ldots, n \); \( X^{(i)} = (x^{(i)}(1), x^{(i)}(2), \ldots, x^{(i)}(n)) \).

Step 2. Define an accumulation sequence after translation transformation.

An accumulation sequence after translation transformation is \( X^{(i)}(\alpha) = (x^{(i)}(1)+\alpha, x^{(i)}(2)+\alpha, \ldots, x^{(i)}(n)+\alpha) \), where \( \alpha \) is the translation distance, \( \alpha \in \left[ \min \{x^{(i)}(1)\}, \max \{x^{(i)}(1)\} \right] \). The growth rate vector of sequence \( X^{(i)}(\alpha) \) is \( q = (q_2, q_3, \ldots, q_n) \), where \( q_i = \frac{x^{(i)}(i) - x^{(i)}(i-1)}{x^{(i)}(i-1)} \).

Step 3. Determine the location of the sudden change of the original data sequence.

When \( \alpha = \min \{X^{(i)}(\alpha)\} \), the growth rate of sequence \( X^{(i)}(\alpha) \) is \( q_0 \), and the position of the trend change is \( l_0 \);

When \( \alpha = \max \{X^{(i)}(\alpha)\} \), the growth rate of sequence \( X^{(i)}(\alpha) \) is \( q_1 \), and the position of the trend change is \( l_1 \);

When \( \alpha \) and \( q_i \) are monotonous, the value of the trend change position \( l \) satisfies \( l \in [l_0, l_1] \). Step 4. Construct an optimized variable weight buffer operator after translation transformation.

The samples of the lockage freight volume in the Three Gorges Dam area are affected by two types of shock wave interventions, such as the implementation of ship type standardization policies and the limited capacity of
the Three Gorges ship lock, but the impact of the two shock wave interventions
is in the opposite direction. The implementation of ship type standardization
policy has a positive impact on freight volume, and the freight volume increases
with the deepening of the policy implementation. However, the limited capacity
of the Three Gorges ship lock has a negative impact on the freight volume, and
the growth rate of freight volume will gradually decrease. When the
implementation of the ship type standardization policy results in the increase in
freight volume reaching the design pass capacity limit of the Three Gorges
Lock, the growth rate of freight volume will slow down in the future. This paper
introduces the weakening buffer operator in the original modelling sequence to
weaken the development trend of the system and achieve the purpose of
regulating the future development trend of the system. Since the original data is
buffered before the position where the trend changes suddenly, compared with
other buffer operators, the full-information variable-weight buffer operator has
the advantages of incorporating the new information priority principle and
having a weight adjustment factor. Therefore, the full information variable
weight weakening buffer operator is used to buffer the sequence after the
cumulative translation transformation, and its formula is as follows:

\[
X^{(i)}_a(k)d = \frac{1 - \lambda}{1 - \lambda^{n-k+1}} \sum_{i=0}^{n-k} \lambda^i X^{(i)}(n-i),
\]

where \(d\) is the weakening buffer operator; \(\lambda\) is the weight adjustment
factor, \(\lambda \in (0,1)\).

When \(\alpha\) is in the interval \(\left[ \min \{X^{(i)}(1)\}, \max \{X^{(i)}(1)\} \right]\), \(\lambda\) reaches the
optimum in the interval \((0,1)\) at the same time, and the optimal values are \(\alpha^*\) and
\(\lambda^*\) respectively. The optimal buffer operator sequence is
\(X^{(i)}_a d^* = (X^{(i)}_a(1)d^*, X^{(i)}_a(2)d^*, ..., X^{(i)}_a(n)d^*)\).

Construction of Improved Grey Prediction Model

In view of the shortcomings of the classic model GM(1,1) based on the
nearly homogeneous exponential growth sequence, Zhan et al. (2013) [10]
extended it and established a general model of the non-homogeneous discrete
gray model (NDGM). This section first gives the NDGM general model, then
introduces the cumulative transformation and the optimized variable weight
buffer operator to establish an improved gray forecasting model for the freight
volume of the Three Gorges Dam.

(1) NDGM General Model

Assume that a non-negative raw sequence is \(X^{(i)}\), \(X^{(i)}\) is the 1-AGO sequence
of \(X^{(i)}\), \(Z^{(i)}\) is the sequence of \(X^{(i)}\)'s immediate mean generation. Then
\(X^{(i)}(k) + \alpha X^{(i)}(k) = 0.5(2k - 1)b + c\) is called a NDGM general model, where \(a, b, c\)
are model parameters. Its final recursion function is

\[
\hat{x}^{(i)}(k) = \frac{1 - 0.5\hat{a}}{1 + 0.5\hat{a}} \hat{x}^{(i)}(k-1) + \hat{b} + \frac{0.5\hat{b} - \hat{c}}{1 + 0.5\hat{a}},
\]

The reduction equation is
\[ \hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k). \] (3)

(2) Improved Grey Prediction Model

The sequence \( X_{a}^{(i)}d \) is accumulated again to generate the sequence, where

\[ x_{a}^{(2)}(k)d = \sum_{i=1}^{k} x_{a}^{(i)}(i)d, k=1,2,...,l. \] (4)

Its immediate mean generation sequence is

\[ \hat{z}^{(2)}(k)d = 0.5\times[x_{a}^{(2)}(k)d + x_{a}^{(2)}(k-1)d], \quad k = 2,3,\cdots,n. \] (5)

The improved grey prediction model is:

\[ x_{a}^{(1)}(k)d + a\hat{z}^{(2)}(k)d = 0.5(2k-1)b + c, \] (6)

The recursive function expression of equation (6) is derived from equations (4), (5) and (6) by least squares method as:

\[ \hat{x}_{a}^{(2)}(k)d = \frac{1-0.5a}{1+0.5a} \hat{x}_{a}^{(2)}(k-1)d + \frac{b}{1+0.5a}k - \frac{0.5b-c}{1+0.5a}, \quad k = 2,3,\cdots,n \] (7)

Then the reduction equation of the sequence \( X_{a}^{(1)} \) obtained by reduction is:

\[ \hat{x}_{a}^{(1)}(k+1) = \hat{x}_{a}^{(2)}(k+1) - \hat{x}_{a}^{(2)}(k). \] (8)

Similarly, the reduction equation of the sequence \( X^{(0)} \) is

\[ \hat{x}^{(0)}(k+1) = \hat{x}_{a}^{(1)}(k+1) - \hat{x}_{a}^{(1)}(k). \] (9)

**EMPIRICAL RESULT ANALYSIS**

(1) The Prediction Results of NDGM General Model

The parameter estimates \( a, b, \) and \( c \) in the NDGM general model are calculated as \( a = 0.9637, \ b = 1.137.4687, \ c = 1.594.2235. \) The average relative simulation error of the model is 5.0235%. It shows that the model has high prediction accuracy and good fitting effect.

(2) Improved Prediction Model Result Analysis

In view of the impact of the system behaviour data on shock waves, the optimized variable weight weakening buffer operator is introduced into the original sequence to obtain the new sequence, and the improved gray model parameter estimates \( a, b, \) and \( c \) are calculated as \( a = 1.0911, \ b = -819.5156, \) and \( c = 11.487.5283. \) The average relative simulation error of the improved gray
model is 0.268 9%, which is far less than 10%. It shows that the prediction accuracy of the model is very high, and the model fitting effect is very good.

The prediction results and prediction accuracy of the traditional general model and the improved model are shown in Table I and Table II, respectively.

### TABLE I. PREDICTION FITTING RESULTS OF DIFFERENT MODELS.

| Year | Actual value | Analog value of NDGM general model | Analog value of improved grey model |
|------|--------------|-----------------------------------|-----------------------------------|
| 2005 | 3291.1       | 3749.737                          | 10837.093                        |
| 2006 | 3939.1       | 4751.140                          | 11004.992                        |
| 2007 | 5370.3       | 5716.205                          | 11188.189                        |
| 2008 | 6088.9       | 6646.250                          | 11388.079                        |
| 2009 | 7880.4       | 7542.547                          | 11606.181                        |
| 2010 | 10032.4      | 10814.088                         | 12696.257                        |
| 2011 | 8611.3       | 11559.147                         | 13033.552                        |
| 2012 | 9706.9       | 12277.171                         | 13401.581                        |
| 2013 | 10897.8      | 12969.140                         | 13803.142                        |
| 2014 | 11981.2      | 13635.999                         | 14241.290                        |

### TABLE II. COMPARISON OF PREDICTION ACCURACY BETWEEN DIFFERENT MODELS.

| Year | Relative error of NDGM general model | Relative error of improved grey model |
|------|--------------------------------------|---------------------------------------|
| 2005 | -                                    | -                                     |
| 2006 | 4.807                                | 0.783                                 |
| 2007 | 1.392                                | 0.179                                 |
| 2008 | 6.441                                | 0.370                                 |
| 2009 | 9.154                                | 0.432                                 |
| 2010 | 4.287                                | 0.067                                 |
| 2011 | 16.208                               | 0.133                                 |
| 2012 | 7.286                                | 0.387                                 |
| 2013 | 3.442                                | 0.126                                 |
| 2014 | 0.768                                | 0.361                                 |
| 2015 | 4.541                                | 0.017                                 |
| 2016 | 2.470                                | 0.259                                 |
| 2017 | 0.536                                | 0.091                                 |
| 2018 | 3.972                                | 0.291                                 |
| Average relative error | 5.024 | 0.269 |

Remarks: The average relative error equation is.

\[
MAPE = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{\hat{y}_i - y_i}{y_i} \right|
\]

### CONCLUSIONS

Since the traditional NDGM general model is not ideal for fitting the series of freight volume with oscillating nature of shock wave interference, an improved gray model based on buffer operator is proposed. By comparing the
prediction results (Table 1) and prediction accuracy (Table 2) of the traditional forecasting model and the improved grey forecasting model, it is found that the improved grey model is significantly better than the traditional forecasting model in predicting the accuracy of the freight volume sequence with oscillating properties. The improved gray model fits better. It can be seen that the new gray prediction model constructed is valuable. The new gray prediction model is suitable for time series prediction of "small samples" and "shock wave interference". However, because the amount of information provided by the "small sample" is too small, the external environment changes rapidly, and the prediction error of the freight volume will increase as the year increases. In addition, there will be sudden events that cause shock waves to impact on the original sequence, and there may be large deviations in the prediction results.

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