Prediction of Chinese seafarers quantity based on improved GM (1,1) model

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Key words: Grey system theory, improved GM (1,1) model, quantity of seafarers

ABSTRACT

The annual quantity of Chinese seafarers is influenced by multiple factors, it may change significantly some year. In order to effectively solve the volatility of sequence, predict the quantity of Chinese seafarers, the improved grey system theory prediction model is put forward. This model will Build mathematical models and calculate the quantity of Chinese seafarers in the next five years. The result shows that the improved model can well predict the quantity of Chinese seafarers year by year. The research results can provide certain data reference for the maritime colleges, shipping companies and Departments to make development plan.

1. Introduction

The 18th National Congress of the Communist Party of China proposed to strengthen the construction of Marine talent echelon, do a good job in Marine talent reserve, ensure full employment of college students related to Marine majors, and build a basic Marine talent team. Seafarers, as skilled maritime personnel, are an important part of achieving maritime power, and their number is increasing year by year with the development of China in recent years. There are many factors that can affect quantity of seafarers[1], mainly including navigation colleges and universities graduates conversion rate(the proportion of the number of graduates serve as seafarers to the total number of graduates), the policy of seafarers management department, the salary, Holiday system, the crew's social status, the outbreak of COVID-19 epidemic, and so on. Accurate prediction of the quantity of Chinese seafarers in the future is of great significance for realizing the goal of maritime power. Based on this background, this paper predicts the quantity of Chinese seafarers in the next five years by using the improved GM (1,1) model.

2. Improvement of grey system theory model

The research object of this paper is the quantity of Chinese seafarers. During 2016-2020, the quantity of Chinese seafarers [(4)] showed an overall upward trend. However, at the beginning of 2020, the COVID-19 epidemic broke out across the world, and China was the first country to fight the epidemic directly. Fortunately, it was controlled in a very short time. In particular, in the second half of 2020, the epidemic situation abroad intensified, which seriously affected global trade, and then affected the global seaborne cargo volume, resulting in a large fluctuation in the market demanding [(7)] for seafarers. The number of seafarers dispatched abroad decreased greatly in China, Indonesia and the Philippines. In 2020, the total number of Chinese registered seafarers, the number of Chinese seafarers dispatched abroad and the number of seafarers holding certificates of competency all show great fluctuations. Therefore, it is necessary to improve the grey system prediction model [(5) - (6)] and reduce the gray level [(3)] of data to achieve accurate prediction. In this paper, the grey system prediction model is improved by using the moving average method [1] to transform the original sequence, so that the fluctuation of its numerical change becomes slow, and the gray level of the system is increased also.

Improved GM (1, 1) model establish the original sequence by using the random raw data, and then transform the original sequence through moving average method, generate transformed original sequence, and then make an accumulation to the transformed original sequence to generate an accumulation sequence, next step, calculate the average of adjacent number in the accumulation sequence to generate an adjacent

mean sequence. Finally, the mathematical model is established by using the adjacent mean sequence and the transformed original sequence. The regression equation of the sequence development is obtained by using regression calculation. In this way, the operation of discrete points is transformed into a continuous linear equation. The data values of other specific points on the graph of the regression equation are predicted and output. Finally, the predicted values of the original sequence in the future time are obtained according to the calculation of the reduction [2]. The following details the implementation steps of the improved grey prediction model GM(1,1) :

2.1 Let $X^{(0)}$ be a nonnegative sequence:

$$\text{Let } X^{(0)} = \left(x^{(0)}(1),\ x^{(0)}(2),\ldots,x^{(0)}(n)\right),\ x^{(0)}(k) \geq 0,\ \mathrm{k} = 1,2,\ldots,\mathrm{n}$$

2.2 Transform the original sequence through moving average method:

$$X'^{(0)} = \left(x'^{(0)}(1),\ x'^{(0)}(2),\ldots,x'^{(0)}(n)\right),\quad x'^{(0)}(k) \geq 0,\ \mathrm{k} = 1,2,\ldots,\mathrm{n}$$

$$x'^{(0)}(k) = \left(\frac{x^{(0)}(k-1)+2x^{(0)}(k)+x^{(0)}(k+1)}{4}\right),$$

For the endpoint:

$$x'^{(0)}(1) = \frac{1}{4}\left(3x^{(0)}(1) + x^{(0)}(2)\right),\ x'^{(0)}(n) = \frac{1}{4}\left(x^{(\mathrm{n}-1)}(1) + 3x^{(0)}(\mathrm{n})\right)$$

$$x'^{(0)}(k) \geq 0,\ \mathrm{k} = 1,2,\ldots,\mathrm{n}$$

2.3 Make an accumulation to the transformed original sequence to generate an accumulation sequence to decrease the gray level of the system.

Let $X^{(1)}$ be the accumulation sequence of $X'^{(0)}$:

$$X^{(1)} = \left(x^{(1)}(1),\ x^{(1)}(2),\ldots,x^{(1)}(n)\right),\text{其中},\ x^{(1)}(k) = \sum_{i=1}^{k} x'^{(0)}(i),\ k = 1,2,\ldots n$$

2.4 Calculate the average of adjacent number in the accumulation sequence to generate an adjacent mean sequence.

let $Z^{(1)}$ be the adjacent mean sequence of $X^{(1)}$:

$$Z^{(1)} = \left(z^{(1)}(2),\ z^{(1)}(3),\ldots,z^{(1)}(n)\right)$$

$$z^{(1)}(k) = \frac{1}{2}\left(x^{(1)}(\mathrm{k}-1) + x^{(1)}(k)\right),\ \mathrm{k}=2,3,\cdots\mathrm{n}$$

The differential equation $x'^{(0)}(k) + az^{(1)}(k) = b$ is called GM(1,1) Model.

The letter "G" is short for the word "grey", and the letter "M" is short for the word "model", GM(1, 1) is a first order model which contains one variable.

2.5 The regression calculation

Let $\hat{a}=[a,b]^T$, and

$$Y=\begin{bmatrix} x'^{(0)}(2) \\ x'^{(0)}(3) \\ \vdots \\ x'^{(0)}(n) \end{bmatrix},\qquad B=\begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix}$$

$x'^{(0)}(k) + az^{(1)}(k) = b$, $\hat{a}=([B]^T B)^{-1}[B]^T Y$

$\frac{dx'^{(1)}(t)}{dt} + ax'^{(1)}(t) = b$, this equation is called winterization equation of $x'^{(0)}(k) + az^{(1)}(k) = b$.

Let B, Y, $\hat{a}$ be as described above, so:

The solution of winterization equation $\frac{dx'^{(1)}(t)}{dt} + ax'^{(1)}(t) = b$ is:

$$x'^{(1)}(t) = \left(x'^{(1)}(0) - \frac{b}{a}\right)e^{-at} + \frac{b}{a}$$

So, the solution for GM (1, 1) model $x'^{(0)}(k) + az^{(1)}(k) = b$ is: $\hat{x}^{(1)}(k+1) = \left(x^{(1)}(0) - \frac{b}{a}\right)e^{-ak}, k = 1,2 \ldots n$

Let $x^{(1)}(0) = x'^{(0)}(1)$, so:

$$\hat{x}^{(1)}(k+1) = \left(x'^{(0)}(1) - \frac{b}{a}\right)e^{-ak}, k = 1,2 \ldots n$$

2.6 Make reduction to obtain the solution of $\hat{x}'^{(0)}(k)$:

$\hat{x}'^{(0)}(k)=\hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1)$, $\hat{x}'^{(0)}(k)$ is the simulation value of $X'^{(0)}$

2.7 Accuracy test of improved GM(1,l)model

There are lots of methods to check the accuracy of GM(1,1)model. We use relative error test in this paper.

Let $\varepsilon^{(k)}=\frac{x'^{(0)}(k)-\widehat{x'}^{(0)}(k)}{x'^{(0)}(k)} \times 100\%$, $\varepsilon^{(k)}$ is the relative error。

2.8 $X^{(0)}$ is predicted by using improved GM (1, 1) model

If the accuracy test is ok, Calculate $\hat{x}'^{(0)}(n+1)$, $\hat{x}'^{(0)}(n+2)$,and so on ,by using the formula $\hat{x}'^{(0)}(k)=\hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1)$. And finally,we can obtain the value of $\hat{x}'^{(0)}(k)$ which is called predicted value of original sequence.

3. An improved GM (1,1) model is used to predict the number of seafarers holding certificates of competency

The Report on the Development of Chinese Seafarers, published annually by the Information Office of the Ministry of Transport of the People's Republic of China, can be obtained through the Internet which can help us to get first-hand official data. Including the total quantity of Chinese registered seafarers, the quantity r of Chinese seafarers dispatched abroad and the quantity of seafarers holding certificates of competency, etc.

many people registered as seafarer, but due to various reasons such as age, getting a new job, etc. the certificate is invalid, and they no longer qualified as seafarers. The people who actually work as seafarers are seafarers with certificates of competency. The following paper takes the quantity of seafarers with certificates of competency as an example, uses the improved GM (1,1) model to calculate and output the number of seafarers with Certificates of Competency of Chinese nationality in the next five years. From 2016 to 2020, the number of seafarers with Chinese certificates of competency was 263,000, 241,000, 251,000, 259,000 and 270,000, respectively.

The number of seafarers holding certificates of competency is generated by performing the steps 1, 2, 3 and 4 above:

Table 1 Accumulation sequence values and adjacent mean sequence values of seafarers holding certificates of competency under the improved GM (1, 1) model

Year	$x^{(0)}(k)$ (10 thousand)	$x'^{(0)}(k)$ (10 thousand)	$x^{(1)}(k)$ (10 thousand)	$z^{(1)}(k)$ (10 thousand)
2016	26.30	25.75	25.75	
2017	24.10	24.88	50.63	38.19
2018	25.00	25.00	75.63	63.13
2019	25.90	25.95	100.63	88.13
2020	27.00	26.50	127.13	113.88

According the fifth step above, so:

$Y=\begin{bmatrix}24.88\\25.00\\25.95\\26.50\end{bmatrix}$, $B=\begin{bmatrix}-38.19 & 1\\-63.13 & 1\\-88.13 & 1\\-113.88 & 1\end{bmatrix}$, By calculating, we know $\hat{a}=\begin{bmatrix}-0.023\\23.83\end{bmatrix}$

The solution of winterization equation $\frac{dx^{(1)}}{dt}-0.023x^{(1)}=23.83$ is:

$$x'^{(0)}(k)-0.023z^{(1)}(k)=23.83$$

So, the solution for GM (1, 1) model $\frac{dx^{(1)}}{dt}-0.023x^{(1)}=23.83$ is: $\hat{x}^{(1)}(k)=\left(x'^{(0)}(1)-\frac{b}{a}\right)e^{-a(k-1)}+\frac{b}{a}=1061.75e^{0.023(k-1)}-1036$, k=1, 2, 3, …n

Let $x^{(1)}(0)=x'^{(0)}(1)$, so:

$$\hat{x}^{(1)}(k+1)=\left(x'^{(0)}(1)-\frac{b}{a}\right)e^{-ak},k=1,2\ldots n$$

Calculate and make reduction to obtain the simulated sequence and test the error

Table 2 Error test for seafarers holding certificates of competency under the improved GM (1, 1) model

Year	$x^{(1)}(k)$ (10 thousand)	$\hat{x}'^{(0)}(k)$ (10 thousand)	$x'^{(0)}(k)$ (10 thousand)	$\varepsilon^{(k)}$ (%)
2016	25.75	25.75	25.75	0
2017	50.45	24.7	24.88	0.72
2018	75.73	25.28	25.00	-1.12
2019	101.60	25.87	25.95	0.31
2020	128.07	26.47	26.50	0.11

According table 2, the maximum relative error is 1.12%, the minimum value of relative error is 0.11%, and they are all lower than 2%. The accuracy standards of prediction are shown in Table 3. As the accuracy of prediction model is so high that meets the requirements. therefore, improved GM (1, 1) model can be used for prediction.

Table 3 Prediction accuracy

Prediction type	Range of relative error /%
Short-term prediction (<1a)	2-5

Medium-term prediction (<1-5a)	10-20
long-term prediction (5-10a)	30-40

The improved GM (1, 1) prediction model is used to predict the number of seafarers holding certificates of Competency in 2021-2025, as shown in Table 4.

Table 4 prediction results of seafarers holding Certificates of Competency in 2021-2025

Year	prediction results (10 thousand)
2021	27.08
2022	27.71
2023	28.36
2024	29.02
2025	29.69

4. conclusion

4.1 Achievements

This paper first studies the policies of the national maritime powers and preliminarily analyzes the main reasons for the changes in the quantity of Chinese seafarers. Then, combined with the trend and reasons of the change of the quantity of Chinese seafarers, the grey system theory prediction model is improved, and then improved GM (1, 1) model is used for mathematical modeling and calculation. The prediction results meet the accuracy requirements, and can be used to predict the quantity of Chinese seafarers. Finally, the quantity of seafarers holding certificates of competency in 2021-2025 is output.

4.2 Deficiencies

As the number of seafarers holding certificates of competency is subject to many influencing factors, it is a grey system, so the data predicted by the improved GM (1, 1) model is only a theoretical value. After changes in national policies and international economic condition, errors in predicted data will inevitably occur. The actual number of seafarers holding the certificate of competency should be calculated again every year to update the prediction results, so as to be more accurate.

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