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Accident Prediction of Special Equipment in China Based on Grey Markov Model

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Abstract. Based on the grey prediction of special equipment accident, Grey Markov model for accident prediction of special equipment is established by combining the Grey model with Markov chain, which can not only have the features of playing the accurate prediction of the grey system, but also have the advantage of using the Markov chain to accurately predict the volatility data. Based on the data of the incidents of special equipment accidents in China from 2006 to 2017, the prediction accuracy of the model is verified. The example calculation shows that the prediction accuracy of the grey Markov chain model for special equipment accidents is higher than that of the GM (1,1) model, which can be used to predict the development trend of special equipment accidents in China.

1. Introduction

With the continuous development of the economy, the application of special equipment, as an important means of production, is becoming more and more extensive. The number of special equipment in China has developed rapidly in recent years, the total number of special equipment in China had reached 12.9652 million by the end of 2017. Due to the great danger of special equipment, once an accident occurs, it will cause irreparable losses. Therefore, accident prediction of special equipment is of great significance for analysing the development trend of accidents and the safety control of special equipment.

Scholars at home and abroad have done a lot of research on it. LIU Jianqi et al. [1] established Grey Model GM (1,1) based on grey prediction theory, and used the model to predict the number of road traffic accidents and the number of deaths respectively. XUE Xunguo et al. [2] adopted the superposition Markov chain prediction principle and used the state transition probability matrix to establish a grey Markov chain prediction model. HE Wenzhang et al. [3] proposed a linear programming optimization method for GM (1,1) parameters based on three different methods of difference quotient. Shin et al. [4] introduced the concept of forgetting factor and the idea of recursion to estimate GM (1,1) model with time-varying parameters by recursive least square method, which improved the prediction accuracy. LI Dong et al. [5] proposed a new dimension unbiased Grey Markov Prediction Model by using the idea of new information priority, and used the model in stock price prediction.

In conclusion, this paper establishes a GM (1,1) grey prediction model for the number of special equipment accidents, and combines the advantages of the Markov model to establish a Grey Markov Prediction Model. Eventually, according to the number of occurrences of special equipment accidents



in China from 2006 to 2017, the accuracy of the two models is compared and analysed, so as to predict the occurrence of special equipment accidents in 2018.

2. Grey Markov prediction model

In this paper, Grey Markov Prediction Model is applied to the prediction of the occurrence times of special equipment accidents in recent years by taking the occurrence of special equipment accident in recent years as an index [6].

2.1. Grey model GM (1,1)

Grey prediction is the process of applying GM (1,1) model to analyse, model, solve and forecast the grey system; after accumulatively pre-processing the original data, a differential equation is established for the obtained data sequence to calculate the prediction result [7].

The steps to establish GM (1,1) model are as follows:

Step 1: Level ratio test and feasibility analysis of modelling.

If $X^{(0)}$ is a non-negative sequence, which is the original data sequence corresponding to the time series t , then obtain:

$$x^{(0)}(k) = \{x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(m)\} \quad (1)$$

Calculate the level ratio $\sigma(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)}$ ($k = 2, 3, \dots, m$); check if $\sigma(k)$ fall within the coverage area $(e^{-2/(m+1)}, e^{2/(m+1)})$.

Step 2: Accumulated Generating Operation.

The original data sequence is accumulated once, then obtain:

$$x^{(1)}(k) = \{x^{(1)}(1), x^{(1)}(2), \dots, x^{(1)}(m)\} \quad (2)$$

In formula: $x^{(1)}(i) = \sum_{k=1}^i x^{(0)}(k)$, $i = 1, 2, \dots, m$.

Step 3: Establish differential equations.

The method of generating equal-time-distance mean is used to calculate the sequence $X^{(1)}(k)$, and the method of neighboring mean equal weight is used to generate sequence $b(k)$, where $b(k) = [x^{(1)}(k) + x^{(1)}(k-1)]/2$, $k = 2, 3, 4, \dots, m$, establish matrix Y and B to obtain:

$$Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(k-1) \\ x^{(0)}(k) \end{bmatrix}, \quad B = \begin{bmatrix} -b(2) & 1 \\ -b(3) & 1 \\ \vdots & \vdots \\ -b(k-1) & 1 \\ -b(k) & 1 \end{bmatrix} \quad (3)$$

Establish differential equations for GM (1,1) grey prediction model:

$$dx^{(1)}/dt + ax^{(1)} = u$$

In formula: a , u are indeterminate coefficients, which is generally determined by the least square method, where

$$\begin{bmatrix} a \\ u \end{bmatrix} = (B^T B)^{-1} B^T Y \quad (4)$$

Introducing the parameters a and u into the albino differential equation, the gray GM (1,1) Prediction model is obtained:

$$\hat{x}^{(1)}(k) = [x^{(0)}(1) - u/a]e^{-a(k-1)} + u/a \quad (5)$$

Step 4: Obtain the accumulated sequence of predicted values, and perform the subtractive reduction on them to obtain the gray prediction model of the original series:

$$\begin{cases} \hat{x}^{(0)}(1) = x^{(0)}(1) \\ \hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) \end{cases} \quad (6)$$

In formula, $\hat{x}^{(0)}(k)$ is predicted values for the original sequence; $\hat{x}^{(1)}(k)$ is predicted values for the cumulative sequence.

2.2. Markov optimization prediction

The research object of Markov probability matrix prediction is a dynamic system with random change, the grey prediction smooth curve is divided into states according to the predicted relative change rate, and the state transition matrix is constructed, and then the original prediction value is processed, so that the prediction accuracy can be improved [8].

If the possibility that an event starts from a certain state E_i and moves to another state at the next moment is called the state transition probability [9]. Then, the matrix P :

$$P = \begin{bmatrix} P_{11} & \cdots & P_{1m} \\ \vdots & \ddots & \vdots \\ P_{m1} & \cdots & P_{mm} \end{bmatrix} \quad (7)$$

It is called the state transition probability matrix. Usually, the principle of frequency approximation equals probability is used to calculate the state transition probability, that is:

$$P_{ij} = M_{ij} / M_i \quad (8)$$

In formula: M_i is the total number of occurrences of state E_i , and M_{ij} is the number of transitions from state E_i to state E_j .

Set the state corresponding to $\max\{P_i, i \in E\}$ to be the Markov prediction state of the prediction object.

$$\hat{y}(k) = [1 - (w_{j-} + w_{j+})/2] \hat{x}^{(0)}(k) \quad (9)$$

In formula: w_{j-} and w_{j+} is the boundary value of the state interval W_j . According to equation (9), the grey predicted value calculated previously is improved, and the final predicted value in the future n years is calculated.

3. Establishment of prediction model of special equipment accident in China

This paper sorts out the number of special equipment accidents that occurred in China over the years 2006-2017 based on the analysis and statistics of the national special equipment safety situation of the State Administration of Market Supervision and Administration from 2006 to 2017, see Table 1.

Table 1. The number of special equipment accidents in China during 2006- 2017.

Year	Number of Accidents	Year	Number of Accidents
2006	299	2012	228
2007	256	2013	227
2008	307	2014	283
2009	380	2015	257
2010	296	2016	233
2011	275	2017	238

3.1. GM (1,1) Prediction

According to formula (1) - formula (6), a grey GM (1,1) Prediction model for the number of special equipment accidents in China is established:

$$\hat{x}^{(1)}(k) = [x^{(0)}(1) - 14882.09]e^{-0.0228(k-1)} + 14882.09 \quad (10)$$

Then the model was used for data calculation to obtain the predictive analysis results of the start number of special equipment accidents, see table 2.

Table 2. The accident prediction results of GM (1,1) model during 2006-2017.

Year	Actual value	Grey prediction value	Residual	Relative residuals /%	State
2006	299	299	0	0	3
2007	256	310	54	21.094	5

2008	307	301	-6	-1.954	3
2009	380	293	-87	-22.895	1
2010	296	285	-11	-3.716	3
2011	275	277	2	0.727	3
2012	228	270	42	18.421	5
2013	227	263	36	15.859	5
2014	283	256	-27	-9.541	2
2015	257	248	-9	-3.502	3
2016	233	241	9	3.863	4
2017	238	234	-4	-1.681	3

The residual of the predicted value and the actual value is relatively large. The average relative residual of the model can be calculated as 8.60% by the accuracy test, and the accuracy is not high.

3.2. Markov chain correction

Because the relative residual fluctuation between the predicted value of Grey Model GM (1,1) and the actual value is large, it is more appropriate to consider the number of states when classifying them [10]. Here, the relative residual interval is divided into five states: state E_1 is $[-22.895, -14.097)$, state E_2 is $[-14.097, -5.299)$, state E_3 is $[-5.299, 3.499)$, state E_4 is $[3.499, 12.297)$, and state E_5 is $[12.297, 21.095)$. The dividing results are shown in table 2.

According to formula (7), the number of special equipment accidents in China from 2006 to 2017 is fitted, and the residual and relative residual of prediction results are calculated, the calculation results are shown in table 3. Then it can be known that average relative residual of the Grey Markov Model is 2.37%, which is much higher than the GM (1,1) model.

Table 3. Prediction results of Grey Markov Model for accidents during 2006-2017.

Year	Actual value	Markov prediction value	Residual	Relative residuals /%
2006	299	299	0	0
2007	256	258	2	0.781
2008	307	304	-3	-0.977
2009	380	347	-33	-8.684
2010	296	288	-8	-2.703
2011	275	279	4	1.455
2012	228	225	-3	-1.316
2013	227	219	-8	-3.524
2014	283	281	-2	-0.707
2015	257	250	-7	-2.724
2016	233	222	-11	-4.721
2017	238	236	-2	-0.840

3.3. Markov prediction

According to the data in Table 2, it can be obtained that $M_1=1$; $M_2=1$; $M_3=6$, $M_4=1$, $M_5=3$. Combining the data of Table 2 and the formula (7) and formula (8), then the 1-step state transition probability matrix of the number of incidents of special equipment accidents is obtained as below:

$$P(1) = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1/6 & 0 & 1/6 & 1/6 & 3/6 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 1/3 & 1/3 & 0 & 1/3 \end{bmatrix}$$

The number of accidents results in 2017 is in the state of E_3 , which can be seen from the state transition probability matrix in the third line of matrix $\max P_{3j}=P_{35}$; and the probabilistic state of the

number of accidents in 2018 are most likely to be in the state E_5 . According to the formula (9) and formula (10), the number of special equipment accidents in China in 2018 is 190.

Draw the prediction curves of the numbers of special equipment accident event GM (1,1) model and the Grey Markov Model, and compare them with the actual numerical curve at the same time, as shown in Figure 1. It can be seen that the relative error between the revised predicted accident number and the actual accident number is smaller, which indicates that the Grey Markov Model can provide reliable prediction results.

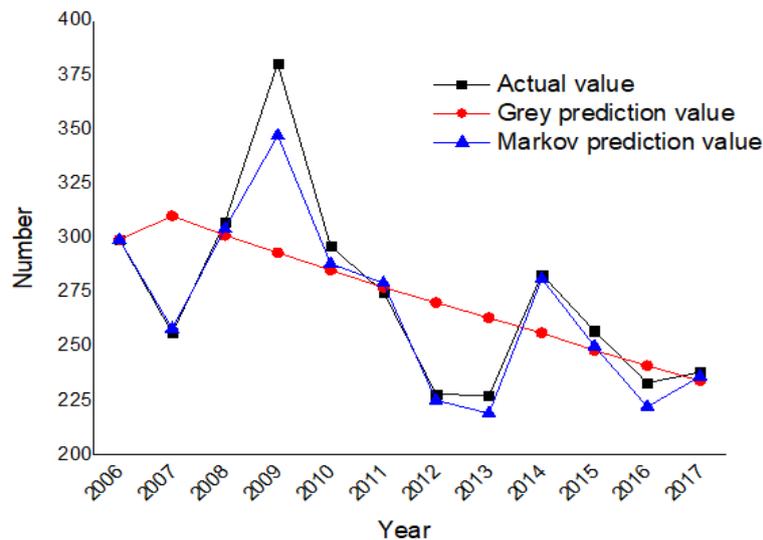


Figure 1. Comparison Curves of Prediction Result of Two Models.

4. Conclusion

The conclusions of this paper could be listed as followed:

- By comparing the data of previous years, the level of special equipment accident control in China has been increasing year by year, and the security situation is generally stable, but further improvement is still needed.
- Grey Markov Prediction Model is used to predict China's Special equipment accident in this paper and the basic algorithm flow of the Model is studied and the algorithm is verified by the examples. In the study, the GM (1,1) model prediction is used to reveal the general trend of the development of the prediction series, while the Markov probability matrix prediction is used to determine the metastasis rule; then the Grey Markov Prediction Model is finally formed by combining the two to eliminate the inherent deviation of GM (1,1) mode. The result shows that the prediction accuracy of the model is higher and it can be used to predict the number of special equipment accidents in China.

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