Study on abnormal behavior of human in safety accidents of special equipment

Hongqi Luo¹ and Xia Liu²*

1 School of Material and Mechanical Engineering, Beijing Technology and Business University, Beijing, China
2 Quality Management Branch of China National Institute of Standardization, Beijing, China
E-mail: lhqfrq@126.com
*Corresponding author

Abstract. The data of the total number of accidents and the number of accidents caused by illegal use of special equipment in China was obtained. The prediction models for the safety accidents of special equipment are establish with grey theory based on the actual data. Then the models are processed through optimization. The results show that the simulation values fit well with the real values, which can be used as a theoretical basis and reference for special equipment safety policy formulation and scientific regulatory decision-making.

1. Introduction
Special equipment is an important driving force and tool to ensure the economic and social development, as well as an important infrastructure to ensure the quality of life of people. Because of the large number of people contacted or affected in the whole life process of special equipment, its structural characteristics are dangerous, and the medium carried by some equipment is harmful. Therefore, the safety of special equipment is directly related to the safety of people's lives and property. The safety situation of special equipment is not optimistic in China. The level of various accident indicators is 4 to 6 times that of developed countries. Serious and extraordinary accidents still occur from time to time, and the safety situation has not yet been fundamentally changed [1, 2]. The abnormal behavior of relevant personnel is the main reason for the accidents of special equipment. In order to improve the safety status of special equipment and meet the needs of the development of special equipment, it is significance to analyze the characteristics and rules of the development of special equipment safety accidents for the safety supervision.

2. Data collection and collation
Through consulting "China Heavy Machinery Industry Yearbook" [3], the actual data obtained and the data processed are shown in Table 1. Because of the randomness of the original data column of the number of accidents, it cannot be directly used for modeling, so the original data column is transformed by moving average, such as moving average processing of the statistical data from 2008 to 2016 [1]. The formulas are shown as follow, which t is from 1 to N.

\[ X^{(0)}(t) = \left[ X^{(0)}(t-1) + 2X^{(0)}(t) + X^{(0)}(t+1) \right] / 4 \]
\[ X^{(0)}(1) = \left[ 3X^{(0)}(1) + X^{(0)}(2) \right] / 4 \]
\[ X^{(0)}(N) = \left[ X^{(0)}(N-1) + 3X^{(0)}(N) \right] / 4 \]

The abnormal behavior of relevant personnel is the main reason for the accident of special equipment. The abnormal behaviors of people include the use of illegal equipment, improper maintenance of safety accessories, illegal operation of operators and other illegal use. It shows that the proportion of accidents caused by illegal use in the total number of accidents is 37.80%–65.67% from Table 1. It is very important to study the abnormal behavior of human beings, which is reflected in the safety accidents of special equipment.

3. Prediction models of GM (1, 1)
The grey forecasting method is to establish a mathematical model from the past to the future based on the known or unascertained information of the past and the present, so as to determine the trend of the development of the system and provide a theoretical basis for planning and decision-making [1, 2]. GM (1, 1) is a first-order and variable differential equation model, which is suitable for predicting the development and change of eigenvalues of system behavior [4-6].

### Table 1. Number of illegal use and total accidents of special equipment in 2008-2016

| Year | Number of accidents | Number of accidents caused by illegal use | Proportion of caused by illegal use |
|------|---------------------|------------------------------------------|----------------------------------|
|      | Actual value | Processed value | Actual value | Processed value |
| 2008 | 307       | 325.25        | 131        | 134.25        | 42.67                |
| 2009 | 380       | 340.75        | 144        | 141.25        | 37.89                |
| 2010 | 296       | 311.75        | 146        | 137.25        | 49.32                |
| 2011 | 275       | 268.50        | 113        | 125.75        | 41.09                |
| 2012 | 228       | 239.50        | 131        | 124.25        | 57.46                |
| 2013 | 227       | 241.25        | 122        | 121.75        | 53.74                |
| 2014 | 283       | 262.50        | 112        | 119.00        | 39.58                |
| 2015 | 257       | 257.50        | 130        | 131.25        | 50.58                |
| 2016 | 233       | 239.00        | 153        | 147.25        | 65.67                |

#### 3.1. Prediction model of accident number Caused by illegal use

The original discrete data sequence of the number of accidents caused by illegal use.

\[
x^{(0)} = \left\{ x_1^{(0)}, x_2^{(0)}, \ldots, x_N^{(0)} \right\}
\]

Where \( N \) is the sequence length, \( N = 9 \).

\[
x^{(0)} = \left\{ 131, 144, 146, 113, 131, 122, 112, 130, 153 \right\}
\]

After moving average transformation, the following results are obtained:

\[
x^{(0)} = \left\{ 134.25, 141.25, 137.25, 125.75, 124.25, 121.75, 119.00, 131.25, 147.25 \right\}
\]

The superscript (0) denotes the cumulative number of times.

\[
x_k^{(1)} = \sum_{j=1}^{k} x_j^{(0)}, \quad k = 1, 2, 3, \ldots, N
\]

The sequence can be obtained by a process of cumulative generation when it is calculated with formula (1).

\[
x^{(1)} = \left\{ 134.25, 275.50, 412.75, 538.50, 662.75, 784.50, 903.50, 1034.75, 1182.0 \right\}
\]

Data matrix \( B \) and \( y_N \) can be obtained as below.

\[
B = \begin{bmatrix}
-\left( x_2^{(1)} + x_1^{(1)} \right)/2, & 1 \\
-\left( x_3^{(1)} + x_2^{(1)} \right)/2, & 1 \\
\vdots & \vdots \\
-\left( x_N^{(1)} + x_{N-1}^{(1)} \right)/2, & 1
\end{bmatrix}
\]

Then
Then $a = -0.0010$, $u = 131.6518$. Substituting $A$ and $u$ to formula (2)

$$
\hat{x}_{k+1}^{(1)} = \left( x_1^{(1)} - \frac{u}{a} \right) e^{-\frac{k}{a}} + \frac{u}{a}
$$

Formula (3) can be obtained.

$$
x_{k+1}^{(1)} = 126.970.6628 - 126.645.4128 e^{0.010 k}
$$

3.2. Prediction model of total number of accidents

The original discrete data sequence:

$$
\chi^{[0]} = \{307, 380, 296, 275, 228, 227, 283, 257, 233\}
$$

The statistical data are processed by moving average method.

$$
\chi^{[0]} = \{325.25, 340.75, 311.75, 268.5, 239.5, 241.25, 262.5, 257.5, 239\}
$$

The sequence can be obtained by a process of cumulative generation.

$$
\chi^{[1]} = \{325.25, 666, 977.75, 1246.25, 1485.75, 1727, 1989.5, 2247, 2486\}
$$

Data matrix $B$, $yN$ can be obtained as follow.

$$
B = \begin{bmatrix}
-495.625 & 1 \\
-821.675 & 1 \\
-1112 & 1 \\
-1366 & 1 \\
-1606.375 & 1 \\
-1858.25 & 1 \\
-2118.25 & 1 \\
-2366.5 & 1 \\
\end{bmatrix}
$$

$$
y_N = [340.75, 311.75, 268.5, 239.5, 241.25, 262.5, 257.5, 239]^T
$$

Then

$$
\hat{a} = \begin{bmatrix} a \\ u \end{bmatrix} = \begin{bmatrix} 0.0465 \\ 338.4034 \end{bmatrix}
$$

$$
\hat{x}_{k+1}^{(1)} = 72729617 - 69477117 e^{-0.0465 k}
$$

3.3. Optimization and improvement of prediction model
In order to improve the accuracy of the model, the parameters are fitted twice to improve the model \([7, 8]\). Taking the forecasting model of the number of accidents caused by illegal use as an example. The above time response equation is written as follows:

\[ x^{(1)}(k + 1) = A e^{0.0010k} + B \]

“A” and “B” are estimated according to the value “a” of the first sequence estimation and the original sequence \( x^{(1)}(k) \). The sequence matrix \( G \) and the sequence vector \( x^{(1)} \):

\[
G = \begin{bmatrix}
e^0, & 1 \\
e^{-a}, & 1 \\
\vdots & \vdots \\
e^{-a(k-1)}, & 1
\end{bmatrix}
\]

\[
x^{(1)} = [x^{(1)}_1, x^{(1)}_2, \ldots, x^{(1)}_n]^T.
\]

namely

\[
x^{(1)} = [134.25, 275.50, 412.75, 538.50, 662.75, 784.5, 903.5, 1034.75, 1182.0]^T
\]

The parameters A and B are obtained.

\[
\begin{bmatrix}
A \\
B
\end{bmatrix} = (G^T G)^{-1} G^T x^{(1)} = \begin{bmatrix}-124224.2923 \\
124369.3079
\end{bmatrix}
\]

The final response equation is obtained, which is shown in formula (5).

\[ x^{(1)}(k + 1) = -124224.2923 e^{0.0010k} + 124369.3079 \]

(5)

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

In the formula, \( k = 0, 1, 2, 3, \ldots, N; x^{(0)}(1) = x^{(1)}(1) \). The calculation results are shown in Table 2.

**Table 2.** Calculating results of accidents caused by illegal use

| Year | Serial number | Actual value | Actual first-order cumulative value | Predictive first-order cumulative value | Predictive value | Residual value |
|------|---------------|--------------|------------------------------------|----------------------------------------|-----------------|---------------|
| 2008 | 1             | 134.25       | 134.25                             | 145.016                                | 145.016         | -10.766       |
| 2009 | 2             | 141.25       | 275.50                             | 273.753                                | 128.737         | 12.513        |
| 2010 | 3             | 137.25       | 412.75                             | 402.357                                | 128.604         | 8.646         |
| 2011 | 4             | 125.75       | 538.50                             | 530.828                                | 128.471         | 8.646         |
| 2012 | 5             | 124.25       | 662.75                             | 659.166                                | 128.338         | -4.088        |
| 2013 | 6             | 121.75       | 784.50                             | 787.370                                | 128.205         | -6.455        |
| 2014 | 7             | 119.00       | 903.50                             | 915.442                                | 128.072         | -9.072        |
| 2015 | 8             | 131.25       | 1034.75                            | 1043.381                               | 127.939         | 3.311         |
| 2016 | 9             | 147.25       | 1182.00                            | 1171.187                               | 127.806         | 19.444        |
| 2017 | 10            | 1298.861     | 127.674                            | 127.674                                | 127.674         |               |
| 2018 | 11            | 1426.403     | 127.542                            | 127.542                                | 127.542         |               |
| 2019 | 12            | 1553.813     | 127.410                            | 127.410                                | 127.410         |               |
| 2020 | 13            | 1681.090     | 127.277                            | 127.277                                | 127.277         |               |
| 2021 | 14            | 1808.236     | 127.146                            | 127.146                                | 127.146         |               |
After the same calculation, the prediction model of the total number of accidents can be optimized. The optimization model is formula (6) and the calculation results are shown in Table 3.

$$x^{(1)}(k+1) = -624.7603e^{-0.0465k} + 7167.9193$$

| Year | Serial number | Actual value | Actual first-order cumulative value | Predictive first-order cumulative value | Predictive value | Residual value |
|------|---------------|--------------|-------------------------------------|----------------------------------------|------------------|----------------|
| 2008 | 1             | 325.25       | 325.25                              | 343.139                                | 343.139          | -17.889        |
| 2009 | 2             | 340.75       | 666.00                              | 653.415                                | 310.276          | 30.474         |
| 2010 | 3             | 311.75       | 977.75                              | 949.584                                | 296.169          | 15.581         |
| 2011 | 4             | 268.50       | 1246.25                             | 1232.289                               | 282.705          | -14.205        |
| 2012 | 5             | 239.50       | 1485.75                             | 1502.141                               | 269.852          | -30.352        |
| 2013 | 6             | 241.25       | 1727.00                             | 1759.725                               | 257.584          | -16.334        |
| 2014 | 7             | 262.50       | 1989.50                             | 2005.598                               | 245.873          | 16.627         |
| 2015 | 8             | 257.50       | 2247.00                             | 2240.293                               | 234.695          | 22.805         |
| 2016 | 9             | 239.00       | 2486.00                             | 2464.318                               | 224.025          | 14.975         |
| 2017 | 10            | 2678.158     |                                     |                                        | 213.840          |                |
| 2018 | 11            | 2882.277     |                                     |                                        | 204.118          |                |
| 2019 | 12            | 3077.115     |                                     |                                        | 194.839          |                |
| 2020 | 13            | 3263.096     |                                     |                                        | 185.981          |                |
| 2021 | 14            | 3440.621     |                                     |                                        | 177.525          |                |
| 2022 | 15            | 3610.075     |                                     |                                        | 169.454          |                |

4. Analysis of prediction results

Based on the above calculation and analysis, the total number of accidents and the number of accidents caused by illegal use of special equipment in 2008-2022 can be predicted. The total number of accidents and the number of accidents caused by illegal use of special equipment in 2008-2022 are estimated and predicted by the established prediction model.

The analysis results are shown in Fig. 1 and Fig. 2. It can be seen from the figure that the model fits well. From the Fig.2, it shows that the total number of accidents of special equipment is decreasing year by year, which is inseparable from the strict supervision system of special equipment in China. However, the number of accidents caused by illegal use does not change significantly, accounting for a large proportion, indicating that there are still large loopholes in the regulation of human abnormal behavior. In order to keep the accident situation of special equipment stable, Scientific and comprehensive quality supervision measures, formulate scientific safety production control indicators should be adopted, which are useful to ensure the safe operation of special equipment [9, 10].
Conclusions
In the theory and method of grey prediction, dealing with the original statistical data can eliminate the influence of random data to a certain extent. The grey model described by cumulative generation and differential equation can effectively deal with poor information and disordered data, and has good prediction accuracy and practicability in a certain period of time. This shows that the prediction method based on grey theory is suitable for the trend prediction of safety accidents of special equipment in China.

The main purpose of establishing the model is to provide scientific theoretical reference for relevant policies and strategic objectives of safety accident control. Grey theory needs relatively few raw data and has strong operability. Abnormal human behavior is the main factor in the occurrence of special equipment accidents, which needs to be monitored more strictly. In order to improve the safety status of special equipment and meet the needs of the development of special equipment, scientific safety supervision of special equipment is particularly important.

Reference
[1] Luo Hongqi, Nie Xuejun, Liu Xia. Mechanization profit portion estimation in agricultural industry based on the grey model[J]. Journal of agricultural mechanization research, 2011, (10):44-46
[2] Cui Qingling, Luo Yun, Cui Gang, et al. Study on predition of special equipment accident based on grey theory[J]. Journal of safety science and technology, 2013, 9(5): 141-144
[3] Executive Editorial Committee of China Heavy Machinery Industry Yearbook. China Heavy Machinery Industry Yearbook [J]. Beijing: China Machine Press, 2009-2017
[4] Li Yuefen, Tang Jie, Li Yanmei. Evaluation of grassland soil quality by principal component analysis and grey correlation analysis [J]. Global Geology, 2004, 23 (2): 169-174
[5] Wu Xinmin, Pan Genxing. Relevance analysis of factors affecting heavy metal pollution in urban soils [J]. Acta Pedologica Sinica, 2003.40 (6): 921-928

[6] Ouyang Tao, Xie Xiaoyun. Statistics [M]. Changsha: National Defense University of Science and Technology Press. 2002

[7] Chen Lei. Application of gray theory in freeway traffic volume prediction [J]. Liaoning communication science and technology, 2004,(10): 37-39

[8] Lin Shaoxia, Lin Changhu, He Tengbing, et al. Application of grey relational degree method in analysis of factors affecting agricultural non-point source contaminated soil [J]. Bulletin of Soil and Water Conservation, 2010,30(4):171-174

[9] Kou Yi. Application of combination forecasting models in road freight turnover [J]. China water transport, 2007,(11): 216-218

[10] Zhang Qinwen, Wang Xuemen. Grey System Analysis of Rural Economy - Model, Method and Application [M]. Beijing: Academic Journal Press. 1989

Acknowledgments
Project is supported by National Key R & D Program of China (2017YFF0207200).