Prediction Research of Death Number in Construction Accident Based on Unbiased Grey-Fuzzy-Markov Chain Method

Yu Li[1, a *] , Mengnan Li[2,b]

[1, 2] Dalinjiaotong University, Dalian, China

[a] 467797823@qq.com,[b] 852576037@qq.com

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Abstract: Some of the inherent characteristics of the construction industry makes frequently construction safety accidents, and as well , that's caused a serious of adverse effects , by now, the effective prediction which is about the trend of death number in construction accident becomes extremely important. However, the statistics of accidents is less and volatility, single evaluation model can not improve the prediction accuracy because of their limitations, leading to the low prediction accuracy of death number. The evaluation model which is combining many kinds of evaluation models has more advantages, put the unbiased theory and the fuzzy into the traditional grey markov prediction model, establish unbiased gray-fuzzy-markov chain model. This method based on the number of deaths in construction accident in 2003-2012,forecast the number in 2013-2015,then proposes some appropriate management measures.

Introduction

Construction is an important sector of gross domestic products; it's closely related to the development of the economy and the improvement of people's lives, it's occupying a pivotal position in the national economy, and playing a significant part in the development of society. The period of "eleventh five year plan", "Fifteen" period, the construction industry accounts for approximately 6% of GDP to 7% [1]. At present, China's construction industry output value accounted for 5.7% of gross domestic product, has become the fourth largest industry [2]. However , in construction field, production workers and machineries are mobile, and there are lots of outdoor workings and high-altitude operations, making construction accidents occur frequently, it's caused serious losses to people's lives and property ,even caused enormous economic losses to the state and companies, lead to great impact on the stability of the society. There are about 1000 accidents each year in construction in the last dozen years, which, in 2000 and 2001, respectively, up to 1164 times and 1108 times. But in those casualty accident , there are great parts caused by human factors, it can be avoided. So , the effective prediction which is about the trend of death number in construction accident becomes extremely important. According to the forecast the trend of the death number in architectural, propose appropriate preventive and improvable measures to reduce the incidence of accidents and the number of death, and reduce the economic losses, there is a very important significance to the state and society.

There has many method to predict the trend of death number in construction accident, such as the BP neural network method, the regression analysis method, the time series forecasting method, the gray theoretical prediction method [3-5]. But the first three methods have some disadvantages-"long period, large area, low confidence", they are require a large sample of data in order to obtain a relatively stable, long-term trends, but the actual trend is the volatility [6]. The major research content of gray system is the uncertainty of "small sample, poor information", according to adding up the date which is time-varying obtain the date which has some laws of orderly to establish the appropriate model[7].Markov model is suited to forecast the accidents in long term and random fluctuations date [8]. While, building safety data is fluctuating wildly, poor regularly, less availably and vulnerable to outside influence, some scholars combine the advantages of gray prediction and Markov model , establish the gray Markov model to predict construction accidents, however, this model has bias and weak anti-interference capability, affecting the accuracy of the predictions.

In this paper, aiming at the problem of the traditional gray Markov chain model, put the unbiased theory and the fuzzy into the traditional model, eliminating bias used by unbiased gray GM (1,1), then definition the state of historical data using fuzzy mathematics, final, forecast the death number of nearly a decade.

Unbiased Grey-Fuzzy-Markov Chain Method

Unbiased Gray-Fuzzy-Markov chain method is based on the traditional Markov method, introduce the unbiased gray theory and fuzzy classification theory into this method to eliminate the bias of the traditional methods. At the same time, through fuzzy classification setting membership status according to the maximum membership principle, further, predicting trends from transform layer to improving its anti-jamming capability.

Building Unbiased GM(1,1)

(1) data validation and processing. Given the original time series data, expressed as:

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(n)) \quad (1)$$

Calculating the level step ratio of series , and verifying the date is consistent with the establishment of GM (1,1) model or not:

$$l(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)} (k = 2,3,...,n) \quad (2)$$

If the level ratio $l(k)$ falls within the range $X = (e^{-2/(n+1)}, e^{2/(n+1)})$, the series $x^{(0)}$ is feasible. If it's not satisfied, the series is required to do the translation, so that it can fall within an allowable range ,its expression as:

$$y^{(0)}(k) = x^{(0)}(k) + c(k = 2,3,...,n) \quad (3)$$

Make the new level ratio of the series satisfied with:

$$l_y(k) = \frac{y^{(0)}(k-1)}{y^{(0)}(k)} \in X(k = 2,3,...,n) \quad (4)$$

(2)Taking AGO to original series to generate a new sequence.

$$x^{(1)} = (x^{(1)}(1), x^{(1)}(2), ..., x^{(1)}(n)) \quad (5)$$

Among them, $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1,2,...,n$

(3)According to the rule model, structuring the average series:

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1)(k = 2,3,...,n) \quad (6)$$

Among them, $z^{(1)} = (z^{(1)}(2), z^{(1)}(3), ..., z^{(1)}(n))$

(4)Establishing differential equations, its gray differential equation is:

$$x^{(0)}(k) + az^{(1)}(k) = b(k = 2,3,...,n) \quad (7)$$

The albinism differential equation is:

$$\frac{dx^{(1)}}{dt} + ax^{(1)}(t) = b \quad (8)$$

Where: a, b is the traditional gray parameters.

(5) Solving the traditional gray parameters used by the least square method:

$$Y = (x^{(0)}(2), x^{(0)}(3), ..., x^{(0)}(n))^T$$

$$B=\begin{bmatrix}-z^{(1)}(2) & 1\\ -z^{(1)}(3) & 1\\ \dots & \dots\\ -z^{(1)}(n) & 1\end{bmatrix} \quad (9)$$

$$[a,b]=(B^TB)^{-1}B^TY \quad (10)$$

(6) Calculating the unbiased gray parameters:

$$a=\ln\frac{2-a}{2+a}, b=\frac{2b}{2+a} \quad (11)$$

(7) Establishing the prediction curve of the unbiased gray model.

$$\hat{x}^{(0)}(k)=\begin{cases}x^{(0)}(1) & k=1\\ b\,e^{a(k-1)} & k=2,3...\end{cases} \quad (12)$$

Inspecting Salvage

The relative salvage is:

$$e(k)=\frac{x^{(0)}(k)-\hat{x}^{(0)}(k)}{x^{(0)}(k)}(k=2,3,...,n) \quad (13)$$

In accordance with the relative residual standard, if the value is less than 0.2 or 20%, then the model prediction accuracy is satisfied with the general requirement; if its value is less than 0.1 or 10%, the model prediction accuracy is satisfied with the fine requirement.

Fuzzy Classification

In accordance with the function prediction curve by above calculate, getting the relative salvage through making a subtraction with the original data and the data calculated from the unbiased gray prediction curve, getting the relative salvage. Subdividing all salvages, according to the random probability to determine the division of fuzzy state which has m states, each state formed their own membership function for fuzzy based on the triangle method, and therefore, a relative salvage $x\in U$ (U is the relative salvage difference)can form fuzzy vector on their basis of function, the state of each data in this system can be represented as a vector: $(m_1(x),m_2(x),...m_m(x))$.

Solving the State Transition Matrix

Calculating the fuzzy state vector of each point data based on subordinating degree function which is formed according as the fuzzy classification, with the principle of maximum degree of membership to determine their status, calculating the time of transition to other states through a step in order to calculating the probability. Its state transition probability is:

$$P_{ij}=\frac{M_{ij}}{M_i} i=1,2,...,n \quad (14)$$

Where, P_{ij} is the probability after the state i through a step transition to the state j; M_{ij} is the time of the original data after the state i through a step transition to the state j; M_{ij} is the number of original data in state i .By calculating the state matrix can be obtained:

$$P=\begin{bmatrix}P_{11} & P_{12} & \dots & P_{1n}\\ P_{21} & P_{22} & \dots & P_{2n}\\ \dots & \dots & \dots & \dots\\ P_{n1} & P_{n2} & \dots & P_{nm}\end{bmatrix} \quad (15)$$

The state transition probability matrix P is the key of the Markov chain, it shows the macro development trends of the original data, describing the statistical law of each state transition in the system.

Fuzzy Markov Residual Error Correction

By the relative residual value $d(n)$ in time n as well as the membership $u_A(d(n))$ of the relative residual value $d(n)$ about each fuzzy state, namely:

$$C(d(n)) = [m_{A1}(d(n)), m_{A2}(d(n)), \ldots\ldots, m_{Am}(d(n))] \tag{16}$$

The sequence of relative residuals is still a fuzzy vector at the moment $n+1$, namely:

$$C(d(n+1)) = C(d(n))P = [m_{A1}(d(n+1)), m_{A2}(d(n+1)), \ldots\ldots, m_{Am}(d(n+1))] \tag{17}$$

Each component in $C(d(n+1))$ represents the membership of the relative residual estimates in each fuzzy state, for the membership as a right, using the method of weighted sum can obtain:

$$d(n+1) = \sum_{i=1}^{m} \frac{1}{2} m_{Ai} d(n)(d_{i-1} + d_i) \tag{18}$$

The predictive value of the $n+1$ is:

$$\hat{y}^{(0)}(n+1) = \frac{\hat{x}^{(0)}(n+1)}{1 - d(n+1)} \tag{19}$$

Prediction of Construction Accident

Mortality of Construction Accident

In this paper, according to the statistics about mortality range 2003 to 2012 of construction accident in nationwide from the Ministry of Housing, predicting the death number from 2013 to 2015, see Table 1

Table 1 Statistics of Construction Accident in Nationwide

Order number	Years	Mortality
1	2003	1524
2	2004	1324
3	2005	1193
4	2006	1048
5	2007	1012
6	2008	989
7	2009	846
8	2010	772
9	2011	712
10	2012	649

Predictions Unbiased GM(1,1) Model

(1)Analyzing the step ratio of mortality, all of them are falling within the coverage.

(2)Taking 1 AGO to the original time series in order to obtain the accumulated sequence, then generating sequence $Z^{(1)}$ by the formula

$$B = \begin{bmatrix} -2186 & 1 \\ -3445 & 1 \\ -4564 & 1 \\ -5595 & 1 \\ -6596 & 1 \\ -7513 & 1 \\ -8322 & 1 \\ -9064 & 1 \\ -9745 & 1 \end{bmatrix} \qquad Y = \begin{bmatrix} 1324 \\ 1193 \\ 1048 \\ 1012 \\ 989 \\ 846 \\ 772 \\ 712 \\ 649 \end{bmatrix}$$

$$[a \quad b] = (B^T B)^{-1} B^T Y$$

By calculation:

$$\begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} 0.09 \\ 1493.79 \end{pmatrix}$$

(3) Calculated its unbiased gray curves.

$$\hat{x}^{(0)}(k) = \begin{cases} 1524 & k=1 \\ 1429.46e^{-0.09(k-1)} & k=2,3... \end{cases}$$

The fitting results and the relative residual value are shown in Table 2, and compared their relative residual, it can be seen that most of the relative residual concentrated in 5% or less. Nearly a decade, only the relative residual in 2008 is exceed 5%, basically, you can say the fitting results are well.

Table 2 Predicting Fitted Value, Actual Value and Fuzzy State of Mortality using Unbiased $GM(1,1)$

Years	Mortality	Predictive value	Salvage value	Relative value（%）	Fuzzy state
2003	1524	1524	0	0	0
2004	1324	1306	18	1.36	3
2005	1193	1194	-1	-0.08	3
2006	1048	1091	-43	-4.1	2
2007	1012	997	15	1.48	3
2008	989	911	78	7.89	5
2009	846	833	13	1.54	3
2010	772	761	11	1.42	3
2011	712	696	16	2.25	4
2012	649	636	13	2	4

Fuzzy Classification

Depending on the application experience and the distribution situation of the relative residual rate about the Markov chain analysis method in random process, the change of increment in construction industry can be divided with the following state(Standard of state division are shown in Table 3)

Table 3 Standard of State Division

State	Description	Boundary	State property
1	Strong decline	＜-5%	Extremely overvalued.
2	Weak decline	-5%～-2%	Overvalued.
3	Normal	-2%～2%	normal
4	Weak rise	2%～5%	Undervalued
5	Strong rise	＞5%	Extremely undervalued

According to the relative value in Table 2and the standard of state division in Table 3 ,we can statistics: state 1 has never appeared in recent 10 years; state 2 occurs only once; state 3 occurs five times, it's the most; state 4 only appears twice; status 5 appear only once.

Determine the State Matrix

Determined the states of each point according to the maximum membership principle, and based on the Relative value in Table 2 calculating the transfer of system state(see Table 4), a transition rule can be confirmed clearly between the relevant state, and the status transition matrix P can be obtained .(the times of State transition is1 step).

Table 4 statistic of 1 step transition frequency

Item	State 2	State 3	State 4	State 5	Total
State 2	0	1	0	0	1
State 3	1	3	1	0	5
State 4	0	1	1	0	2
State 5	0	0	0	1	1
Total	1	5	2	1	9

According to Table 4, the status transition matrix:

$$P=\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0.2 & 0.6 & 0.2 & 0 \\ 0 & 0.5 & 0.5 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Correction of Markov Chain

The Relative value in 2012 is 2%, so the fuzzy vector of original state is (0,0,1,0), calculating the state fuzzy vector from 2013 to 2015 based on the fuzzy vector of original state, as shown in Table 5. And then calculate the relative predictive value using weighted method, to clarify the deaths predicted results of national building construction accident, as shown in Table 6.

Table 5 Fuzzy Vector and Residual Predicted Value

Years		2013	2014	2015
Fuzzy vector	State 2	0	0.1	0.11
	State 3	0.5	0.55	0.605
	State 4	0.5	0.35	0.285
	State 5	0	0	0
Residual predicted value（%）		1.42	1.59	1.34

Table 6 Forecasting Results of Unbiased Grey-Fuzzy-Markov Chain Method

Years	Residual predicted value（%）	Model calculative value	model predicted value
2013	1.42	636	645
2014	1.59	581	590
2015	1.34	531	538

As we can be seen from the above empirical calculations, in the future trend, the death number in construction accident is decreasing year by year and its decreasing trend tends to a normal state.

Countermeasures and Suggestions

In recent years, the construction industry has made great development. People has paid more attention to the construction and the government and the relevant departments has formulated a series of specifications about construction safety operation, construction enterprises has invested more human, material and financial resources to ensure the security management, all these measures make the casualty showed a downward trend year by year. However, compared with developed countries, the situation is not optimistic, there are still many casualties can be predicted and avoid.

Drawing on advanced technology and management theory from foreign developed countries, improving our safety management system , raising the existing building operation methods and techniques to prevent construction accident and control its losses in fundamentally.[2]In view of the current situation of construction safety, this paper will give three suggestions from the business management, government supervision and management, market management:

(1)Construction company is the most effective preventer and controller in the construction accident. Enterprises should increase their prediction and prevention ability, strengthen their own management capability. First, enhancing safety education efforts, including safety consideration and safety practice. The education can help all staff establish the safety awareness, realize the potential dangers that may existing in their jobs and the adverse consequences , master of technical skills and abide by the post operating regulations. Second, strengthen the management of the construction site, avoid irrelevant person entering the scene, put materials in suitable site, arrange for the use and transportation of large-scale machinery effectively. Finally, establishing safety management system to construct a standardized, systematic management system. Formulating safety production duties and responsibilities, and put it into practice implemented by the person responsible, establishing and executing the rewards and punishment system.[9]

(2)The administration of construction safety represent our government supervised and inspected the equipment of security measures and safety assurance system in the production and service, its behavior is mandatory, scientific and authoritative. [10]The effective supervision has great benefit to regulate building construction and reduce construction accidents. On the one hand ,the supervisor should reinforce construction safety laws and regulations, establish a unified, standardized safety laws and regulations and all relevant safety laws. On the other hand, the supervisor should be based on the development and current status of the construction industry to repeal, modify or improve the old administrative rules and regulations , safety rules and regulations which did not fit the production and life. The supervisor also should strengthen the enforcement of safety production supervision.[11]

(3)Actively establish and improve the construction market management mechanisms can effectively clean the air of the construction market, to a certain extent, it can protect the quality of construction, reduce construction accidents. To standardize the market order, we should build a healthy and orderly development bidding market, to ensure a fair, justice, open bidding, prevent the illegal behavior such as accompanying-bidding and colluded bidding, control the phenomenon of random lower prices from out-contracting units.[11]

Summary

(1)Unbiased gray-fuzzy-Markov chain method has the characteristics of the micro forecast and macro forecast, to a certain extent, unbiased GM (1,1) model eliminate the gray bias inherent in the traditional model, it's better than the other methods to death number in construction accident which is less, volatility and disorder, the result of prediction is more accurate.

(2) In this paper, predicting death number in construction accident based on unbiased grey-fuzzy-Markov chain method, and proposing some suggestions about the building security's control and response. China's casualty of construction showed a downward trend year by year, but the situation is still not optimistic, maybe the improvement and perfection from different aspects can't prevent the occurrence of accidents, but accidents and the losses can be reduced to a large extent.

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