Application Study of the Grey Prediction Model in Emergency Decisions on Accidents in Stadiums

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Abstract

Public security is an important problem in the process of social development. Accidents that occur in stadiums are investigated in this study. The focus is on the complicated randomness of such accidents. Grey theory is utilized for modeling, and the grey prediction model is applied to emergency decisions on accidents in stadiums. The GM(1,1) model is adopted to predict accidents in stadiums. Specifically, two models are established: a GM(1,1) model for the number of times accidents occur and a GM(1,1) model related to death tolls in accidents in stadiums. Experimental results show that the two established models satisfy the accuracy required for prediction and exhibit rapid computing speed and small time consumption. These models have good stability in terms of long-term prediction and thus have a potential for practical application.

Keywords: Gymnasium, Accidents, Grey prediction model, GM(1,1) model

1 Introduction

At present, urbanization is ensuing rapidly in China. The economy is growing rapidly, contacts with overseas countries are increasing continuously, and social relations and structures are changing significantly [1]. As a result, many conflicts and problems arise in both the natural field and social environment. These problems tend to trigger all types of public events and have significant negative effect on people's properties and social order [2]. After conducting a general survey of international and domestic situations, particularly the 911 Event in America, we find that such situations have drawn a significant amount of global attention to the construction of an emergency command system. Thus, research on the management of public emergencies is very important [3]. Management of public emergencies needs be studied continuously after the 21st century and has a direct relationship with the sustainable development of human society.

As a special public site, a gymnasium is a place where people participate in and watch sports events. The population density and mobility in this setting are high [4]. Chaos ensues easily when threatening public incidents, such as fire, group congestion and trampling, and terrorist attacks, occur. Such chaos results in numerous casualties and significant losses in economic properties [5]. With development of the sports cause and improvement in people's living standards, the number of people who watch sports events has increased continuously in recent years. Such increase has resulted in an increase in the occurrence rate of gymnasium accidents [1], such as the congestion and trampling accident in Mecca Stadium and the terrorist attack in Munich Stadium. By analyzing statistical data, the causes of accidents in stadiums can be mainly divided into natural hazards (e.g., fire), terrorist explosions and attacks, human congestion (e.g., riot among soccer fans), and structural problems (e.g., exit jamming and collapse of the grandstand). However, regardless of the cause of public accidents, whether immediate crowd evacuation is carried out is the decisive factor that causes mass death and casualties.

Currently, research on human evacuation models encounters several problems, such as insufficient data on model parameters and lack of basis. Such problems result in the establishment of human evacuation models that lack credibility [6]. Thus, methods such as observation, surveys on evacuation, and tests should be utilized to obtain characteristic data on human evacuation behavior when accidents occur so as to construct a reliable human evacuation model [7]. The essence of a reliable human evacuation model lies in its prediction of accidents that may or will occur to allow emergency measures to be implemented for purposeful human evacuation and settlement.

The prediction of accidents in stadiums involves estimating and predicting future situations in stadiums by systematically analyzing the previous and current status of a gymnasium and considering the changes in related factors [8]. "In all things, we will succeed if we make preparations in advance. Otherwise, we may only fail." This statement indicates the importance of prediction. Prediction is an important premise of scientific decision making. Emergency security decisions for accidents in stadiums are no exception. Although the occurrence of accidents in stadiums has a contingency to some extent, it can be predicted based on indexes related to accidents; scientific and reasonable prediction is of practical significance for emergency decisions on accidents in stadiums in China nowadays [2]. The prediction of accidents in stadiums is also significant in the improvement of the level of public security management. It does not only establish laws on the occurrence of accidents in stadiums and future

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developmental trends of accidents in stadiums under the existing conditions of gymnasiums but also reasonably predicts accidents that may occur in the future and provides reliable theoretical basis upon which countermeasures and technical measures can be formulated. Under the condition that the robustness of prediction models of accidents in stadiums is increased, a prediction model can also be applied to emergency decisions on accidents in other public sites (such as large shopping malls and amusement parks).

2 Analysis of a prediction model

Many types of prediction models exist. Thus, we cannot confirm if a certain prediction model is superior to others in any application. Selecting an appropriate prediction model for accidents in stadiums is critical [6]. Four standards, namely, rationality, accuracy, stability, and simplicity, are utilized to determine if a prediction model is good or bad. Prediction models for accidents in stadiums follow a development law with a specific environment; thus, the prediction results of prediction models are consistent with the development law [9]. The accuracy of prediction models is also important. If prediction accuracy does not satisfy the requirements, the prediction model is unpractical regardless of how reasonable it is. In addition, prediction models need have stability and simplicity and must be able to accurately reflect the development and changes in accident prediction over a long period of time. Furthermore, they must be simple and easy to use, and their computing time must be short. Only prediction models that satisfy the four standards above can be considered good and applicable to practical situations.

Grey system theory is a model system whose core is the grey model (GM) [10]. By overcoming the disadvantages of regression and experience prediction models, grey prediction method does not require a list of the factors that affect the occurrence of accidents in stadiums; it begins with accidents in stadiums, acquires useful information, and explores internal laws to establish a grey prediction model. The term "grey" represents the condition where some information is known while some are unknown. According to the definition, prediction models for accidents in stadiums can be built with a grey system. Grey prediction models for accidents in stadiums only require minimal information; the calculation is simple, the errors between predicted and actual results are small, and the prediction accuracy is high. Hence, these models are appropriate for the prediction of all indicators of accidents in stadiums, which only contain a small amount of historical data. The means to generate a grey system frequently utilized at present involve an accumulated generating operation (AGO), an inverse accumulated generating operation (IGAO), average generation, and grade ratio generation [3]. As a typical trend analysis model, the GM(1,1) model is particularly suitable for trend prediction of the indexes of a socioeconomic system with many factors, a complicated structure, wide coverage, high level, strong comprehensiveness, and good interaction. The GM(1,1) model not only has a unique effect (e.g., weakening the randomness of the sequence and excavating the system evolution law) but also exhibits ideal fusion power and penetration for common models. Consequently, integrating the GM(1,1) model with the entire modeling process of common models or combining it with other models for prediction can achieve functional complementation and profound excavation of the system evolution law. A grey prediction model reveals the continuous development and change in things inside a system and attempts to explore and discover the hidden internal law in chaotic phenomena. Thus, a grey prediction model is usually described by a differential equation. The most typical grey prediction model is the GM(1,1) model.

3 Establishment of a GM(1,1) model

The non-negative original sequence is assumed to be

$$X^{(0)} = \left\{ x^{(0)}(1), x^{(0)}(2), ... \right\} \tag{1}$$

$X^{(0)}$ is accumulated once, i.e., the first number of $X^{(1)}$ is the accumulation of the first and second numbers of $X^{(0)}$. The second number of $X^{(1)}$ is the accumulation of the first, second, and third numbers of $X^{(0)}$. Accordingly, sequence $X^{(1)}$ can be obtained as follows:

$$X^{(1)} = \left\{ x^{(1)}(1), x^{(1)}(2), ... \right\} \tag{2}$$

We can obtain $X^{(1)}$ through successive accumulation. $X^{(1)}$ involves seven numerical values. Thus,

$$x^{(1)}(k) = \sum_{i=0}^{k} x(i) \tag{3}$$

The GM(1,1) differential expression of $x^{(0)}(k)$ is

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = u \, , \tag{4}$$

where a, u are undetermined parameters. If the foregoing formula is discretized, we can obtain

$$\Delta^{(1)}(x^{(1)}(k+1)) + az^{(1)}(x(k+1)) = u \, , \tag{5}$$

where

$$\Delta^{(1)}(x^{(1)}(k+1)) = x^{(1)}(k+1) \cdot x^{(1)}(k) = x^{(0)}(k+1) \tag{6}$$

$$z^{(1)}(x^{(1)}(k+1)) = \frac{1}{2}(x^{(1)}(k+1) + x^{(1)}(k)) \, . \tag{7}$$

The foregoing differential equation is solved by the least squares method as follows [4]:

$$\hat{x}^{(1)}(k+1) = [x^{(1)}(1) - \frac{\hat{u}}{a}]e^{-\hat{a}k} + \frac{\hat{u}}{\hat{a}} \tag{8}$$

The least squares method reveals the dependency among variables from a group of measured data. This type of function relationship is called an empirical formula. The best function is obtained by matching of a group of data through a quadratic sum of minimized errors. By reducing the original data, we obtain

$$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k)=(1-e^{-\hat{a}})[x^{(1)}(1)-\frac{\hat{u}}{\hat{a}}]e^{-\hat{a}k} \quad (9)$$

The equation above is the computing formula for the model's grey prediction.

4 Establishing a GM(1,1) model for accidents in stadiums

In accordance with grey theory, a GM(1,1) model was applied to investigate and analyze the number of accidents in stadiums and death tolls in accidents occurring at all stadiums in China. A suitable prediction model was constructed for research on the number of accidents in stadiums and death tolls in accidents occurring at all stadiums in China.

4.1 GM(1,1) MODEL FOR THE NUMBER OF ACCIDENTS IN STADIUMS IN CHINA

The grey model, GM(1,1), only requires a small amount of sample data. The number of accidents in stadiums is related to the quantity of sports or entertainment activities undertaken in a particular year. To reflect the current occurrence of accidents in stadiums, data on accidents that have occurred in stadiums in the past eight years were predicted.

TABLE 1 Statistical table of accidents in stadiums in China from 2002 to 2009

Year	2002	2003	2004	2005	2006	2007	2008	2009
Number of accidents	323	331	176	120	108	85	63	58

In accordance with Table 1, a grey model GM(1,1) was established. Accidents that may occur in stadiums afterward were then predicted according to the established model. The specific process of modeling and prediction is shown below.

Step 1:

(1) An operation that involves the extraction of a root for the number of accidents is implemented to ensure that the grade ratio coverage of data on accidents stays within a reasonable range.

$$x^{(0)}=(\sqrt{323},\sqrt{331},\sqrt{176},\sqrt{120},\sqrt{108},\sqrt{85},\sqrt{63},\sqrt{58})$$
$$=(17.97,18.19,13.27,10.95,10.39,9.22,7.94,7.62)$$

(2) The grade ratio sequence of $x^{(0)}$ is obtained as

$$\sigma^{(0)}=(0.9879,1.3707,1.2119,1.0539,1.1269,1.1612,1.0420)$$

, where grade ratio sequence $\sigma^{(0)}$ is composed of the ratio of two numbers (i.e., the previous single bit and the following single bit) of $x^{(0)}$. In other words, the ratio of the first number to the second number in $x^{(0)}$ is the first numerical value of $\sigma^{(0)}$, and the ratio of the second number to the third number in $x^{(0)}$ is the second numerical value of $\sigma^{(0)}$. A successive analogy can be applied. According to the results of the grade ratio sequence, $x^{(0)}$ can serve as the modeling sequence of GM(1,1).

(3) The $x^{(1)}$ sequence is obtained as $x^{(1)}=(17.97,36.16,49.43,60.38,70.77,79.99,87.93,95.55)$.

(4) The mean value of $x^{(1)}$ is obtained as $z^{(1)}=(27.065,42.795,54.905,65.575,75.38,83.96,91.74)$.

Step 2:

(1) Parameters a and b are calculated.

$$\begin{aligned}\Delta_a&=C\times D-(n-1)E\\ \Delta_b&=D\times F-C\times E\\ \Delta&=(n-1)\times F-C^2\end{aligned} \quad (10)$$

$$a=\frac{\Delta_a}{\Delta},b=\frac{\Delta_b}{\Delta} \quad (11)$$

Then $C=\sum_{k=2}^{8}z^{(1)}(k)=441.42$, $D=\sum_{k=2}^{8}x^{(0)}(k)=77.58$, $E=\sum_{k=2}^{8}z^{(1)}(k)x^{(0)}(k)=4403.4408$, $F=\sum_{k=2}^{8}[z^{(1)}(k)]^2=31026.2195$.

It means that:

$$a=\frac{\Delta_a}{\Delta}=\frac{C\times D-(n-1)E}{(n-1)\times F-C^2}=0.1532$$

$$b=\frac{\Delta_b}{\Delta}=\frac{D\times F-C\times E}{(n-1)\times F-C^2}=207.5554$$

(2) GM(1,1) is determined.

$$x^{(0)}(k)+az^{(1)}(k)=b$$

Then, we obtain:

$$x^{(0)}(k)+0.1532z^{(1)}(k)=207.5554.$$

by solving

$$x^{(0)}(1)=17.97,\ \frac{b}{a}=1354.8001$$

$$x^{(1)}(k+1)=-1172.5424e^{-0.1532}+1354.8001$$

$$\hat{x}^{(0)}(k+1)=x^{(1)}(k+1)-x^{(1)}(k) \quad (12)$$

By reducing the accumulated subtraction, the obtained prediction model for accident data in gymnasiums is

$$\hat{x}^{(0)}(k+2)=(e^{-a}-1)(x^{(0)}(1)-\frac{b}{a})e^{-ak}$$
$$=162.82312875e^{-0.1532k}$$

The number of accidents in stadiums in the next three years, which is obtained with the prediction model, is as follows:

$\hat{x}^{(0)}(9) = 55.7158$, $\hat{x}^{(0)}(10) = 47.8019$, $\hat{x}^{(0)}(11) = 41.0120$.

Step 3:

This step involves testing the accuracy of the grey prediction model for accidents in stadiums. The accuracy of a model reflects the veracity and practicability of model prediction. After selecting an appropriate model, the selected model must be tested to determine if it is reasonable. Only models that have passed the test can be utilized for prediction. Three methods can be utilized to test the prediction accuracy of a grey model. These methods are relative error test method, after-test residue checking, and relevancy test method.

1) Relative error test method, a visual means of arithmetic checking that implements a comparison point by point, compares the predicted results with the results of practical data. In other words, the results obtained by the ratio of the absolute value of two values' difference to the result of practical data are relative errors. The method then compares whether the relative error satisfies practical requirements or not.

2) After-test residue checking has a statistical scope and is implemented according to the probability distribution of residual errors. The smaller the specific value of the after-test difference is, the better the situation is. A small ratio of after-test difference implies that the difference between the predicted value obtained by a prediction model and the practical value is not too disperse, such that practical situations are satisfied although the original data are rather disperse.

3) Relevancy test is a geometric test method that explores the similarities between curves for the predicted values of a model and curves related to the practical values used by modeling. In relevancy test method, the relevancy coefficient value of the predicted value sequence of the model must be compared with that of the practical data sequence at each point. Thus, the grey correlation degree (i.e., the degree to which the model's predicted value sequence is correlated to the actual numerical value sequence) must be measured. The larger the correlation degree is, the better the prediction effect of the model is.

The most common relative error test method was adopted in this study.

TABLE 2 Prediction accuracy of the grey prediction model for accidents in stadiums

Year	Actual data	Predicted data	Relative error
2010	52.8613	55.7158	5.4%
2011	45.0112	47.8019	6.2%
2012	38.7271	41.0120	5.9%

Table 2 shows that the number of accidents in stadiums in 2010, 2011, and 2012 is 55.7158, 47.8019, and 41.0120, respectively. These values approach the actual data. The errors between the predicted values and actual data are small; all of them are between 6.2% and 5%, which is in accordance with the accuracy that the prediction needs to obtain (within 10%). The long-term predicted values of the model change smoothly. This result is consistent with practical situations and proves that the grey model GM(1,1) constructed in this study is suitable for the prediction of accidents in stadiums. The computing speed of the model is high, and the model has a potential practical application.

4.2 GM(1,1) MODEL FOR DEATH TOLLS IN ACCIDENTS IN STADIUMS IN CHINA

Equation (1) describes the GM(1,1) model for the number of accidents in stadiums in China. The experimental results show the effectiveness and rationality of the GM(1,1) model. We utilized the same modeling method to construct a GM(1,1) model for death tolls in accidents in stadiums in China.

TABLE 3 Statistical of death tolls in accidents in stadiums in China from 2002 to 2009

Year	2002	2003	2004	2005	2006	2007	2008	2009
Death toll	150	147	144	149	164	163	151	137

In accordance with the steps by which the grey model for the number of accidents in stadiums in China was constructed, we can establish a GM(1,1) model for death tolls in accidents in stadiums in China.

Statistical data on death tolls in accidents in stadiums in China from 2002 to 2009 were utilized to construct a GM(1,1) model. The obtained model equation is as follows: $x^{(0)}(k) + 0.00052183z^{(1)}(k) = 1512.302423$.

The obtained prediction model is solved as

$$\hat{x}^{(0)}(k+1) = 1512.302423e^{-0.00052183k}.$$

TABLE 4 Prediction accuracy of the greedy prediction model for death tolls in accidents in stadiums

Year	Actual data (number of people)	Predicted data (number of people)	Relative error
2010	131	140.2456	6.7%
2011	128	135.7385	5.8%
2012	124	131.4354	6.2%

Table 4 shows that the number of people who died in accidents in stadiums in 2010, 2011, and 2012 is 140.2456, 135.7385, and 131.4354, respectively. These values are close to the actual data. The errors between predicted and actual data are small; all of them are within the range of 6.7% to 5.8% and meet the accuracy that the prediction needs to satisfy (within 10%). The long-term predicted values of the model change smoothly. This result is consistent with practical situations and proves that the grey model GM(1,1) constructed in this study is suitable for the prediction of death tolls in stadiums.

The predicted results of the GM(1,1) models for the number of accidents in stadiums in China and for death tolls in accidents in stadiums in China reveal the robustness of the GM(1,1) model in the process by which the prediction model was established. Thus, the prediction model can be applied to emergency decisions on accidents in other public sites (such as large shopping malls and amusement parks).

5 Conclusion

The frequent occurrence of emergencies has caused huge economic losses and serious social problems for China in recent years. Public security cannot be ignored. Stadiums as special public sites have a high population density and large mobility. When threatening public incidents such as fire, group congestion and trampling, and terrorist attacks occur, huge casualties and losses in economic properties are generated easily. Thus, studying emergency decisions on accidents in stadiums is highly necessary. Predicting accidents that may or will occur poses a problem; purposeful emergency measures to evacuate people in time and deal with accidents must be undertaken. Targeting the complicated randomness and grayness of accidents, this study adopted grey theory for modeling and established the data law by analyzing and studying statistical data on accidents in stadiums in China. The grey model GM(1.1) was utilized to predict accidents in stadiums in China. A GM(1,1) model for the number of accidents in stadiums in China and a GM(1,1) model for death tolls in accidents in stadiums in China were established. The experimental results show that the relative errors of the two established models are within 7%. The models have good stability in terms of long-term prediction, and their computing speed is high. The obtained prediction models have a potential for practical application and provide a reliable theoretical basis for emergency decisions on accidents in stadiums.

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