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Grey Modeling Method for Predicting the Occurrence and Epidemic Time of Major Human Diseases

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Abstract: The occurrence of a major epidemic is a catastrophic event that may occur at any time in the development of human society. It is uncertain and unavoidable. If human beings can predict the occurrence and epidemic time of major diseases, people will take the initiative in the prevention and control of major diseases, make response plans in advance, calmly face the sudden occurrence of major epidemics, so as to reduce the run on medical resources and short-term shortage, reduce the death of patients, maintain social peace, and maintain the stable development of economy and society. The grey system theory, which was founded by Chinese scholar Deng Julong in the 1980s, is a new method to study the few data, poor information and uncertain events. The purpose: to introduce the grey theory into the prediction of the occurrence and epidemic time of major epidemics, and to find a new scientific, simple and fast method to predict the occurrence and epidemic time of major epidemics. Research methods: Using the time of occurrence and epidemic of major epidemics in China recorded in the Chinese Plague Chronicles and other books in history, the occurrence and epidemic time numbers of major epidemics (plagues) were extracted from the three periods A, B and C, and the original data sequence was formed through sequential arrangement. Then, grey modeling is carried out with the modeling steps of GM(1,1) and the error and accuracy of the model are checked. Research results: The occurrence and epidemic times of major epidemics in periods A, B and C were selected, and the GM(1.1) grey modeling was carried out on the obtained data in the order of year number, and the corresponding grey prediction models of periods A, B and C were obtained respectively: $\widehat{M}_A^{(1)}(\mathrm{K}+1)$; $\widehat{M}_B^{(1)}(\mathrm{K}+1)$ and $\widehat{M}_C^{(1)}(\mathrm{K}+1)$ (see the text for details of the models), the simulation errors of the three models were tested, and the relevant parameters all reached the level of first-class qualified models, and the simulation accuracy was 99.80%, 99.93% and 99.98%, respectively, reaching the qualified level. The prediction and verification of the occurrence and epidemic time of the n+1 major epidemic in the period of A and B were carried out respectively, and the accuracy rate reached 99.88% and 99.91%, both of which achieved satisfactory results.

Keywords: Major Human Epidemic, Occurrence and Epidemic, Greytheory, Modeling, Prediction, Method

1. Introduction

The epidemic of human major infectious diseases refers to the outbreak or epidemic of infectious diseases in a certain region. The occurrence of a major epidemic is uncertain and unavoidable in the development process of human society, and it is a catastrophic event that may occur at any time in the development process of human society [1]. Most major human epidemics are infectious diseases, which can spread rapidly in a short period of time, with a large number of infected people and patients, sometimes resulting in a large number of patients and even a high mortality rate. For example, as of December 31, 2023 Beijing time, the total number of confirmed COVID-19 cases in the world has reached 83720315 and the total number of deaths has reached 1823584 [2]. If human beings can predict the occurrence time of major epidemics, people will grasp the initiative of prevention and control of major epidemics, make response plans in advance, and calmly face the sudden occurrence of major epidemics, so as to reduce the run on medical resources and temporary shortage, reduce the death of patients, maintain social peace, and maintain the stable development of economy and society [3]. Grey system theory, which was founded by Chinese scholar Deng Julong in 1980s, is a new method to study the uncertainty of information with few data and poor information [4]. Grey modeling forecasting method is widely used in industry, agriculture, economic and social planning analysis, hydrology, geology, breeding and natural disaster forecasting and so on [5]. Grey modeling prediction is mainly through the generation and development of "part" of known information, extracting valuable information to achieve the correct description and effective monitoring of system operation behavior and evolution law [6]. Using available data materials, the author studied the grey modeling prediction method for major epidemic outbreaks and epidemic occurrence time, and the results are reported below.

2. Material Sources and Methods

2.1. Source of Materials

Chinese literati have always had the cultural tradition of "Record for history, history into a book, to teach future generations". [7] In 1940, Chen Gaoyong published a «List of Natural and Man-made Disasters in China», in the Past Dynasties of China, which sorted out a Chinese plague chronicle from ancient works such as the «Guide to Capital Management» and «Collection of ancient and modern books» Hundreds of major outbreaks (then called plagues) were recorded in the books. [8] This study is based on the years of major epidemics recorded in Chinese plague Chronicles and other books and periodicals to dig out the basic data for the study.

2.2. Extraction and Sorting of Data

In order to find the reliability of grey modeling in predicting the occurrence time of major epidemics and facilitate decision-making, we extracted the occurrence time of major epidemics and epidemics in three periods as the basic data of modeling. These three time periods are the period from 1760 to 1795, called time period A; The period from 1855 to 1895 is called time period B; The period from 1980 to 2020 is called Schedule C. In each time period, five grey modeling basic data (time number) were extracted from successive year numbers for the moment of major epidemic occurrence and epidemic (year number), which are now sorted out and shown in Table 1.

Table 1. *Chronology of major epidemic occurrence time in different time periods.*

Time segment	Time period of major outbreaks				
A	1760	1767	1770	1775	1783
B	1855	1861	1866	1867	1869
C	1981	1988	1999	2003	2020

2.3. Research Methods

First, the GM(1,1) gray prediction model is established according to the original data, and then the simulation error of the built model is analyzed [9] to determine the simulation accuracy of the model. Finally, the actual prediction is verified according to the qualification level of the model [10].

3. Model Establishment and Error Analysis

In order not only to simplify the calculation, but also to introduce the mathematical methods in the process of gray modeling in detail, this study only introduced the gray modeling process and parameter calculation of major epidemic occurrence and epidemic moment in time period A in detail, and the prediction model of the rest time period was given by analogy.

3.1. Establishment of GM(1,1) Prediction Model Process

The original sequence was obtained according to the occurrence time of major epidemics in period A in Table 1. $M_A^{(0)}$= [1760 1767 1770 1775 1783]; The series $M_A^{(1)}$= [1760 3527 5297 7072 8855] is obtained by summing the original series. Then, the $M_A^{(1)}$ sequence is generated by the adjacent mean value, and the sequence $Z_A^{(1)}$= [1760 2643.5 4412 6184.5 7963.5] is obtained. The basic type of the grey GM(1,1) model is $MA^{(0)}(K)+a_A Z_A^{(1)}(k)=b_A$ (k=1, 2, 3... n. In this article, n = 5), $\hat{a} = [a_A, b_A]^T$ column for a parameter, and $M_A^{(0)}(K) + a_A Z_A^{(1)}(K) = b_A$ least squares estimates of parameters of meet baty $\hat{a} = (B_A^T B_A)^{-1}$. $B_A^T y$ Among them:

$$B_A{}^T = \begin{bmatrix} -2643.5 & -4412 & -6184.5 & -7963.5 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

$$Y = \begin{bmatrix} 1767 \\ 1770 \\ 1775 \\ 1783 \end{bmatrix}$$

B_A^T is the transpose of B_A. Through calculation, $\hat{a} = [a_A, b_A]^T$= [-0.00300056,1757.901975,] is a_A=-0.00300056, b_A=1757.90917. By substituting the parameters intothe time response function, the grey prediction model of the occurrence or epidemic time of the major epidemic outbreak or epidemic in the period A is obtained, and the grey prediction model of the occurrence and epidemic time of the n+1 major epidemic in the period A:

$$\begin{cases} \widehat{M}_A^{(1)}(K+1) = 587617.96e^{0.00300056k} - 585857.96 \\ \widehat{M}_A^{(0)}(K+1) = \widehat{M}_A^{(1)}(K+1) - \widehat{M}_A^{(1)}(K) \end{cases}$$

In the same way, the gray prediction model of major epidemic outbreak or epidemic moment in period B is obtained, and the gray prediction model of the occurrence and epidemic of the n+1 major epidemic in paragraph B is obtained:

$$\begin{cases} \widehat{M}_B^{(1)}(K+1) = 1231683.584e^{0.001511k} - 1229828.584 \\ \widehat{M}_B^{(0)}(K+1) = \widehat{M}_B^{(1)}(K+1) - \widehat{M}_B^{(1)}(K) \end{cases}$$

And by the same token, The grey prediction model of major epidemic outbreak or epidemic moment in period C is obtained, and the grey prediction model of the occurrence and epidemic of the n+1 major epidemic in paragraph C is obtained:

$$\begin{cases}\widehat{M}_C^{(1)}(\mathrm{K}+1) = 378462.896e^{0.0052397\mathrm{k}} - 376481.896 \\ \widehat{M}_C^{(0)}(\mathrm{K}+1) = \widehat{M}_C^{(1)}(\mathrm{K}+1) - \widehat{M}_C^{(1)}(\mathrm{K})\end{cases}$$

3.2. Model Accuracy Analysis

In the study, we applied the obtained data and the gray prediction model to calculate the relative errors s_1 and s_2 of the original data and the simulated data of the prediction model in the above three periods, and obtained the relative errors and C value ($C=s_2/s_1$), [11] and compared the calculated values with the critical value of the first-level qualified model. Details are shown in Table 2:

Table 2. *Error and precision parameters of grey model of major epidemic.*

Time period model	Relative error pattern	Original series varianceS_1	Residual variance S_2	Value C
First-order model critical value	0.01			0.35
A period	0.00199	7.589	2.555	0.3367
B period	0.00071	5.054	0,572	0.1132
C period	0.00194	763.11	1.577	0.0021

It may be known from Table 2 that the relative errors of the grey prediction model established at the time of major epidemic occurrence in the three periods A, B and C are 0.00199, 0.00071 and 0.00019 respectively, and the c value is respectively 0.3367, 0.1132, and 0.0021 are all less than the critical value of 0.35 for the first-level qualified model. Therefore, all the grey models established in this study are first-class qualified models, which meet the modeling requirements. The simulation accuracy of the grey prediction models established in each period of A, B and C is 99.80%, 99.93% and 99.98%, respectively, reaching the qualified level.

3.3. Model Verification

In the study, in order to verify the accuracy of the prediction of the n+1 major epidemic outbreak and epidemic occurrence time in each time period, we predicted the n+1 major epidemic outbreak and epidemic occurrence time in the past period, time period A and time period B. Using the prediction model for period A:

$$\begin{cases}\widehat{M}_A^{(1)}(\mathrm{K}+1) = 587617.96e^{0.00300056\mathrm{k}} - 585857.96 \\ \widehat{M}_A^{(0)}(\mathrm{K}+1) = \widehat{M}_A^{(1)}(\mathrm{K}+1) - \widehat{M}_A^{(1)}(\mathrm{K})\end{cases}$$

The occurrence time of the n+1 major epidemic outbreak and epidemic in period A was predicted. The predicted occurrence time was 1787.17 years, and the actual occurrence time in history was 1785 years, which was 2.17 years earlier than the predicted time. The prediction error was 0.00121, and the accuracy rate of the forecast was 99.88%. Satisfactory results have been achieved.

Using the prediction model for period B:

$$\begin{cases}\widehat{M}_B^{(1)}(\mathrm{K}+1) = 1231683.584e^{0.001511\mathrm{k}} - 1229828.584 \\ \widehat{M}_B^{(0)}(\mathrm{K}+1) = \widehat{M}_B^{(1)}(\mathrm{K}+1) - \widehat{M}_B^{(1)}(\mathrm{K})\end{cases}$$

The occurrence and epidemic time of the n+1 major epidemic outbreak in period B were predicted, and the predicted occurrence time was 1873.77. According to records, in 1872, the plague was circulating in Hubei, Hebei, Shaanxi and Zhejiang provinces of China, and it had been prevalent for 4 years. This time is 1.7 years earlier than the forecast time, the forecast error is 0.00095, and the forecast accuracy is 99.91 percent, which is satisfactory.

4. Discussion

The data used in this paper are collected from many ancient Chinese classics, and the verification of the data has certain limitations. The grey modeling method is a method to solve the problem of little data and poor information. [12] The application of grey modeling forecasting in practical work has less original data, easy computation and simple method, which is conducive to the development of forecasting work. The model established by this method has low error, high accuracy of simulation and prediction, and achieves satisfactory results. When using the grey model for prediction, [13] the model established with the latest information should be used for prediction, so as to improve the accuracy of prediction and prediction. The grey GM (1,1) model established this time only conducted the prediction and verification of the occurrence and epidemic time of the n+1 major epidemic outbreak in each time period. No extended prediction verification was made for subsequent likely occurrences.

5. Conclusion

5.1. Model Built

In this study, guided by the grey modeling theory, the author made use of the chronology of major epidemics (plagues) and epidemics in the history of China, which were divided into three periods, A, B and C, and selected the major epidemics and epidemic moments in order of time number as the original data sequence [14]. GM(1.1) grey modeling was carried out on the obtained data, and the GM(1,1) grey prediction model of major epidemic occurrence and epidemic in period A was successfully obtained:

$$\begin{cases}\widehat{M}_A^{(1)}(\mathrm{K}+1) = 587617.96e^{0.00300056\mathrm{k}} - 585857.96 \\ \widehat{M}_A^{(0)}(\mathrm{K}+1) = \widehat{M}_A^{(1)}(\mathrm{K}+1) - \widehat{M}_A^{(1)}(\mathrm{K})\ \mathrm{GM}(1,1)\end{cases}$$

grey prediction model for occurrence and prevalence of major epidemic in period B;

$$\begin{cases}\widehat{M}_B^{(1)}(\mathrm{K}+1) = 1231683.584e^{0.001511\mathrm{k}} - 1229828.584 \\ \widehat{M}_B^{(0)}(\mathrm{K}+1) = \widehat{M}_B^{(1)}(\mathrm{K}+1) - \widehat{M}_B^{(1)}(\mathrm{K})\end{cases}$$

and the GM(1,1) greyprediction model for the occurrence and prevalence of major epidemics in the c period;

$$\begin{cases}\widehat{M}_C^{(1)}(\mathrm{K}+1) = 378462.896e^{0.0052397\mathrm{k}} - 376481.896 \\ \widehat{M}_C^{(0)}(\mathrm{K}+1) = \widehat{M}_C^{(1)}(\mathrm{K}+1) - \widehat{M}_C^{(1)}(\mathrm{K})\end{cases}$$

5.2. Model Grade and Accuracy

The simulation error detection of the three models above is carried out, and the relevant parameters reach the level of first-level qualified models, and the simulation accuracy is 99.80%, 99.93% and 99.98%, respectively, reaching the qualified level. The accuracy of predicting the occurrence and prevalence of n+1 major epidemic in A period and B period reached 99.88% and 99.91% respectively [15], and both achieved satisfactory results.

5.3. Modeling Methods and Steps

First of all, the original data is extracted and sorted to obtain real and reliable establishment data, and then the model is modeled according to the steps of establishing GM (1,1) gray model. After modeling, the error and accuracy of the model are tested to determine whether the model meets the requirements. Finally, the model is used for prediction and actual verification.

5.4. Evaluation of the Built Model

It is of practical significance to verify the method of establishing grey model in this study. Simulation error detection was carried out on the above three models, and the relevant parameters reached the level of first-level qualified models, and the simulation accuracy was 99.80%, 99.93% and 99.98%, respectively, reaching the qualified level. The accuracy of predicting the occurrence and prevalence of n+1 major epidemic in A period and B period reached 99.88% and 99.91% respectively, and both achieved satisfactory results.

Abbreviations

There is no content here.

Conflicts of Interest

The authors used research data from publicly published, freely available books, journal and online articles, The authors declare no conflicts of interest.

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Biography

Li Ming Quan, male, was born in 1957 with a postgraduate degree in economics, senior animal husbandry division. Long - term engaged in agricultural and animal husbandry economic research work.