# Application of Improved GM(1, 1) Model in Predicting Nutritional Status of Youth Athletes from She Minority Group

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**Abstract**

GM(1, 1) is a gray dynamic prediction model that is applied most extensively in gray system theory. Nutrition is an important issue in the healthy development of youth athletes. In this study, we take youth athletes from the She minority group as an example and predict their nutritional status based on the improved GM(1, 1) model to better determine and effectively improve the nutritional status of these athletes. Based on a nutrition survey of youth athletes from the She minority group, gray system theory and relevant research on GM(1, 1) model are used to conduct data analysis of the nutritional disease detection rate of youth athletes from the She minority group in the past five years as well as construct a comprehensive and scientific prediction system. Moreover, we conduct instance analysis of their nutritional status using the GM(1, 1) model and obtain analysis results and the corresponding prediction conclusions.

*Keywords*: gray system theory, GM(1, 1) model, youth athletes, nutrition

## 1 Introduction

GM(1, 1) model is a gray dynamic prediction model, which is applied most extensively in gray system theory [1]. This model is composed of a univariate first-order differential equation. This model is mainly used to fit and predict the eigenvalue of a leading factor in a complex system to reveal change rules of the leading factor and future development and change trends. Although the fitting or prediction effect of this model can provide good results, sometimes it exhibits significant deviations or is even ineffective in practice [2]. Thus, this model needs significant improvement. Mathematical principles are used to optimize distinct effects caused by modeling defects. Improvement can be achieved in two aspects, namely, (1) using the least squares method on the original data to add smoothness and (2) employing the differential equation to improve the approximation degree of the fit system and the system to be fitted with the GM(1, 1) equation [3]. The improved GM(1, 1) model has a more extensive application potential and development prospect.

Currently, the GM(1, 1) model has been studied and analyzed by numerous scholars. Researchers mainly concentrate on four aspects [4]. (1) Most researchers briefly introduce the GM(1, 1) model and elucidate its development history, model theories, significance, and functions. (2) Domestic and foreign academic circles have proven that this model has significant effects on the development of science and technology [5]. The applications of this model mainly cover agriculture, industry, energy, petroleum, geography, hydrology, zoology, medicine, military, and economy. The GM(1, 1) model has successfully solved a large number of practical problems in production and scientific research. (3) The SERVQUAL scale is modified under the network environment based on the characteristics of network service [6]. (4) Significant improvements have been made for the GM(1, 1) model, such as Euler improvement method, precision index fitting method, GM(1, 1) numerical fitting, and improvement of boundary conditions, to enhance its applicability and accuracy [7]. Although domestic and overseas scholars have obtained significant results, a comprehensive and accurate prediction system has not been established and application fields are not extended to the largest extent. Therefore, this model needs further optimization and study.

With rapid economic development, people start to focus on sports and the physical quality of athletes (especially youth athletes). Their nutritional status has significant value [8]. The minority group is a shifting cultivation nation and one of the minorities with a small population, of which most are farmers. Many young people face malnutrition, which has a direct bearing on their future growth and development. In this study, we survey youth athletes from the She minority group, determine their nutritional status, and conduct prediction research [9]. The precision and fitting degree aspects of the GM(1, 1) model are improved. Moreover, the application of the GM(1, 1) model is extended to nutritional status prediction to construct an improved prediction model [10]. In addition, example verification and analysis are conducted to contribute to the prediction of the nutritional status of youth athletes from the She minority group [11]. This study provides a reference value and theoretical support for model improvement.

## 2 Overview of GM(1, 1) model

### 2.1 BASIC CONCEPT OF GRAY MODELLING

Gray system theory is aimed at systems with incomplete

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information. The basic modeling principle of gray system theory is to set up an abstract model through qualitative and quantitative analysis, gradually make the model more specific from abstraction, and finally develop an optimized model. Gray system theory considers the initial data series containing a large amount of information and traces all other variables in the dynamic process of the system. In the modeling process, gray system theory fully develops and utilizes explicit and implicit information from the initial data series.

### 2.2 GM(1, 1) MODEL

GM(n, h) model is a general GM model established using the n-order differential equation for h variables. In the GM(n, h) model, when h ≥ 2, the GM model cannot be used for prediction, but can be only used to analyze mutual relationships among factors. The GM model used for prediction is generally GM(n, 1). The GM(1, 1) model is the most important and most frequently used model in practice.

The winterization model of GM(1, 1) is:

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

This formula is a differential equation used to determine the development trend. The obtained value represents different development trends. If the value of $a$ is negative, then an increasing trend is observed. If the absolute value of $a$ is larger, then the growth rate is faster. If the value of $a$ is positive, a decreasing trend is observed. If the absolute value of $a$ is larger, then the reduction speed is faster. $\mu$ denotes gray action. The size of $\mu$ represents data changes. When $\mu$ changes, the behavior mode also changes. $\mu$ plays a role as an action in the system and has a gray property. Thus, $\mu$ is called gray action. $\mu$ is a specific expression of system connotation and a key quantity to distinguish gray modeling and general modeling.

If we assume that $X^{(0)}(k)$ is a nonnegative sequence number, then

$$X^{(0)}(k)=\left\{X^{(0)}(1),X^{(0)}(2),\cdots,X^{(0)}(n)\right\} \quad (2)$$

Using the least squares method and reduction treatment of the initial data series, we obtain the following equation:

$$\hat{x}^{(0)}(k)=\left(1-e^{a}\right)\left(x^{(0)}(1)-\frac{u}{a}\right)e^{-a(k-1)} \quad (3)$$

We substitute k = 2, 3, …, n into the previously presented formula and obtain the fitted value of the initial data series. When k > n, the predicted value of the gray model can be obtained.

## 3 Establishment of improved GM(1, 1) model

### 3.1 PRINCIPLES OF IMPROVED GM(1, 1) MODEL

If we assume the original sequence number

$$X^{(0)}(k)=\left\{X^{(0)}(1),X^{(0)}(2),\cdots,X^{(0)}(n)\right\} \quad (4)$$

Then we can calculate Formula (1) and obtain the following equation:

$$X^{(1)}(t)=\left\{X^{(1)}(1),X^{(1)}(2),\cdots,X^{(1)}(n)\right\} \quad (5)$$

where $x^{(1)}(t)=\sum_{i=1}^{t}x^{(0)}(i) \quad (t=1,2,\cdots,n)$, if $Z^{(1)}(t)$ is the adjacent mean value generation sequence of $X^{(1)}(t)$, then

$$Z^{(1)}(t)=\left\{Z^{(1)}(2),Z^{(1)}(3),\cdots,Z^{(1)}(n)\right\} \quad (6)$$

*Definition 1*: $x^{(0)}(k)+az^{(1)}(k)=b$ is called the gray differential equation and GM(1, 1) model. The winterization equation is (1).

*Theorem 1*: $X^{(1)}(t)$ is a nonnegative quasi-smooth sequence and an accumulation generation sequence. $Z^{(1)}(t)$ is an adjacent mean value generation sequence. $\hat{a}=[a,b]^T$ is a parameter, and

$$Y_n=\begin{bmatrix}x^{(0)}(2)\\x^{(0)}(3)\\\vdots\\x^{(0)}(n)\end{bmatrix},\quad B=\begin{bmatrix}-z^{(1)}(2)&1\\-z^{(1)}(3)&1\\\vdots&\\-z^{(1)}(n)&1\end{bmatrix} \quad (7)$$

The least squares estimation parameter of the gray differential equation satisfies the following equation:

$$\hat{a}=\left(B^TB\right)^{-1}B^TY_n \quad (8)$$

*Theorem 2*: If we assume that $B, Y_n,$ and $\hat{a}$ are conditions described in Theorem 1, then the time response function of the winterization equation can be expressed as follows:

$$x^{(1)}(t)=\frac{b}{a}+ce^{-at}, \quad (9)$$

where $c=\sum_{i=1}^{n}x^{(0)}(i)e^{-ai}\Big/\sum_{i=1}^{n}e^{-ai}\left(1-e^{a}\right)$.

The time response function of the gray differential equation is expressed as follows:

$$\hat{x}^{(1)}(k)=u/a+ce^{-ak} \quad (k=1,2,\cdots,n) \quad (10)$$

The reducing value is obtained using the following equation:

$$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k) \quad (11)$$

### 3.2 PRECISION MEASUREMENT OF IMPROVED GM(1, 1) MODEL

The precision of the prediction result of the gray modeling method depends on the smoothness of the initial data series. When the traditional GM(1, 1) model is used for fitting, the error is large. Thus, the key to expanding the application scope of gray prediction and improving its precision lies in enhancing the smoothness of the initial data series. Generally, three methods are used to test the gray GM(1, 1) model, namely, residual, relevancy, and posterior error. In this study, we adopt residual examination. Standard examination is conducted for the error sum of squares and/or the average relative error.

If we assume that the residual is $e(k)=x^{(0)}(k)-\hat{x}^{(0)}(k)$ and the relative error is:

$$\varepsilon(k)=\left[e(k)/x^{(0)}(k)\right]\times 100\% \quad (k=1,2,\cdots,n),$$

then the error sum of squares of the model is expressed as follows:

$$d=\sum_{k=1}^{n}e(k)^2 \quad (k=1,2,\cdots,n) \tag{12}$$

The relative error of the mean value is expressed as follows:

$$\bar{\varepsilon}=\frac{1}{n}\sum_{k=1}^{n}\left|\varepsilon(k)\right| \tag{13}$$

If the error sum of squares and relative error of the mean value are small, then the prediction is more accurate. During the evaluation of the effectiveness of the GM(1, 1) model, a general reference precision test table is finally obtained, as shown in Table 1.

TABLE 1 Prediction precision grade reference table of gray model (%)

| Test index | Relative error |
|---|---|
| Good | <0.01 |
| Qualified | <0.05 |
| Barely qualified | <0.25 |
| Unqualified | ≥0.25 |

## 4 Application of improved GM(1, 1) model in predicting nutritional status of youth athletes from She minority group

### 4.1 NUTRITION SURVEY OF YOUTH ATHLETES FROM SHE MINORITY GROUP

Representative urban and rural youth athletes from the She minority group aged 11 to 18 years were selected, including 60 male and 58 female athletes. Meanwhile, youth athletes from the Han nationality in the same area were selected as the control group. The age composition, health conditions, and urban–rural proportion of the Han nationality and She minority group were determined.

Based on relevant rules formulated by the health sector in China, the "height and standard body weight of students at the age of 7 to 22" were used as statistics of the nutritional status of the two groups of youth athletes (see Table 2).

TABLE 2 Height and standard body weight magnitude of youths

| Height and standard body weight magnitude | Nutritional status |
|---|---|
| >120% | Obesity |
| 110%–120% | Overweight |
| 90%–110% | Normal |
| 80%–90% | Light malnutrition |
| 70%–80% | Moderate malnutrition |
| <70% | Severe malnutrition |

Based on the data, the nutritional status of youth athletes from the She minority group and Han nationality are shown and compared in Tables 3, 4, and 5.

TABLE 3 Comparison of nutritional status of youth athletes from She minority group and Han nationality

| Nation | Light malnutrition rate (%) | Moderate malnutrition rate (%) | Overweight rate (%) | Obesity rate (%) |
|---|---|---|---|---|
| She minority | 31.38 | 4.98 | 3.09 | 1.68 |
| Han nationality | 10.51 | 12.38 | 23.69 | 5.38 |

TABLE 4 Comparison of nutritional status of male and female youth athletes from She minority group

| Gender | Malnutrition rate (%) | Overweight rate (%) | Obesity rate (%) |
|---|---|---|---|
| Male | 34.85 | 2.18 | 2.07 |
| Female | 37.88 | 4.02 | 1.27 |

TABLE 5 Comparison of nutritional status of youth athletes from She minority group in urban and rural areas

| Area | Malnutrition rate (%) | Overnutrition rate (%) |
|---|---|---|
| Urban area | 32.62 | 6.33 |
| Rural area | 42.92 | 2.02 |

Tables 3, 4, and 5 show that the She minority group has more malnourished youth athletes and fewer overweight and obese youth athletes than the Han nationality. The She minority group has more malnourished male youth athletes than female youth athletes and more overweight female youth athletes than male youth athletes. In the comparison of urban and rural youth athletes, rural youth athletes are more malnourished than their urban counterparts. Generally, the She minority group has more malnourished and more overnourished youth athletes than the Han nationality, which may have resulted from different dietary habits of different nationalities. The She minority group mostly lives in rural areas and mostly eats vegetables. They seldom eat meat and fish. In general, the nutrition awareness of families in underdeveloped rural areas is weak. Moreover, male and female youth athletes from the She minority group show no significant differences, which may be related to ethnic characteristics. Members of the She minority group are lively, fond of sports, and good at singing and dancing. Moreover, their poor dietary habits are few. Members of this minority group focus more attention on natural growth and almost have no diet control habit.

### 4.2 PREDICTION OF NUTRITIONAL STATUS OF YOUTH ATHLETES FROM SHE MINORITY GROUP

Based on the survey and analysis, a major problem faced by youth athletes from the She minority group is malnutrition. In this study, we take rural youth athletes from the She minority group from 2009 to 2013 as the example and conduct analysis and prediction in accordance with the improved GM(1, 1) model and nutritional disease detection rate (see Table 6).

TABLE 6 Nutritional disease detection rate of rural youth athletes from She minority group (%)

| Nutritional status | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|
| Serious malnutrition | 20.45 | 16.96 | 14.66 | 11.66 | 9.33 |

Based on the modeling principle of gray system theory, the original data series and one-off accumulation generation sequence are expressed as follows:

$$x^{(0)}(t) = \{20.45, 16.96, 14.66, 11.66, 9.33\}$$

$$x^{(1)}(t) = \{20.45, 37.41, 52.07, 63.73, 73.06\}$$

Then, smoothness detection is conducted for the original data series. The smoothness of the original data series complies with the requirements. Based on the correlation theorem, $x^{(1)}(t)$ (one-off accumulation generation sequence) also complies with the quasi-index rules. a = −0.02349 and b = 16.23454 are obtained using the MATLAB software. These values are substituted into the GM(1, 1) model and improved GM(1, 1) model, respectively. Then, the simulation results are obtained, as shown in Table 7. The average relative error and error sum of squares of the two models are shown in Table 8.

TABLE 7 Comparative analysis of fitted value and actual value of models

| One-off accumulation generation sequence | GM(1, 1) model | | Improved GM(1, 1) model | |
|---|---|---|---|---|
| | Fitted value | Relative error (%) | Fitted value | Relative error (%) |
| 20.45 | 20.4500 | 0.0000 | 20.4500 | 0.0000 |
| 37.41 | 37.3375 | 0.1938 | 37.4010 | 0.0241 |
| 52.07 | 52.0520 | 0.0346 | 52.0629 | 0.0136 |
| 63.73 | 63.6329 | 0.1524 | 63.6500 | 0.1255 |
| 73.06 | 72.5891 | 0.6445 | 72.8812 | 0.2447 |

TABLE 8 Statistics of average relative error and error sum of squares of models

| Model | Detection standard | |
|---|---|---|
| | Average relative error (%) | Error sum of squares (%) |
| GM(1, 1) model | 0.2051 | 0.0534 |
| Improved GM(1, 1) model | 0.0816 | 0.0085 |

Based on Tables 7 and 8, the traditional GM(1, 1) model and improved GM(1, 1) model comply with the precision requirements. The improved GM(1, 1) model has higher precision than the traditional GM(1, 1) model. Furthermore, the average relative error (0.0816%) and error sum of squares (0.0085%) of the improved GM(1, 1) model are significantly less than the average relative error (0.2051%) and error sum of squares (0.0534%) of the traditional GM(1, 1) model because the improved GM(1, 1) model utilizes the original data to the largest extent. Moreover, the background value and original data are optimized. Therefore, the error sum of squares of the predicted and original values can satisfy the minimum constraint requirement. The model has better simulation and prediction effects.

The improved GM(1, 1) model is used to further detect the nutritional disease detection rate of youth athletes from the She minority group. Effective prediction of the nutritional status of rural youth athletes from the She minority group for 2014–2018 is conducted, and the results are presented in Table 9.

TABLE 9 Predicted value of serious malnutrition disease detection rate of rural youth athletes from She minority group

| Nutritional status | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|
| Serious malnutrition | 8.33 | 7.98 | 5.35 | 4.95 | 3.78 |

Table 9 shows that the malnutrition disease detection rate of rural youth athletes from the She minority group are expected to improve in the future. Urban malnutrition is likely to further narrow in relation to rapid economic development and improved living standards in rural areas in China. As material living standards improve, people focus increased attention on nutrition. However, the current situation is not optimistic. We have to monitor the nutritional status of youth athletes of national minorities represented by the She minority group. The youth is the hope of a country, and a healthy body is the foundation. Thus, special attention should focus on the nutritional status of Chinese youth athletes. Meanwhile, considering the importance of the overnutrition problem is also necessary. Although this problem is not yet prominent, as material conditions become increasingly high, the obesity problem caused by overnutrition may gradually emerge. In summary, effectively controlling the obesity problem and detecting the dual effect of nutrition are required to solve malnutrition.

## 5 Conclusions

In this study, we apply the improved GM(1, 1) model in predicting the nutritional status of youth athletes from the She minority group and conduct contrastive analysis of the improved GM(1, 1) model and traditional GM(1, 1) model. Based on the empirical comparison, the feasibility and practicability of the improved GM(1, 1) model are high, and prediction is more accurate. In the prediction process, the improved GM(1, 1) model comprehensively considers various factors and therefore complies with the actual conditions. The analysis and prediction in this study provides, to a certain extent, references for further studying the GM(1, 1) model.

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