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Building Waste Output Forecasting Model based on Gray Metabolism GM (1,1)

Yabo He[1], Wang Hongtao[2], Yang Lin[3] and Qin Wei[4]

(1,2,3 ,4School of Civil Engineering, Wuhan University, Wuhan, China,430072)

Abstract

With the increase of construction investment and urbanization, building waste output in our country is huge. This paper first constructs a set based on the construction area and per unit area of garbage generated quantity of urban building waste estimation method, then using grey system theory prediction and analysis of the next four years of building waste output. By the introduction of metabolic thought, the grey metabolic GM (1,1) forecast model was constructed, overcoming the shortages of conventional GM (1, 1) model. Prediction results show that the model is higher than the conventional GM (1,1) model prediction accuracy, which is suitable for the prediction of the short term of building waste in our country and for the treatment and reuse of building waste to provide certain reference.

Keywords*: Grey system theory;building waste; GM (1, 1) model;* metabolism

1. Introduction

With the rapid development of social economy and the continuous improvement of people's cognition, the concept of building waste has been improved and perfected. Building waste refers to construction units, the construction unit of the new, alteration, expansion and removing all kinds of buildings, building materials, pipe network and residents decoration housing in the process of muck, abandoned material and other waste collectively. With the pace of urbanization, building waste in the proportion of urban waste increased continuously. According to statistics, the total domestic building waste has reached 7 billion tons of total, and an increase of about 300 million tons a year of. According to incomplete estimate, China's building waste output has accounted for 30% ~ 40% of the total municipal waste[1].The output is quite huge, and the number is still growing trend. Building waste has become a can not be ignored problem in the process of production and life, not only exacerbated the situation of China's land and resource constraints, but also hindered the urban economic development, serious impact on social economy and ecological environment sustainable development. According to estimates, building waste in our country produces every year a huge number of, however building waste recycling utilization rate is not very high, most untreated shipped directly to the outskirts of open dumps, landfill and incineration. Therefore, it is necessary for the scientific and reasonable forecast of the city's future building waste output.

At present, the domestic scholars on the building waste prediction analysis of the research use more conventional regression analysis and time series analysis method. Through the actual construction waste output, the annual construction area, the area and the annual commercial housing sales area and other factors, Feng Yanli[4]has established a multiple regression building garbage prediction model. Zhang Hongyu, Yang Huafei[5] use of the history of the past few years to use the time series of methods to build the ARIMA forecast model of Chaoyang District of Beijing building garbage. Through the establishment of index trend model, Liao Zhiqiang, Zhu Ning [6]get a reasonable forecast of city garbage. However, the amount of building waste is a complicated system which has many factors, and its development process is characterized by continuous and gray

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dynamic, and is a typical gray system. In China, a few scholars have tried to use the method of artificial neural network and grey system theory to predict the building waste. In this paper, by use of grey system theory to build GM (1,1) model of urban building waste for analysis and prediction, can have a profound understanding of the status of China's building waste yield, and can also be relevant departments of building waste management planning and regeneration utilization and provide an important basis. This has great significance for the building waste management and resource planning and management.

2. Grey Prediction Theory and Model Building

Grey forecasting theory was founded by Professor Deng Julong in the early 80s of the 20th century. It to some of the information is unknown, partly known information of poor information and it is a small sample of uncertainty in the system as the object of study by a small amount of information on known to develop processing, extraction for the prediction of the future usefulness of the information, the future prediction [6].At present, the conventional GM (1,1) model is the most commonly used, and its model only considers the whole data of the real time $t = n$ [7].Over time, some of the disturbance of the future will continue to impact on the system, and the more backward, the more weak the forecast of the model. Therefore, the introduction of the idea of gray metabolism, not only inherited the advantages of conventional GM (1, 1) model; and in a timely manner will have continuous access to the system disturbance factors into consideration, the forecast accuracy is higher [8].

2.1 Traditional GM (1, 1) Model

The conventional GM (1,1) model is the basis of grey forecasting, and it is composed of a single variable differential equation. First, obtaining the original sequence data:

$$x^{(0)} = \left\{x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\right\} \qquad (1)$$

than calculating the sequence level, and test data:

$$\lambda(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)}, \quad k = 2, 3, \cdots, n \qquad (2)$$

. If all level $\lambda(k)$ fall within the covering $(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+2}})$, the sequence $x^{(0)}$ can be used as a model of GM (1, 1) grey forecasting data. Otherwise, the need to make necessary change in the sequence of processing, make its fall into covering. Namely take appropriate constant c do translation transformation:

$$X^{(0)}(k) = x^{(0)}(k) + c \quad k = 1, 2, , \cdots, n \qquad (3)$$

So can make the grade sequence $X^{(0)}(k)$ level. $\lambda_X(k) = \frac{X^{(0)}(k-1)}{X^{(0)}(k)}$ $k = 2, 3, \cdots, n$

(4)

And then to a sum of data sequences, getting generated module:

$$x^{(1)} = \left\{x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n)\right\}$$

(5)

among them

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), \quad (k = 1, 2, \cdots, n)$$

(6)

Then by defining the ash bottom of $x^{(1)}$, $d(k) = x^{(0)}(k) = x^{(1)}(k) - x^{(1)}(k-1)$

(7)

For the sequence of $x^{(1)}$ adjacent to mean $z^{(1)}$, namely:

$$z^{(1)}(k)=0.5x^{(1)}+0.5x^{(1)}(k-1) \quad (8) \quad z^{(1)}=\left\{z^{(1)}(2),z^{(1)}(3),\cdots,z^{(1)}(n)\right\} \quad (9)$$

So GM (1, 1) grey differential equation model is $d(k)+az^{(1)}(k)=b$ (10)

Namely: $x^{(0)}(k)+az^{(1)}(k)=b$ (11)

And $x^{(0)}(k)$ is Grey derivative, a is development coefficient, $z^{(1)}(k)$ is albino background value, b is Grey action. By the first-order grey model $x^{(1)}$ made of albino differential equation:

$$\frac{dx^{(1)}}{dt}+ax^{(1)}(t)=b \quad (12)$$

Making $u=(a,b)^T$,

$$Y=\begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix} (13) \quad B=\begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} \quad (14)$$

The GM (1, 1) model for the matrix equation is $Y = Bu$. Obtained by the least squares method:

$$u=(a,\hat{b})^T=(B^TB)^{-1}B^TY \quad (15)$$

So the corresponding differential equation solution:

$$x^{(1)}(k+1)=(x^{(0)}(1)-\frac{b}{a})e^{-ak}+\frac{b}{a} \quad (16)$$

To restore to the original data getting $x^{(0)}(k+1)=x^{(1)}(k+1)-x^{(1)}(k)$ (17)

According to the above calculation formula of grey prediction, can get the prediction model.

2.2 The Principle of Grey Metabolism GM (1, 1) Model Prediction

Metabolism model of the main thought that with the development of the system, the significance of information of old data will be gradually reduced, in continue to add new information at the same time, timely remove the old information, so as to better reflect the characteristics and development trends of the system and obtain the higher prediction accuracy. The corresponding metabolic GM (1,1) model of the modeling process is as follows:

Usually the original sequence $x^{(0)}: x^{(0)}=\left\{x^{(0)}(1),x^{(0)}(2),\cdots,x^{(0)}(n)\right\}$ (1)

Use the conventional GM (1, 1) model, getting the numerical procedure $x^{(0)}(n+1)$. Then use new data sequence:

$$Nx=\left\{x^{(0)}(2),\ x^{(0)}(3),\cdots,x^{(0)}(n+1)\right\} \quad (18)$$

With conventional GM (1, 1) model. It can get metabolism GM (1, 1) model.

2.3 Model Accuracy Test

The accuracy of the gray GM (1,1) forecasting model is generally tested by the residuals and the posteriori difference methods. What's more the accuracy of the model was evaluated by mean square error ratio, average relative error and small error probability. The average relative error of the mean square error ratio and the average relative error are smaller, and the smaller the probability of small error, the higher the accuracy of the forecasting model is.

Order $x^{(0)}$ is the original sequence, $\hat{x}^{(0)}$ is the simulation sequence of GM (1, 1) model, $\varepsilon^{(0)}$ is residual error sequence.

$$\bar{x} \text{ is mean: } \bar{x} = \frac{1}{n}\sum_{k=1}^{n} x^{(0)}(k) \tag{19}$$

$$S_1^2 \text{ is variance : } S_1^2 = \frac{1}{n}\sum_{k=1}^{n}(x^{(0)}(k) - \bar{x})^2 \tag{20}$$

$$\bar{\varepsilon} \text{ is mean residual: } \bar{\varepsilon} = \frac{1}{n}\sum_{k=1}^{n}\varepsilon^{(0)}(k) \tag{21}$$

$$\varepsilon^{(0)}(k) \text{ is residual: } \varepsilon^{(0)}(k) = x^{(0)}(k) - \hat{x}^{(0)}(k) \tag{22}$$

$$S_2^2 \text{ is residual variance: } S_2^2 = \frac{1}{n}\sum_{k=1}^{n}(\varepsilon^{(0)}(k) - \bar{\varepsilon})^2 \tag{23}$$

$$C \text{ is mean square error ratio: } C = \frac{S_2}{S_1} \tag{24}$$

$$\bar{\Delta} \text{ is average relative error: } \bar{\Delta} = \frac{1}{n}\sum_{k=1}^{n}\left|\frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)}\right| \tag{25}$$

p is Small error probability:

$$p = P\left\{\left|e(i) - \bar{e}\right| < 0.6745 S_1\right\} \tag{26}$$

When the model by the above inspection is unqualified, the GM (1,1) model can be established by the residual data sequence, so that the original model can be corrected and the forecast precision of the model can be improved in Table 1.

Table 1. Accuracy Level

Prediction accuracy level	P	C
Good (level 1)	>0.95	<0.35
Qualified (level 2)	>0.80	<0.50
Barely (level 3)	>0.70	<0.65
Unqualified (level 4)	≤0.70	≥0.65

3. Prediction of Building Waste Production

3.1 Estimation of Building Waste Production

In recent years, with the accelerating of urbanization and the increasing of construction investment, the construction area and completion area is increasing year by year. A large number of building waste is produced. The building waste which this paper referring to is generated during building construction and building demolition. The production of building construction waste is obtained from construction area multiplied by construction waste production of unit area, and the production of demolition waste is obtained from demolition area multiplied by demolition waste production of unit area.

According to related statistics, the building waste production per ten thousand square meters is 500 ~ 600 tons of construction and is 1000~1500 tons of demolition[2]. The building demolition area is about 10% of completion area[3].

The building construction waste production of unit area is 0.055t/㎡ and the building demolition waste production of unit area is 1.3 t/㎡ in China. According to the relevant statistics in <<China Statistical Yearbook -2013>>,the building waste production from 2005 to 2013 is shown in Table 2.

Table 2. The Building Waste Production from 2005 to 2013

Year	Building waste (ten thousand tons)	Construction waste (ten thousand tons)	Demolition waste (ten thousand tons)	Construction area (ten thousand square meters)	Completion area (ten thousand square meters)
2005	54624	8767	45857	352745	159406
2006	63202	9882	53320	410154	179673
2007	73880	11220	62661	482006	203993
2008	81265	12298	68967	530519	223592
2009	90014	13497	76517	588594	245402
2010	107303	15260	92643	708024	277450
2011	128141	17404	110738	851828	316429
2012	147966	19730	128236	986427	358736
2013	168304	21408	146896	1129968	389245

According to Table 2, the building waste production is increasing year by year in China. This is related to the increasing investment of real estate industry during the eleventh "Five-Year Plan".

The building waste production increased by more than 1 billion tons and the average annual growth rate is 15.15%. The building waste production of 2009 is about 8.7×108 tons which is estimated by Shi Jianguang, et al and the production is 9.0×108 tons according to Table 2. This suggests that the two numbers are very close.

3.2 Prediction of Building Waste Production

GM(1,1) model I is built according to building waste production from 2005 to 2012 and GM(1,1) model II is built according to building waste production from 2008 to 2012.

The prediction result of model I is shown in table 3 and prediction result of model II is shown in table 4. According to table 5, the accuracy grade for both models are good. This result indicates the simulation accuracy is high.

By comparing the average relative error and mean square ratio, it is obviously that the simulation accuracy of model II is higher than model I. So this paper choses model II as a base model of the metabolism model to predict the building waste production.

Table 3. The Actual and Forecast Production of Building Waste from 2005 to 2012

Year	Actual production (ten thousand tons)	Forecast production (ten thousand tons)	Difference (ten thousand tons)	Relative error （%）
2005	54624	54624.00	0	0
2006	63202	61004.92	2197.08	3.48
2007	73880	70534.07	3345.93	4.53
2008	81265	81551.69	-286.69	0.35
2009	90014	94290.30	-4276.30	4.75
2010	107303	109018.71	-1715.71	1.60
2011	128141	126047.75	2093.25	1.63
2012	147966	145736.77	2229.23	1.51

Table 4. The Actual and Forecast Production of Building Waste from 2008 to 2012

Year	Actual production (ten thousand tons)	Forecast production (ten thousand tons)	Difference (ten thousand tons)	Relative error （%）
2008	81265	81265.00	0	0
2009	90014	90712.20	-698.20	0.78
2010	107303	106909.59	393.41	0.37
2011	128141	125999.15	2141.85	1.67
2012	147966	148497.30	-531.30	0.36

Table5.The Simulation Accuracy of Two Models

Model	Average relative error $\overline{\Delta}$	Small error possibility P	Mean square ratio C
I	2.23%	100%	0.0784
II	0.64%	100%	0.0415

This paper constructs the building waste data sequence according to the production of building waste from 2009 to 2013. The examination of the metabolism GM (1,1) model shows that the accuracy grade is good. So the metabolism GM (1,1) model can be used to predict the building waste production. The following formula is the model:

$$\begin{cases} x^{(1)}(k+1) = 692154e^{0.1463188k} - 602140 \\ x^{(0)}(k+1) = x^{(1)}(k+1) - x^{(1)}(k) \end{cases}$$

The prediction result of building waste production in the next four years is shown in table 6.The production increases 300 million tons per year with an average annual growth rate of 14.70%. The building waste production will be 3 billion tons in 2017 according to the prediction. This is in accordance with the urban economic growth and large-scale infrastructure construction in China.

If the current treatment of building waste keeps on, China’s land resources will be much more scarce and the sustainable development of society will be affected. It is very urgent for China to find an effective way to deal with building waste from the fundamental.

The prediction result is very useful to understand the present situation of building waste production in China. Meanwhile, the prediction result can help government and enterprise recycle building waste and turn some of them into treasure, and the sustainable development of economic, resources and environment can be achieved.

Table 6. The Forecast Production of Building Waste from 2014 to 2017

Year	Forecast production of building waste（ten thousand tons）
2014	195814
2015	224065
2016	257222
2017	295527

4. Conclusions

This paper first constructs an estimation system of urban building waste production based on building area and building waste production of unit area and then introduces the metabolism method to process the data against the shortcomings of conventional GM (1,1) model. Adding new information and removing old information can also avoid the difficulty of increasing calculation.

The examination of the metabolism GM (1,1) model shows that the accuracy grade is good and the prediction result of building waste production according to the metabolism GM (1,1) model is accurate. The prediction result is very useful to understand the present situation of production, treatment and recycling of building waste in China.

The model is suitable for the near forecast and not suitable for long-term forecast due to the restriction by its algorithm.

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