THE ENERGY CONSUMPTION PREDICTION MODEL BASED ON GREY MARKOV MODEL

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ABSTRACT

To grasp the overall situation of energy consumption in our country, constructing grey markov model, which through the process of energy consumption from 2001 to 2013 in our country history data, the GM (1, 1) model is established, and the application of markov model is revised, on this basis to predict energy consumption data from 2014 to 2015, finally, the prediction result was analyzed. The calculation results show that the grey markov model can not only eliminate the traditional grey GM (1, 1) model the inherent deviation, and can improve the prediction accuracy especially for medium and long-term prediction accuracy. The grey markov average relative error was 1.4876%, lower than 13.88% of the traditional grey GM (1, 1) model.

Key words: GM (1, 1) model; Markov model; energy consumption; prediction.

1. INTRODUCTION

Energy is an important material guarantee for economic development and social progress. It is an important strategic material for the economic lifeline and national defense security of a relationship and plays an important role in the modernization drive. It is of great significance to make the correct energy security strategic planning. In recent years, the continuous growth of energy demand has brought about the imbalance of energy supply and demand, which has become the focus of the industry and academia. Many scholars and related organizations have conducted extensive research on energy prediction, and many scholars have studied the prediction of energy demand. The prediction methods of ARMA model, BP neural network prediction, trend extrapolation, grey system, exponential smoothing and moving average are frequently used. Different forecasting methods have their advantages and disadvantages. They are not mutually exclusive, but are interrelated and complementary. Grey system theory from different angles and different aspects discusses the processing of various kinds of theories and methods of the uncertainty information, which studies how to based on limited gray information to predict the future trend of the change of the system and decision-making, has allowed the advantages of less capacity of sample. Markov prediction model is used in the dynamic process of random volatile, it can long-term projections for sequences of random fluctuations, this paper combined grey prediction model and markov model application, complement each other. Grey markov prediction model can make full use of grey GM (1, 1) model of less data, high precision and can reflect a long-term trend of the system characteristics and make full use of the advantage of markov process volatile random dynamic process, which can predict the energy consumption of medium and long-term prediction.

2. ESTABLISHMENT OF GREY MARKOV MODEL

2.1GM (1, 1) prediction model

(1) GM (1, 1) model of prediction model

The GM (1, 1) model is the most widely used grey dynamic prediction model in grey system theory, which is composed of a single variable first-order differential equation. It is mainly used for the fitting and prediction of the characteristic values of a certain dominant factor in the complex system to reveal the changing rules of the dominant factors and the trend of future development. Grey prediction is to establish a mathematical model to predict which through the change rules of grey quantity time series.

(2) operation procedure of GM (1, 1) model

Grey series GM(1,1) model prediction is a kind of realistic ,dynamic analysis and prediction. If a given original data sequence $X^{(0)}=\{x^{(0)}(1),x^{(0)}(2),\cdots,x^{(0)}(n)\}$, the continuous data of different lengths can be selected as subsequences from the $X^{(0)}$ sequence separately.

Build the GM(1,1) model for the subsequence, then determine the any subsequence as

$$X_i^{(0)}=\{x^{(0)}(1),x^{(0)}(2),\cdots,x^{(0)}(m)\} \qquad (1)$$

A cumulative generation of the sub data sequence is carried out, which attain

$$X_i^{(1)}=\{x^{(1)}(1),x^{(1)}(2),\cdots,x^{(1)}(m)\} \qquad (2)$$

which, $x^{(1)}(t)=\sum_{k=1}^{t}x^{(0)}(k)$, $t=1,2,\cdots,m$。

Construct the summation matrix B and the constant term vector Y_m, that is

$$B=\begin{bmatrix} -\frac{1}{2}[x^{(1)}(1)+x^{(1)}(2)] & 1 \\ -\frac{1}{2}[x^{(1)}(2)+x^{(1)}(3)] & 1 \\ \vdots & \vdots \\ -\frac{1}{2}[x^{(1)}(m-1)+x^{(1)}(m)] & 1 \end{bmatrix} \qquad (3)$$

$$Y_m=[x^{(0)}(2),x^{(0)}(3),\cdots,x^{(0)}(m)]^T \qquad (4)$$

Using the least square method to solve the grey parameter $\hat{a}$, that is

$$\hat{a}=\begin{bmatrix} a \\ u \end{bmatrix}=(B^TB)^{-1}B^TY_m \qquad (5)$$

Establishment of GM(1,1) model is

$$\hat{x}^{(0)}(t+1)=[x^{(0)}(1)-\frac{u}{a}]e^{-at}+\frac{u}{a} \qquad (6)$$

So we take the derivative reduction of $\hat{X}^{(1)}$,then get

$$\hat{x}^{(0)}(t+1)=-a[x^{(0)}(1)-\frac{u}{a}]e^{-at} \qquad (7)$$

(3) The test of the GM (1, 1) model

If $\varepsilon^{(0)}(k)$ is the residuals of the original value $x^{(0)}(k)$ and its predicted value $\hat{x}_k^{(0)}$,the residuals mean $\bar{\varepsilon}$ and residuals variance S_1^2 are

$$\bar{\varepsilon}=\frac{1}{n}\sum_{k=1}^{n}\varepsilon^{(0)}(k), \quad S_1^2=\frac{1}{n}\sum_{k=1}^{n}(\varepsilon^{(0)}(k)-\bar{\varepsilon})^2 \qquad (8)$$

The mean $\bar{x}$ and the variance S_2^2 of the original sequence $X^{(0)}$ are

$$\bar{x}=\frac{1}{n}\sum_{k=1}^{n}x^{(0)}(k), \quad S_2^2=\frac{1}{n}\sum_{k=1}^{n}(x^{(0)}(k)-\bar{x})^2 \qquad (9)$$

$C=S_1/S_2$ referred to as the mean variance ratio.

$\alpha=P(|\varepsilon^{(0)}(k)-\bar{\varepsilon}|)<0.6745S_2$ is called the small error probability, and the accuracy of the prediction model can be evaluated by using the two indexes C and α . The specific indexes are shown in table 1.

Table 1 The accuracy test grade index

accuracy test grade	α	C
good	>0.95	<0.35
qualified	>0.80	<0.50
reluctant	>0.70	<0.65
incompetent	≤0.70	≥0.80

2.2 markov prediction model

Markov models predict future trends based on the probability of transition between states. Markov model can be expressed as

$$X_{(n)} = X_{(t)}P^{n-1} \qquad (10)$$

Where, $X(t)$ for the initial state probability vector, $X(n)$ is the state probability vector after $(n-t)$ moments, P is a one-step state transfer probability matrix.

2.3 gray markov prediction model

The Operation steps of grey markov model is:

In order to optimize the prediction results, the predicted results are divided into state and the probability of transfer is determined, and finally, the markov model is applied to it.

(1) state division

In order to make the change of energy consumption data conform to markov's unstable random sequence, the relative accuracy should be the standard when dividing the state, i.e. the relative precision is the original value divided by the gray forecast value. The change interval of the relative precision is assumed to be $[K, L]$, and then the state is divided into m kinds of possible state $(E_1, E_2, E_3, \cdots, E_{m-1}, E_m)$,The ith state interval is $E_i = [K_i, L_i]$,where $i = 1, 2, \cdots, m-1, m$.

The state number and interval span are not only related to the sample data, but also the error range of the fitting results. Generally 3~5 is preferred, and data must be kept within the interval.

(2) The construction of state transfer matrix.

The probability of E_i transition from state a to the next state E_j is the p_{ij} of state transfer probability, then the one step state transfer probability matrix P is:

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{bmatrix}_{m\times m} \qquad (11)$$

Usually, the probability of transfer probability is calculated by using frequency approximation, that is $p_{ij} = M_{ij} / M_i$

Where, M_i is the total number of occurrences of state E_i, M_{ij} is the number of data of state E_i transferred to state E_j.

(3) Calculate markov prediction value.

Assuming that the gray predicted value of t moment is $\hat{x}_t^{(0)}$, the markov model is predicted to be $\hat{y}(t)$, and the state transfer probability vector is $X(t)$, So it's always going to be the maximum probability state E_i as the future develop state, the variation interval of the predicted value is between k, and the middle value of this interval can be used as the final prediction result of t moment ,that is

$$\hat{y}(t) = \hat{x}_t^{(0)}(K_i + L_i)/2 \qquad (12)$$

(4)Update the original data in each prediction with the thought of new information priority.

3. THE APPLICATION OF GREY MARKOV MODEL TO ENERGY CONSUMPTION

3.1 GM (1, 1) model of China's energy consumption

From the historical data of China's energy consumption (see table 2, column 1), it can be seen that energy consumption has an increasing trend over the long term, but its complexity and volatility are large.

Table 2 GM (1, 1) model fitting results

Years	Total energy consumption (tons of standard coal)	GM (1, 1) predictive value	absolute error	The ratio of the actual value to the predicted value
2001	155547	155547.00	0.00	1.00
2002	169577	203782.82	34205.82	0.83
2003	197083	218493.19	21410.19	0.90
2004	230281	234265.44	3984.44	0.98
2005	261369	251176.24	10192.76	1.04
2006	286467	269307.76	17159.24	1.06
2007	311442	288748.14	22693.86	1.08
2008	320611	309591.85	11019.15	1.04
2009	336126	331940.20	4185.80	1.01
2010	360648	355901.79	4746.21	1.01
2011	387043	381593.09	5449.91	1.01
2012	402138	409138.95	7000.95	0.98
2013	416913	438673.25	21760.25	0.95

Due to the energy consumption is affected by many factors, through its own change law of time series, can forecast the future energy consumption, according to the principle of GM (1, 1) model, the corresponding computer program compiled by using matlab, are:

$$\hat{\alpha} = [\alpha \quad u]^T = [-0.0697 \quad 185921.8585]^T$$

$$\hat{x}^{(0)}(t+1) = 190062.8549 e^{0.0697t}$$

3.2 The predicted value is modified with markov chain

(1) division system state interval

According to the markov analysis method 's application experience and actual situation, according to the ratio between the actual value and the grey forecasting of the energy consumption (see table 2, column5), can be divided into three kinds of state: overvalued, more accurate, underestimate (see table 3).

Table 3 the state division of energy consumption in China

Numbering	Names	Interval	Number of years
E_1	overvalued	[0.83 0.91)	2
E_2	accurate	[0.91 1.00)	3
E_3	underestimate	[1.00 1.08)	8

(2) calculate the state transfer probability matrix and revise the predicted valueAccording to the determination method of the state transfer probability matrix, we get:

$$P^{(1)} = \begin{bmatrix} 0.500 & 0.500 & 0 \\ 0 & 0.500 & 0.500 \\ 0.125 & 0.125 & 0.750 \end{bmatrix}, \left[P^{(1)}\right]^2 = \begin{bmatrix} 0.2500 & 0.5000 & 0.2500 \\ 0.0625 & 0.3125 & 0.6250 \\ 0.1563 & 0.2187 & 0.6250 \end{bmatrix}$$

Since 2013 in the second state, so consider the highest value in the second row of the matrix $P^{(1)}$, determine the energy consumption in China in 2014 in the second state, take the second state interval relative error in the values of the grey prediction for correction, for 2014 energy consumption at 421126.3209 million tons, through the above transfer matrix $(P^{(1)})^2$ determines the state of energy consumption in 2015, and considers the maximum of the second row of the matrix, and determines that the state of 2015 is the third state, and the calculated predicted value should be 437971.3738 million tons.

(4) RESULTS AND ANALYSIS

By can be seen in table 3, using the gray markov predict the average absolute error is 6373.0264, the relative error is 1.4877%, the traditional GM (1, 1) predicting the average absolute error is 59460.10428, the relative error is 1.4877%, so the grey markov model is superior to the traditional GM (1, 1) model.

Table 3 The prediction results comparison of the GM (1, 1) and grey markov

Year	actual value	GM（1,1）			grey markov		
		prediction	Absolute error	relative error	prediction	Absolute error	relative error
2014	425806	421126.3209	44533.5275	10.4586	470339.5275	4679.6791	1.0990
2015	429905	437971.3738	74386.6810	17.3031	504291.6810	8066.3738	1.8763
Mean absolute error		59460.10428			6373.0264		
Mean relative error		13.8808			1.4877		

(5) THE TEST OF GREY MARKOV MODEL

The grey markov model small error probability P is more than 95%, the difference of posterior ratio C < 0.35, The prediction model test index P and C are compared with the grey prediction accuracy test grade (see table 1), the model for optimal accuracy grade, proved that the model prediction accuracy is higher, can long-term projections for energy consumption. similarly, the total energy consumption in China can be predicted in 2016-2020 (see table 4). As can be seen from table 4, China's total energy consumption will reach 532859.43 million tons of standard coal by 2020, with an average annual growth of 3.397%.为3.397%。

Table 4 The energy consumption in China from 201t o2020: units tons of standard coal

Year	2016	2017	2018	2019	2020
The energy consumption	455490.2287	473709.8379	492658.2314	512364.5606	532859.143

6. CONCLUSION

Based on the characteristics of energy consumption system, combined with the grey system theory and markov theory, the grey markov prediction model was established, and applied to the prediction of energy consumption in our country, the research shows that the precision of grey markov model is higher than the grey forecasting model , the average relative error is 1.4877%, and single grey prediction relative error less than 11.39%, combined grey prediction model and markov prediction model, can complement each other, not only to overcome the defects of the two kinds of forecast methods ,but also can play their respective advantages, to the time series with higher volatility ,which has a strong advantage.

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