The Research of Railway Coal Dispatched Volume Prediction Based on Chaos Theory

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Abstract. Applying the feature of analyzing the chaotic characteristics of nonlinear dynamic system of chaos theory, the railway coal dispatched volume time series was analyzed. On the base of Takens phase space reconstruction, C-C method was used to calculate embedding time-delay and embedding window , G-P method was used to calculate the embedding dimension, and then Small-data method was used to calculate the maximum Lyapunov exponent of railway coal dispatched volume time series. The Lyapunov exponent was used to analyze the chaotic characteristics of the time series. The analytical results show as the following: the growth amount and growth rate of railway coal dispatched volume have chaotic characteristics, but the coal dispatched volume doesn't. The maximum Lyapunov exponent method and BP neural network were separately used to forecast the growth amount and growth rate of railway coal dispatched volume from 1st January 1999 to 26th June 2012. The result shows that the predicted data using maximum Lyapunov exponent method is anastomotic with the real data. The maximum Lyapunov exponent method is better than BP neural network in predicting. The maximum Lyapunov exponent method is useful in railway coal dispatched volume prediction.

Keywords: railway coal dispatched volume time series, chaos prediction, maximum Lyapunov exponent, phase space reconstruction, chaotic judgment

1 Introduction

Chaotic time series analysis is a new development of nonlinear time series analysis. It is the method on the base of the development of nonlinear time series analysis in recent 20 years. Chaotic time series is the time series with chaotic characteristic generated by the chaotic model and it contains rich dynamics information. Prediction of chaotic time series analysis is a bridge from theory to the real world. It is one of the main applications of chaos theory, while the maximum Lyapunov exponent method is an important method in chaotic time series prediction [1].

Coal is the largest component of China's railway freight volume,Transportation plays an important role in the process of coal circulation. To china, coal transportation mainly depends on the railway. The railway coal dispatched volume accounted for more than 70% of the country's total coal dispatched volume, accounting for more than 40% of the total railway freight volume. The prediction of railway coal dispatched volume is basing on the statistical data to conduct dynamic analysis. Considering the national economic and social development planning, it is the quantitative calculation on the basis of qualitative analysis. Correctly predicting coal dispatched volume will play an important role in the development of railway freight, resource allocation and business management.

How to predict railway coal dispatched volume effectively has been an important issue of processing railway freight volume. In recent years, some freight volume prediction mathematical model was proposed on the basis of extensive research. In literature [2,3,4], neural network was used to predict railway freight volume as it has the feature of better nonlinear fitting, simple learning rule and easy to be realized by computer. But it has the defects of undue reliance on learning samples, easy to fall into local optimum and weak generalization ability. In literature [5,6], fractal theory was used to predict railway freight volume as it has the feature of complete self-similarity and strong recursiveness, but it has the defects of covering a wide range but not mature and large amount of calculation. In literature [7,8,9],the grey theory is also used to build model to predict railway freight volume as it has the feature of small data demand, small amount of calculation, not being influenced by distribution and trend. But its development is relatively short and it is not suitable for long-term prediction. In literature [10,11] support vector machine model is used to predict using its feature of strong generalization ability, independence of algorithm complexity and feature space，but it also has the defects of difficult to accurately analyze the performance indicators and change the system characters to data, easy to lose information.

As the above theories all have defects in prediction, in this paper, the maximum Lyapunov exponent is used to predict railway coal dispatched volume. This method has the advantages of not easily being influenced by noise data, not falling into the local optimal solution, higher accuracy of the solution and high convergence speed. According to the process of chaotic dynamics, firstly the phase space reconstruction of chaos theory is introduced, and then the chaotic characteristics of railway coal dispatched volume time series is judged. The data used is the data of railway coal dispatched volume from 1st January 1999 to 26th June 2012, just as Figure 1 shows. The maximum Lyapunov exponent is calculated and then model is built to predict railway coal dispatched volume. The maximum Lyapunov exponent method enriches the railway dispatched volume prediction methods. The results can be used to predict the future development trend of railway dispatched volume and used as planning reference.

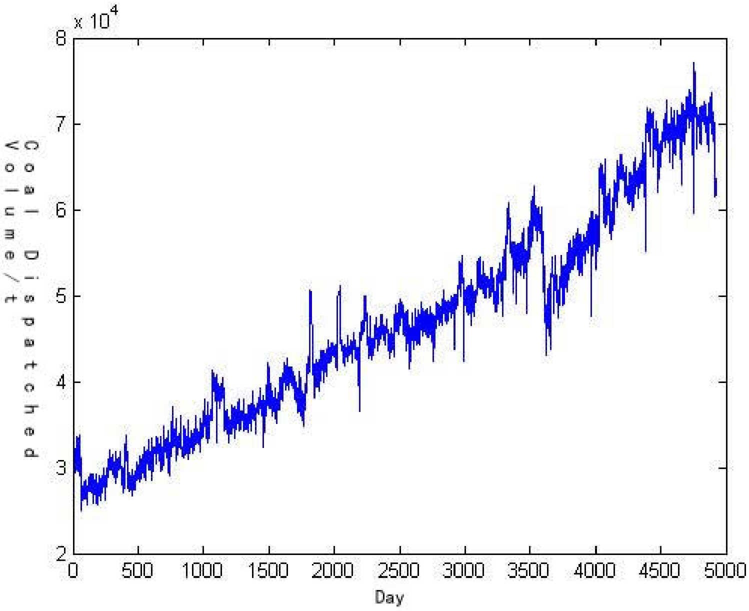


Fig. 1. The trend of railway coal dispatched volume per day.

2 Phase Space Reconstruction

The purpose of the phase space reconstruction is to recover chaos attractor from the high-dimensional phase space. As one of chaos system characters, chaos attractor reflects the regularity of chaos system and it means chaotic system will eventually fall into a particular trajectory. Such a trajectory is called chaos attractor. PACHARD [12] and Takens [13] proved that a suitable embedded dimension m and time-delay τ can be found to reconstruct phase space.

$$X(j) = [x(j), x(j+\tau), x(j+2\tau), \cdots, x(j+(m-1)\tau)] \tag{1}$$

In the formula, $j = 1, 2, \cdots, N-(m-1)\tau$,

The phase space series constructed by the points is:

$$[X(1) \quad X(2) \quad \cdots \quad X(j) \quad \cdots \quad X(N-(m-1)\tau)]^{-1} =$$

$$\begin{bmatrix} x(1) & x(1+\tau) & x(1+2\tau) & \cdots & x(1+(m-1)\tau) \\ x(2) & x(2+\tau) & x(2+2\tau) & \cdots & x(2+(m-1)\tau) \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x(j) & x(j+\tau) & x(j+2\tau) & \cdots & x(j+(m-1)\tau) \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x(N-(m-1)\tau) & x(N-(m-2)\tau) & x(N-(m-3)\tau) & \cdots & x(t_n) \end{bmatrix} \tag{2}$$

Equation (2),*X(j)* is time series, τ is time-delay, m is embedded dimension. Chaos time series phase space reconstruction is expanding the dimensions of one-dimension time series from one to three or more, in order to fully reveal the information hidden in the time series. The key to the phase space reconstruction is the selection of time-delay τ and embedded dimensions m .

3 Chaotic Time Series Judgment

In this chapter, C-C method is used to calculate the time-delay and embedded window of railway coal dispatched volume. G-P method is used to calculate embedded time-delay and the maximum Lyapunov exponent of railway coal dispatched volume is calculated.

3.1 C—C Method to Calculate Embedded Time-Delay and Embedded Window

In order to reveal the hidden information from the given time series so that the attractor characteristics can be restored, time-delay technique is often used to reconstruct phase space. In the course of phase space reconstruction, time-delay τ and embedded dimensions m are of great importance. Now there are two views: One is that the two are unrelated, it means that the selection of τ and m is independent, and the other is that the two are related. On the base of embedded window, Kim et al. [14] , proposed *C-C* method. In this method, correlation integral is used to estimate time-delay τ_d and embedded window τ_w. Time-delay τ_d ensures that the components of x_i are interdependent, but do not depend on m , but the embedded window τ_w depends on m and changes with m .

The steps of *C-C* method to determine optimal embedded time-delay:

Step1 Calculate the standard deviation of time series σ , select N.

Step2 Calculate the following three variables

$$\overline{S}(t)=\frac{1}{16}\sum_{m=2}^{5}\sum_{j=1}^{4}S(m,r_j,t) \tag{3}$$

$$\Delta\overline{S}(t)=\frac{1}{4}\sum_{m=2}^{5}\Delta S(m,t) \tag{4}$$

$$S_{cor}(t)=\Delta\overline{S}(t)+\left|\Delta\overline{S}(t)\right| \tag{5}$$

In the above equations, m is embedded dimensions and m =2, 3, 4, 5. t is time variable and r is the radius of the points in phase space. $r_j = j\sigma/2$ and σ is standard deviation, j =1, 2, 3, 4.

$$\Delta S(m,t)=\max\{S(m,r_j,t)\}-\min\{S(m,r_j,t)\} \tag{6}$$

Step3 Make figure according to the results, and use the figure to get the following three values.

(a) The first zero point of $\overline{S}(t)$ is optimal embedded time-delay

(b) The first minimum value of $\Delta\overline{S}(t)$ is optimal embedded time-delay.

(c) According to the minimum of $S_{cor}(t)$ to discover time series overall maximum embedded window

Using *C-C* method, after the phase space is constructed, substituting coal dispatched volume time series data of 4926 days, by calculating, the embedded time-delay and embedded window are shown in Figure 2. The line is $\overline{S}(t)$. The point is $\Delta\overline{S}(t)$. The "*" is $S_{cor}(t)$.

The embedded time delay and embedded window calculated by C-C method are given in Table 1.

3.2 G-P Method to Calculate Embedded Dimension

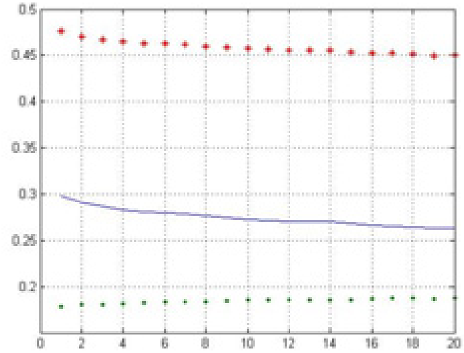
On the base of time-delay embedded space, Grassberger and Procaccia [15] proposed a method for the experimental data in 1983. It uses the relation of correlation integral *C(r)* and distance r in reconstructed space of univariate time series to get fractal dimensions. It is called G-P algorithm. By the reconstruction of phase space of the time series, the constructed singular attractor can reflect the evolution regularity of the system. By analyzing the structure of reconstructed attractor in phase space to evaluate the chaotic characteristics of the dynamic system is the basic idea of the GP algorithm [16].

Usually by calculating correlation dimension to determine embedded dimension, when correlation integral is known, the equation is:

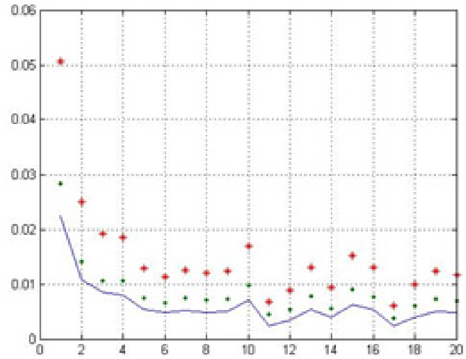
$$C_m(r)=\frac{2}{N_m(N_m-1)}\sum_{i,j=1}^{N_m}H(r-r_{ij}) \tag{7}$$

In the equation, *N* is the number of points in reconstructed space and H is Heaviside function, just as Equation (8) shows:

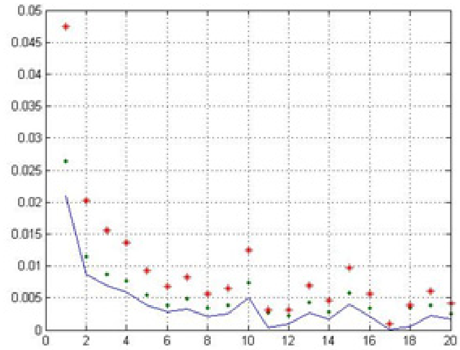
$$H(x)=\begin{cases}0, & x<0\\ 1, & x\geq 0\end{cases} \tag{8}$$



(a) C-C method to calculate coal dispatched volume



(b) C-C method to calculate coal dispatched volume growth amount



(c) C-C method to calculate coal dispatched volume growth rate

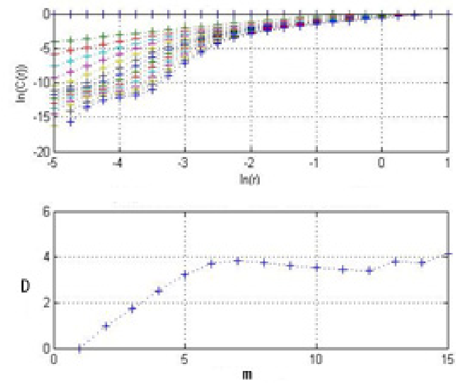
Fig. 2. C-C method to calculate embedded time-delay and embedded window of railway coal dispatched volume related time series

Table 1 . The optimal embedded time-delay and embedded window of railway dispatched volume time series

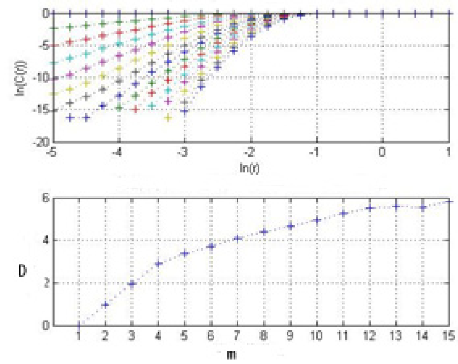
time series	optimal time-delay per day	embedded window per day
coal dispatched volume	1	16
coal dispatched volume growth amount	3	11
coal dispatched volume growth rate	6	17

Set *D* as correlation dimensions and R is given value, then get $\lim_{r \to 0} C_n(r) \propto r^D$. In actual calculation, n is increased to make *D* constant. It means in double-log relation, beside the lines whose slope is 0 and ∞ , the best fitting line slope is *D*. The stable value of *D* is embedded dimension m.

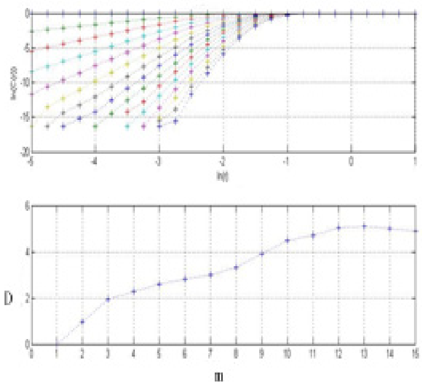
The following is the results of embedded dimensions get by G-P method. In calculation, the embedded dimension value is from 1 to 15. The value of optimal time-delay is in table 1. Figure 3 shows the changes of the railway coal dispatched volume time series correlation dimensions as embedding dimensions increase.



(a) G-P method to calculate coal dispatched volume



(b) G-P method to calculate coal growth amount



(c) G-P method to calculate railway coal growth rate

Fig. 3. G-P method to calculate correlation dimension and the relation of embedded dimension and correlation dimension of railway coal dispatched volume related time series

In Figure 3, the lower part of each table show the changes of correlation dimension *D* as embedded dimension m increases. Table 2 shows the changes. The convergence value of railway coal dispatched volume correlation dimension *D* is about 3.6104 and the corresponding embedded dimension m is 9. The convergence value of railway coal growth amount correlation dimension *D* is about 5.4922 and the corresponding embedded dimension m is 12. The two values of railway coal growth rate is respective 5.0337 and 12.

In Figure 3, the upper part of each table shows that as the embedded time-delay increases, the railway coal dispatched volume is saturated within the linear region. The increase of time-delay almost does not affect the value of the correlation integral, which shows three time series are not random series. By the chaos theory, the saturation phenomenon is only a necessary condition to judge whether the time series is chaotic. To judge more accurately, the maximum Lyapunov exponent is needed.

Table 2. The relation of embedded dimension m and correlation dimension *D* of railway coal dispatched volume related time series

embedded dimension m	2	3	4	5	6	7	8
coal dispatched volume	0.9853	1.7243	2.4984	3.2182	3.7133	3.8524	3.7522
coal growth amount	0.9583	1.9356	2.8967	3.3669	3.6928	4.0776	4.3858
coal growth rate	0.9731	1.9634	2.2588	2.5992	2.8316	2.9851	3.3121
embedded dimension m	**9**	**10**	**11**	**12**	**13**	**14**	**15**
coal dispatched volume	3.6104	3.5148	3.4424	3.4183	3.8055	3.7341	4.1221
coal growth amount	4.6359	4.9638	5.2311	5.4922	5.5154	5.5089	5.7927
coal growth rate	3.893	4.4941	4.7029	5.0337	5.1009	4.9856	4.8927

3.3 The Maximal Lyapunov Exponent

The basic characteristic of chaotic movement is that it is sensitive to initial conditions. The Lyapunov exponent can measure the characteristics of the system effectively. Lyapunov exponent is the average divergence rate of phase space adjacent orbit.

In 1983, Grippo Ki proved that as the maximal Lyapunov exponent is above zero, then there was chaos in system. In practical problem, we need to judge if there is chaos in system. To do this, it is not necessary to calculate all Lyapunov exponents. The maximal Lyapunov exponent is enough.

$$\lambda = \lim_{n\to\infty}\frac{1}{n}\sum_{i=0}^{n-1}\ln\left|\frac{dF(x)}{dx}\right|_{x=x_i} \tag{9}$$

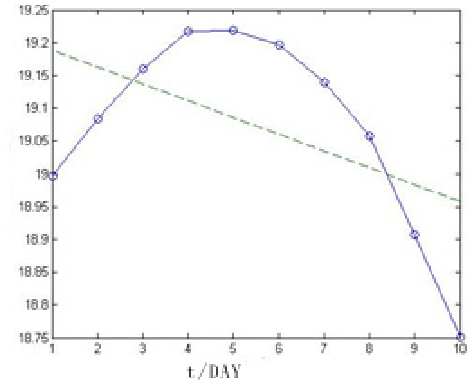
The Lyapunov exponent is chaotic characteristics. The size of the exponent can be used to measure the degree of chaos. If the maximal Lyapunov exponent λ is above 0, then we can make sure that there is chaos attractor and the system is chaotic. If the maximal Lyapunov exponent λ is below 0, then we can make sure that the system is random system or definite system. If λ is equal to 0, it means the system has periodic solution corresponding to breakout point or the system and the system id periodic. The reciprocal of Lyapunov exponent is maximal predictable time. And if λ is larger, it means the predictable time of system movement is shorter the predictability is worse.

The Small data Method is used to calculate the maximal Lyapunov exponent of three groups of coal dispatched volume time series. Figure 4 shows the change of distance between the two points in the phase space attractor trajectory.

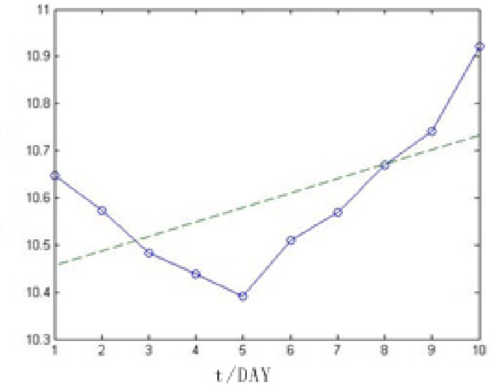
The chaotic orbit is sensitive to the initial value. The distance between the two orbits starting from the adjacent initial conditions will increase as the time go on. This sensitivity can be quantitatively described by the Lyapunov characteristic exponent. For multi-dimensional dynamical systems, if the maximal Lyapunov exponent is positive, then the system is chaotic. If the maximal Lyapunov exponent is above zero can be a condition to judge whether the time series is chaotic. The maximal Lyapunov exponent of railway coal dispatched volume is in Table 3.

In table 3, three groups of time series are all composed of floated data. The coal dispatched volume time series is different from the other two time series. Though the embedded time-delay and embedded window of three groups time series can be calculated and as the embedded dimensions increase, the slope of the G-P method tends to be a stable value, only the two groups time series whose maximal Lyapunov exponent is above 0 are chaotic.

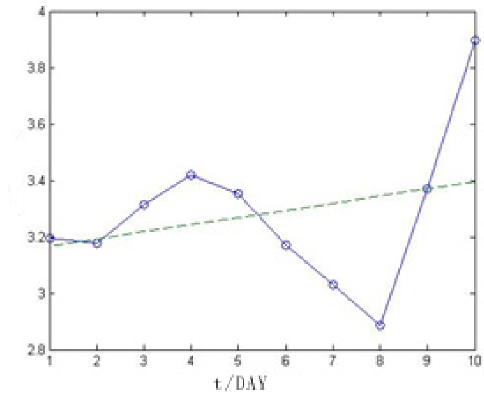
From the maximal Lyapunov exponent of the above three groups time series, we can judge that the time series of coal dispatched volume is not chaotic while the time series of growth amount and growth rate are chaotic.



(a)The maximal Lyapunov exponent of coal dispatched volume



(b) The maximal Lyapunov exponent of coal dispatched volume growth amount



(c)The maximal Lyapunov exponent of coal dispatched volume growth rate

Fig. 4. The maximal Lyapunov exponent of coal dispatched volume related time series

Table 3. The maximal Lyapunov exponent of coal dispatched volume related time series

time series	the maximal Lyapunov exponent	state of motion
coal dispatched volume	-0.0255	not chaotic
coal dispatched volume growth amount	0.0308	chaotic
coal dispatched volume growth rate	0.0253	chaotic

4 Railway Coal Dispatched Volume Prediction Based on Maximal Lyapunov Exponent

In this chapter, the maximum Lyapunov exponent is introduced and the phase space three-dimensional phase diagram of railway coal dispatched volume growth amount and growth rate is described. The prediction results are analyzed and validated.

4.1 The Prediction Steps

The prediction based on maximal Lyapunov exponent is to use the calculated maximal Lyapunov exponent which is also the orbit average divergence and to track the evolution of most neighboring points to predict using phase space reconstruction method. The most neighboring point of *Yi* is *Yj* and after a period of time, the distance between the two points will increase e^{λ_1} times. It is:

$$\left\|Y_{i+1}-Y_{j+1}\right\|=e^{\lambda_1}\left\|Y_i-Y_j\right\| \tag{10}$$

Besides the last dimension of Y_{i+1}, the other data is known, so that the value of $x_{i+1+(m-1)\tau}$ can be got and it is the predicted value. The prediction steps are as following [1].

(1) To do *FFT* transformation on time series $\{x(i), i=1,2,\cdots,N\}$ and calculate average cycle p. Use *C-C* method to calculate embedded dimension m and time-delay τ

(2) Base on time-delay τ and embedded dimension m to reconstruct phase space $\{y(t), t=1,2,\cdots,M\}$ and use C-C method and *G-P* algorithm to calculate embedded dimension and time-delay.

(3) Find the most neighboring point $y(t)$ of each $y(t)$ and limit the temporary separation, it is

$$d_t(0)=\min_{\hat{t}}\left\|y(t)-y(\hat{t})\right\|, \quad \left|t-\hat{t}\right|>p \tag{11}$$

(4) To each point $y(t)$ in phase space, calculate the distance $d_t(i)$ after i steps in neighborhood.

$$d_t(i)=\left\|y(t+i)-y(\hat{t}+i)\right\|, \tag{12}$$

(5) Calculate $x(i)$ for each i and it is

$$x(i)=\frac{1}{q\Delta t}\sum_{j=1}^{q}\ln d_j(i) \tag{13}$$

In the equation, q is the number of nonzero $d_t(i)$. Calculate the regression line by the least squares method and the slope of the line is the maximal Lyapunov exponent λ_1.

(6) Find the neighboring state point y_{nb} of center point y_N and calculate $d=\left\|y_N-y_{nb}\right\|$.

(7)On the base of above equation, calculate x_{n+1} and select the root according agreed rule.

4.2 The Selection of Parameters and The Construction of Attractor Three-dimension Phase Figure

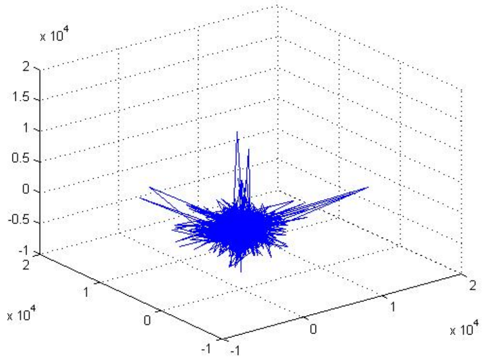
The growth amount and growth rate of railway coal dispatched volume from 1st January 1999 to 26th June 2012 are selected to constitute time series $\{x(t)\}, t=1,2,\cdots,n, n=4926$. According to chaotic dynamics theory, the reciprocal $T_m=1/\lambda_1$ of Lyapunov exponent λ_1 is the longest predicted time of chaotic system. The λ_1 of growth amount is 0.0308 so the $T_m=1/\lambda_1$=32 days. The λ_1 of growth rate is 0.0253 so the $T_m=1/\lambda_1$=40days. Compare the two longest predicted time and choose 30 days as predicted length to improve prediction accuracy. It means in selected 4926 days, the data of first 4896 days is for the calculation of relevant parameters and the data of last 30 days is for the validation of model.

Select the data of first 4896 days of the growth amount, the parameters are m=12 and τ=3 which are calculated in chapter 2. The reconstructed phase space is $X_i(i=1,2,\cdots,4863)$, just as Equation(14) shows. The figure 5 is the attractor phase figure by phase space reconstructing the growth amount series.

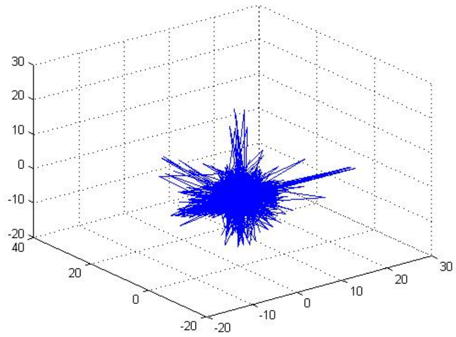
$$X=\begin{pmatrix}X_1\\X_2\\\vdots\\X_{4863}\end{pmatrix}=\begin{pmatrix}x_1 & x_4 & x_7 & x_{10} & x_{13} & x_{16} & x_{19} & x_{22} & x_{25} & x_{28} & x_{31} & x_{34}\\ x_2 & x_5 & x_8 & x_{11} & x_{14} & x_{17} & x_{20} & x_{23} & x_{26} & x_{29} & x_{32} & x_{35}\\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots\\ x_{4863} & x_{4866} & x_{4869} & x_{4872} & x_{4875} & x_{4878} & x_{4881} & x_{4884} & x_{4887} & x_{4890} & x_{4893} & x_{4896}\end{pmatrix} \tag{14}$$

Select the data of first 4896 days of the growth rate, the parameters are m=12 and τ=6 which are also calculated in chapter 2. The reconstructed phase space is $X_i(i=1,2,\cdots,4863)$, just as Equation(15) shows. The Figure 5 is the attractor phase figure by phase space reconstructing the growth rate series.

$$X=\begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_{4830} \end{pmatrix}=\begin{pmatrix} x_1 & x_7 & x_{13} & x_{19} & x_{25} & x_{31} & x_{37} & x_{43} & x_{49} & x_{55} & x_{61} & x_{67} \\ x_2 & x_8 & x_{14} & x_{20} & x_{26} & x_{32} & x_{38} & x_{44} & x_{50} & x_{56} & x_{62} & x_{68} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{4830} & x_{4836} & x_{4842} & x_{4848} & x_{4854} & x_{4860} & x_{4866} & x_{4872} & x_{4878} & x_{4884} & x_{4890} & x_{4896} \end{pmatrix} \quad \textbf{(15)}$$



(a) attractor three-dimension phase figure of coal dispatched volume growth amount

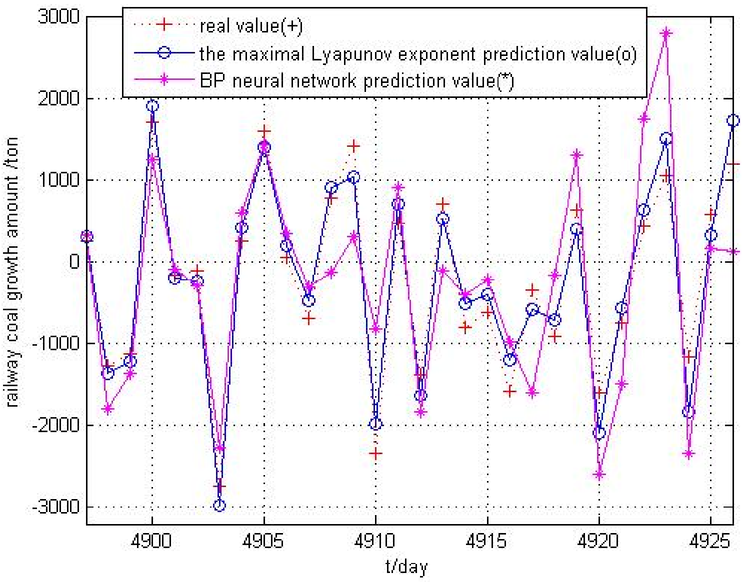


(b) attractor three-dimension phase figure of coal dispatched volume growth rate

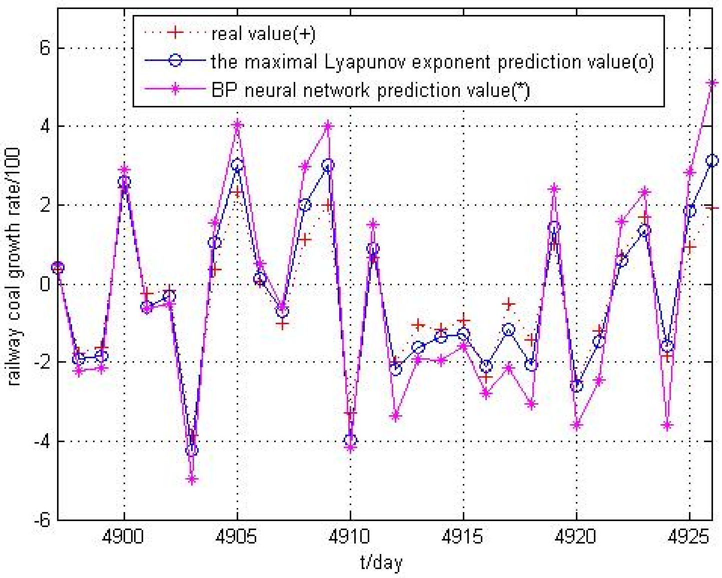
Fig. 5. Attractor three-dimension phase figure of coal dispatched volume related time series

4.3 The Prediction Result and Analysis

On the base of above prediction steps, the maximal Lyapunov exponent prediction of railway coal growth amount and growth rate is compared with BP neural network prediction. According to the prediction results, the curve is as Figure 6 shows. In the curve, "+" is the real value, "o" is the prediction value of maximal Lyapunov exponent, "*" is the prediction value of BP neural network. The data of first 4896 days is the basic data which is used to predict the data of 30 days from the 4897th day to the 4926th day. The prediction value is compared with the real value. The structure of BP neural network is determined by the system input and output data characteristics. In chapter 2.3, we know the embedded dimension of railway coal growth amount m=12. It means there are 12 state variables in the phase space so the BP input layer neurons number of neural network model is 12. The neural model prediction step is 1, so the number of neurons of BP neural network model output layer is 1. Use formula $n_1=\sqrt{n+m}+a$ **(16)** to calculate the number of hidden layer neurons. In the formula, n_1 is the number of hidden layer neurons, n is the number of input layer neurons, m is the number of output layer neurons, a is the constant value from 1 to 10. Using Equation 16 to calculate the hidden layer neurons of railway coal growth amount, we can get $4\le n_1\le 13$. By calculation, the number is selected as 5. At last the neural network model of railway coal growth amount is 12-5-1 and the neural network model of railway coal growth rate is 12-6-1. After the structure is known, the BP neural network training is conducted and the prediction is done. The predicted value is as Figure 6 shows. The real value, the predicted value by the maximal Lyapunov exponent and the predicted value by BP neural network model are compared. From Figure 6 we can see the real value and predicted value by the maximal Lyapunov exponent of first 15 days data have high degree of fusion. As the days increase, the value of last 15 days has consistent trend and the discreteness is unobvious. The error of BP neural network prediction is larger than the maximal Lyapunov exponent prediction. The result shows that the maximal Lyapunov exponent prediction can reflect the change of railway coal dispatched volume growth amount and growth rate per day and its accuracy is high.



(a) coal dispatched volume growth amount time series prediction



(b) coal dispatched volume growth rate time series prediction

Fig. 6. Coal dispatched volume growth amount and growth rate time series prediction

In order to clarify the chaos predicted effects of railway coal dispatched volume growth amount and growth rate, the accuracy verification of the predicted results is conducted. In this paper, the mean square error of predicted value and real value is as an indicator to judge the prediction effect, as shown in Equation (17).

$$ESS = \left[\frac{1}{L} \sum_{i=1}^{L} \left(\frac{(x(n+i) - \bar{x}(n+i))}{x(n+i)} \right)^2 \right]^{1/2} \quad \textbf{(17)}$$

In the equation, $x(n+i)$ is real value and $\bar{x}(n+i)$ is predicted value. If ESS is small, it means the deviation degree from predicted value to real value is lower and the predicted effect is better. If ESS is large, it means the degree is high and the effect is worse. Experiments show that to maximal Lyapunov exponent prediction, the factors effecting ESS are the chaos characteristic of predicted series, the dimension of constructed phase space, the distance determining the terminate state of predicted point, the series length N and prediction length L. By Equation (17), the error of railway coal growth amount prediction basing on the maximal Lyapunov exponent is 7.621% while the error of growth rate is 6.323%. The error of growth amount basing on BP neural network prediction is 16.927% while the error of growth rate is 15.673%. The prediction results show that the prediction value of the maximum Lyapunov exponent has the same trend with the actual value. The prediction accuracy is higher than that of BP neural network prediction and the prediction error can satisfy the prediction of railway coal dispatched volume requirements, so the method can be applied in the railway coal dispatched volume prediction.

5 Conclusions

Railway coal dispatched volume is an important index in railway freight. To the nonlinear characteristics of railway coal dispatched volume time series, the paper proves that the railway coal growth amount and growth rate are chaotic time series. The C-C method and G-P algorithm are used to calculate the embedded time-delay and embedded dimensions. The characteristics of time series reconstruction attractor are discussed. The maximal Lyapunov exponent is used to predict the growth amount and growth rate of railway coal and the prediction result is compared with the BP neural network prediction. The results are as following.

(a) By calculation, the Lyapunov exponent of railway coal growth amount and growth rate is above 0 and below 1. It shows that the data is strong quasi-periodic and the limited step prediction is feasible. The time series is chaotic. In real project, the prediction of growth amount and growth rate is more meaningful than the prediction of dispatched volume.

(b) In the research, using the nonlinear characteristics of time series, the maximal Lyapunov exponent and BP neural network are used to predict the railway coal dispatched volume. The result shows that the prediction basing on the maximal Lyapunov exponent is better than *BP* neural network in aspects of aproximation capability, classification ability and learning speed. Besides that, *BP* neural network has the shortcomings of low convergence speed and easily falling into the local minimum extreme point. The predicted results show that the accuracy of the maximum Lyapunov exponent model is higher and such model is more useful in real life.

(c)The prediction method is of intuitive and clear meaning and the amount of calculation is small. It is relatively easy to operate so that the human factors such as the selection of r,θ in Wolf method are reduced. The predicted result is approximately similar with the real data so it can satisfy the need of real production. The maximal Lyapunov exponent method enriches the railway freight volume prediction method and the predicted results can be the reference of railway freight planning.

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