Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 13 (19): 3995-4000, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.3995.4000

Method for Prediction of Coal and Gas Outburst Based on Data Mining Technology

Cheng Zhai, Xu Yu, Bai-Quan Lin and Wei Yang
School of Safety Engineering, China University of Mining and Technology, 221116, Xuzhou, China

Abstract: Coal and gas outburst is one of the main disasters in coal mine, the outburst forecasting is the main part of prevention work which affects the prevention measures establishment and production plan directly. However, only several factors such as ground stress, gas pressure or coal structure is taken into account, the forecasting results can not be very accurate. It's urgent to get more kinds of parameters into consideration and enhance the outburst forecasting accuracy. Risk forecasting in working face is the first step of mine wit outburst andan accurate determination of the sensitive index of coal and gas outburst is very important. Aiming at the problems of low accuracy of risk forecasting and lack of proper method to determine the critical value of the outburst sensitive index, the Statistical Process Control (SPC) method was proposed, the selecting method of SPC control chart was discussed andthe drawing process of SPC control chart and the determination of critical value of the outburst sensitive index were analysed. At the same time, the "three-rate" method was used to analyse the field data of the outburst index and the accuracy of calculation results was proved. The results showed that the affected extent of coal is different in underground working face with the change of drilling depth, the critical value should be changed and it should be not uniformly determined as a fixed value simply. The outburst risk would lead to a "dynamic" change along with changes of space and time. The SPC is a dynamic forecasting method which may determine the sensitive index of outburst forecasting accurately and reduce the accident rate of the coal and gas outburst.

Key words: Statistical process control method, coal and gas outburst, sensitive index, critical value

INTRODUCTION

Coal and gas outburst is one of the disasters which seriously threaten the safe production of coal mine. More than 95% of coal mines in China are underground mining, the high-gas mines or with outburst risk may account for about 48%. The occurring times of the outburst disaster are the highest in the world andthe outburst size would achieve a few hundred tons and thousands of tons (Hu *et al*., 2006). The risk is increasing along with the increasing of mining depth. So, the forecasting and prediction of outburst are important links to control outburst (Wang *et al*., 2008), especially, accurate determination the sensitive index of coal and gas outburst is very important to safe production of coal mine.

In the late 1980s in China, the forecasting and prediction indexes such as drilling capacity, gas flooding velocity and the gas desorption characteristics were taken as the forecasting methods in working face. According to the measured data (Wang and Wang, 1991), the "three-rate" method and the proved data of the outburst forecasting results were used to determine the outburst sensitive index and critical value. The coal sampling testing combined with the field investigation was adopted to ascertain the outburst sensitive index and critical value. The mathematic model of gray relating analysis in gray system theory was used to analyze four kinds of indexes for forecasting the coal and gas outburst quantitatively (Li, 1992; Yan *et al*., 2009). A multi-index parameter forecasting method was proposed when using the "three-rate" method combined with the field investigation (Chen, 2006). A mathematic model to determine the outburst sensitive indexes was put forward via a combination of the fuzzy mathematics with the probability theory andthe abstract sensitive index to confirm problems was expressed by the concrete numerical values (Tian and Wang, 2006). The outburst risk critical value was determined in advance, meanwhile, this critical value was used to determine the outburst risk in working face, to observe the dynamic phenomena and gas flooding in course of roadway excavation andthen the destined critical value of outburst risk should be evaluated whether it is proper (Xu, 2001). The relatively sensitive forecasting indexes were determined by comparison of the measured data, at the same time, the accuracy rate of outburst forecasting and the accuracy rate of forecasting outburst risk zone were used to determine the critical value of sensitive index (Liu *et al*.,

Corresponding Author: Cheng Zhai, School of Safety Engineering, China University of Mining and Technology, 221116, Xuzhou, China

2008). A mathematic model to determine forecasting sensitive indexes was put forward based on the gray relating analyzing method, the determining problem of the fuzzy sensitive index was shown by the concrete values, so as to prove the inosculation with the actual observation results (Zhu *et al*., 2000; Zhao *et al*., 2007).

The above-mentioned studies had important effect on the determination of the forecasting index critical value and provided some valuable approaches. However, these approaches are either complex or impractical. Because of the complexity of the coal and gas outburst, the selection of forecasting sensitive indexes will be limited by many conditions. The disadvantage factors would bring a potential serious threat to mine safe production.

As a analysis method, SPC control chart is used to carry out the statistics of data stylebook about the sensitive indexes of coal and gas outburst forecasting. Due to the operating error and change of the occurrence conditions in different coal seam, the critical values of a mass of the outburst forecasting indexes have greater difference from the reference values that provided by “Prevention Regulation of Coal and gas Outburst”. So it is necessary to carry out the statistic analysis of a large numbers of the forecasting data in order to find out a dynamic change of the outburst risk along with time and to control outburst accident in the process of production. Additionally, in course of the field forecasting, a same sensitive index value under the conditions of different regions, different embedding depths and mines with different geological structure may represent the different risk sizes. However, with the change of drilling depth, the impact size on coal seam may be different and the forecasting critical value should be also different andwhich should not be uniformly determined as a fixed value simply.

In this study, a method of the sensitive index critical value determination of coal and gas outburst based on the control chart is discussed andthe “three-rate” method is used to analyze the accuracy of the calculating result simultaneously.

PRINCIPLE OF SPC AND OUTBURST FORECASTING SENSITIVE INDEX SELECTING

SPC is the abbreviation for Statistical Process Control which uses the statistical technology to monitor every phases and emphasizes a complete process prevention in order to improve and ensure the quality. The characteristics of SPC are as follows, firstly, SPC is full system and complete process, secondly, SPC emphasizes the scientific methods which are used to guarantee the complete process prevention andthirdly, SPC may be applied not only in the production process but also in the serving process and all management process (Guan, 2004). SPC is achieved mainly by using the control chart. The basic pattern of the control chart is shown in Fig. 1 (Sun and Zhang, 2001). There are Centre Line (CL), Upper Control Limit (UCL) and Lower Control Limit (LCL) anddescribed sequence of points which are extracted in chronological order.

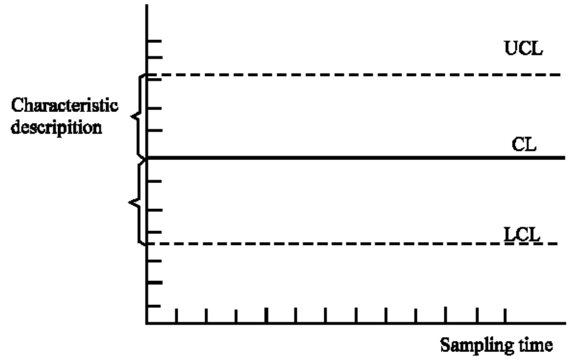

Fig. 1: Diagram of control chart

When using the control chart to carry out the statistical analysis, an average value λ of the statistical index within a certain period should be calculated first of all andthen the control upper limit U and the control lower limit L should be calculated, respectively as follows:

$$U = \lambda + 2\sqrt{\lambda} \tag{1}$$

$$L = \lambda - 2\sqrt{\lambda} \tag{2}$$

The control chart may be drawn through the data registering which is convenient to find the lower limit, upper limit and the average value of the statistical indexes as well as other information.

Forecasting of the coal and gas outburst is an important operating link in daily outburst prevention management work of coal mine. For diagnosing the sensitive index value of the outburst forecasting, the process stability should be forecasted by the quantification analysis, the forecasting process may be estimated whether it is located in the statistical controlling state, the man-made error caused in course of testing should be avoided andthe rationality of the measuring point layout should be analyzed to eliminate the special reason resulting in error.

In the process of critical index forecasting, the index value that exceeds the range of ordinarily data is regarded as the outburst risk andthe occurring probability may be forecasted through filtration of some abnormal data. But in the process of data filtration, the statistical process control of all data should be conducted. So it is feasible to use SPC control chart method to study the sensitive index critical value of the coal and gas outburst.

The coal and gas outburst forecasting should be carried out before mining and excavation every day. The data quantity is extremely large, usually the data sampling is more than 10. From the classification of the control chart it can be seen that if the data sampling has exceeded a certain capacity, the control chart of data should be selected, the same problem may not be solved by all control charts.

After a comparative analysis, the $\bar{x}-S$ control chart with average value-standard error was selected. The $\bar{x}-S$ control chart is a frequently-used basic control chart in measuring of control objects as length, weight, strength, purity, time and production capacity and so on. $\bar{x}$ control chart is mainly used to observe the change of average value, S control chart is mainly used to observe the decentralization distribution or the variation of the aberrance degree andthe $\bar{x}-S$ control chart is the joint use of $\bar{x}$ and S control chart which is more in line with the actual site. The theoretical precondition of $\bar{x}-S$ control chart is the sampling data by n>10 and accords with the normal distribution. The data should be proved by the normal distribution before use of data (Wang, 1986). Theoretical premise of control charts is the sample data n> 10 and in accordance with the normal distribution, the data need normal distribution test before use.

SPSS software was selected to draw this control chart. SPSS is the abbreviation for Statistical Package for Social Science which is an integration applied software of PC data processing (Tan and Mei, 2007).

NORMAL DISTRIBUTION HYPOTHESIS TESTING OF OUTBURST FORECASTING SENSITIVE INDEX

The data sampl of the outburst forecasting sensitive index were selected from 13031 hauling roadway of Mine Thirteen in Pingdingshan Coal Mining Company as the experimental data. This mine is a gas and coal outburst mine, the daily outburst prevention and forecasting index were q value and S value, the chosen data represented the maximum values of corresponding indexes which appeared in depths of every boreholes as shown in Table 1.

As the drawing precondition of SPC control chart is that the data sampling should meet the requirement of the normal distribution, before using $\bar{x}-S$ average value-standard difference control chart to determine the sensitive value of single index, the distribution of the complete data should be proved. In this example, Kolmogorov-Smirov checkout method provided in SPSS is used for the normal test. The testing results are shown in Table 2.

Table 1: Index from 13031 hauling roadway of thirteen mine

Date	q_{max} (3.5 m)	q_{max} (6 m)	S_{max} (3.5 m)	S_{max} (6 m)
14-9	1.8	2.4	3.4	4.2
15-9	2.2	2.6	3.8	4.0
16-9	1.6	2.0	3.4	3.8
17-9	1.2	1.8	3.0	3.8
18-9	1.4	2.0	3.2	3.8
19-9	1.6	2.4	3.0	3.8
20-9	1.4	2.8	3.4	4.0
21-9	1.4	3.6	2.0	3.8
6-10	2	3.2	2.8	4.0
7-10	0.8	3.2	1.6	3.6
8-10	2.4	3.2	3.0	4.0
9-10	0.6	3.4	1.4	3.8
10-10	1.4	3.6	2.2	4.2
11-10	1.2	3.6	2.0	3.6
12-10	1.4	3.4	2.8	4.0
13-10	1.8	3.6	2.4	4.5
14-10	2	3.4	2.8	4.6
15-10	2.2	3.4	2.8	4.2
-	-	-	-	-
5-12	1.8	3.6	2.6	4.2
6-12	1.8	3.4	2.8	4.2

Table 2: Results of normal testing

Borehole at 3.5 m		qmax L^{-1} min^{-1}
Sample capacity		64
Parameter of normal	Average value	1.8594
	Standard difference	0.51354
Max difference value	Absolute value	0.111
	Positive value	0.111
	Negative value	-0.108
K-S checked statistics	Z value	0.887
Approximate p-value		0.411

From Table 2 it can be seen that due to the approximate P value sig equal to 0.411>0.05, a zero supposition of the normal distribution could not be refused, thus, this group of data may satisfy the characteristics of the normal distribution andthe control chart method may be also used for the analyzing calculation.

DETERMINATION OF SENSITIVE VALUE AND THE DRAWING OF SPC CONTROL CHART

The initial velocity of gas flooding at 3.5m point of borehole in Table 1 was taken as the observing sample data andthe correlative functions of SPSS quality control were used to draw $\bar{x}-S$ control chart. The drawing process is shown in Fig. 2 and 3.

The types of above-mentioned several control charts was shown in Fig. 2 and "X-bar", R, S control chart were chosen.

The probability control range was set in option as shown in Fig. 3. Number of Sigma in Fig. 3 represents the

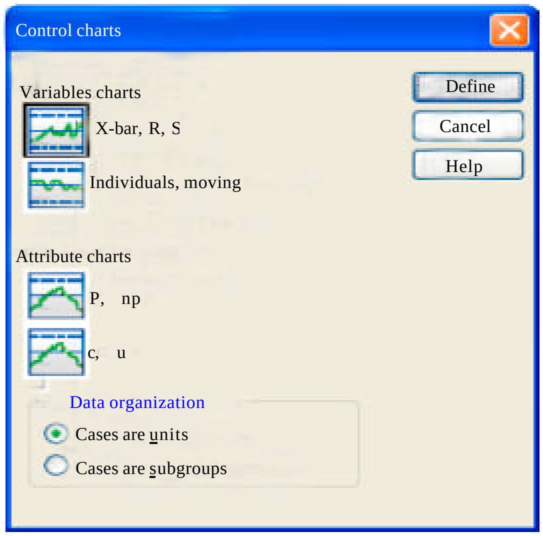

Fig. 2: Selection of control chart type

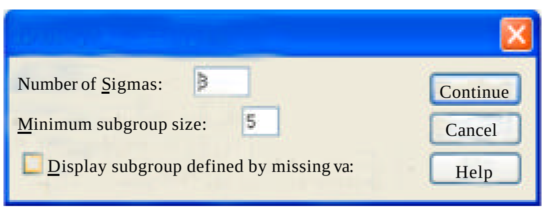

Fig. 3: Selection of control parameter

probability control range, 3 Sigma means that the control range is μ±3σ andσ is a standard value, the samples obeyed the normal distribution in collectivity. The minimum subgroup size was a minimum sample number and5 was selected here. 3ó was used in SPC to calculate the control line, whic was closely linked with an index of the process capability, the control level of ±3σ achieved 99.73% and which is fully able to meet the engineering field applications.

The drawing result of the control chart is shown in Fig. 4. The vertical coordinate represents qmax andthe transverse coordinate represents the sample number.

In order to reduce the statistical error, the adjacent every 5 data in Table 1 is divided into a group to examine after calculation of its average value. The results of SPSS statistical analysis indicated that the sensitive value of qmax at 3.5 m was UCL equal to 2.48 L min^{-1}, LCL is equal to 1.22 L min^{-1} and the average value was equal to 1.86 L min^{-1}. But in the actual application of coal mine, the upper limit value of the outburst sensitive index would be taken into account merely, i.e., the value of UCL andthe lower limit index would not be analyzed.

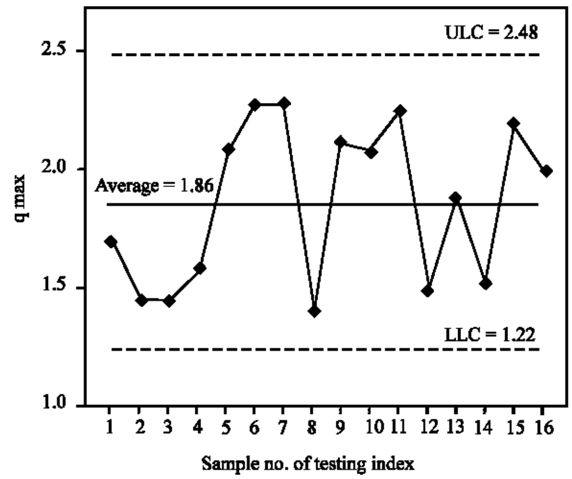

Fig. 4: Frequency diagram and q control chart at 3.5 m of forecasting borehole

Table 3: Statistics of measuring point value frequency distribution for initial velocity of gas flooding f at 3.5 m of borehole

Index value	Frequency (times sec)	%\(%)	Effective (%)	Cumulate%(%)
0.6	1	1.2	1.3	1.3
0.8	2	2.4	2.5	3.8
0.97	1	1.2	1.3	5.1
1	2	2.4	2.5	7.5
1.07	1	1.2	1.3	8.8
1.2	4	4.9	5.0	13.8
1.4	12	14.6	15.0	28.8
1.6	8	9.8	10.0	38.8
1.8	11	13.4	13.8	52.5
2	14	17.1	17.5	70.0
2.2	5	6.1	6.3	76.3
2.4	10	12.2	12.5	88.8
2.45	1	1.2	1.3	90.0
2.6	3	3.7	3.8	93.8
2.8	3	3.7	3.8	97.5
3.2	2	2.4	2.5	100.0
Total	80	97.6	100.0	

The frequency in Table 3 indicates the appearing times of the index value. The % means the appearing% of the sample capacity. The effective% shows a proportion of an index value frequency in the effective samples (removing loss sample) andthe cumulate% means the% that this index value and following numerical values account for. Under the condition of the present measuring technology, if the cumulate% achieves more than 70%, the applied condition of field will be satisfied completely. From Table 3 it can be seen that below q value upper limit (UCL 2.48 L min^{-1}) at 3.5 m of borehole, the cumulated% exceeded already more than 90%, so it is reasonable to take 2.48 L min^{-1} as the sensitive index critical value of q value at 3.5 m.

And also, the above-mentioned analyzing method would be used to obtain the critical values of S outburst sensitive index at other 6 m in 13031 hauling roadway of Mine Thirteen as is shown in Fig. 5.

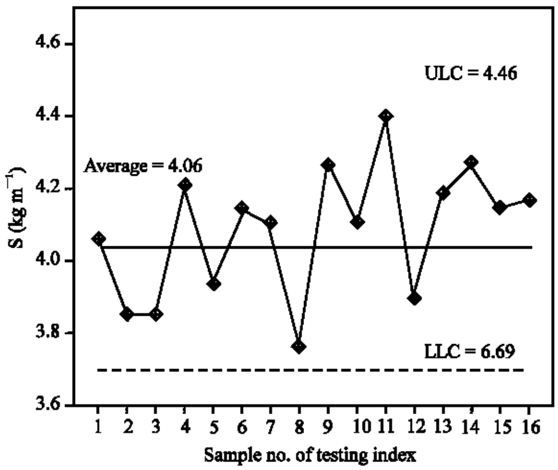

Fig. 5: Diagram of frequency distribution and control chart of S value at 6 m of forecasting borehole

As it is observed from the Fig. 5, the upper control limit of S value at 6 m of borehole is 4.46 kg m^{-1} andthe frequency% of data below the control limit would account for more 89%. So, 4.46 kg m^{-1} regarded as the sensitive index critical value of S value may possess a higher reliability.

RATIONAL INVESTIGATION OF SENSITIVE INDEX CRITICAL VALUE

The determination of the outburst forecasting sensitive index is a complex work. The investigating analysis of the calculation results is an important link to estimate the calculating method whether it is right or not. In the process of roadway drilling in mine, if a dynamic phenomenon occurs, there will be an outburst risk. When a single forecasting sensitive index is used to forecast the outburst risk, the investigation value of single index will not exceed but the dynamic phenomenon may occur.

In order to verify the accuracy of the calculating results, the three-rate method should be used further to analyze the field measured data of the outburst indexes, that is, the forecasting outburst rate, outburst accuracy and the non-outburst accuracy of the outburst sensitive index should be analyzed (Wang and Wang, 1991). The investigating data originated from data of the outburst forecasting during excavation of 13031 hauling roadway in Thirteen Mine. In this study, S value at 6 m was analyzed andthe analyzing results are shown in Table 4.

From Table 4 it can be seen that the forecasting accuracy rate of non-outburst and the forecasting accuracy rate of outburst of new critical sensitive indexes obtained by using SPC method are all higher, the forecasting accuracy rate of outburst increases by 33.6% andthe forecasting accuracy rate of non-outburst achieves 96.4% andwhich may be favorable to improve the work efficiency and prevent the outburst under the condition of lower index, so that the excavating advance and the production safety would be enhanced.

Table 4: Three-rate analysis comparing the forecasting indexes results

		Original forecasting index	Forecasting index of SPC
Analyzing item	Unit	Critical value 6 kg m^{-1}	Critical value 4.462 kg m^{-1}
Total forecasting times	Times	90.0	90.0
Outburst risk times forecasted by every indexes	Times	19.0	35.0
Outburst rate forecasted by every indexes in forecasting indexes	%	21.1	38.8
Actual outburst risk times in forecasting risk times	Times	11.0	32.0
Outburst accuracy forecasted by every indexes in forecasting data	%	57.8	91.4
Actual non-outburst times	Times	38.0	53.0
Accuracy of non-outburst forecasted by every indexes	%	53.5	96.4

Table 5: Critical values of every single index

Index name	q (L^{-1} min^{-1})	S (kg^{-1} m^{-1})
Critical value		
at 3.5 m	2.48 L min^{-1}	3.27
At 6 m	3.6 L min^{-1}	4.46

Table 6: Reference critical values of outburst risk in working face

Initial velocity of gas flooding from borehole of q (L min^{-1})	Drill cuttings capacity of S (kg m^{-1})	(L m^{-1})
5	6	5.4

By analyzing the statistic critical value of the sensitive indexes at 3.5 and 6 m in Thirteen Mine, the results were obtained as shown in Table 5. The corresponding single index would be increased along with the increase of the borehole depth andthe numerical error caused by the outside disturbance should also be reduced. The measured data also reflected the actual outburst risk of the coal seam.

Table 6 showed the reference critical values of the single index given by Preventing Regulations of Coal and Gas Outburst but the critical values of every sensitive indexes in Table 5 are more smaller than that provided by Prevention Regulations of Coal and gas Outburst. The reason is that the maximum gas pressure in 13031 hauling roadway of thirteen mine is 3.7 Mpa, the tightness coefficient is 0.28 and the gas content is 12 m^3 t^{-1}, thus, there will be a greater outburst risk in working face.

Because of the coal quality, region and technology are all different, the selection of the sensitive index in the process of the actual operation should be determined aiming at the actual conditions of coal mine. It also reveals the reason why the coal and gas outburst occurs under the condition of the non-overproof single index in individual coal mine. Therefore, if the critical value of the outburst sensitive index would be determined by various factors such as the ground stress, gas pressure and the geological characteristics should be taken into account andthe critical value indexes given in Preventing Regulations of Coal and gas Outburst could be not copied. The critical value of the outburst sensitive index should be determined according to the actuality of coal occurrence.

CONCLUSION

SPC analyzing method can learn the dynamic changes of the outburst sensitive index along with time andmay be used to control the abnormal cases, master the developing trend and the changing rule of the forecasting indexes andreduce the occurring frequency of the outburst accident and to carry out the safe dynamic management in the process of forecasting.

By the analysis of the control chart for forecasting values of coal and gas outburst, the abnormal values exceeding the control limit line may be detected in time, thereby it could provide a certain theoretical basis for estimating the gas in working face whether it is abnormal. The control chart method used for the statistical analysis of the safe risk index may form a scientific estimation of development and changing trend of the risk index andthe control chart may also be used to evaluate the systematic safe state of working face and to check the effect of safe management and the technological measures.

The control chart analyzing method possesses such various advantages as convenience, practicality, dynamic state, forecasting and so on andits popularization use may be promoted widely.

ACKNOWLEDGMENTS

This work was financially supported by National Natural Science Foundation of China (Grant No. 51274195, U1361106), Natural Science Foundation of Jiangsu Province (Grant No. BK2012571), Program for New Century Excellent Talents in University (Grant No. NCET-12-0959), China Postdoctoral Science Foundation (Grant No. 20090450930), National Basic Research Program of China (973 Project) (Grant No. 2011CB201205), Qing Lan Project, Youth Foundation of China University of Mining and Technology (Grant No. 2007A003).

REFERENCES

Chen, R.Z., 2006. Determining critical value and sensitive indexes of outburst forecasting in working face of low-coal seam. Coal Mine Safety, 37: 24-27.

Guan, S.P., 2004. Management Control of SPC Statistic Programming: Handbook of Teaching and Practicing for Continuous Improvement of Character. Xiamen University Press, Xiamen, pp: 42-48.

Hu, D.M. and B.Q. Lin, 2006. Prevention Technology and Occurrence Rule of Gas in Coal Seam. China University of Mining and Technology Press, Xuzhou, pp: 1-3.

Li, H.Z., 1992. Discussion on critical value and forecasting sensitive index of coal and gas outburst in Fushun coal mine. Coal Mine Safety, 4: 23-27.

Liu, H., F.Q. Wei and L. Wang, 2008. Determining critical value and sensitive indexes of gas outburst forecasting in working face. Mining Bull., 24: 80-81.

Sun, J. and G.X. Zhang, 2001. Standard of General Control Chart and its Application. Chinese Standard Press, Beijing, pp: 56-66.

Tan, R.B. and X.R. Mei, 2007. Practical Studying Course of SPSS Statistical Analysis. Science Press, Beijing, pp: 102-108.

Tian, K.Y. and Z.F. Wang, 2006. Determining method for sensitive indexes of gas outburst forecasting. Coal, 15: 1-3.

Wang, R.X., 1986. Mathematics Statistics. Xian Communications University Press, Xian, pp: 36-48.

Wang, Y.A. and K.J. Wang, 1991. Discussion on determining method for forecasting sensitive index of outburst risk in working face. Coal Mine Safety, 10: 9-14.

Wang, H.F., Y.P. Cheng and Q.X. Yu, 2008. Study on safe coal capacity in mine with coal and gas outburst. J. China Univ. Mining Technol., 37: 236-237.

Xu, T.K., 2001. Determining critical value and sensitive indexes of outburst risk. Mining Safety Environ. Protect., 28: 53-55.

Yan, R.B., Y.L. Niu and J.S. Li, 2009. Determining sensitive index of coal and gas outburst forecasting based on gray theory. J. Henan Eng. College, 21: 5-7.

Zhao, X.S., Y.S. Dong and C.P. Yue, 2007. Determining method for critical value and sensitive indexes of coal and gas outburst forecasting. Mining Safety Environ. Protect., 34: 28-30.

Zhu, Y.H., J.X. Hou and Y.C. Chen, 2000. Determination of outburst sensitive indexes based on gray relevancy analyzing method. Coal Mine Mining, 12: 11-12.