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Calculation Model of Safety Level of Production Logistics System in Coal Mine

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Abstract: Many factors affecting the safety of production logistics system of coal mine and the impact of these factors on the safety degree is not consistent, this study determines the safety indicators from five aspects, such as, the personal quality, mechanical equipment, environment, safety management and emergency rescue, etc. This study fitted the interaction of safety indicator and safety level by using the polynomial model and constructing security level calculation model through the analysis of regression model and its coefficient. This article proposes a method of calculating the safety production level of coal mine by using polynomial model, this method helps to indicate direction for analyzing safety production status and raising safety level of coal mining enterprise.

Key words: Production logistics of coal mine, safety indicators, safety level, psolynomial model

INTRODUCTION

Coal is the lifeblood of the National economy, the widely used of coal has made and will continue to make great contribution for promoting the process of our national economy construction and raising people's living standard. Otherwise, comparing with other industries, coal production has its obvious characteristics which is mainly the transform of physical form (Mining and Crushing) and changes of space position (underground and ground transportation) and the variety of materials and material flow such as equipment, materials, wind and water in the mining process constituting production logistics system of coal mine, the particularity and complexity of production logistics system of coal mine determines the coal industry is the most serious casualty accidents in China's industrial production industry. The safe state of coal mine in our country has long been changed over time, the level of safety production is not stable, so how to calculate the coal mine safety level scientifically and reasonably has great significance of analyzing the safety status of coal mining enterprises in our country and improving the level of safety production.

At present, most of research on security of the production logistics system of coal mine focused on the aspect of safety evaluation and prediction, including the selection and application of method, evaluation indicator and model constructing, safety evaluation method including the method of neural network in the field of operational research, fuzzy comprehensive evaluation method, gray comprehensive evaluation method, Analytic Hierarchy Process (AHP) and the factor analysis and cluster analysis method in the field of mathematical statistics. Tan and Li (2011) solves the problem of coal mine safety using the extension theory, constructing comprehensive evaluation indicator system of coal mine security and matter-element model of coal mine based on the analysis of factors affecting safety production; He gang (He *et al*., 2008), etc, predict the key factors of people's safety behavior by using system dynamics, building the level model of people's safety behavior indicator in the process of coal production, the simulation results show that this model helps to reducing the accident rate of coal mine and improve the safety level of coal mine production; Pang cheng, Xu yang, Liu, etc (Cheng, 2011; Xu *et al*., 2009; Liu *et al*., 2007), building the evaluation indicator system of coal mine security from the aspects of people, machine, environment and management, meanwhile and doing quantitative analysis on coal mine security adopting the method such as fuzzy comprehensive judgment method, grey clustering analysis method, extension theory and Support Vector Machine (SVM) method, etc.

The changeable geological environment and complicated mining method determines that there are many factors affecting the safety of coal mine production logistics, the impact of these factors on the safety degree is not consistent and these factors have dynamic and nonlinear characteristics, while polynomial model has more powerful approximation ability, it can form fitting many complicated functions (Mosleh *et al*., 2011; Kukush *et al*., 2005; Sekido, 2012) Therefore, this studyr fit the interaction of safety indicator and safety level by using the polynomial model and constructing securitylevel calculation model.

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SAFETY INDICATOR OF PRODUCTION LOGISTICS SYSTEM OF COAL MINE

Due to the complexity of coal production process, the multiple attribute, the changing environment over time, the complexity of the fuzzy characteristics of the technological process, combine with its particularity and general in industry, lead to many influence factors of coal mine production logistics, the security indicators can be divided into five parts based on the principles of scientific, comprehensive, comparable, etc from the man-machine-ring-tube in four sections which including personal quality X_1, mechanical equipment X_2, environment improvement X_3, safety management X_4, emergency rescue X_5.

- **Personal quality X_1:** Pushing the process of coal mine safety production and personal quality coordinated development is the main topics of the coal producting enterprises. the comprehensive quality of workers can be improved by increasing the financial input in homework personal, carrying out safety education training
- **Mechanical equipment X_2:** The production of coal mining, excavation, transportation, ascension in coal mine production, ventilation, drainage, drilling equipment such as machinery and equipment (that is, the coal mine production logistics system) level of coal mine production capacity decision, improve the level of machinery equipment, strengthening daily maintenance management, to carry out the maintenance personal skills training having great influencing on promoting the safety production
- **Environmental improvement X_3:** Creating a safe and comfortable working environment not only can reduce fatigue and people's unsafe behavior, reduce the happening of accident but also can improve the efficiency of coal mine production. Badly coal mine production conditions and the workplace as coal mining and tunneling changing, always facing the threat of water, fire, gas, roof pressure and other disasters which is very important from to ensure coal mine safety production from two aspects of natural environment and working environment
- **Safety management X_4:** safety management is a decision to implement coal mine safety production, plan, organize and control activities. The prevention of coal mine production accident and the improvement of the level of safety in production can be worked by making safety norms, strengthening the management of safety culture, analyzing of coal mine production process of all kinds of unsafe factors, taking effective measures to control it
- **Emergency rescue X_5:** The production logistics system of coal mine has the characteristics such as complexity and uncertainty, there are all kinds of hazards in mining process and it is very important to establish and improve the emergency rescue system, be equipped with the emergency rescue equipment, training and rehearsal of emergency rescue

Table 1: Multiple linear regression data

Response	Affecting variables			
y_1	x_1	x_2	-	x_k
y_2	x_{11}	x_{21}	-	x_{k1}
-	-	-	-	-
y_n	x_{1n}	x_{2n}	-	x_{k13}

CALCULATION MODEL OF SAFETY LEVEL

Basic principle of polynomial regression: In most problems, the function relationship between independent variable and the response can be expressed by first order or second order model. If the dependent variable is applicable to the independent variable in the process of linear function modeling, the approximating function can use first order model (Francisco-Fernandez *et al.*, 2004).

$$y_s = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon \tag{1}$$

If the system is more complicated and bending, the approximation function between the dependent and independent variables can adopt high order polynomial, for example, the second order model is very complicated due to its own function, it can fit a lot of functional form and has widely used in practice (Chen, 2011; Liu and Tan, 2012).

$$y_s = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{k} \sum_{j=1, i<j}^{k} \beta_{ij} x_i x_j + \sum_{i=1}^{n} \beta_{ii} x_i^2 + \varepsilon \tag{2}$$

Equation 1 indicates that the first-order regression model belongs to the multivariate linear regression problem, assuming there are n observed values (n>k), the date x_{ij} present j observed value of variable X_i, as shown in Table 1.

So, the first order model-Eq. 1 can be expressed as:

$$\begin{aligned} y_j &= \beta_0 + \beta_1 x_{1j} + \beta_2 x_{2j} + \cdots + \beta_k x_{kj} + \varepsilon_j \\ &= \beta_0 + \sum_{i=1}^{k} \beta_i x_{ij} \end{aligned} \tag{3}$$

Dimensionless processing of observed value, Eq. 3 can be expressed used as matrices:

$$Y = X\beta + \varepsilon \tag{4}$$

Using least squares estimation vectors can be obtained:

$$\hat{\beta} = (X'X)^{-1}X'Y \tag{5}$$

For the sec order regression model, assuming the influence variable of a system as (x_1, x_2, x_k), the response variable is y, the matrix expressions of Eq. 2 are as follows:

$$Y = \beta_0 + X'b + X'BX + \varepsilon \tag{6}$$

Using each coefficient of the least squares estimate (3.11), assuming the fitted second order model is as follows:

$$Y = \beta_0 + X'b + X'BX \tag{7}$$

While,

$$b = (X^{m'}X^{m})^{-1}X^{m'}Y \tag{8}$$

CALCULATION MODEL OF SAFETY LEVEL

Data collection and dealing: Considering the characteristics of each coal mine and regional characteristics, this article selects 20 typical coal mines as the empirical object, obtaining resource investment of each coal mine from 2008 to 2009 through investigation, inviting experts on the coal mine pits in grade and comprehensive grade, as shown in Table 2.

Due to the coal mine safety production level is difficult to quantify directly, in this study, coal mine safety production level is defined as four levels, according to the expert scoring method divided interval (60 ~ 100), respectively, for the best production safety level (90~100), better safety level (80~89), general safety production level (70 ~ 79), no t safe production level (60~69).

According to the safety indicators of coal mine production logistics, using second-order polynomial model fitting production safety level, using the least squares estimates the parameters in the model, testing the effectiveness of model from the analysis of variance, regression coefficient, significant inspection, etc and to correct the model until the coal mine safety production level fitting values are in conformity with actual conditions (Duan and Duan, 2012).

$$y_s = \beta_0 + \sum_{i=1}^{5}\beta_i x_i + \sum_{i=1}^{5}\sum_{j=1,i<j}^{5}\beta_{ij}x_i x_j + \sum_{i=1}^{5}\beta_{ii}x_i^2 + \varepsilon \tag{9}$$

In the Equation. 4, the linear item β_i x_i press the linear effect the influence on the variable Xi to the safety level of coal mine production logistics; Squared item β_{ii} x_i^2 express the squared influence on variable Xi to the safety level of coal mine production logistics; the interactive item $\beta_{ij}x_i$ x_j press the interactive influence on variable Xi and variable Yi to the safety level of coal mine production logistics; ε express error term, obey normal distribution N (0, Q^2).

Regression model and factor analysis: It summarizes the personnel quality, mechanical equipment, environmental improvement and the analysis of variance including the linear term, square and interaction term of emergency rescue in Table 3. Among them, the factors of linear variance proportion is small, the linear term P value is 0.108 which indicates that the factors linear item has unconspicuous significant effects on the coal mine safety level; while the squared term and interaction of each factor has large proportion, P value of the squared (p = 0.026) and P values of the interaction (p = 0.009) is small, suggesting that the interacting factors squared and has significant effects on coal mine safety level, the coal mine production logistics security level response surface is bent. For the sec order model, the lost fitting P value is 0.203, it shows that the second-order model can fully fitting data and the model is more reasonable.

The safety hard constraints estimated regression coefficients of coal mine production logistics is summarized in Table 4. Results show that the effect on interaction of the personnel quality and safety management, the machinery and equipment and safety management, personnel quality and the mechanical

Table 2: Coal mine safety indicator and safety level

Coal mining enterprise	First year					……	Second year				
	X_1	X_2	……	X_n	Safety level	……	X_1	X_2	……	X_n	Safety level
1	X_{111}	X_{121}	……	X_{1n1}	Y_{11}	……	X_{11t}	X_{12t}	……	X_{1nt}	Y_{1t}
2	X_{211}	X_{221}	……	X_{2n1}	Y_{21}	……	X_{21t}	X_{22t}	……	X_{2nt}	Y_{2t}
……	……	……	……	……	……	……	……	……	……	……	
m	X_{m11}	X_{m21}	……	X_{mn1}	Y_{m1}	……	X_{m1t}	X_{m2t}	……	X_{mnt}	Y_{mt}

Table 3: Model analysis of variance

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Regression	20	213.2	213.2	10.7	5.77	0.012
Linear	5	23.3	13.7	2.74	2.60	0.108
Square	5	66.2	36.2	7.24	4.82	0.026
Interaction	10	123.7	123.7	12.37	6.46	0.009
error						
Residual	39	53.5	53.5	1.37	-	-
Unfitted	9	38.6	38.6	4.29	3.12	0.203
Pure error	30	14.9	14.9	0.50	-	-
In total	59					

Table 4: Model regression coefficient

Source	Coefficient	Coefficient of standard deviation	t-value	p-value
Constant term	-16.64	20.66	-0.805	0.425
Personal quality	-258.34	62.77	-4.116	0.000
Mechanical equipment	330.36	131.52	2.512	0.016
Environmental improvement	-22.39	24.52	-0.913	0.057
Safety management	194.07	135.94	1.428	0.032
Emergency rescue	-272.21	56.23	-4.841	0.000
Personal quality * personal quality	304.01	211.00	1.441	0.158
Mechanical equipment * mechanical equipment	-191.77	96.18	-2.015	0.051
Environmental improvement * environmental improvement	-80.78	31.27	-2.583	0.014
Safety management*safety management	-209.23	166.99	-1.253	0.218
Emergency rescue * emergency rescue	197.75	81.49	2.427	0.020
Personal quality * mechanical equipment	1339.27	503.83	2.658	0.131
Personal quality * environmental improvement	-289.35	53.68	-5.391	0.000
Personal quality * safety management	-263.49	442.44	-0.596	0.215
Personal quality * emergency rescue	-1222.67	300.31	-4.071	0.000
Mechanical equipment * environmental improvement	385.51	76.37	5.048	0.000
Mechanical equipment * safety management	-236.42	205.83	-1.149	0.258
Mechanical equipment * emergency rescue	-653.00	176.29	-3.704	0.001
Environmental improvement * safety management	-346.88	98.28	-3.224	0.003
Environmental improvement * emergency rescue	224.32	49.54	4.528	0.000
Safety management * emergency rescue	1058.99	235.52	4.496	0.000

equipment is inconspicuous. The P values to the security level of coal mine production logistics are 0.215, 0.131, 0.258. Further analysis, Although the intensity of personnel training, management ability, equipment advanced degree affects the coal mine safety level but as the coal legal system mechanism in our country has been more and more perfect, the basis management of coal mine safety get continuous improvement, the safety training of enterprise managers is continuously strengthened, the support ability of equipment and technology has been enhanced obviously, the degree of interaction between the personnel quality and safety management, machinery equipment and safety management to the improving of overall security level has been gradually weakened, so their interaction effect is not obvious. While the P values of the remaining two interactions between the two variables were less than 0.05, it shows that the interaction of the remaining variables to the overall security level has the significance, thus it needs to fully consider the interaction of these variables for further improving the level of coal mine safety of coal mining enterprises.

CALCULATION MODEL

Thus the calculation model of safety level of production logistics system of coal mine is as follows:

$$\begin{aligned} y_s = & -16.64 - 258.34x_1 + 330.36x_2 - 22.39x_3 + 194.07x_4 - 272.21x_5 + 304.01x_1^2 \\ & - 191.77x_2^2 - 80.78x_3^2 - 209.23x_4^2 + 197.75x_5^2 + 1339.27x_1x_2 - 289.35x_1x_3 \\ & - 263.49x_1x_4 - 1222.67x_1x_5 + 385.51x_2x_3 - 236.42x_2x_4 - 653x_2x_5 \\ & - 346.88x_3x_4 + 224.32x_3x_5 + 1058.99x_4x_5 \end{aligned} \tag{10}$$

Through the above calculation model, it can calculate the safety level of production logistics system of coal mine according to the real-time production situation of each indicator. it can also reflect the function relationship between the safety indicator and safety level of coal mine and can judgment of the safety production status of coal mine.

CONCLUSION

This study proposes a method using a polynomial model to calculate the coal mine safety production level.

Determining the safety indicators from the personal quality, mechanical equipment, environment, safety management and emergency rescue five aspects, by using the polynomial model fitting the relationship between the safety indicators and safety level of the role, through the analysis of regression model and its coefficient, building the security level calculation model, the analysis for coal mining enterprise safety production status, raise the level of safety foundation, also indicate the direction of the allocation of resources to achieve security.

However, the process of coal mine production is affected by many factors and the impact on safety degree changed over time, as a result, it still needs further research on safety level of production logistics system of coal mine from the perspective of temporal dynamics.

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REFERENCES

Chen, G.H., 2011. Sample estimate based on local polynomial regression method. Stat. Decis., 4: 4-6.

Cheng, P., 2011. Study on coal mine dust safety evaluation system. Mining Safety Environ. Prot., 38: 76-78.

Duan, S. and F. Duan, 2012. Grid electricity sales forecasting method based on polynomial regression function. Math. Pract. Theory, 18: 76-81.

Francisco-Fernandez, M., J. Opsomer and J.M. Vilar-Fernandez, 2004. Plug-in bandwidth selector for local polynomial regression estimator with correlated errors. Nonparametric Stat., 16: 127-15

He, G., G. Zhang and Q. Chen, 2008. A System Dynamics (SD) simulation analysis on the influencing factors of human behavior in coal mine work safety. China Saf. Sci. J., 9: 43-47.

Kukush, A., H. Schneeweiss and R. Wolf, 2005. Relative efficiency of three estimators in a polynomial regression with measurement errors. J. Stat. Planning Inference, 127: 179-203.

Liu, T. and J. Tan, 2012. Unit root test of series with nonlinear trend based on local polynomial regression. J. Quant. Tech. Econ., 8: 137-149.

Liu, Y.J., S.J. Mao, M. Li and J.M. Yao, 2007. Study of a comprehensive assessment method for coal mine safety based on a hierarchical grey analysis. J. China Univ. Mining Technol., 17: 6-10.

Mosleh, M., M. Otadi and S. Abbasbandy, 2011. Fuzzy polynomial regression with fuzzy neural networks. Applied Math. Modelling, 35: 5400-5412.

Sekido, H., 2012. An algorithm for calculating *D*-optimal designs for polynomial regression through a fixed point. J. Stat. Planning Inference, 142: 935-943.

Tan, H.Y. and J.Y. Li, 2011. Coal mine safety comprehensive evaluation based on extension theory. Proc. Eng., 26: 1907-1913.

Xu, Y., Y. Zhou, X. Sun and Y. Yue, 2009. Synthesized assessment method for coal mine safety based on fuzzy analytic hierarchy process. China Safety Sci. J., 19: 147-152.