Evaluation on Safety Investments of Mining Occupational Health and Safety Management System Based on Grey Relational Analysis

Jiangdong Bao, Jan Johansson, and Jingdong Zhang

***Abstract*—In order to effectively evaluate the relationship between safety investments and accident impact losses in the mining occupational health and safety management system, a grey relational analysis model is established. Firstly, 4 first-grade indicators including safety technical measures fee etc. and 23 second- grade ones including ventilation system etc. are established. Secondly, by calculating the grey relational analysis between the variables of the data sequence and the system characteristic variables, analysis results of advantages and the evaluation ones are obtained. Finally, the model is validated by case study. The results demonstrate that the investments of safety technical measures and safety management and training have a great impact on the accident losses. The quantitative analysis of safety investments and losses is realized by the model, which provides the direction for the enterprise's strategic investments and reduces the economic losses.**

***Index Terms*—Mining, OHSAS18001, safety investments, accident losses, grey relational analysis.**

I. Introduction

Safety production of mining enterprises is a topic of much concern, for many years, China's mining accidents occur frequently, resulting in immeasurable personnel death and economic losses, insufficient safety investments. Among them, insufficient safety investments [1] are an important reason that leads to frequent mining accidents. Although almost all of the mining are in accordance with the occupation health and safety management system (OHSAS18001), there are a lot of blindness in mining safety investments required for system operation, many of which are passive investment, lack of safety investments allocation of scientific rationality. Feasible grey relational analysis method used in this paper provides a clear goal for mining safety investments and a reasonable allocation for safety resources of mining enterprises. Additionally, it plays an important decisive role in the analysis of accident losses [2]-[4].

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II. Mining Occupational Health and Safety Management System Safety Investments Indicator

According to the OHSAS18001 [5] standard terms of 4.4.1 Resources, roles, responsibility, accountability and authority, 4.4.2 Competence, training and awareness, 4.4.6 Operational control, 4.4.7 Emergency preparedness and response and 4.5.1 Performance measurement and monitoring, four safety investments indicators of mining OHSAS18001 are established. They include the following: safety technical measures, industrial hygiene measures, safety management and training and labor protection products [6].

A. Safety Technical Measures

They are to prevent casualty accidents such as ventilation system, protection device, insurance device, signal device etc.

B. Industrial Hygiene Measures

They refer to the technical measures of improving the production environment which is harmful to the health of workers and preventing poisoning and occupational diseases. They include dust, anti-virus, anti vibration and noise, ventilation, cooling, cold and other equipment or facilities etc.

C. Safety Management and Training

They include hardware and software equipment, technical services, training, three levels of safety education, occupation health examination of employees, all kinds of emergency supplies and training etc. They can ensure the OHSAS18001 runs smoothly.

D. Labor Protection Products

They are the necessary housing and all labor hygiene protection measures such as shower room, changing room or clothing room, disinfection room, women's health room, etc. for dust and poison operation workers.

III. Grey Relational Analysis Model of Mining Occupational Health and Safety Management System Safety Investments

The grey system theory was created and developed by Chinese scholar Professor Deng Julong [7], [8] in 1880s. The grey system theory has been successfully applied to industrial, agricultural, social, economic and other fields for more than 20 years, and many practical problems of production, life and scientific research are solved.

Grey system is the one that information is not fully known, that is, partial information is known and some information is

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unknown. Grey relational analysis is an important part of grey system theory, which is a method of analyzing the correlation degree of each factor in the system. The method is to calculate the grey relation between the variables of the data sequence and the system characteristic variables, and analysis results of advantages and the evaluation ones are obtained [9]-[11].

At present, the calculation model of judging the grey relation between the sequences is the following [12]. Deng Relational Analysis [13], B-Mode Relational Analysis [14], C-Mode Relational Analysis [15], T's correlation Degree [16], Generalized Degree of Grey Incidence [17], absolute correlation degree [18], Grey Euclid Relation Grade [19]. The common method of Deng Relational analysis method is used in this paper.

A. Determining the Number of Analysis Sequence

Select reference series and let $X=\{x_0,x_1,\cdots,x_m\}$ be grey relational factor set, x_0 be a reference sequence, x_i be a comparison sequence, and $x_0(k)$, $i=\{1,2,\cdots,m\}$ $x_i(k)$ be the K point number of x_0 and x_i as shown below.

$$\begin{aligned} x_0 &= (x_0(1), x_2(2), \cdots, x_0(n)), \\ x_1 &= (x_1(1), x_1(2), \cdots, x_1(n)), \\ x_2 &= (x_2(1), x_2(2), \cdots, x_2(n)), \\ &\dots\dots \\ x_m &= (x_m(1), x_m(2), \cdots, x_m(n)) \end{aligned} \tag{1}$$

B. Non Dimensional Variables

Various factors of the data in the column may be different due to the dimension, so it is not easy to get the correct conclusion when in comparison. The data is generally performed by non dimensional treatment when the grey relational analysis is carried out.

$$x_i(k)=\frac{x_i(k)}{x_i(1)},\ \mathrm{k}=1,2,\ldots\mathrm{n};\mathrm{i}=1,2,\ldots\mathrm{m} \tag{2}$$

C. Calculating the Relational Coefficient

The relational coefficient of $x_0(k)$ and $x_i(k)$ is shown below.

$$\zeta_i(k)=\frac{\min_i\min_k\left|X_0(k)-X_i(k)\right|+\rho\max_i\max_k\left|X_0(k)-X_i(k)\right|}{\left|X_0(k)-X_i(k)\right|+\rho\max_i\max_k\left|X_0(k)-X_i(k)\right|} \tag{3}$$

$$r(x_0(k),x_i(k))=\frac{\Delta_{\min}+\rho\ \ \Delta_{\max}}{\Delta_{0i}(k)+\rho\ \ \Delta_{\max}} \tag{4}$$

In the Formula, $\Delta_{0i}(k)=\left|x_0(k)-x_i(k)\right|$ is the absolute difference, $\Delta_{\min}=\min_i\min_k\Delta_{0i}(k)$ is the minimum difference between two poles, $\Delta_{\max}=\max_i\max_k\Delta_{0i}(k)$ is the maximum difference between two poles, ρ is the resolution ratio, $\rho\in(0,1)$ (remarks: ρ value normally equals 0.5 in actual calculation.), and ω_k is the weight of K point number which satisfies $0\le\omega_k\le1,\sum_{k=1}^{n}\omega_k=1$.

D. Calculating Grey Relation

Because the relational coefficient is the degree value at all times (that is, each point of the curve) between comparison sequence and reference sequence, and there is more than one value, the information is too scattered for the overall comparison. Average value is treated as the degree value between comparison sequence and reference sequence, and r_i formula of the relational coefficient is as follows.

$$r_i=\frac{1}{n}\sum_{k=1}^{n}\zeta_i(k) \tag{5}$$

E. Grey Relation Ranking

Normally, if $r(x_0,x_i)>r(x_0,x_j)$, the relation of x_i and x_0 is higher than that of x_j and x_0. That is to say, the Influence degree of x_i on x_0 is higher than that of x_j on x_0.

IV. Case Study

The mining is located in the Southwest of the Hubei Province of China, and it has general hydrogeological conditions. Additionally, OHSAS18001 has been utilized for more than three years. As a result, it has a good reputation in the society and the local community. Utilizing the mining as an example, this paper evaluates and analyses the safety investments and losses of OHSAS through grey relational analysis.

A. Safety Investments and Losses Statistics

As shown in Table I, the 4 first-grade indicators of the mining safety investments are refined to 23 second-grade indicators. Quantified statistical information of safety investments from 2011 to 2015 is selected. In the comparison sequence of safety investments, the indicators of accident losses from 2011 to 2015 are selected including the direct accident losses of the first-grade indicator and accident property losses etc. of second-grade indicator. Common total accident losses algorithm is the 1:4 direct and indirect ratio method of Heinrich [20] from the United States and total losses method of Symonds [21] accidents from the United States which can be calculated by

$$\begin{aligned} Total\ loss = (&Covered\ losses + A\times Laying-off\ injury\ times \\ &+ B\times Hospitalization\ injury\ times \\ &+ C\times Emergency\ medical\ times \\ &+ D\times No\ accident\ times) \end{aligned}$$

In the formula, A, B, C and D refer to the average amount of non insurance costs which stands for a variety of different degree of injury accident. Due to the limited space, accident indirect losses are not evaluated in this paper.

TABLE I: SAFETY INVESTMENTS AND LOSSES STATISTICS OF OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEM IN SOME MINING (UNIT: TEN THOUSAND)

First-grade indicator	Second-grade indicator	2011	2012	2013	2014	2015
1Safety technical measures	Ventilation system	45.5	47.3	44.3	55.3	57.1
	Protection device	22.4	30.8	28.6	31.2	33.4
	Insurance device	28.5	40.5	41.3	40.2	41.3
	Signal device	31.1	30.9	28.4	56.5	58.1
	Others	5.9	7.7	2.5	6.6	7.5
2 Industrial hygiene measures	Dustproof device	3.1	3.4	2.8	2.8	3.2
	Anti noise and vibration	1.4	1.6	1.3	1.4	1.5
	Gas defense	1.1	1.4	1.1	1.5	1.4
	Ventilation, cooling, and cold proof	2.1	2.6	1.5	1.7	1.7
	Others	1.0	0.5	0.6	0.7	1.1
3 Safety management and training	OHSAS operating	29.8	33.5	29.7	35.4	36.6
	Specific type of worker training	2.8	2.9	2.6	2.9	2.9
	Three levels of safety education	0.8	0.8	0.8	0.8	0.8
	Occupational health examination	22.0	27.4	24.1	28.1	28.8
	Emergency rescue	21	21.9	19.5	22.7	24.3
	Others	2.3	2.6	2.2	2.4	2.4
4 Labor protection products	Individual protection	22.4	25.5	24.1	33.2	36.7
	Special protection	37.4	40.2	40.1	51.2	52.2
	Others	7.8	11.1	6	4.2	6.2
Direct accident losses	Accident property losses	8.5	8.9	10.8	14.5	10.1
	Accident disposal	65.3	65.7	61.4	67.9	68.9
	Occupational disease Prevention	14.3	14.5	14.2	14.6	14.9
	Others	1.2	1.3	1.1	1.3	1.4

B. Establishing Reference Sequence and Comparison Sequence

As shown in Table II, reference sequence is 0.Direct accident losses. Comparison sequence is as follows. 1. Safety technical measures. 2. Industrial hygiene measures. 3. Safety management and training. 4. Labor protection products.

TABLE II: THE ORIGINAL SEQUENCE OF SAFETY INVESTMENTS AND LOSSES STATISTICS IN THE OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEM (UNIT: TEN THOUSAND)

Indicators	2011	2012	2014	2014	2015
0.Direct accident losses	89.3	90.4	87.5	98.3	95.3
1.Safety technical measures	133.4	157.2	145.1	189.8	197.4
2. Industrial hygiene measures	8.7	9.5	7.3	8.1	8.9
3. Safety management and training	78.7	89.1	78.9	92.3	95.8
4.Labor protection products	67.6	76.8	70.2	88.6	95.1
Total safety investments	288.4	332.6	301.5	378.8	397.2

C. Establishing Initialization Sequence

According to the formula (2), the initialization value of safety investments and losses in the occupational health and safety management system from 2011 to 2015 is shown in Table III.

TABLE III: THE INITIALIZATION VALUE OF SAFETY INVESTMENTS AND LOSSES IN THE OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEM (UNIT: TEN THOUSAND)

Indicators	2011	2012	2013	2014	2015
0.Direct accident losses	1.000	1.012	0.980	1.101	1.067
1.Safety technical measures	1.000	1.013	0.935	1.287	1.272
2. Industrial hygiene measures	1.000	1.044	0.802	0.890	0.978
3. Safety management and training	1.000	1.084	0.960	1.123	1.165
4.Labor protection products	1.000	1.136	1.038	1.311	1.407

D. Establishing Absolute Difference Sequence

According to the formula (4), safety investments absolute difference sequence of occupation health and safety management system from 2011 to 2015 is as follows.

$$\Delta_{01} = \left(0, 0.001, 0.045, 0.186, 0.205\right),$$
$$\Delta_{02} = \left(0, 0.032, 0.178, 0.211, 0.089\right),$$
$$\Delta_{03} = \left(0, 0.072, 0.020, 0.022, 0.098\right),$$
$$\Delta_{04} = \left(0, 0.124, 0.059, 0.210, 0.340\right).$$

Obviously, $\Delta_{\min} = 0, \Delta_{\max} = 0.34$

E. Calculating Relational Coefficient

According to the formula (3), let $\rho = 0.5$, then the following can be obtained.

$$\xi_{0j(k)} = \frac{0 + 0.5 \times 0.234}{\Delta_{0i} + 0.5 \times 0.234};$$

$$\xi_{01} = \frac{0 + 0.5 \times 0.34}{\Delta_{01} + 0.5 \times 0.34} = \left(1, 0.997, 0.791, 0.478, 0.454\right),$$

$$\xi_{02} = \frac{0 + 0.5 \times 0.34}{\Delta_{02} + 0.5 \times 0.34} = \left(1, 0.843, 0.489, 0.447, 0.656\right),$$

$$\xi_{03} = \frac{0 + 0.5 \times 0.34}{\Delta_{03} + 0.5 \times 0.34} = \left(1, 0.704, 0.895, 0.447, 0.634\right),$$

$$\xi_{04} = \frac{0 + 0.5\times 0.34}{\Delta_{04} + 0.5\times 0.34} = \left(1, 0.579, 0.744, 0.448, 0.334\right).$$

F. Analyzing Relation

Let $\omega_1 = \omega_2 = \omega_3 = \omega_4 = \omega_5 = 1/5$, the relation of the comparative factor x_i and reference indicator x_0 can be obtained as the following.

$$r_{01} = \frac{1}{5}\sum_{k=1}^{5}\xi_{01}\left(k\right) = 0.744,$$

$$r_{02} = \frac{1}{5}\sum_{k=1}^{5}\xi_{02}\left(k\right) = 0.687,$$

$$r_{03} = \frac{1}{5}\sum_{k=1}^{5}\xi_{03}\left(k\right) = 0.736,$$

$$r_{04} = \frac{1}{5}\sum_{k=1}^{5}\xi_{04}\left(k\right) = 0.621.$$

Obviously, $r_{01} > r_{03} > r_{02} > r_{04}$

From the result, we can know that safety technical measures are the highest relation on the safety losses of the mining, that is, safety technical measures are the greatest impact. Additionally, safety management and training are next only to that. Industrial hygiene measures and labor protection are the last two relation on the safety losses. In other words, not only should the mining increase the safety technical measures investment, but it also should invest more in safety management and training. Thus the accident losses of the mining can be reduced.

V. Conclusion

The effectiveness of mining occupational health and safety management system is reflected in the effective reduction of accident losses and prevention of accidents. Reasonable scientific safety investments are not only the requirement of the system, but also the needs of mining sustainable and healthy development. The case study of the mining in Southwest of Hubei Province confirms the important impact of safety technical measures on the accident losses. At the same time, safety management and training investments are half of that of safety technical measures, whose relaiona on economic losses is almost the same as that of safety technical measures. This shows that employee's daily safety management and safety operation training are very important to the economic development, which has put forward the people-oriented management appeal to the mining.

Because of the different production scale and management style of each mining, the influence degree of the different safety investments factors on accident losses is different. Most importantly, the relation of each safety investment factor can be calculated, accurately judged and adjusted in time according to the grey relational analysis.

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