Academic Journal of Management Science and Engineering
ISSN: 3080-9827 (Print), ISSN: 3080-9835 (Online) | Volume 1, Number 1, Year 2026
DOI: https://doi.org/10.62051/ajmse.v1n1.01
Journal homepage: https://ajomse.com

Cause analysis of coal mine accidents in China based on principal component analysis

Jing Wang*

Henan Polytechnic University, School of National Safety and Emergency Management, Jiaozuo, China

ABSTRACT

In order to explore the correlation between various types of coal mine accidents in China, and based on the accident data of Henan Province from 2009 to 2023 from the National Coal Mine Safety Administration and the Coal mine Safety Network, the principal component analysis method in SPSS26.0 statistical software was used to carry out a statistical analysis of the main types of coal mine death accidents in the past 15 years. The two main components of coal mine accidents are calculated, and then the main roof and gas accidents are analyzed and identified, and the correlation between the types of accidents is determined, which provides guidance for the development of corresponding coal mine accident prevention measures in the future.

KEYWORDS

Coal mine accident; SPSS; Emergency management; Monitoring and early warning.

1. INTRODUCTION

The coal mining industry is an important energy pillar of our country, and its safety production is of utmost importance. However, in recent years, coal mining accidents have occurred frequently, causing serious losses and impacts on people's lives and property as well as the social and economic development. In order to deeply explore the root causes of coal mining accidents in our country and find effective prevention and control measures, this study adopts the principal component analysis method for in-depth analysis. Principal component analysis is a multivariate statistical analysis method that can extract the main components from numerous complex influencing factors, thereby simplifying the problem and revealing the key information hidden behind the data. Therefore, the author uses SPSS26.0 software to conduct principal component analysis on the collected coal mining accident data from 2009 to 2023, and mainly analyzes the main types of coal mining deaths and the contribution rate of each accident type to the occurrence of accidents, providing a basis for formulating corresponding effective prevention measures.

2. PRINCIPAL COMPONENT ANALYSIS METHOD CONCEPT AND MODEL

(1) Concept of Principal Component Analysis

Principal Component Analysis is a multivariate statistical analysis method used for handling high-dimensional data. Its core essence lies in achieving variable dimensionality reduction through the linear combination of existing variables and the solution of each principal component. The proportion of principal components in the variance information is the greater, the more significant their role in comprehensive evaluation becomes. This method not only eliminates the mutual influence among evaluation indicators and reduces the workload of indicator selection, but also can simplify the calculation process through mathematical software, with a rapid calculation process and precise results.

(2) Mathematical Model of Principal Component Analysis Method

Suppose there are n samples, and each sample has p indicators (variables): X1, X2, …, Xp. The original data matrix is obtained:

$$X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1p} \\ X_{21} & X_{22} & \cdots & X_{2P} \\ \cdots & \cdots & \cdots & \cdots \\ X_{n1} & X_{n2} & \cdots & X_{np} \end{bmatrix} = (X_1 \quad X_2 \quad \cdots \quad X_p) \tag{1}$$

Here, Xi = X1i X2i ⋯ Xni, i = 1, 2, ⋯, p

Usually, we assume that in the actual problem we are discussing, there are p indicators. We regard these p indicators as p random variables, denoted as X1, X2, …, Xp. Principal component analysis is to transform the problem of these p indicators into the problem of discussing the linear combination of p indicators. These new indicators F1, F2, …, Fk (k ≤ p) fully reflect the information of the original indicators according to the principle of retaining the main information content, and are mutually independent. The usual approach in principal component analysis is to seek the linear combination Fi of the original indicators.

Using the p vectors X1, X2, …, Xp of the data matrix X for linear combination:

$$\begin{cases} F_1 = u_{11}X_1 + u_{21}X_2 + \cdots + u_{p1}X_p \\ F_2 = u_{12}X_1 + u_{22}X_2 + \cdots + u_{p2}X_p \\ \cdots\cdots \\ F_p = u_{1p}X_1 + u_{2p}X_2 + \cdots + u_{pp}X_p \end{cases} \tag{2}$$

Abbreviated as Fj = u1j X1 +u2j X2 +…+upjXp

j = 1，2，…，m，m≤p

(3) Calculation Steps of Principal Component Analysis

There are n samples to be evaluated, and each sample has m indicator variables. Then the original data matrix is $X = (x_{ij})_{nxm}$, representing the evaluation scores of safety evaluation factors at a certain time point.

The original data matrix is standardized. Let the standardized data matrix be: $Z = (z_{ij})_{nxm}$.

Based on the standardized matrix, the corresponding correlation coefficient matrix: $R = (r_{ij})_{nxm}$.

According to the characteristic equation $|\lambda p - R| = 0$, the m characteristic roots λp (p = 1, 2, …, m) are obtained. Through standardized orthogonalization, the characteristic vectors are obtained, that is, LP = lP1, lp2, …, lpm. Then the standardized principal component indicator variable expression Fp is:

$$F_p = l_{p1}x_1 + l_{p2}x_2 + \cdots + l_{pm}x_m \tag{3}$$

Where: Fm means the mth principal component

Select k indicators (k < m) that are fewer than the original number of indicators. Calculate the contribution rate and cumulative contribution rate of the eigenvalues. Generally, it is advisable that the cumulative contribution rate of the selected k principal components reaches more than 85%.

Sum the weighted values of the selected first k principal components, which is the final evaluation value:

$$F = \sum_{p=1}^{k} (\lambda P / \sum_{p=1}^{m} \lambda p) Fp \tag{4}$$

3. THE APPLICATION OF PRINCIPAL COMPONENT ANALYSIS METHOD IN THE STATISTICAL ANALYSIS OF COAL MINE ACCIDENTS IN CHINA IN THE PAST DECADE

(1)Data Collection

The coal mine accidents in China can be classified into roof collapse, gas explosion, mechanical equipment failure, water disaster, transportation accident, blasting, fire, and other types. Based on the accident statistics provided by the National Coal Mine Safety Supervision Bureau and the Henan Coal Mine Safety Supervision Bureau, the data on the types of coal mine accidents in China from 2009 to 2023 was obtained, as shown in Table 1.

Table 1. Incomplete Statistics of Coal Mine Accidents-Related Fatalities in China from 2014 to 2023 (Unit: Persons)

year	Accident Type							
	Top Plate	Asphyxiation	Electrical/Mechanical	Transportation	Blasting	Water Inrush	Fire	Other
2009	939	755	97	319	75	166	31	249
2010	829	623	78	281	37	224	168	193
2011	665	533	57	279	35	192	34	178
2012	459	350	58	201	25	122	27	142
2013	325	348	43	124	18	89	16	104
2014	292	266	37	103	19	79	4	131
2015	171	171	31	68	7	64	23	63
2016	86	221	38	72	14	27	3	37
2017	60	132	22	42	8	18	4	63
2018	60	34	13	41	2	18	0	16
2019	71	77	3	44	7	10	3	61
2020	39	20	10	19	12	14	0	50
2021	35	24	8	10	1	30	0	44
2022	50	10	12	13	3	12	4	53
2023	37	10	9	26	14	4	21	126

(2)The calculations were carried out using the SPSS software.

Based on the collected data, the 8 types of coal mine accident deaths with the highest occurrence rates in China were selected as evaluation indicators, represented as: X1 roof, X2 gas, X3 electromechanical, X4 transportation, X5 blasting, X6 water disaster, X7 fire, and X8 others. The KMO and Bartlett tests were conducted on the data, as shown in Table 2.

Table 2. KMO and Bartlett's Test

KMO and Bartlett's Test		
KMO: Sampling Adequacy Index.		.872
Bartlett's Sphericity Test	Approximate Chi-square	205.126
	Degree of freedom	28
	Significance	.000

From the test results, it can be seen that KMO = 0.872, which is greater than 0.6. The Bartlett's sphericity test is significant ($\rho < 0.05$). The results indicate that the data have good reliability and validity and can be subjected to principal component analysis. Then, principal component analysis was conducted on the data to determine the number of main factors for evaluation. At the same time, the number of principal components was determined based on the eigenvalues, eigenvectors, contribution rates of principal components, and cumulative contribution rates. The calculation and analysis results are shown in Table 3.

Table 3. Total Variance Explanation Component Initial Eigenvalue Extracted Loadings Squared Sum Rotation Loadings Squared Sum

Components	Initial Eigenvalue			Extracted Load Squared Sum			Rotated Load Squared		
	Total	Variance percentage	Cumulative %	Total	Variance percentage	Cumulative %	Total	Variance percentage	Cumulative %
1	6.970	87.128	87.128	6.970	87.128	87.128	5.516	68.948	68.948
2	.653	8.162	95.290	.653	8.162	95.290	2.107	26.342	95.290
3	.196	2.455	97.746						
4	.113	1.408	99.154						
5	.036	.447	99.602						
6	.015	.185	99.787						
7	.012	.149	99.936						
8	.005	.064	100.000						

By analyzing the results of principal component extraction in Table 4 and the amount of information extracted by principal components, it can be known that the principal component analysis has extracted a total of 2 principal components. The variance explanation rates of these 2 principal components are 87.128% and 26.342% respectively, and the cumulative variance explanation rate is 95.290%. Additionally, this component has extracted 2 principal components, and the weighted variance explanation rates corresponding to them, i.e., the weights, are as follows: 5.516/7.623 = 72.4%; 2.107/7.623 = 27.6%.

The number of principal components extracted can be judged with the help of Figure 1. When the line suddenly becomes stable, the number of steep-to-stable principal components is the reference for extracting the principal components. Combining the relationship between the principal components and the number of deaths from various coal mine accidents in China, it is determined that the number of principal components is 2.

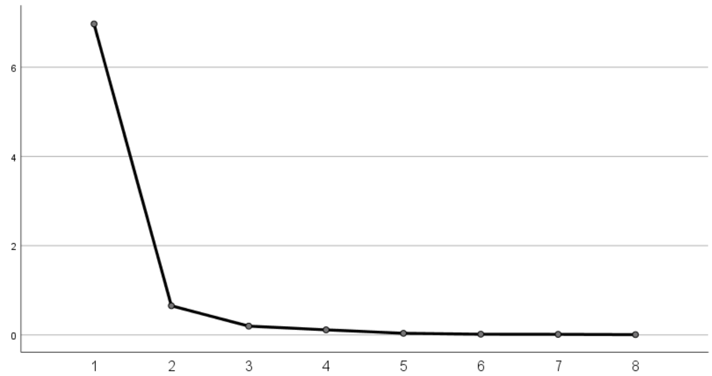

Figure 1. Stone Fragment Diagram

Table 4. Common Factor Variance

	Initial	Extract
Top floor	1.000	.990
Gas	1.000	.971
Electrical machinery	1.000	.940
Transportation	1.000	.973
Blasting	1.000	.945
Water hazard	1.000	.944
Fire	1.000	.974
Others	1.000	.885
Extraction method: Principal component analysis method.		

In Table 4, the "Initial" column indicates that when all components are included, no information is excluded and all the variations in the data can be explained. The degree of explanation for each variable is 1, which means 100% of the variations are explained. The "Extracted" column indicates that when only the selected components are retained, only some components are kept, and the degree of explanation for each variable will decrease.

Table 5. Component Matrix a Component

	Component	
	1	2
Top floor	0.995	-0.19
Gas	0.982	-0.81
Electrical machinery	0.965	-0.93
Transportation	0.985	-0.48
Blasting	0.919	-.318
Water hazard	0.957	.167
Fire	0.696	.700
Others	0.932	-.128
Extraction method: Principal Component Analysis.		
a. Two components were extracted.		

Based on the component matrix in Table 5 and the eigenvalues of each principal component, the weight values of each part were calculated and the functional expressions of each principal component were obtained, which are as follows:

$F1=0.995X1/\sqrt{5.516}+0.982X2/\sqrt{5.516}+0.965X3/\sqrt{5.516}+0.985X4/\sqrt{5.516}+0.919X5/\sqrt{5.516}+0.957X6/\sqrt{5.516}+0.696X7/\sqrt{5.516}+0.932X8/\sqrt{5.516}$; $F2=-0.19X1/\sqrt{2.107}+-0.81X2/\sqrt{2.107}+-0.93X3/\sqrt{2.107}+-0.48X4/\sqrt{2.107}+-0.318X5/\sqrt{2.107}+0.167X6/\sqrt{2.107}+0.700X7/\sqrt{2.107}+-0.128X8/\sqrt{2.107}$,

Here, X1, X2, X3... X8 represent different evaluation index systems. A comprehensive evaluation model is constructed by using the variance contribution rates of the two principal components as the respective weights, and the comprehensive score:

$F=5.516/(5.516+2.107)F1+2.107/(5.516+2.107)F2$

By using the SPSS software for analysis, the component score coefficient matrix can be obtained. Each coefficient represents the relationship between the principal component and the corresponding variable. The results are shown in Table 6.

Table 6. Component Score Coefficient Matrix

	Component	
	1	2
Top floor	.139	.044
Gas	.183	-.041
Electrical machinery	.19	-.059
Transportation	.349	-.364
Blasting	.159	.003
Water hazard	-.002	.290
Fire	-.426	.988
Others	.212	-.108
Extraction method: Principal Component Analysis.		
Rotation Method: Cauchy Normalization Maximum Variance Method.		

According to Table 6 and Formulas (3) and (4), the corresponding principal component expressions and comprehensive evaluation functions can be obtained as follows:

F1=0.139X1+0.183X2+0.19X3+0.349X4+0.159X5-0.002X6-0.426X7+0.212X8；

F2=0.44X1-0.41X2-0.59X3-0.364X4+0.003X5+0.290X6+0.988X7-0.108X8；

$$F=\frac{\lambda_1}{\lambda_1+\lambda_2}F_1+\frac{\lambda_2}{\lambda_1+\lambda_2}F_2=0.72F1+0.28F2$$

From the above calculation formula, it can be seen that in the first principal component, the weight coefficients of blasting accidents and other accidents are relatively large, and the two indicators have the same direction of change and are positively correlated, indicating that the causes of the changes in these two indicators are similar, and the handling methods are also related. Therefore, the factors that closely affect the coefficient of the first principal component are blasting, other accidents, and these three items; similarly, the factors that affect the coefficient of the second principal component are roof fall and fire accidents. This indicates that blasting, roof fall, fire, and other accidents are the main types of accidents that have caused a large number of coal mine safety accidents in China over the past 15 years.

4. MEASURES FOR PREVENTING COAL MINE ACCIDENTS

The coal mining industry, as one of the important energy pillars of our country, its safety production is of vital importance. However, coal mine accidents occur frequently, posing a huge threat to people's lives and property as well as social stability. To effectively prevent the occurrence of coal mine accidents, based on the results of SPPS analysis, it is necessary to take comprehensive preventive measures from multiple aspects.

(1)Strengthen safety management

Establishing a complete and well-developed safety management system is the fundamental cornerstone for preventing coal mining accidents. For coal mining enterprises, they should meticulously formulate extremely strict and detailed safety production regulations. These regulations must comprehensively cover all aspects and processes of coal mining production, clearly defining the specific safety responsibilities of all levels of management and every employee, so as to effectively ensure that safety responsibilities can be accurately and precisely implemented by each individual.

At the same time, coal mining enterprises must continuously strengthen the strict supervision and comprehensive inspection of the implementation of safety regulations. By establishing a dedicated supervision and inspection mechanism, using various methods such as regular inspections, irregular spot checks, and on-site patrols, they can closely monitor the implementation process and effect of safety regulations. For any violation of safety regulations, a zero-tolerance attitude must be adopted, and serious handling must be carried out without any leniency. Through this approach, the authority and seriousness of safety regulations can be effectively maintained, making it an unbreakable red line, thereby prompting all personnel to strictly abide by safety regulations and forming a good safety production order and atmosphere.

(2)Enhance employee training

Employees are the main body of coal mining production. Improving employees' safety awareness and skill levels is the key to preventing accidents. Coal mining enterprises should regularly organize employees to participate in safety training, including knowledge on safety regulations, operation procedures, emergency rescue, etc. Through case analysis and simulation exercises, employees can deeply understand the hazards of accidents and master correct operation methods and emergency response skills. In addition, employees should be encouraged to actively participate in safety management and put forward reasonable suggestions, forming a safety culture atmosphere involving all personnel.

(3)Ensure equipment safety

Advanced and reliable equipment is undoubtedly the key and important guarantee for achieving safe production in coal mines. During the coal mining process, coal mining enterprises must further increase investment in equipment. In the selection of equipment, strict control must be exercised, and high-quality equipment that fully complies with national standards and industry norms should be carefully selected. Moreover, a regular maintenance and inspection mechanism for equipment should be formed.

For those aging, damaged, and difficult-to-repair equipment, they must be promptly updated and replaced without hesitation, and equipment with potential safety hazards must not be allowed to continue to be used. This effectively ensures that all equipment is always in good operating condition.

At the same time, coal mining enterprises should also focus on the professional training of equipment operators. Through systematic and comprehensive training, operators can fully understand the performance characteristics of the equipment they operate, and master correct and standardized operation methods and procedures. This ensures that they strictly follow operating procedures in actual work, avoiding equipment failures due to improper operation or mistakes, and effectively reducing the risk of accidents caused by equipment failures.

(4)Optimize ventilation system

A good ventilation system is undoubtedly a key and important means for coal mines to prevent various major accidents such as gas explosions and coal dust explosions. Coal mining enterprises must attach great importance to the construction and optimization of the ventilation system. They should carefully and reasonably design the ventilation system based on the unique actual conditions of the mine. This design should not only comprehensively consider various factors such as the depth of the mine, the layout of the tunnels, and the distribution of mining faces, but also precisely calculate and plan to ensure that the ventilation air volume is always sufficient and the airflow remains stable and continuous.

In addition, coal mining enterprises should conduct in-depth inspections and comprehensive evaluations of the ventilation system on a regular basis. By using advanced detection technologies and scientific assessment methods, various potential problems in the ventilation system can be discovered and effectively addressed in a timely and accurate manner. Whether it is the blockage of ventilation lines, insufficient air volume, or abnormal air flow direction, targeted measures should be taken promptly for handling, ensuring that the ventilation system remains in a good operating condition and providing a solid and powerful guarantee for the safety production of the coal mine.

(5)Strengthening Roof Management

Roof management is an important part of coal mine safety production. The following are some key measures for strengthening roof management: Firstly, do a good job in roof monitoring. Use advanced monitoring equipment and technologies, such as roof pressure monitors and displacement sensors, to monitor the force and deformation of the roof in real time. Through data analysis, potential roof hazards can be detected in a timely manner, providing a basis for taking targeted measures. Secondly, scientifically and rationally select support methods. Based on the geological conditions, roof rock properties, and mining methods in the coal mine underground, select appropriate support materials and support forms. For unstable roofs, for example, combined support with anchor rods and anchor cables, or the use of hydraulic supports, can be adopted to enhance support. Thirdly, strengthen the management of support construction quality. Ensure that the quality of support materials meets the requirements and the construction process is carried out in accordance with the design and operating procedures. Conduct regular inspections and maintenance of the support project, and handle problems promptly to ensure the effectiveness of the support. Moreover, enhance the awareness and skills of employees in roof management. Strengthen training for employees to make them understand the hazards of roof accidents and preventive measures, and master the basic knowledge and operational skills of roof support and monitoring. In their work, they can consciously abide by the regulations of roof management and improve their self-protection ability. Finally, establish a complete roof management system. Clearly define the responsibilities of managers at all levels and employees in roof management, and formulate strict roof inspection and hazard investigation systems. Conduct regular evaluations and summaries of roof management, and continuously improve management methods and measures.

(6)Developing Emergency Plans

Coal mining enterprises should attach great importance to and develop complete and comprehensive emergency plans, which must cover detailed and feasible emergency response plans for various possible major accidents such as fire, explosion, water inrush, and collapse. These plans should make precise predictions and scientific planning for each accident's characteristics, potential hazards, and development trends.

In addition, coal mining enterprises must, according to the established plan, regularly organize targeted and practical emergency drills. Through simulating real accident scenarios, employees can experience and participate in the emergency response process, thereby significantly improving their emergency response speed and agility when facing sudden situations, and enhancing their collaborative and cooperative combat capabilities.

Furthermore, coal mining enterprises must ensure that the necessary supplies and equipment for emergency rescue have adequate reserves. For various rescue supplies, such as medical supplies, protective equipment, and communication tools, regular inspections, replenishments, and updates should be carried out; for key rescue equipment, such as fire trucks, drainage pumps, and cranes, their performance should be good and they should be ready for use at any time. Only in this way, in the emergency situation when an accident occurs, can rescue supplies and equipment be quickly deployed for rescue work, minimizing casualties and property losses, and building a solid defense line for ensuring safety production and the life and property safety of employees.

5. CONCLUSION

In summary, this study adopts the principal component analysis method to analyze the causes of coal mine accidents in China, extracts key influencing factors and reveals their deep-seated mechanisms, and this achievement is only a phased exploration. In the future, it is necessary to strengthen safety management, increase investment, improve the institutional and regulatory mechanisms, promote technological innovation to enhance the intelligent level and reduce human-induced risks based on these findings. Coal mine safety production is a long-term and arduous task, which requires the joint efforts of the government, enterprises, scientific research institutions and every practitioner. Only through the collaborative cooperation of the whole society can we effectively reduce the incidence of coal mine accidents, protect miners' lives, and promote the safe, efficient and sustainable development of China's coal mine industry. This study also hopes to provide a useful reference for the prevention and control of coal mine accidents and contribute to the long-term stability of the coal mine industry.

DATA AVAILABILITY

Data will be made available on request.

REFERENCES

[1] Liu Ying. Analysis of Emergency Management Capability of Coal Mine Enterprises and Strategies for Enhancement [D]. Liaoning Institute of Engineering Technology, 2022.

[2] Li Hongcheng, Zhang Maojun, Ma Guangbin. Practical Tutorial on SPSS Data Analysis [M]. People's Posts and Telecommunications Press: 201703. 338.

[3] Huang Jiguang. Analysis of Causes of Coal Mine Accidents in Henan Province Based on Principal Component Analysis Method [J]. Journal of North China University of Science and Technology, 2018, 15 (06): 98-102.

[4] Lei Xianrui. Characteristics and Prevention Measures of Coal Mine Accidents in China in Recent Years [J]. Shaanxi Coal, 2023, 42 (03): 199-203.

[5] Shen Minghui, Liu Yang, Mao Yunpeng, et al. Construction and Application of Evaluation Index System for Service Capacity of Primary Medical and Health Institutions Based on Principal Component Analysis Method [J]. Journal of Health Economics Research, 2023, 40 (11): 39-43.

[6] Miao Yingchun, Li Rui. Analysis of Satisfaction with Accessibility of Community Residents' Health Services Based on Principal Component Analysis Method - Taking Taiyuan City, Shanxi Province as an Example [J]. Journal of Jinyang Studies, 2023, (01): 109-117.

[7] Zhang Ailing, Cheng Cheng, Yang Zhigang, et al. Strengthening Supervision of Safety Evaluation Institutions and Cultivating High-Quality Safety Production "Guardian Team" [J]. China Safety Production, 2023, 18 (11): 16-33.

[8] Wang Haijun, Cao Yun, Wang Honglei. Research on Key Technologies of Coal Mine Intelligence and Practical Practice [J]. Coal Field Geology and Exploration, 2023, 51 (01): 44-54.

[9] Ma Yonglong, Tang Xiaoling. Research on Prevention of Roof Accidents in Coal Mine Excavation Roadways and Section Optimization [J]. Inner Mongolia Coal Economy, 2024, (04): 145-147.

[10] Wang Shijia. Research on Emergency Management System of Coal Mines Based on Business Continuity Management [J]. Energy and Environmental Protection, 2018, 40 (03): 29-33+39.