

# Mining Area Production Safety Optimization Based on Multi-objective Particle Swarm Optimization Model

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**Abstract:** Safe production in metal mines is an important task to ensure the safety of workers and the integrity of production equipment. From the perspective of optimization, this paper establishes an early warning model and a multi-objective particle swarm optimization algorithm model by analyzing the relevant production data affecting the indicator system of mine safety production, and then solves the model through the multi-objective particle swarm optimization algorithm to give an optimization scheme for maximizing the safety production of the relevant mines. For the safety production problems in metal mines, four indicator systems are proposed, namely, production ecological environment safety, production personnel safety standards, production equipment safety and production information security, and then the relevant production data of the four indicator systems are analyzed and the early warning model is established. Based on the relevant production data of the four indicator systems, the mathematical relationship between the production data affecting each indicator system is constructed. Then, a multi-objective particle swarm optimization algorithm is established to construct the relationship between the maximum safe production of the mine and each indicator system, and the index of the maximum safe production production data of the mine is obtained. The feasibility of the mine safety production optimization scheme is given.

**Keywords:** Multi-objective Particle Swarm Optimization, Early Warning Model, Production Safety Optimization.

## 1. Introduction

Production safety in mining area is an important issue related to miners' life and property safety. There are many safety hazards and risks in the production process of mining area, including gas explosion, mine collapse, fire, accident, equipment failure, etc [1]. These safety problems directly affect the safety and production efficiency of miners. Based on the analysis of production safety and production efficiency in underground mining areas, this paper establishes relevant early warning models by analyzing the four indicator systems affecting mineral safety (such as production ecological environment safety, production personnel safety standards, production equipment safety and production information security), and investigates the production data required for calculating various indicators [2-4]. Select and establish the most suitable mathematical model for calculating mine safety production. By analyzing the production data and safety monitoring data of mining area with mathematical model, an effective safety early warning system can be established to warn the possible safety risks in advance so that timely measures can be taken to avoid accidents [5-6].

## 2. Establish Index System and Early Warning Model

According to the analysis of the production ecological index system, the main production data include dust concentration and toxic combustible mixed gas concentration, as well as related production data such as the input cost of environmental treatment and the frequency of personnel safety accidents. When one of the dust concentration or toxic combustible mixed gas concentration reaches the safety production warning threshold, the production will be stopped.

In the underground mining working space, a large number of toxic and combustible gases are mixed in the working space through factors such as mining breakage and the oxidation of minerals themselves. All kinds of toxic and combustible gases have explosion limits in air or oxygen. Any gas mixture with a concentration below the lower explosive limit (LEL) or above the upper explosive limit (UEL) in contact with the ignition source (ambient temperature above the ignition point) will not cause an explosion. The explosion limit of toxic combustible gas under the mine is shown in Table 1.

Table 1. Explosive limits of toxic combustible gases

Poisonous flammable gas	Explosion limits (%)		Gas relative density (atmosphere =1)
	Lower explosive limit (LEL)	Upper explosive limit (UEL)	
Steam	5.0	15.0	0.55
Methane	12.5	80.0	0.97
Carbon monoxide	4.3	46	1.19
Sulfuretted hydrogen	15.0	28.0	0.6

Based on the analysis of the explosion limits of toxic combustible gases, the upper explosion limit, the lower explosion limit and the point of failure are calculated, as

shown in Tables 2 to 4, and warnings are issued for gases that are about to exceed the limits.

**Table 2.** Early warning index of carbon monoxide concentration trend

Serial number	Warning indicator /h	Warning level
1	$1.5 \leq T < 2$	Blue alert
2	$1 \leq T < 1.5$	Yellow alert
3	$0.5 \leq T < 1$	Orange alert
4	$0 \leq T < 0.5$	Red alert

**Table 3.** Warning index of threshold of carbon monoxide concentration change

Serial number	Warning indicator /10-4%	Warning level
1	22.8	Red alert
2	21.6	Orange alert
3	19.2	Yellow alert

**Table 4.** Warning index of carbon monoxide concentration change threshold

Serial number	Warning indicator /(10-4%·h-1)	Warning level
1	4.75	Red alert
2	4.5	Orange alert
3	4.0	Yellow alert

According to the precursor information of coal mine gas disaster and the connected beam tube and safety monitoring system, the gas early warning index system database is established, and the difference between the time point when the gas concentration reaches the prescribed alarm value and the current time point is evaluated, which is divided into blue,

yellow, orange and red from low to high. Evaluate the gas concentration and key monitoring areas such as gas probe, high gas area, prominent threat area, prominent danger area, etc. The warning indicators of gas trend are shown in Table 5, and the warning indicators of gas based on GIS graphics are shown in Table 6.

**Table 5.** Warning index of gas trend

Serial number	Warning indicator /h	Warning level
1	$1.5 \leq T < 2$	Blue alert
2	$1 \leq T < 1.5$	Yellow alert
3	$0.5 \leq T < 1$	Orange alert
4	$0 \leq T < 0.5$	Red alert

**Table 6.** Gas warning index of GIS graph

Warning category	Evaluation item	Warning indicator/m	Warning level
Excavation face of uncovering coal rock roadway	Distance from uncovering point	$\leq 50$	Red alert
High gas area	Distance from high gas area	$\leq 50$	Red alert
Prominent threat area	Distance from the threat area	$\leq 50$	Red alert
Protruding danger area	Distance from danger zone	$\leq 50$	Red alert
Through roadway	Distance from shaft face	$\leq 50$	Red alert
	Distance from excavation face	$\leq 30$	Red alert

Firstly, the distance warning based on the mining position is measured by GIS. When approaching a certain distance from a dangerous area, an early warning signal is issued to realize the function of warning and warning when approaching a dangerous area. Second, based on the monitoring data, the change trend of the water level of the

mine inflow and the water level of the regular observation hole is warned. According to different warning indicators, it is divided into yellow, orange and red levels from low to high. The warning indicators of mine water damage distance and trend are shown in Table 7 and Table 8.

**Table 7.** Warning index of mine water damage distance

Warning object	Warning indicator/m	Warning level
Drainage areas, old alleys, fault waterproofing coal pillars, geophysical hydrological anomaly areas	30~60	Orange alert
Surface water alluvium, deep well	$\leq 30$	Red alert
	$\leq 120$	Orange alert

**Table 8.** Mine water hazard trend warning index

Warning object	Type of warning	Warning indicator/%	Warning level
Mineral inflow	Variation amplitude of water inflow	19	Red alert
		18	Orange alert
		16	Yellow alert
Always observe the water level of the hole	Amplitude of water level change	19	Red alert
		18	Orange alert
		16	Yellow alert

### 3. A Multi-objective Particle Swarm Optimization Model Is Established

Production ecological environment ESI is determined by dust concentration, toxic combustible mixed gas concentration, environmental treatment input cost and personnel safety accident frequency. ESI is calculated by the following formula:

$$ESI = \sqrt{(C_d - C_{d0})^2 + (C_g - C_{g0})^2} - C_E \times R_a \quad (1)$$

Where,  $C_{d0}$  is the alarm threshold of dust concentration,  $C_{g0}$  is the concentration of toxic combustible mixed gas.

$$DSI = \sqrt{(F_e - F_{e0})^2 + (N - N_o)^2} + PSI^2 \quad (2)$$

Among them,  $F_{e0}$  is the maximum failure rate of equipment affecting safe production,  $N_o$  is the maximum number of overdue maintenance times of equipment affecting safe production, and PSI is the safety standard function of production personnel.

Production information security ISI is mainly determined by the number of information leaks  $N_c$  and network attacks  $N_a$ , ISI calculation formula is as follows:

$$ISI = \sqrt{N_c^2 + N_{co}^2 + (N_a - N_{a0})^2 + (C_I \times P_I)} \quad (3)$$

Among them,  $N_{c0}$  is the maximum number of information leakage affecting production safety,  $N_{a0}$  is the maximum number of network attacks affecting production safety, and  $C_I$  is the investment in information security protection.

According to the function formulas of production data related to the four index systems of production ecological environment safety, production personnel safety standards, production equipment safety and production information security obtained above, we obtained the function calculation formula between the maximum production safety of mining area and the four index systems:

$$F = \sqrt[3]{ESI + PSI + DSI} + \ln(1 + ISI) \quad (4)$$

### 4. Solving the Mathematical Model of Production Safety Management in Mining Area

PSO algorithm is an algorithm based on bird behavior research. For PSO, each particle performs two update

formulas for the current position and velocity of each particle based on the current locally optimal particle and the velocity global optimal particle, and the update formulas are defined in equations (4) and (5). Carlos A. et al. added the concepts of Pareto domination and global optimization of external storage to the PSO algorithm, and proposed MOPSO to solve MOPs. Where,  $V = (V1, V2, \dots, Vn)$  represents a velocity vector of  $n$  dimension;  $V(i)$  refers to the velocity vector of the  $i$ th particle in a particle swarm.  $x = (x1, x2, \dots, xn)$  represents the position vector  $n$  dimensional particle;  $x(i)$  refers to the position vector  $i$ th particle in a particle swarm;  $Pbest = (pbest1, pbest2, \dots, pbestn)$  represents a  $n$  dimensional optimal position vector for a particle in a particle swarm;  $Pbest(i)$  refers to the best position vector experienced by the  $i$ th particle in a particle swarm;  $Gbest = (Gbest1, Gbest2, \dots, Gbestn)$  represents the best particle experienced by a  $n$  dimensional optimal position vector.  $W$  is a constant that represents the inertia weight, usually set to 0.4.  $R1, R2$  are two random numbers between 0 and 1, usually 0.2.

$$V(i) = W * V(i) = R_1 * (Pbest(i) - x(i)) + R_2 * (Gbest - x(i)) \quad (5)$$

$$x(i) = x(i) + V(i) \quad (6)$$

The production data of the above four index systems are input into the established function calculation formula and optimized with the help of multi-objective particle swarm optimization algorithm. Through data analysis, Table 9 was compiled:

Among them, X1 is the dust concentration, X2 is the concentration of toxic combustible mixed gas, X3 is the accident rate, X4 is the training pass rate, X5 is the equipment failure rate, X6 is the number of equipment maintenance delays, X7 is the number of information leakage, X8 is the number of network attacks, so as to maximize the production safety of the mining area.

According to the obtained data table, we obtained that when the dust concentration reached  $0.149607\mu\text{g}/\text{m}^3$ , the concentration of toxic combustible mixed gas reached  $2.688430\mu\text{g}/\text{m}^3$ , the accident rate was 4.9361%, the training pass rate was 97.74457%, the equipment failure rate was 0.0111%, and the equipment maintenance was delayed once. When the number of information leakage is 0 times and the number of network attacks is 3 times, the production safety of the mining area is maximized.

**Table 9.** Multi-objective particle swarm optimization model for mining area production safety maximization analysis

X1	X2	X3	X4	X5	X6	X7	X8	F
0.149607	2.688430	0.049361	0.977457	0.000111	1	0	3	1.5205
0.334449	2.896525	0.013514	0.960058	0.000404	3	1	2	1.1697
0.006297	2.913343	0.007590	0.977877	0.000212	2	1	3	1.0843
0.760061	2.431954	0.217815	0.944240	0.000186	1	3	2	1.0728
0.263809	2.896208	0.037548	0.932492	0.000909	1	1	3	1.0322
0.187147	2.646826	0.031826	0.951676	0.000440	1	2	2	0.9889
0.762554	2.981617	0.032937	0.917950	0.000399	1	2	3	0.953
0.025449	2.391459	0.015184	0.981828	0.000011	1	2	3	0.8983
0.404887	2.595719	0.225826	0.908767	0.000834	2	2	2	0.8983
0.783789	2.864738	0.045302	0.901102	0.000269	2	3	2	0.8756
0.666705	2.811698	0.047000	0.913522	0.000514	1	3	2	0.8442
0.360720	2.616313	0.032408	0.903745	0.000587	2	3	3	0.6604
0.688912	2.966869	0.073304	0.957915	0.000653	2	2	3	0.6164
0.036088	2.809397	0.034845	0.953648	0.000259	1	3	2	0.2775
0.253413	2.700802	0.011634	0.997200	0.000319	2	2	3	0.2754

## 5. Mining Area Production Safety Management Optimization Scheme

### 5.1. Intensive safety training

Conduct comprehensive and regular safety training for mine employees, covering accident emergency treatment, safety operation procedures, etc. The training content is customized according to the characteristics of employees' positions, including accident case analysis, operation specifications and on-site practical operation drills. Establish employee safety training files through assessment and evaluation to ensure that each employee has the necessary safety knowledge and operational skills. At the same time, according to the training effect and employee feedback, continuously improve the training content and methods to enhance the training effect.

### 5.2. Improve safety facilities

Strengthen the construction and maintenance of safety facilities in mining areas, ensure the normal operation of equipment and meet safety standards. Regular inspection of safety channels, emergency evacuation channels, fire fighting equipment and other facilities, and constantly update and upgrade safety equipment, including personal protective equipment. Establish the equipment integrity rate monitoring mechanism and maintenance management system to ensure that the equipment is complete and intact. At the same time, establish a safety monitoring system, improve early warning and emergency response capabilities, and carry out training on facility use and maintenance to improve employee safety awareness.

### 5.3. Establish an emergency plan

In view of the potential risks in metal mining areas, formulate detailed emergency plans, clarify the processing process, responsible departments and emergency disposal measures. Establish emergency equipment and materials reserve list, organize emergency drills regularly, and improve employees' emergency handling ability. Establish cooperative relations with relevant rescue departments and form an emergency rescue linkage mechanism. Periodically evaluate and improve emergency response plans to ensure their applicability and usefulness.

### 5.4. Strengthen the safety culture

Advocate the "safety first, prevention first" safety culture, through training, slogans, signs and other ways to enhance employee safety awareness. Establish incentive and reward mechanism to encourage employees to participate in safety management and make suggestions for improvement. Establish a sound security communication mechanism to report and deal with security risks in a timely manner. Set up safety assessment indicators, and promote all departments and posts to perform safety responsibilities. Leaders should practice, set a good example, and guide employees to establish safety awareness and behavioral norms.

### 5.5. Protect employee information security

Organize information security awareness training for employees, clarify information processing procedures and operational norms, and prohibit information disclosure and tampering. Strengthen the construction of internal network security, take multi-level protection measures, manage access rights, and ensure the security of information equipment. Regular information system security review and vulnerability scanning, timely repair potential vulnerabilities, to ensure employee information security.

### 5.6. Improve ecological and environmental security

In the planning and design of mining areas, we should pay attention to the protection of ecological environment, adopt clean production technology and equipment, and reduce environmental pollution. Establish a sound environmental monitoring system, regularly assess the environmental situation around the mining area, and take timely restoration and treatment measures. After the end of mining, ecological environment restoration work will be carried out to restore vegetation and soil and protect water bodies. Strengthen the awareness of environmental protection and publicity and education of laws and regulations, and jointly protect the ecological environment of mining areas.

## 6. Conclusion

Using advanced mathematical modeling technology, the optimization model of production safety in mining area is established. The model will comprehensively consider multiple factors such as production safety, economic benefit

and environmental protection, and improve the overall safety management level and production efficiency of mining areas through algorithm analysis and optimization strategies. This will help make scientific decisions in complex production environments, reduce the risk of accidents, and improve the efficiency of resource use. Through the analysis of the relevant production data of several safety production indicators, the calculated safety production in mining areas is highly accurate and the effect is ideal. The model considers the influence of relevant production data of each safety production index on the maximization of safety production, which is more in line with the actual situation. Finally, according to the model analysis results and actual production data, the specific management optimization scheme is proposed. These programs will include environmental management, personnel training, information protection and other measures aimed at improving the overall safety culture and operational performance.

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