Simulation Study on the Safety Evaluation of Coal Mine General Mining Working Face Production System

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Abstract: Based on the understanding of China's coal mine production system and the analysis of coal mine comprehensive mining working face safety, combined with a large amount of literature, according to the principles and process of index system construction, using the literature frequency analysis method to construct five primary indicators and 25 secondary indicators of personnel, mechanical equipment, management, environment and information factors, to determine the index system of production system safety evaluation of 5203 comprehensive mining working face of Gaojiayao coal mine The index system was determined. The AHP method was selected to determine the index weights, and the fuzzy comprehensive evaluation method was used to evaluate the safety of the production system of coal mine comprehensive mining working face, to determine the risk status of the working face at the present stage, and to construct a simulation model with the help of a AnyLogic system simulation software to analyze the sensitivity of the indexes, which provides a scientific basis for the safe production and safety management of coal mines and guarantees the safe operation of coal mining and high-quality development of enterprises.

Keywords: comprehensive mining working face, safety evaluation, index system, safety management

1 INTRODUCTION

At present, many scholars have made a lot of researches on the reliability of the production system of comprehensive mining working face, and the corresponding research results have been achieved. Generally speaking, most of the scholars have constructed the index evaluation system from the perspective of human-machine-environment-management according to the actual production situation of the header face and put forward relevant suggestions. yang Yang [8] analyzed the factors affecting coal mine safety management based on the "man-machine-loop-management" safety production theory, combined with literature research method, summarized the digitization process of coal mine safety management technology, fully understood the current research status, and proposed the "man-machine-loop-management" safety production theory as the research framework. " safety production theory as a research framework model, which will be continued in the digital mine safety management, and at the same time will be deeply integrated with artificial intelligence, Internet of Things, and big data to jointly promote coal mine safety management. Li Hongxia [4] evaluated the level of coal mine safety management

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based on hierarchical analysis and decision test and evaluation laboratory, and constructed a five-level coal mine safety management level evaluation index system by combining the characteristics of coal industry. chen Miao [6] indicated that the header working face is a complex production system, and in order to ensure the smooth operation of the production system of the header working face, the reliability analysis of the production system of the header working face of thick coal seam was carried out from three research perspectives of human-machine and environment, combined with the reliability analysis theory, to further improve the stability of the system through reasonable improvement. In order to explore the environmental reliability of the proposed mining working face, Huimin Zhang [10] analyzed the relationship between coal mine environment and coal mine accident hazards, took environmental factors as the evaluation object of coal mine safety hazards, used literature research method and field research method, constructed environmental factors affecting the safety of coal mine comprehensive mining working face, used entropy weight method to determine the weight of environmental factors index to avoid the problem of excessive subjective factors, and also established The quadratic linkage degree was used to evaluate the environmental factors of the comprehensive mining working face, and the results indicated that the proposed working face has less safety hazards and excellent environmental conditions and is suitable for mining.

Through literature combing, it can be seen that the above literature rarely explores the influence degree of index factors on each subsystem for research to further optimize the evaluation results. Therefore, this paper introduces the system dynamics method and constructs a simulation model with the help of AnyLogic system simulation software to visually show the influence of different indicator factors on system reliability through indicator sensitivity analysis, so as to explore the degree of influence of different countermeasures on the reliability of production system.

2 EXTRACTION OF INDEX FACTORS OF PRODUCTION SYSTEM OF COMPREHENSIVE MINING WORKING FACE

Based on the method of Shuicheng Tian [7] in constructing the evaluation index system of the study to initially screen the indicators. A literature search was conducted using the CNKI database of China Knowledge Network, with a time span from 2015-2023, using "subject=(coal mine and safety evaluation) and subject=(influence factor or indicator system)" as the search formula for a precise search, including PhD and master's theses and journal literature, drawing on literature [1-5] The indexes of the relevant systems in the coal mine integrated mining working face were summarized from five perspectives: operators, mechanical equipment, working environment, safety management, and information security, and the index system was constructed by combining the composition characteristics of the coal mine integrated mining working face production system and the representative literature on system reliability evaluation in coal mine safety, as shown in Table 1 below.

Table 1: Table of safety index system of production system of header working face

Objective level	Objective level	Objective level
	Worker impact	Professional knowledge level

Safety of production system of coal mine integrated mining working face		Average length of service
		Equipment operation level
		Monthly training time
		Physical and mental health status
	Mechanical equipment impact	Transport equipment completeness rate
		Mechanical and electrical equipment integrity rate
		Perfection rate of ventilation and defense equipment
		Perfect rate of safety protection facilities
		Degree of mechanical maintenance
	Work environment impact	Temperature
		Air velocity
		Dust volume at working surface
		Gas concentration
		Stability of the roof
		Coal seam gangue
	Management System Impact	Pass rate of staff assessment and evaluation
		Rate of three violations
		Perfection rate of safety rules and regulations
		Strength of safety inspection
		Perfect rate of emergency response mechanism
	Information Security Impact	Information forecast
		Degree of informatization
		Degree of information accuracy
		Feedback of monitoring information

3 SYSTEM DYNAMICS MODELING

3.1 Relationship Diagram of the Safety Influencing Factors of the Production System of the Hewed Working Face

The study integrates the evaluation of the safety of the production system of X heaving workface with the system dynamics simulation, which can simulate the whole production system from a macroscopic perspective and consider the qualitative and quantitative indicators in the system comprehensively to simulate the changes of the system reliability. In addition to considering the influence of each indicator on the system, the degree of interaction between the factors of each indicator is also considered, which can clearly simulate the safety management of the production system of the comprehensive mining working face and also rigorously verify the safety evaluation model of the production system of the comprehensive mining working face. The construction of the system dynamics dynamic model for the safety evaluation of the production system of a specific header workface is as Figure1.

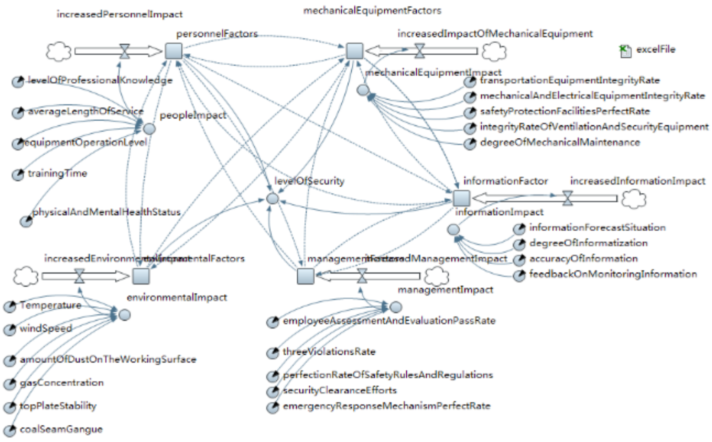

Figure 1: Safety stock flow diagram of the production system of the integrated mining workings(Modeling Interface)

Through the above analysis, it can be seen that the reliability of coal mine production system is mainly influenced by personnel factors, mechanical equipment factors, environmental factors, management factors and information factors, based on the hierarchical analysis method and the confused comprehensive evaluation method to determine the parameters of indicators, and establish the safety evaluation model of the production system of coal mine production, the specific DYNAMO equation is as follows.

(1) Personnel subsystem

Personnel impact = professional knowledge level*0.1199+average working years*0.0705+equipment operation level*0.2501+training time*0.0379+0.5216*physical and mental health status

Personnel impact increase=uniform(personnel impact*0.95,personnel impact*1.05)

Personnel factor (personnel impact increase + mechanical equipment factor*0.0687*0.608+ environmental factor*0.1358*0.750+ management factor*0.2632*0.608+ information factor*0.0366*0.608)*0.4966

(2) Machinery and equipment subsystem

Mechanical equipment impact = 0.1339*transportation equipment integrity rate + 0.4855*mechanical and electrical equipment integrity rate + 0.2637*command and defense equipment integrity rate + 0.0752*safety and protection facilities perfect rate + 0.0417*maintenance degree of machinery

Mechanical equipment impact increase=uniform(mechanical equipment impact*0.95,mechanical equipment impact*1.05)

Mechanical factors = (mechanical equipment impact increase + personnel factors *0.4966*0.1315 + environmental factors *0.1358*0.25 + management factors *0.2623*0.2721 + information factors *0.0366*0.1199)*0.0687

(3) Environmental subsystem

Environmental impact=0.03*temperature+0.2564*wind speed+0.0802*working face dust volume+0.1344*gas concentration+0.4506*roof stability+0.0484*coal seam gangue

Environmental impact increase=uniform(environmental impact*0.95,environmental impact*1.05)

Environmental factor= (environmental impact increase+ personnel factor*0.4966*0.26+mechanical equipment factor*0.0687*0.2721)*0.1358

(4) Management subsystem

Management impact = 0.0405*employee assessment and evaluation pass rate + 0.0772*three violations rate + 0.4731*improvement rate of safety rules and regulations + 0.1512*safety exclusion efforts + 0.2580*improvement rate of emergency mechanism

Management impact increase=uniform(management impact*0.95,management impact*1.05)

Management factor= (management impact increase+ personnel factor*0.4966*0.5379+information factor*0.0366*0.2721)*0.2623

(5) Information subsystem

Information impact = 0.1409* information prediction + 0.5200* information degree + 0.2682* information accuracy + 0.0709* monitoring information feedback

Information impact increase= uniform(information impact*0.95,information impact*1.05)

Information factor=(information impact increase+ personnel factor*0.4966*0.0706+mechanical equipment factor*0.0687*0.1199+management factor*0.2623*0.1199)*0.0366

(6) Comprehensive system

Level of security = personnel factor*0.4966+mechanical equipment factor*0.0687+environmental factor*0.1358+management factor*0.2623+information factor*0.0366

4 SIMULATION RESULTS ANALYSIS

Based on the AnyLogic simulation model of the safety of the production system of the header, the sensitivity analysis of the index factors of each scheme layer is performed by using the parameter comparison experiment in AnyLogic system dynamics, and the change of the safety level of the production system of the header caused by the change of each index is output to comprehensively grasp and analyze the different sensitivity of the production system of the header to each index factor. The sensitivity level of the production system for each index factor. On the basis of the simulation experiment main, a new indicator Compare Runs analysis experiment is built, and the indicator factors under each criterion are selected to study the degree of system safety and the sensitivity of each factor by changing the degree of safety of each factor.

As shown in Figure 2 below, The trend graph of the influence of the operator on the reliability of the raw system of the heaving workface. The curve marked in red in the graph represents the initial reliability degree of the production system of this heaving workface, and the yellow curve represents the influence of the other factors with constant training time reliability degree increased by 0.2 on the whole system; the same green curve represents the physical and mental health state index factor, the blue curve represents the expertise level, the purple curve represents the average working age, and the pink curve represents the equipment operation level. It can be seen that as the reliability level of single factor index increases, the reliability level of the whole system also increases, and the curves from top to bottom in the figure represent the level of influence. Therefore, among the operator factors, the effects on the degree of system reliability are, in descending order: physical and mental health > equipment operation level > professional knowledge level > average working age > training time.

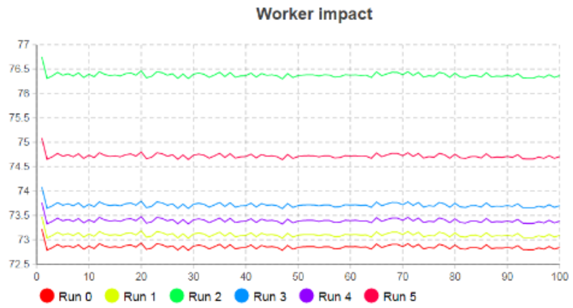

Figure 2: Sensitivity diagram of operator factor indicators(Model Export)

As shown in Figure 3 below, The trend graph of the influence of mechanical equipment on the reliability of the raw system of the header workings. The curve marked in red in the graph represents the initial reliability degree of the production system of the heaving face, and the yellow curve represents the influence of increasing the reliability degree of transport equipment completeness rate by 0.2 on the whole system with other factors unchanged; the same green curve represents the index factor of mechanical and electrical equipment completeness rate, the blue curve represents the perfect rate of safety protection facilities, the purple curve represents the degree of mechanical maintenance, and the pink curve represents the through-proof equipment completeness rate. Therefore, among the mechanical equipment factors, the effect on the degree of system safety is, in descending order, as follows: mechanical and electrical equipment completeness rate > safety and security equipment completeness rate > transportation equipment completeness rate > safety and security facilities perfect rate > mechanical maintenance degree.

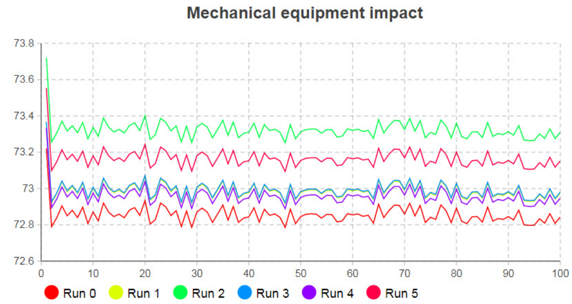

Figure 3: Sensitivity diagram of machinery and equipment factor indicators(Model Export)

As shown in Figure 4 below, The trend graph of the influence of the environment on the reliability of the raw system of the header workface. The red curve in the graph represents the initial reliability of the production system of the comprehensive mining workface, and the yellow curve represents the influence of increasing the reliability of other factors by 0.2 on the whole system; the same green curve represents the wind speed index factor, the blue curve represents the amount of dust at the workface, the purple curve represents the gas concentration, the pink curve represents the stability of the roof plate, and the orange represents the coal seam gangue. Therefore, among the environmental factors, the effect on the safety degree of the system in descending order is: roof stability > wind speed > gas concentration > dust quantity at the working face > coal seam gangue > temperature.

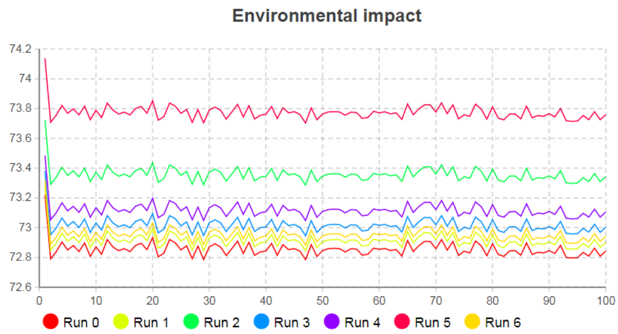

Figure 4: Sensitivity diagram of environmental factor indicators(Model Export)

As shown in Figure 5 below, The trend diagram of the influence of management on the reliability of the raw system of the header workface. The curve marked in red in the graph represents the initial reliability degree of the production system of this heaving workface; the yellow curve represents the influence of other factors unchanged staff assessment and evaluation pass rate reliability degree increased by 0.2 on the whole system; the same green curve represents the index factor of three violations rate, the blue curve represents the perfect rate of safety rules and regulations, the purple curve represents the safety exclusion strength, and the pink curve represents the emergency mechanism perfection rate. Therefore, among the management factors, the effects on system safety are, in descending order: perfect rate of safety rules and regulations >

perfect rate of emergency mechanism > perfect rate of safety inspection > rate of three violations > pass rate of staff assessment and evaluation.

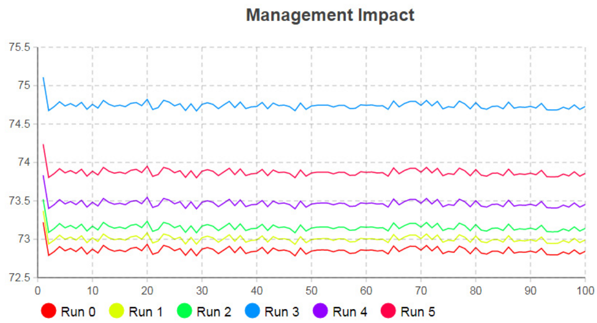

Figure 5: Sensitivity graph of management factor indicators(Model Export)

As shown in Figure 6 below, The trend diagram of the influence of information on the reliability of the raw system of the heaving workface. The curve marked in red in the graph represents the initial reliability degree of the production system of this heaving workface, and the yellow curve represents the influence of other factors constant information prediction situation reliability degree increase by 0.2 on the whole system; the same green curve represents the index factor of information degree, the blue curve represents the information accuracy degree, and the purple curve represents the monitoring information feedback situation. Therefore, among the mechanical equipment factors, the effects on the degree of system security are, in descending order: the degree of information technology, the degree of information accuracy, the prediction situation, and the feedback situation of monitoring information.

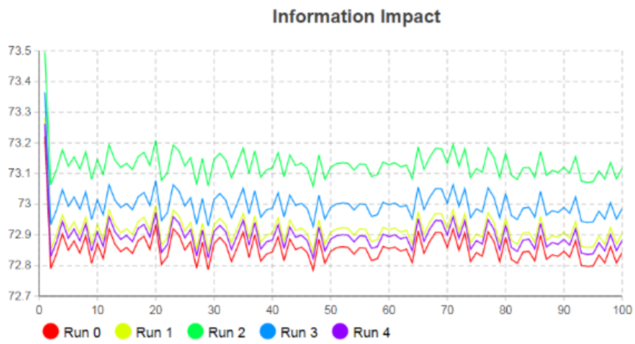

Figure 6: Sensitivity of information factor indicators(Model Export)

5 CONCLUSION

At the present stage of coal mine production, the safety of production system is still the primary consideration of the enterprise. In this paper, based on the engineering background of coal mine enterprise production, the production system of comprehensive mining working face is used as the research object, and the hierarchical analysis method, fuzzy comprehensive evaluation method and system simulation method are used to make comprehensive evaluation of system safety and further develop optimization research, and the specific research results are as follows.

The system safety evaluation index system of hewed working face was constructed. The safety of hewed working face is affected by various factors such as personnel factors, mechanical equipment factors, environmental factors, management factors and information factors, among which personnel factors are the key factors affecting the reliability of the production system of hewed working face.

A system dynamics simulation model was established to evaluate the safety of the production system of the comprehensive mining face. Among the operator factors, the physical and mental health status indicator is more sensitive; among the mechanical equipment factors, the mechanical and electrical equipment integrity rate indicator is more sensitive; among the environmental factors, the roof stability indicator is more sensitive; among the management factors, the safety rules and regulations perfect rate indicator is more sensitive; among the information factors, the informationization degree indicator is more sensitive. Therefore, the improvement and strengthening of these aspects should be paid attention to in the safety management of the production system of coal mine comprehensive mining working face.

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