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Research Article

Evaluation and Early Warning Simulation of Personnel Unsafe Behavior in Mines Prone to Coal-Rock Dynamic Disasters

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At present, aging mines are faced with development bottlenecks such as lack of national policy support, serious problems left over from history, and difficulties in enterprise transformation and development, which seriously restrict the safe production and sustainable development of aging mines. In order to deeply analyze the influencing factors of group unsafe behavior in aging mines, the evolution law of unsafe behavior is qualitatively simulated and quantitatively analyzed to realize the safety evaluation of group unsafe behavior in aging mines. Based on this analysis of the emergence mechanism and influencing factors of unsafe behavior in aging mines, the evaluation index of unsafe behavior in the aging mine population was established. These include six criterion layers and 30 index layers; the mutation level value of the target layer is 0.9405. Group dynamic effect and safety management factors are the two important factors restricting their development and safety. The unsafe behavior of the aging mine groups was evaluated based on game theory and system dynamics—dynamic game simulation on the influence of unsafe behavior in aging coal mines. A qualitative simulation analysis was also performed using the QSIM algorithm. The evolution law of the safety psychology and behavior of aging mine workers are analyzed. This paper shows the importance of the unsafe behavior of aging mines, which helps the safety production and clarifies the safety psychology and the behavior evolution law. This paper puts forward new methods and theories on the safety psychology and behavior evolution law of the safety behavior and provides a reference for the sustainable development of aging mines.

1. Introduction

The mines in China are gradually mined deep, and the danger of coal power disaster facing the deep mines increases. China is a country with frequent coal mine disasters in the world. As of 2020, the death rate of one million tons of coal mines has decreased from 0.288 in 2013 to 0.058. The number of deaths has also decreased year by year, but the number of coal mine accidents is still huge [1]. In view of the frequent accidents in the coal mine industry, national and local governments have also formulated many management measures. Since the Twelfth Five-Year Plan, backward production capacity industries have been gradually eliminated, and exhausted resources and aging mines have gradually closed [2]. Studies show that 12,000 backward mines are expected to be closed by 2020, and this number is likely to become 15,000 by 2030 [3].

As the number of closed mines increases, many scholars have put forward the development road of pit closure mines. However, in the process of resource depletion and the orderly exit of the aging pit, how the mine before pit closure is conducted in this stage of safe development must also be considered. The gradual backwardness of the aging mine industrial structure, increasing enterprise losses, high production costs, decreasing coal resources, and insufficient development motivation are becoming increasingly prominent. There is a huge demand for the characteristics of group unsafe behavior, risk evaluation, and early warning and control of aging mines, which is also a problem that must be faced to realize the safe development of aging mines [4–6].

At present, many scholars at home and abroad have carried out research on the unsafe behavior of mine personnel and groups [7–10]. Liu et al. [11] discussed the impact of artificial factors on coal mine accidents in China through the AHP analysis method. Pang and Li [12] studied the relationship of organizational sense of fairness and unsafe behavior of miners in a regulatory mediation model; Siu et al. [13] proposed the attitude of mine personnel to safety and the safety behavior and safety benefits; Rundmo [14] studied that the safety atmosphere and safety awareness of mine personnel will seriously affect the safety behavior of workers.

Scholars at home and abroad are using simulation technology to study the safety of coal mine production. Chen et al. [15] established a cause model for human error in the mine accident and put forward new ideas of safety management in line with China's national conditions. Tian et al. [16], using the theory of unsafe behavior, CGP model, and NetLogo simulation platform, analyzed and simulated the causes of unsafe behavior of mine personnel; Liao et al. [17] studied the system emergence driven by safety information force. Tong et al. [18] used the integrated DEMATEL/ISM method to build the CGP miner unsafe behavior emergence model and analyze the miner unsafe behavior emergence using the NetLogo platform. Since the French mathematician Leetm formally proposed the mutation theory in 1972, in recent years, Li et al. [19] evaluated the support effect of the mutation series method and improved the mutation series method. Wang et al. [20] evaluated the fire hazard of the mine based on the gray correlation entropy-mutation series method, and Luo et al. [21] evaluated the gas explosion risk with the improved mutation series method.

The use of simulation technology has certain advantages in studying the unsafe behavior of coal mine personnel. Li et al. [22] used the SD method to establish the miners' emotional stability model and simulate the factors affecting the effects of miners' emotions with the means of Vensim software. Liu et al. [23] conducted a data survey of the Wangzhuang Coal Mine, used software to conduct dynamic simulation experiments on the model, and put forward four management modes to improve the unsafe behavior of miners. Lin and Li [24] proposed that the most effective effect on the self-control ability image is temporary psychology and rebellious psychology. Han et al. [25] took the investigation of China's rock explosion original coal mine as an example to investigate the deterioration and dislocation of a variety of organizational relations.

The above research results to the aging mine unsafe safety evaluation have brought huge guiding effect; the aging mine is facing a lack of national policy support, enterprise transformation difficulties, historical problems, etc.; a series of unsafe behavior seriously affect the aging mine safety production and sustainable development; the related areas of aging mine unsafe safety evaluation and simulation analysis are less. Based on the production background of aging mines, analyze the theory of aging mine accidents, establish the evaluation index system to realize the evaluation of the aging mine population, and make the analysis of the safety behavior of aging mines and guiding value for the safety development of aging mines.

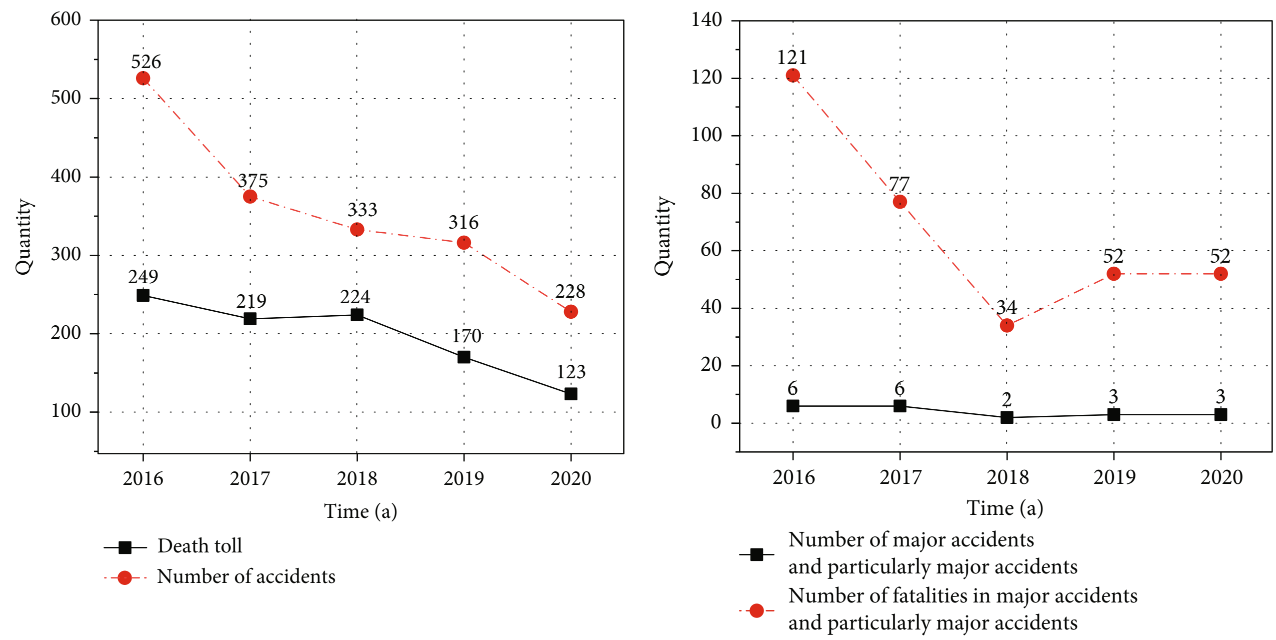
2. Emerging Mutation Mechanism of Unsafe Behavior in the Aging Mine Population

The production of the mine is generally divided into the following 6 periods, the mine gestation period, mine growth period, mine maturity period, mine recession period, mine exit period, and mine transformation period [26]. The mines entering the recession period had their coal production exhausted, production capacity declined, market demand reduced, production growth rate technical level declined, labor efficiency declined, and production structure contraction management level scattered [26]. The aging mine has general production personnel, mainly on the well and underground production personnel. Statistically, coal mine accidents occurred in China in the 5 years from 2016 to 2020, as shown in Figure 1 [1].

As obtained from Figure 1, the number of coal mine accidents gradually decreased in the past five years. The total number of accidents decreased from 249 in 2016 to 123 in 2020, down by 50.6%. The death toll also dropped from 526 in 2016 to 228 in 2020, down by 56.7%. This is closely related to improving Chinese coal mine production technology and constructing a safety management and prevention system. In the major and particularly major accidents in the past five years, the number of gas, fire, roof, and other accidents occurred more, resulting in a large number of deaths. This shows that the accident prevention and treatment of coal mine enterprises, especially aging mines, should mainly focus on gas prevention, fire prevention, roof prevention, and the prevention of other accidents. Human resources, material resources, and financial resources are the important reasons restricting the safe production of aging mines.

2.1. Group Composition and Unsafe Behavior Reasons of Aging Mines. In the accidents caused by mistakes in aging mines, the fault of the mine personnel group is unsafe behavior. The generation of unsafe behavior in aging pit groups is affected by multiple factors, which itself also has complex characteristics and uncertainty, divided into two categories: conscious unsafe behavior and unconscious unsafe behavior. Aging mine personnel have been working in mines for a long time. Aging mines have high requirements, low working resources, and low social support. The miners are under great pressure, which leads to this group being prone to unsafe behavior in mine work [27, 29]. The reasons for the psychological insecurity of aging mine staff are shown in Figure 2.

Available in Figure 2, the insecurity of the aging mine population goes through three important processes, including nine important stages. The three important processes are the initial psychology, the individual intention formation psychology, and the final behavior formation psychology. The nine important stages are stable behavior, interference stimulation, memory query, knowledge discrimination, behavior discrimination, external interference, secondary



(a) Number of deaths and number of accidents

(b) Number of major accidents and particularly major accidents and the number of deaths

Figure 1: Coal mine accident statistical diagram for 2016-2020.

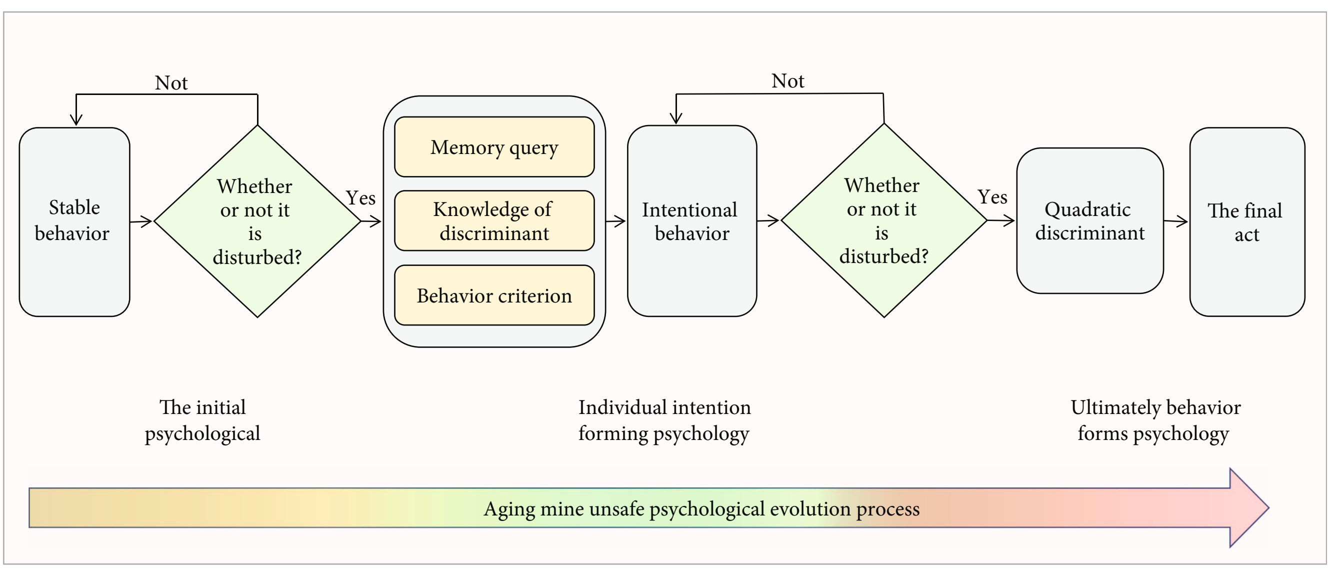


Figure 2: Mechanism diagram of unsafe psychological generation in the aging mine group.

knowledge discrimination, secondary behavior judgment, and actual behavior. Aging mine personnel groups will form a certain amount of time. The stable behavior will be disrupted. The change of stable behavior starts from the individual and is affected by individual psychology, which mainly includes memory query, knowledge discrimination, and behavior discrimination. After further interference, individual intention behavior will be formed to determine whether to implement individual behavior and finally leads to the generation of individual behavior. Generally speaking, the aging mine group unsafe behavior formation process is the personnel group in a stable state that maintains an initial state of psychology, and external interference stimulation began to start memory query, knowledge discrimination, and behavior discrimination processes and then form individual intention formation psychology and intention behavior, and under the action of subsequent interference stimulation, after secondary discrimination and multiple discrimination, the individual intention forms psychological convergence into a group of unsafe behavior. Individual psychology and individual behavior belong to the causal relationship. The two are interrelated and promote each other, which is the key to forming unsafe behavior in aging mine groups. The group characteristics and unsafe psychology of the aging pit group have formed the uncertainty of the aging mine population. Abnormalities of some or certain factors such as physical fitness, mentality, and skills will eventually lead to the occurrence of unsafe behavior. Therefore, the development process of unsafe behavior in the aging mine population is shown in Figure 3.

From Figure 3, the aging mine group unsafe behavior development process is affected by many factors, both internal individual factors and external objective factors. Internal individual factors mainly include emotional disorders, attitude influence, attention influence, motivation influence, physiological defects, knowledge and skill defects, interests and management defects, working environment defects, and personnel specification defects. These factors have strong complexity and high comprehensive effect. External objective factors mainly include environmental and management elements. Different from the general construction of high-yield mines, they are greatly affected by the aging mine environment. Group unsafe behavior is the result of the joint action of various factors.

2.2. Emerging Mutation Mechanism of Unsafe Behavior in the Aging Mine Population. The emergent theory is an emerging methodology. Emergency response is from low level to high level and from local to whole, which will not only increase functions and elements but also make a qualitative leap, which has the advantages of greater than the sum of parts, simple and complex generation, and decentralization [17]. The essential characteristics of the emergent theory are as follows: bottom-up, randomness, process, contingency, and complexity. The research on the emergence of the safety circle started in the 1960s [18]. At present, the research on the emergence of the mine safety system is still in its initial stage, mainly focusing on the emergence of unsafe behavior of personnel groups and analyzing the change trend of human safety consciousness from the emergence characteristics [33, 34].

The aging mine group unsafe behavior emergence process refers to the coal mine safety management system individual miners and managers and organizers through association coupling, who changed their own safety elements and structure, causing the overall unsafe behavior elements and structure change. Generally speaking, the aging mine group unsafe behavior emergence process refers to individual miners in the aging mine working environment after mutual influence, with its unsafe behavior interaction from individual to group of a concentrated emergence and mutation process [18]. Figure 4 shows a schematic representation of the unsafe behavior emergence mechanism in aging pit populations.

Aging mine personnel are different from other mine staff, and unsafe behavior and individual behavior are under the influence of surrounding factors from the overall accumulation, with the accumulation process from individual to the random and irreversible process of randomness, and in the process of accumulation, individual unsafe behavior will also affect the environment and construction, and when the individual unsafe behavior accumulation reaches a certain threshold, it will change from quantitative change to qualitative change, and at a certain place, a sudden outbreak occurs, thus leading to group unsafe behavior, namely, safety accidents and safety disasters.

Main influencing factors in aging mines include organizational leading factors, safety management factors, group dynamic effect, external environment and management, human-machine environment state, worker personal quality, and other disordered system states, including the interaction between miners and small groups, from a long period of stable state to a short period of stable state, until the overall state of the system from disorder to order, namely, the concentration of aging mine unsafe behavior, manifested as group orderly unsafe behavior.

The emergence of unsafe behavior in aging mine groups occurs when individual miners gather into the mining group. The whole process has bottom-up properties and randomness. The emergent results cannot be deduced by logical reasoning. Once it happens, the process is irreversible; the moment of emergence is sudden. Emergence is a process ranging from quantitative change to qualitative change, showing suddenly at the moment from quantitative change to qualitative change; different stages of the emergent process have different complexities. Complexity increases as the stage evolves, hence the more complex the manifestations and characteristics are.

3. Analysis of Unsafe Behavior in Aging Mines

3.1. Steps for Mutation Series Evaluation. The mutation series method has evolved from mutation theory. On the basis of mutation theory and fuzzy mathematics, the research system is a hierarchical decomposition of indicators to form a distinct multitarget inverted dendritic evaluation system, which is a multistandard comprehensive evaluation method [35, 37].

The specific evaluation steps commonly seen in the catastrophe progression method are as follows [38].

3.1.1. Establishment of the Evaluation Index System. This process is to decompose the target layer structure into subindexes layer by layer until the decomposed subindexes can be measured through specific data and finally form an inverted tree multilevel evaluation index system.

3.1.2. Dimensionalization of Evaluation Indicators. Nondimensionalization treatment is to put forward the division of positive and inverse indexes for each index. Moreover, the nondimensionalization treatment of the system index is also divided into the positive index and inverse index, and the corresponding nondimensionalization treatment formula is as follows.

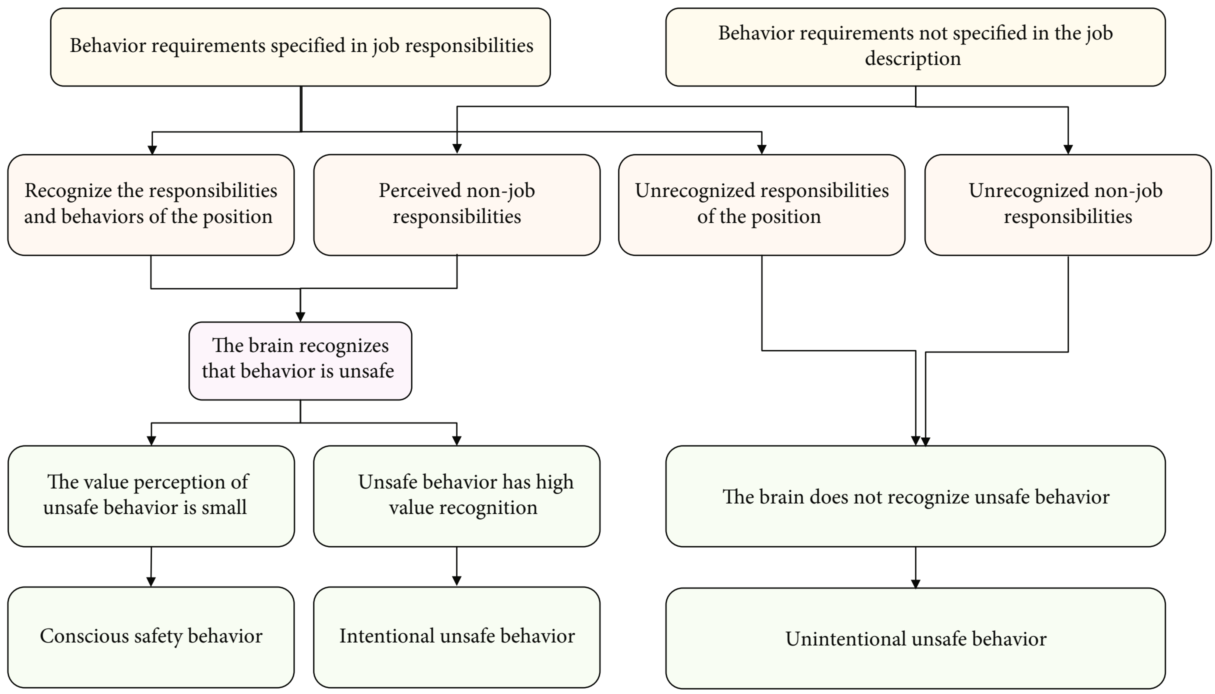


Figure 3: Development process of unsafe behavior in aging mine groups.

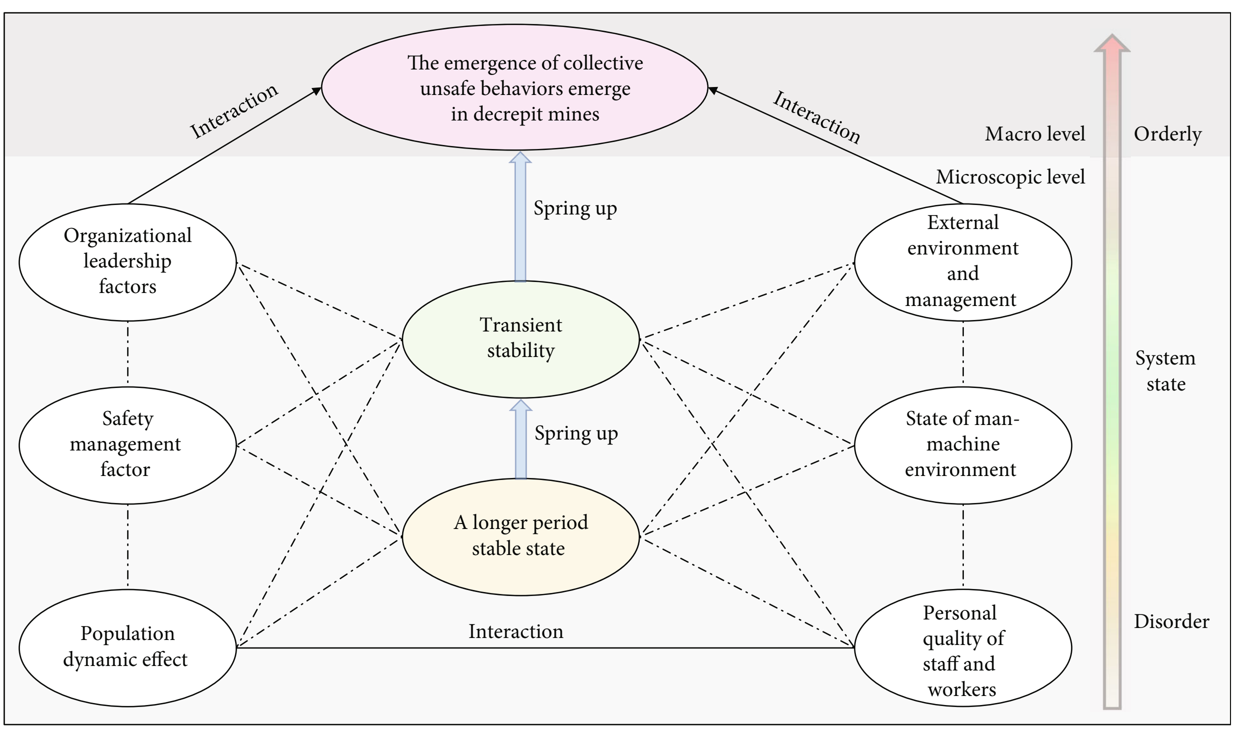


Figure 4: Schematic diagram of the emergence mechanism of unsafe behavior in aging pit groups.

Positive indicators (i.e., the better indicators) were non-dimensionless:

$$Yi = \frac{Xi - X\min}{X\max - X\min}. \quad (1)$$

The reverse index (i.e., the smaller, the better index) is as follows:

$$Yi = \frac{X\max - Xi}{X\max - X\min}. \quad (2)$$

Yi in the formula above represents the normalized data after using the extreme difference transformation method, while in the formula, the Xi term indicates the original data. X max and X min are the maximum and minimum values of the data in the same evaluation index, respectively.

3.1.3. Normalization of the Evaluation Indicators. Taking the most widely used sharp point mutation model as an example, the potential function of the sharp point mutation model can be obtained after the first-order and second-order guidance and multiple combinations of the divergence point set equations, and the corresponding normalization formula can be obtained after decomposition.

3.1.4. Calculation of the Mutation Level Value. In the comprehensive evaluation, obtain the mutation level value of the previous target according to the "complementary" and "noncomplementary" principles, calculate the mutation level layer by layer, and finally find the mutation level value of the target layer and then conduct the comprehensive evaluation.

3.1.5. Order of Importance and Evaluation Results. According to the calculated value of the standard layer mutation level, the risks of safety evaluation should be graded, and the results and conclusions of safety evaluation are finally drawn.

The mutation series method is different from the static evaluation method; is a dynamic evaluation method; compensates for the lack of the static evaluation method, without calculating the evaluation index weight; simplifies the evaluation process; avoids the deviation caused by the unreasonable empowerment method; fully considers the internal connection between lattice risk elements; and can highlight the main risk, to take targeted preventive measures, reduce subjectivity, and improve the scientificity and rationality of the evaluation results.

3.2. Analysis of Safety Evaluation Results of Unsafe Behavior in the Aging Pit Population

3.2.1. Establishment of the Evaluation Index of Group Unsafe Behavior. In the production process of aging mines, there will be many risk factors, which are not obvious but have a certain hidden nature and are not easy to be identified; they connect and interact with each other. We carefully studied the relevant literature to make a scientific, comprehensive, and objective evaluation index [39–42]. For the evaluation of the aging mine population, we analyzed nine guiding principles, respectively, the scientific principle, purpose principle, objective principle, systematic principle, timeliness principle, feasibility principle, operability principle, qualitative and quantitative combination principle, and determinability principle. According to the surrounding environment and internal factors of the aging mine, unsafe behavior of the aging mine group is taken as the target layer of safety evaluation, and macrofactors are directly related to the unsafe behavior of the aging mine group. Fish thorn plots for specific divisions of evaluation indicators at all levels are shown in Figure 5.

According to Figure 5, the evaluation indicators at all levels of the main organizational leadership factors, safety management factors, group dynamic effect, external environment and management, human-machine environment status, and worker personal quality of six indicators function as a standard layer, and the leadership state, safety guidance, safety care, safety control, safety training, and other 30 factors function as the index layer. The evaluation index system of the aging mine population is shown in Table 1.

3.2.2. No Dimensitreatment and Normalization Calculation of the Evaluation Index. Effective assignment of indicators is the premise of accurate evaluation. This section invites the aging coal mine management personnel and production safety experts on the basis of referring to the coal mine safety regulations to score. According to the score, the positive indicators of unsafe behavior in the aging mine group were 26 in $\{C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C12, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C27, C28, C29\}$ and 4 in $\{C11, C13, C26, C30\}$.

The classification standard of the aging mine group unsafe behavior risk assessment index is level 5. The corresponding classification standard is shown in Table 2.

In the process of calculation, the dimensionless treatment of each index is conducted according to the dimensitreatment principle of the evaluation index. In this paper, the corresponding normalization formula of the butterfly mutation model is selected for calculation. Safety management factor B2, group dynamic effect B3, external environment and management B4, human-computer environment state B5, and worker personal quality B6 belong to the parabolic mutation model, swallowtail mutation model, and shed mutation model. Choose the corresponding mutation model normalization formula, and calculate the index layer of mutation level. According to the mutation level value of the index layer and the complementary and noncomplementary principles, the complementarity principle is selected for calculation. According to the number of standard layers, the control variables are normalized to calculate the mutation level value of the standard layer.

The results of the nondimensionalization treatment, the mutation level values of the index layer, the nondimensionalization values of the criterion layer, and the criterion layer mutation level values according to the above analysis are shown in Table 3.

3.3. Analysis of the Comprehensive Evaluation Results. The calculations are available from Sections 3.1 and 3.2, and the mutation level of the target layer is 0.9405. The corresponding safety level is general safety. The mutation level values of each standard layer are organizational leadership factor 0.8665, safety management factor 0.8273, group dynamic effect 0.8253, external environment and management 0.8797, human-machine environment state 0.8464, and personal quality of workers 0.8448, and the safety evaluation rating belongs to the general safety level. According to the size of the mutation level value, the relative importance order of the standard layer is group dynamic effect>-safety management factors>employee personal

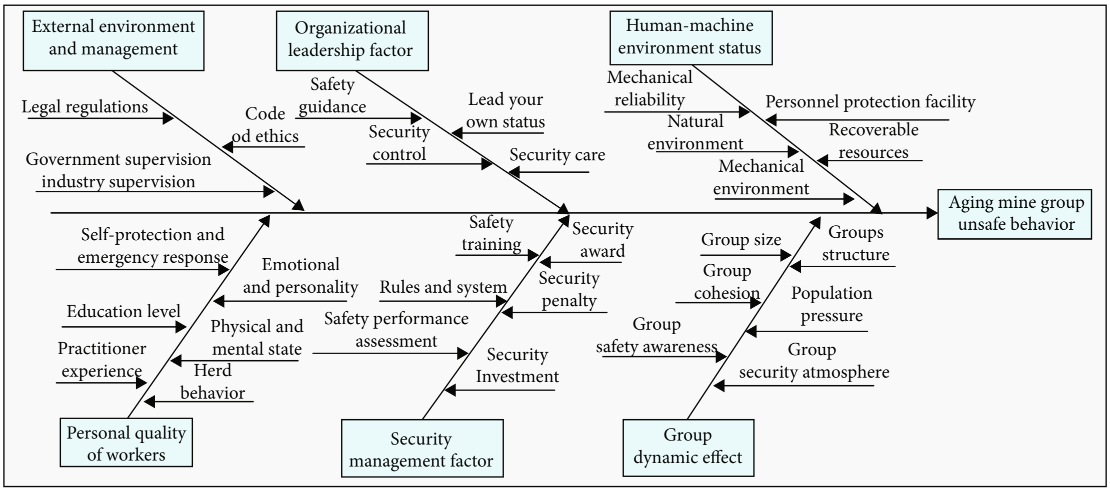


Figure 5: Fish thorn diagram of the unsafe behavior evaluation index system of the aging pit population.

Table 1: Evaluation index system of unsafe behavior in aging pit groups.

Target layer	Code layer	Index layer
Aging mine group unsafe behavior A	Organizational leadership factor B1	Lead your own status C1
		Safety guidance C2
		Security care C3
		Security control C4
	Security management factor B2	Safety training C5
		Security penalty C6
		Security award C7
		Security investment C8
		Rules and systems C9
		Safety performance assessment C10
	Group dynamic effect B3	Group size C11
		Group structure C12
		Population pressure C13
		Group cohesion C14
		Group safety awareness C15
		Group security atmosphere C16
	External environment and management B4	Legal regulations C17
		Code of ethics C18
		Government supervision, industry supervision C19
	Human-machine environment status B5	Natural environment C20
		Mechanical environment C21
		Mechanical reliability C22
		Recoverable resource C23
		Personnel protection facility C24
	Personal quality of workers B6	Education level C25
		Emotional and personality C26
		Self-protection and emergency response C27
		Physical and mental state C28
		Practitioner experience C29
		Herd behavior C30

Table 2: Classification of unsafe behavior in aging mines.

Order of evaluation	Very secure I	General safety II	Negligible risk III	General danger IV	Very dangerous V
Affiliate interval Take value range	(0.95 ~ 1]	(0.80 ~ 0.95]	(0.70 ~ 0.80]	(0.60 ~ 0.70]	(0 ~ 0.60]

Table 3: Safety evaluation results of unsafe behavior in aging pit groups.

Indicator number		The index layer has no dimensional value y_{Ci}	Mutation level value of the index layer x_{C_i}	The criterion layer has no dimensional value y_{B_i}	Breakthrough stage value of the accurate layer x_{B_i}	Values of the mutation level of the target layer x_A
B1	C1	0.700	0.837	0.8665	0.9405	0.9405
	C2	0.643	0.863			
	C3	0.575	0.871			
	C4	0.575	0.895			
B2	C5	0.475	0.689	0.8273	0.9483	
	C6	0.363	0.713			
	C7	0.517	0.848			
	C8	0.525	0.879			
	C9	0.640	0.919			
	C10	0.543	0.916			
B3	C11	0.459	0.677	0.8253	0.9531	
	C12	0.475	0.780			
	C13	0.350	0.769			
	C14	0.505	0.872			
	C15	0.635	0.927			
	C16	0.591	0.927			
B4	C17	0.688	0.829	0.8797	0.9747	
	C18	0.744	0.906			
	C19	0.668	0.904			
B5	C20	0.542	0.736	0.8464	0.9726	
	C21	0.563	0.826			
	C22	0.544	0.859			
	C23	0.532	0.881			
	C24	0.646	0.930			
B6	C25	0.620	0.787	0.8448	0.9762	
	C26	0.531	0.810			
	C27	0.460	0.824			
	C28	0.500	0.871			
	C29	0.447	0.874			
	C30	0.491	0.903			

quality>human-machine environment state>organizational leading factors>external environment and management.

According to the evaluation results, the mutation level values of population dynamic effect and safety management factors were the lowest, with 0.8253 and 0.8273, respectively. This also shows that the group dynamic effect of the aging mine population is the biggest safety risk factor. The most important factor causing frequent aging mine safety accidents, followed by safety management factors, also impacts safety accidents. We must first strengthen the personnel group management of aging mines from these two aspects.

4. Qualitative Simulation Study of Population Safety Behavior of Aging Mines

4.1. Construction of the Group Safety Behavior Game Model. There is a function relationship between the income and the time produced in the behavior game of managers and

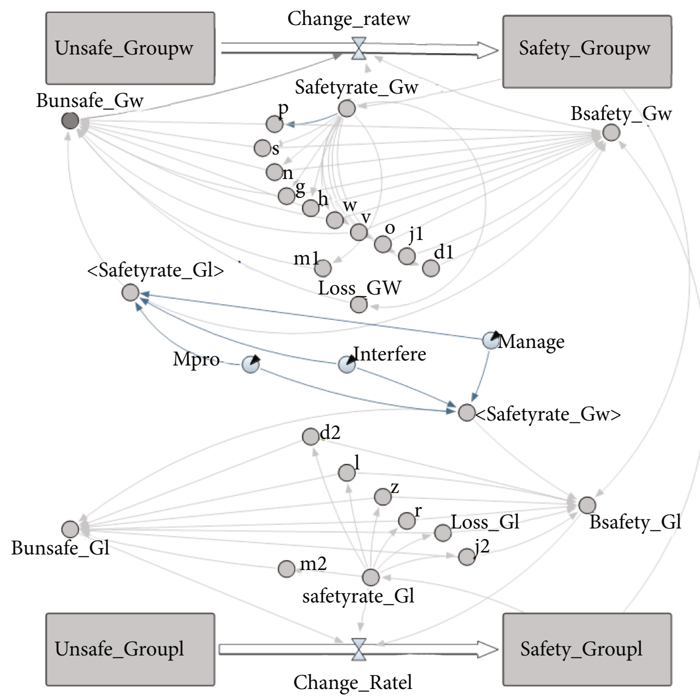


Figure 6: Manager-worker group safety behavior game SD model.

Table 4: SD model variable symbol information table.

S/N	Variable symbol	Model variable	S/N	Variable symbol	Model variable
1	$Unsafe\_Group_w$	Unsafe behavior of worker groups	18	p	Safety performance of staff groups
2	$Safety\_Group_w$	Safety behavior of worker groups	19	v	Spirit of the worker group
3	$Unsafe\_Group_l$	Manager for unsafe behavior	20	o	Staff group conformity behavior
4	$Safety\_Group_l$	Manager safety behavior	21	d_1	Safety cost of worker groups
5	$Change\_Rate_w$	Change rate of safety behavior of worker groups	22	j_1	Safety reward for worker groups
6	$Change\_Rate_l$	Rate of change in management safety behavior	23	$Loss\_G_w$	Accident loss of worker groups $(e_1 * f_1)$
7	$Safetyrate\_G_w$	Safety behavior rate of worker groups	24	m_1	Staff group punishment
8	$Safetyrate\_G_l$	Safety behavior rate of managers	25	l	Manager safety learning to learning
9	$Bunsafe\_G_w$	Income from the unsafe behavior of the worker groups	26	z	Leadership execution
10	$Bsafety\_G_w$	Safety behavior income of worker groups	27	r	Leadership interpersonal relationship
11	$Bunsafe\_G_l$	Manager unsafe behavior income	28	d_2	Manager safety costs
12	$Bsafety\_G_l$	Manager safety behavior income	29	j_2	Manager safety reward
13	s	Psychological security of the worker group	30	$Loss\_G_l$	Management accident loss $(e_2 * f_2)$
14	n	Working status of worker groups	31	m_2	Manager punishment
15	g	Safety norms for worker groups	32	Mpro	Managers check the probabilities
16	h	Safety awareness of worker groups	33	Interfere	External disturbance
17	w	Safety atmosphere of worker groups	34	Manage	Measure

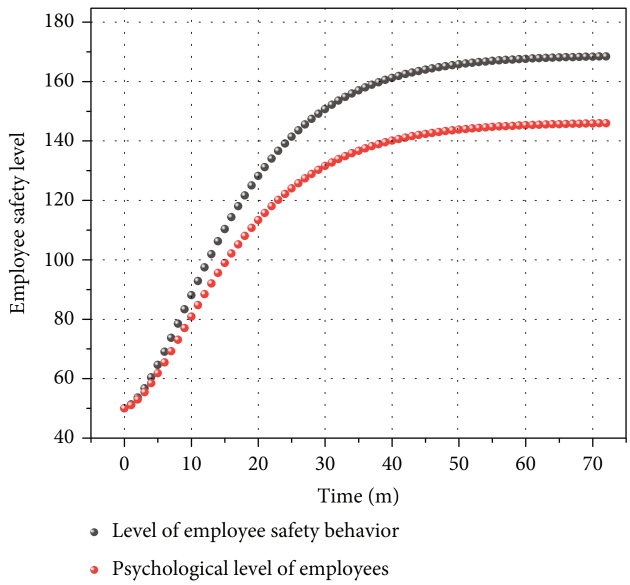


FIGURE 7: Population status is initial.

workers in aging mines; that is, the income changes with time. The game process is calculated by calculating the game equilibrium point, and the stability strategy is complex and cannot clearly observe and analyze its dynamic evolution process. SD can macroscopically analyze global changes but also can comprehensively investigate the evolution process.

In order to further study the generation of unsafe behavior in aging mine groups, it is modeled and simulated based on the evolutionary game relationship between the safety behavior of managers and workers. System dynamics were employed, using AnyLogic as a platform for its simulations. According to the psychological and behavioral characteristics of aging mine workers, the game assumptions of this article are as follows.

Assumption 1. The environment of the worker group is just an external condition and does not participate in the process of the behavior game.

Assumption 2. Group safety behavior is mainly a comprehensive result of the interaction of the related elements of the group. If safety behavior is used, its performance improves. Factors change when the strategies are consistent and unsafe behavior.

Assumption 3. In different strategies between the two games, the manager and worker will have mutual interaction and interference, and the influence intensity coefficient is λ_1, λ_2 $(0 < \lambda_1, \lambda_2 < 1)$.

Assumption 4. If the behavior of both sides of the game is safe, then the game needs to pay other security costs such as physical strength and time, that is, d_1 and d_2, and will also get security rewards, that is, j_1 and j_2.

According to the above assumptions, the SD model of the manager-worker group security behavior game is shown in Figure 6 and Table 4, which is symbolic according to the naming characteristics of Java programming variables, so that the variables in the model can participate in the background logic operation and data analysis processing.

4.2. Simulation and Analysis of the Evolution Law of the Safety Behavior of Managers and Workers. Considering the game expected return, average income, etc., design the quantitative relationship between SD variables and build the SD model of the aging mine worker group safety behavior game, using the qualitative simulation analysis theory and QSIM algorithm principle, combined with the group safety behavior evolution process characteristics and qualitative simulation analysis, with QSIM as a simulation and analysis tool and simulation analysis of aging mine worker group safety behavior evolution characteristics and rules. The simulation results of the initial state of the population are shown in Figure 7.

As shown in Figure 7, as the game proceeds, group safety behavior and psychology grow similar, and the rate gradually slows down and finally reaches equilibrium in 64 time periods. The final level of group safety behavior in the equilibrium state (about 168) is higher than the group psychology level (about 145). A comparative analysis of the impact of management decisions and external interference on group safety behavior and psychology was used. Using the sensitivity analysis properties of AnyLogic, behavioral and psychodynamic change processes were simulated at different intensities. The evolution laws and characteristics of the safety behavior of aging mine managers and workers are shown in Figure 8.

As seen from Figure 8(a), if the management decision power improves, when the game reaches equilibrium, the level of the group security behavior gradually increases from 168 in the initial state to about 195 in the final state (Manage = 10). As managers' decision-making ability increased, the growth rate of the group safety behavior level gradually increased. The time to reach the game average state also gradually decreased from the initial state (Manage = 0), with about 64 time periods before reaching the game balance and 61 times reduced by 4.688% in the final (Manage = 10).

Figure 8(b) represents the sensitivity analysis of managers' decisions to group psychology. As the decision-making capacity increases, the analysis shows that the level of safety psychology in the population gradually increases from the initial state of 145 (Manage = 0). It is intuitively seen from the figure that the growth rate of the group safety psychology level also increases by increasing the strength of management decisions, reducing the time to reach equilibrium by 23.333% from 64 cycles (Manage = 0) to 50 cycles (Manage = 10).

As shown in Figure 8(c), the greater the interference intensity, the lower the level of population safety behavior, which decreased from 145 in the initial equilibrium state to about 25 and by 82.75%. Figure 8(d) shows the sensitivity analysis of external interference to group psychology, from

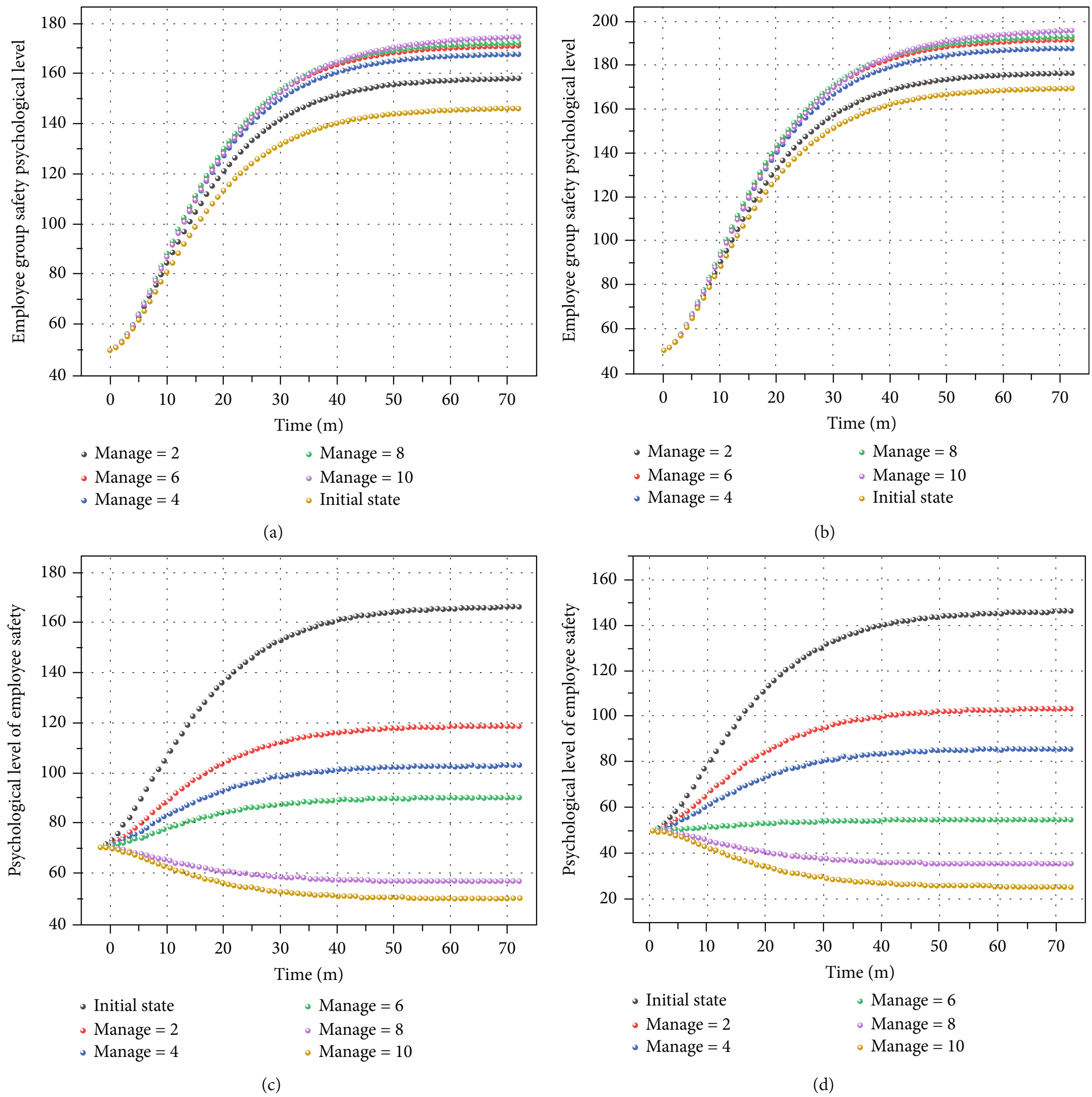
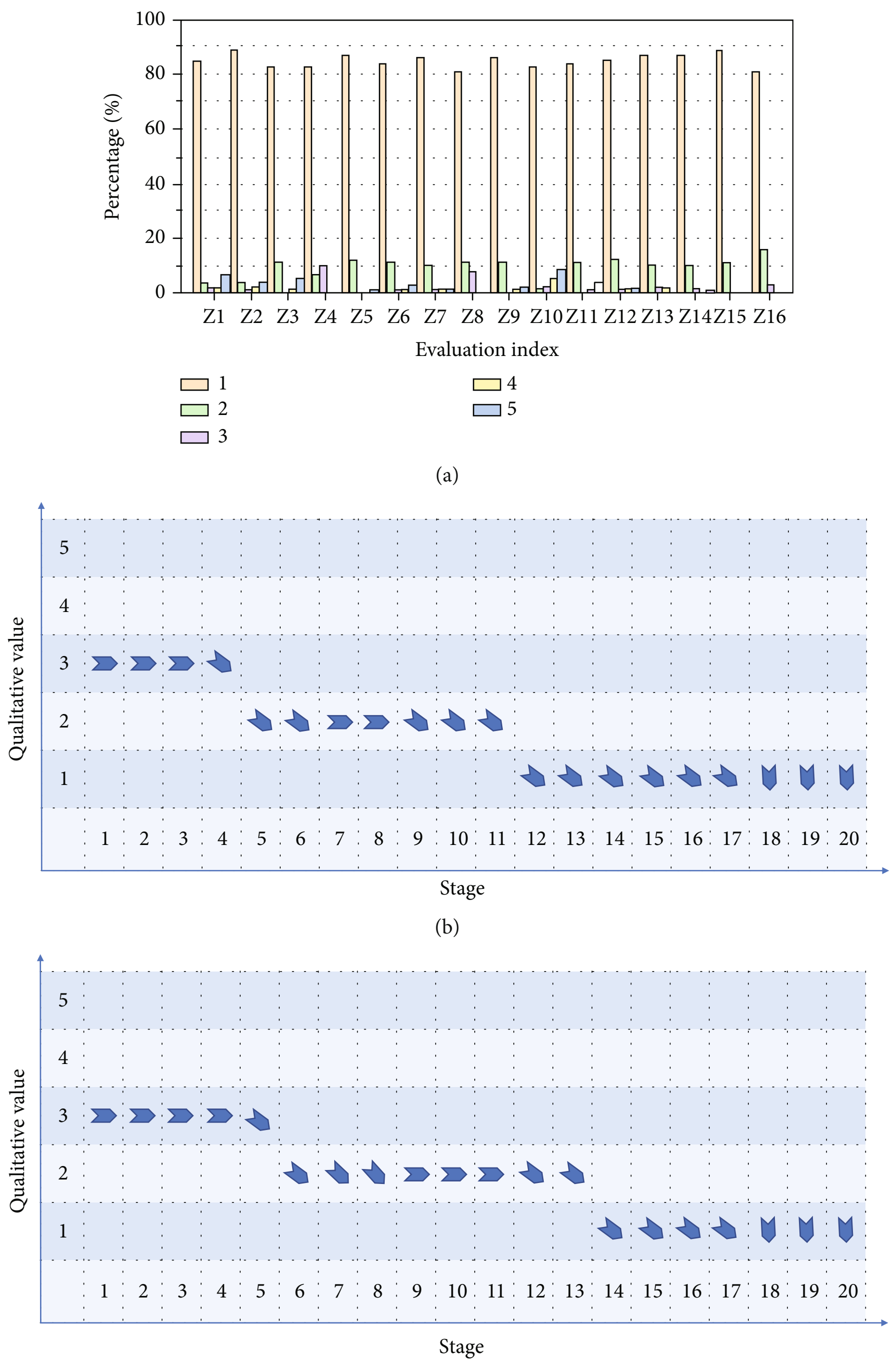


Figure 8: Evolution law of safety behavior among managers and worker groups. (a) Effects of management decisions on group behavior. (b) Impact of management decisions on group psychology. (c) Effect of external interference on group behavior. (d) Effect of external interference on group psychology.

Table 5: Simulation scheme table.

Modeling scheme	Management decision variables X X_1-X_{10}	Interference variables Y Y_1-Y_8	System state variables Z Z_1-Z_{16}	Remarks
1	0	1	<3, ⟶ >	In the face of interference, no countermeasures are taken
2	1	1	<3, ⟶ >	Take decisions comparable to the interference intensity
3	2	1	<3, ⟶ >	In the face of interference, high-intensity countermeasures are adopted

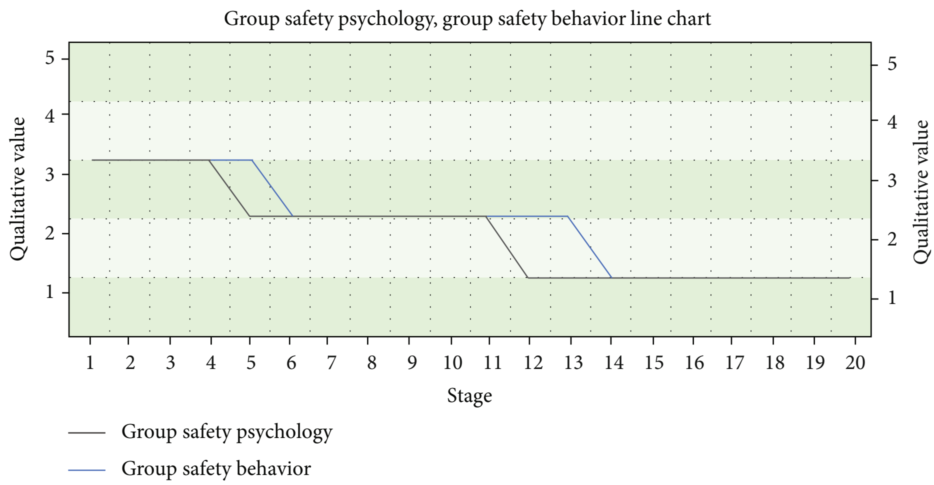


(a)

(b)

(c)

Figure 9: Continued.



(d)

Figure 9: Simulation results and comparative analysis diagram of Scheme 1. (a) Simulation result statistics. (b) Trend chart of group safety psychological change. (c) Trend plot of group safety behavior change. (d) Plot of comparison of trends in group safety psychology and behavior change.

which we can see that with the increased external interference intensity, the group safety psychological level gradually decreased from 145 in the initial state to about 24, which decreased by 83.448%.

Through game simulation and comparison of the safety behavior of aging mines and psychological levels in the initial state, management decision, and interference, we found that aging mine workers' safety behavior and psychological development rules and characteristics are as follows. (1) Whether the incentive includes management decisions or external factors, the trend of both the aging mine workers' behavior and psychological evolution process is basically the same. (2) Good management decisions will significantly increase the safety behavior and psychological level of the group. From Figure 8, the level of safety behavior of the high-intensity management decision is higher than the group (Manage = 10) in the game equilibrium. (3) External interference will interfere with the safety behavior and psychological level of the group. According to the analysis in Figure 8, the group safety psychology level decreases faster than the safety behavior level due to high-intensity interference (Interfere = 10).

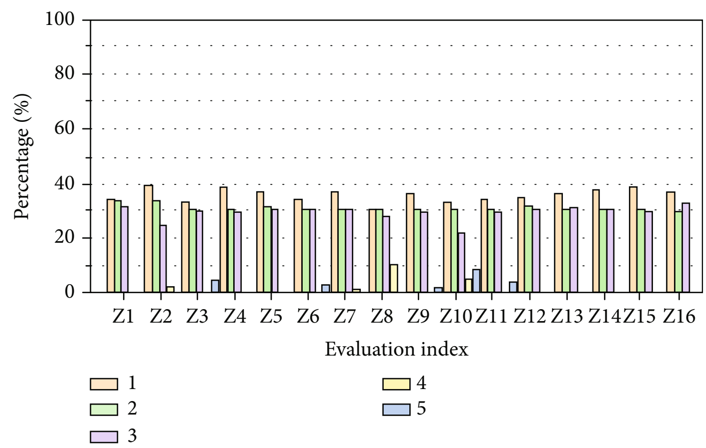
4.3. Qualitative Simulation and Result Analysis of Population Safety Behavior of Aging Mines. According to the characteristics of group behavior combined with the aging mine worker group safety behavior model, considering the combination of possible states (management decision variables, interference variables, and system state variables), three simulation schemes are formulated (Table 5). Each scheme represents the typical safety behavior of aging mine workers. The initial states of the management decision variables, interference variables, and system state variables of the safety behavior model of the aging mine personnel population are different; the initial status of the worker group is different; and the final simulation results are different. In order to analyze the impact of different management decisions and interference factors on the safety behavior and psychology of miners, this paper sets the initial value of the initial state, divided into three situations: no countermeasures to interference, countermeasures comparable to interference intensity, and high-intensity countermeasures, and we adjust the value of management decision variables, interference variables, and system state variables, so as to clarify the influence of different factors on the safety behavior and psychology of aging mine workers.

4.3.1. Scheme 1. Scheme 1 is that the elements of aging mine workers are general, and no control measures are taken for interference, namely, $X = 0$, $Y = 1$, and $Z = <3 \text{ and} \longrightarrow>$. Simulation calculation results and summary analysis are shown in Figure 9.

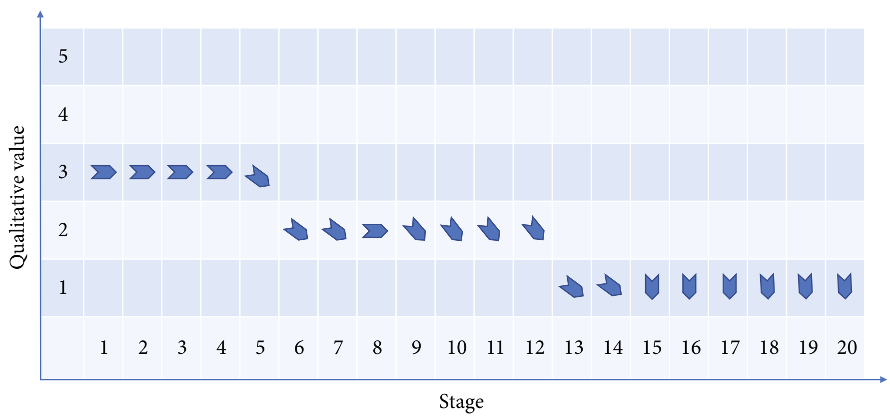
Figure 9 shows various external disturbances around the coal mine workers. Enterprises did not implement any management measures. The safety behavior level (Z_{16}) concentrated on "very low" (qualitative 1) is 81.00%; group safety psychology (Z_4) (1) is 83.00%, respectively; and other factors affecting group safety behavior are concentrated at the "very low" level, and the proportion is above 80.00%.

Simulation results show that there is a variety of outside interference around coal mining workers. Enterprises did not implement any management measures; then, the level of safety behavior (Z_{16}) concentrated on "very low" (qualitative value of 1) is 81.00%, the level of group safety psychology (Z_4) concentrated in "very low" (qualitative value of 1) is 83.00%, other factors affecting the group safety behavior level are concentrated in the "very low" level, and the proportion is above 80.00%.

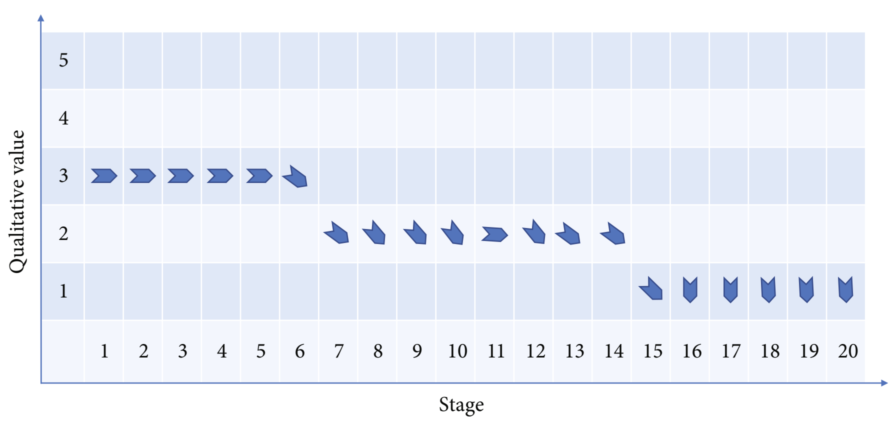
The trend diagram of changes in group safety psychology indicates that the level of group safety psychology is "weakened" ("↘") starting from stage 4, which showed the tendency to decline. In stage 5, the psychological level of group safety decreases to "low" (qualitative value 2). By stage 12, psychological levels of group safety continued to be "very



(a)

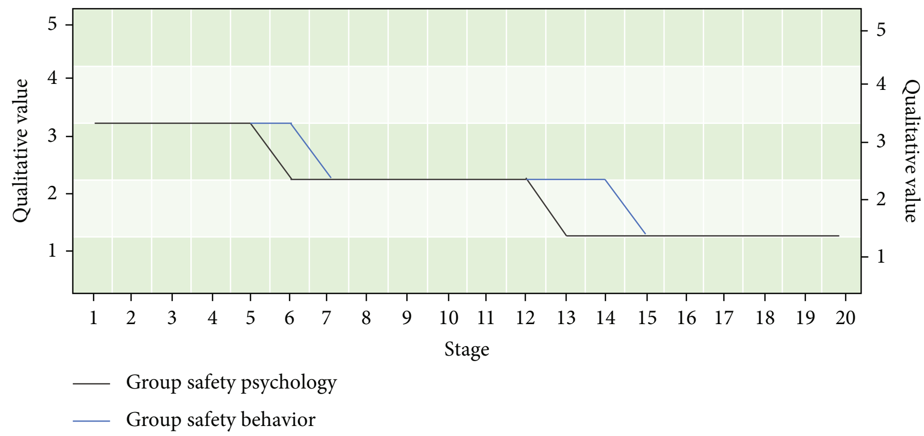


(b)



(c)

FIGURE 10: Continued.



(d)

Figure 10: Simulation results and comparative analysis diagram of Scheme 2. (a) Simulation result statistics. (b) Trend chart of group safety psychological change. (c) Trend plot of group safety behavior change. (d) Plot of comparison of trends in group safety psychology and behavior change.

low" (qualitative value 1). At this stage, the direction of change became "↓," indicating a continued deterioration in the psychological levels of group security.

The relationship between group safety psychology and behavior was further compared, and the change trends of the two elements were summarized, as shown in the comparison chart of group safety psychology and behavior change trends. It is not difficult to see from the figure that the trend of group safety psychology and behavior is similar, which is consistent with the conclusion obtained from the game analysis; careful observation found that the trend of group safety behavior is slightly later than that of psychological change, which shows that with external interference, the worker group psychology changes first and then affects its behavior change.

4.3.2. Scheme 2. The statistics of the simulation results in Scheme 2 show that the qualitative values of each system state variable are relatively scattered. The main distribution is in "very low" (qualitative value 1), "low" (qualitative value 2), and "general" (qualitative value 3). None of the proportions exceeded 40.00%. Group safety behavior (Z_{16}) mainly focused on "very low" (qualitative value 1), "low" (qualitative value 2), and "general"(qualitative value 3) levels. Percentages were 37.50%, 30.00%, and 33.00%. The proportions of group security psychology (Z_4) at the "very low," "low," and "general" levels were 39.00%, 31.00%, and 30.00%, respectively. Qualitative values of the individual system state variables were relatively scattered, with the final states distributed mainly at "very low," "low," and "general" levels, and also sporadic at "very high" and "high" levels. However, the proportion of each system state variable concentrated at the "very low" (qualitative value of 1) level is slightly higher than that of the other qualitative values. This shows that when the initial state is general and when management measures are comparable to interference intensity, the elements and safety behavior in the evolution direction are uncertain; that is, they may eventually evolve to "high" or to "low" but concentrated on "very low" (qualitative value 1) and may be higher than other qualitative values.

Further, the comparison and analysis of the relationship between group safety psychology and behavior and the summary of the change trends of group safety behavior and group safety psychology are presented in Scheme 2, as shown in Figure 10. It is not difficult to see from the figure that the change trend is similar. Careful observation shows that the change trend of group safety behavior is slightly later than that of psychological change, which shows that when management measures comparable to their intensity are taken, the psychology of the worker group will change first and then affect the change in their behavior.

4.3.3. Scheme 3. In general conditions, high-intensity control measures are $X = 2$, $Y = 1$, and $Z = <3, \longrightarrow>$. The simulation analysis yielded the results shown in Figure 11.

The statistical chart of simulation results in Scheme 3 shows that the qualitative values of each system state variable are concentrated at "high" (5), accounting for 80.00% or above, among which the group safety behavior (Z_{16}) is "high" (5), 85.00%, and the level of group safety psychology (Z_4) is 86.00%. The qualitative values of the various system state variables are mainly concentrated at "very high" levels, with a minimal proportion of other qualitative values. This shows that the initial state of coal mine workers is general. The management decision intensity is much higher than the external interference intensity. Under the action of management decision-making, all elements and safety behavior of coal mine workers will change to a "high" direction in the process of evolution.

The trend chart shows that with high-intensity control measures taken due to external interference, the safety psychological level of the group starts to "weakly increase" from stage 3 of the trend of the diagram, which begins to rise; the psychological level of group safety rises to a "high" level.

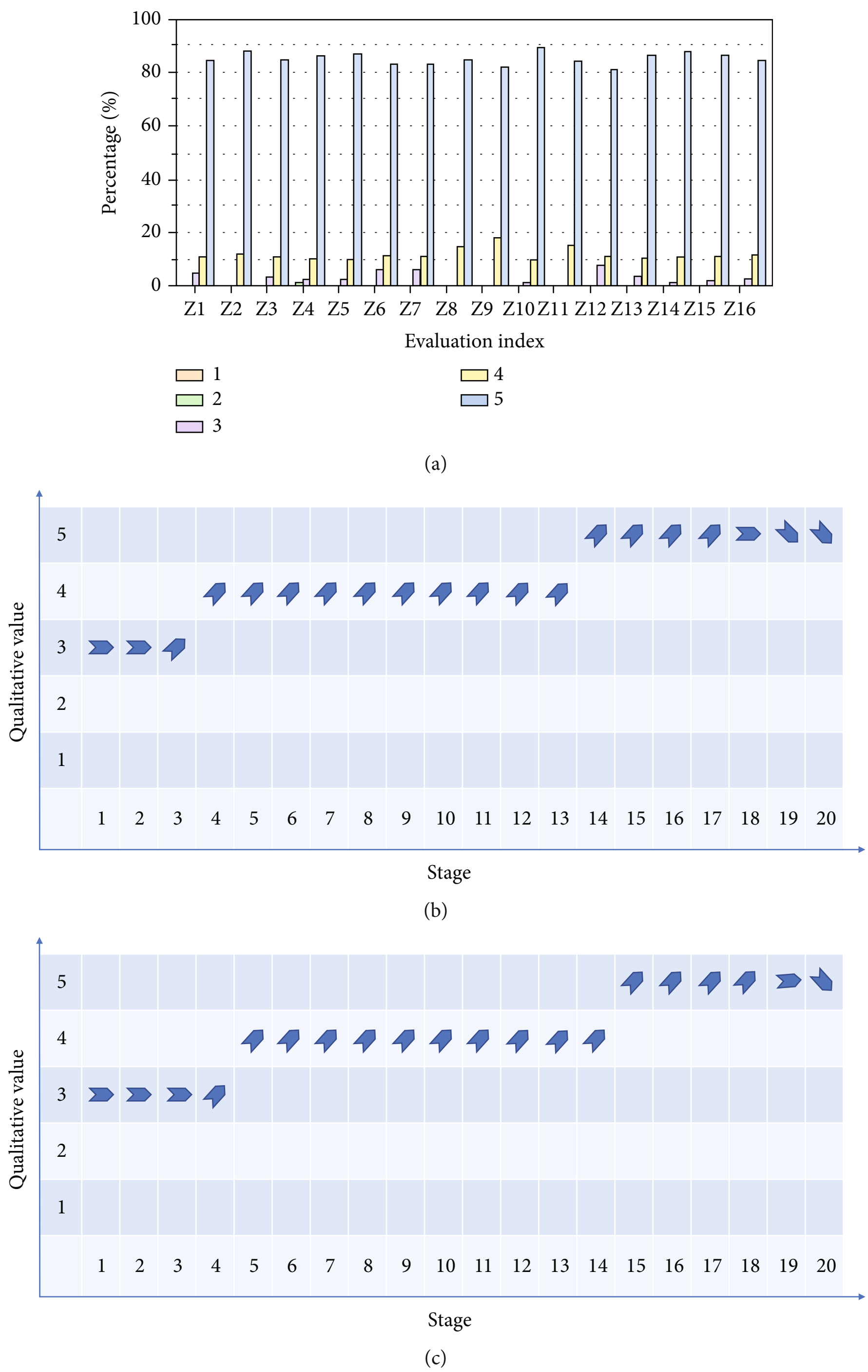
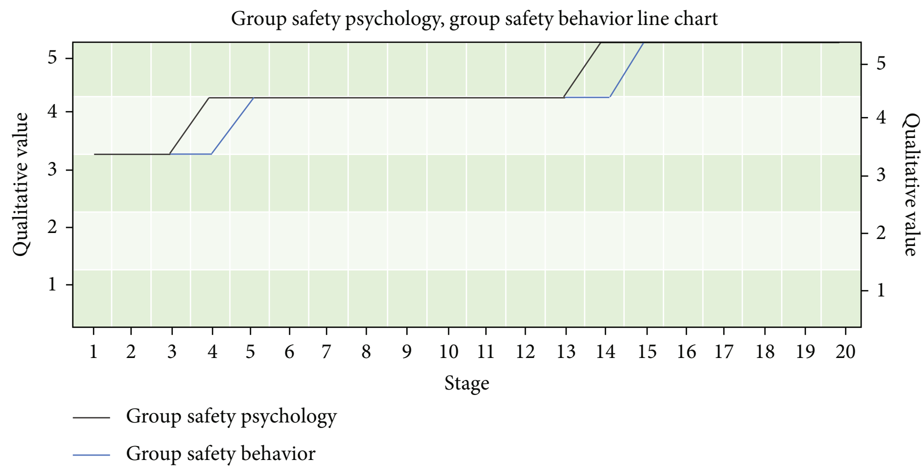


Figure 11: Continued.



(d)

Figure 11: Simulation results and comparative analysis of Scheme 3. (a) Simulation result statistics. (b) Trend chart of group safety psychological change. (c) Trend plot of group safety behavior change. (d) Plot of comparison of trends in group safety psychology and behavior change.

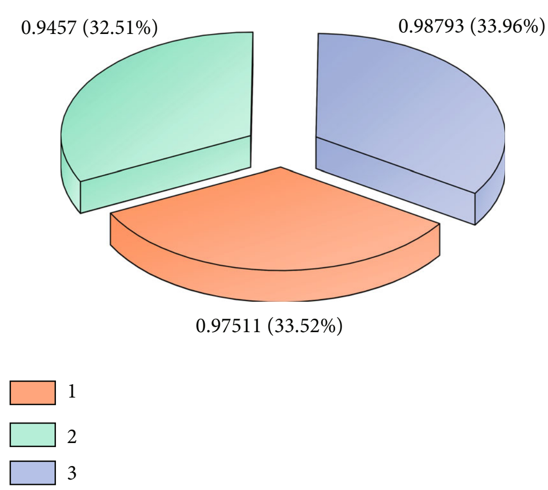


Figure 12: Schemes 1–3. Impact of group safety psychology on behavior change.

Until stage 14, the direction continues to "weakly decrease," but in stage 19, the group safety psychological level shows a downward trend and may develop to a low level (Figure 11(b)). The trend of group safety psychology shows the overall trend of first increasing, then rising and weakening, indicating that high-intensity effective control measures can realize the control and prevention effect of group safety psychology.

The group safety behavior change trend chart shows that the level of group safety behavior starts at level 4. The direction of change is "weak plus" under the influence of external interference, indicating that the high-intensity adoption of management measures begins to show an upward trend. The level of group safety behavior rose to "high" levels, and by stage 15, it continued to "high" levels. However, in stage 20, the direction of change was "weak," and the level of safety behavior showed a tendency to decline, indicating the possibility of development to low levels (Figure 11(d)). The change trend of group safety psychology and safety behavior is always earlier than the time of group safety behavior changes; that is, the group safety behavior is affected by the group safety psychology, and the changes of group safety psychology cause the changes of group safety behavior. By comparing and analyzing the change trend of group safety psychology and behavior, the change trend is similar. The change trend of group safety behavior is slightly later than that of the psychological change, which shows that when external interference and high-intensity management measures are taken, the psychology of worker groups will change first and then affect the change in their behavior. This also suggests that the prevention and control of changes in group safety psychology is a key element in preventing and controlling group safety behavior.

Based on an in-depth analysis of the three simulation results, the following conclusions are as follows:

(1) If the miner group is disturbed by the outside world and if the targeted management measures are not taken, the safety psychology and behavior of the group will evolve into a "very low" level

(2) When the miners are affected by various external environments and when the intensity of the safety behavior management measures and the interference intensity are equal, the change level of group safety psychology and the behavior of various state variables will change. Correctly, this is a manifestation of administrative decisions and external interference. If the intensity of the management means is higher than the interference intensity, the safety psychological and behavioral status will be greatly improved,

and the level of group behavior is the direction of safety, but the level will still decrease over time

(3) In the face of external interference, the safety psychology of the aging mine workers will always respond before the behavior and affect the change in the group safety behavior

The extent to which the impact of group safety psychology had on its behavior was analyzed, as shown in Figure 12.

Figure 12 shows that group safety psychology has a great impact on safety behavior. Whether or not taking management measures when the initial group safety state is "general," its impact is above 94.00%. It is worth noting that when the management decision variables are comparable to the intensity of external interference, the psychological impact on group safety behavior is slightly lower than Schemes 1 and 3 because the management measures or incentive policies are not clear, and the psychological phenomenon of group members fluctuates, which then affects the choice of their behavior.

5. Conclusions

(1) Study the mechanism of the unsafe behavior of the aging mine group, analyze the influencing factors of the aging mine group, and explain the influence of the unsafe behavior from 7 aspects; the emergent theory is introduced to study the formation process of the unsafe behavior of the aging mine group

(2) Innovate using the mutation series method of aging mine group safety evaluation; establish the organizational leadership factors, safety management factors, safety dynamic effect, safety monitoring, human-machine environment, worker personal quality, and safety evaluation index system; and finally affect the importance of safety behavior indexes such as group dynamic effect>safety management factors>worker personal quality>human-machine environment state>organizational leadership factors>safety monitoring

(3) The analysis of the evolution game and system dynamic theory constructed the aging mine population unsafe behavior game income matrix, using computer simulation of the sensitivity analysis of the management decision and external interference, and analyzed the aging mine group safety psychology and behavior under the influence of external interference

(4) According to the characteristics of group safety psychology and behavior qualitative simulation, three simulation schemes of unsafe behavior in aging mine personnel were formulated and simulated and analyzed. According to the simulation results of the three schemes, the evolution of the safety behavior is analyzed

Data Availability

The data used in this paper are all obtained from the authors' research, experiment, and simulation, and the relevant data are all reflected in the article, and there is no data plagiarism behavior.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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