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Simulation of Unsafe Behavior in Mine Operation Based on the SMAPP Model

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Abstract: Mine accidents are mostly caused by human unsafe behavior. To reduce the unsafe behavior of mine operation and reduce the accident of mine operation, the main body of unsafe behavior 'people' is analyzed, and 24 attribute factors are selected from five aspects of people's emotions, motivation, ability, personality, and pressure to construct the comprehensive model of human behavior SMAPP (sentiment–motivation–ability–personality–pressure). The program tool for recording, saving, and executing the mutual and interactive influence relationship of 24 attribute factors under different state values and the simulation process framework of SMAPP was constructed by using 1071 rule statements written in Python language. The fuzzy rules are used to simulate different scenarios. The simulation results are consistent with the actual research results, which shows the reliability and scientificity of the model. In addition, additional events are added to the simulation process to make the model more realistic. Through the simulation results, the influence of employees' emotions, motivations, abilities, personalities, pressures, and additional events on the unsafe behavior of mine operations is analyzed and predicted, and the measures to reduce the unsafe behavior of mine operations are further proposed.

Keywords: SMAPP model; unsafe behavior; fuzzy rules; simulation framework

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1. Introduction

Mine operation is a high-risk industry. Although the number of mine production accidents and deaths has decreased significantly in recent years, it still occasionally occurs. According to statistics and analysis of coal mine production safety accidents in China from 2010 to 2019, statistics of major gas explosion accidents in coal mines from 2011 to 2020, statistical analysis and prevention countermeasures of coal mine accidents from 2008 to 2020, it is found that the number of accidents and deaths is the least in winter, and the number of accidents and deaths is the most in summer. The main reasons are as follows: the production days in winter are less, and the safety management of coal mines during the Spring Festival is more strict; in summer, the weather is hot and humid, and there are many mosquitoes, which affect the rest of the employees. Employees are prone to being impetuous and sleepy, and their safety awareness is relaxed. The unsafe behavior of employees is affected by emotions, the working environment, and the management system, which leads to mine accidents [1–5]. Therefore, predicting people's unsafe behavior and taking corresponding preventive measures is one of the effective means to reduce accidents.

A large number of scholars at home and abroad have studied the unsafe behavior of people. Dana Willmer summarizes the degree of various factors of 338 accidents in the United States. Human factors are the most important cause of accidents, and management is the second most important reason [6]. Donald et al. found that the personality characteristics of miners are closely related to the occurrence of accidents [7]. Glenn Legault et al. believed that the miners' working environment, unsafe psychological state, working pressure, and coal mine shift system would hurt and harm miners' unsafe behavior [8–10].

Hu Zhe et al. established a cognition-based model of workers' safety behavior ability to study the effect of safety training on the improvement of safety behavior ability [11]. Zhang Han et al. analyzed coal mine production accidents and their causes from 2001 to 2015 and proposed a new idea of production safety management based on risk pre-control management [12]. Zhang Denghao et al. pointed out through a questionnaire survey and analysis that emotional burnout played a complete mediating role between job demands and unsafe behaviors, and behavior style moderated the indirect effect of job demands on unsafe behaviors [13]. Yang Dong et al. studied the relationship between safety awareness and unsafe behavior of electric power employees with different personality traits and found that neuroticism was significantly positively correlated with unsafe behavior. Agreeableness, extraversion, openness, and conscientiousness were significantly negatively correlated with unsafe behavior. Openness has a negative predictive effect on unsafe behavior, and neuroticism and agreeableness have a significant regulatory effect on safety awareness of unsafe behavior [14]. Based on the theoretical framework of social cognition, Yang Zhenhong et al. established the regulating effect of accident experience on miners' unsafe behavior under the regulating effect of a safe atmosphere [15]. Zhou Jianliang et al. found that psychological adjustment can effectively control workers' unsafe behaviors [16]. Li Guangli et al. found that tension, infirmity, anxiety, depression, irritability, boredom, and drowsiness are the key unsafe emotions that miners experience more frequently in daily life. Anger and tension have certain differences among different marital statuses and different types of work, and depression has certain differences among different types of work and working years [17]. Zhang Yuliang studied the influence of outport employees' emotional changes on production safety in coal enterprises and proposed corresponding management countermeasures [18]. Liu Jialun et al. found that when workers have more safety knowledge and work experience, the cognitive process of dangerous accidents tends to be objective and rational, and the risk sensitivity increases accordingly [19], and Tian Shuicheng adopted the entropy weight TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to comprehensively evaluate the unsafe state of front-line miners and concluded that the importance of family support was the largest, while the importance of self-efficacy was the least [20].

As a complex individual, there are many factors affecting human behavior. Some scholars have clarified the attributes of human beings. There is no unified view on which characteristics and factors of human beings will affect human behavior. Ren Hao believes that physiological factors, such as the human nervous system and endocrine system, psychological factors, such as human motivation, feeling, ability, character, etc., and family, media, public policy, and other social factors, can affect people's behavior [21]. Zhang Jian also pointed out that people's emotions are related to people's performance, and proved this with the famous Yex–Dodson's law [22].

This paper attempts to make a comprehensive analysis of the subject 'person' of unsafe behavior, based on fuzzy rules (fuzzy rules are binary fuzzy relations R defined on $X \times Y$). There are two explanations for $A \rightarrow B$: one is A coupling B, and the other is A leading to B. Based on these two explanations and different operators, fuzzy rules can have a variety of legal calculation formulas). According to the existing research results, this paper constructs the SMAPP (sentiment–motivation–ability–personality–pressure) model from five aspects—emotion, motivation, ability, personality, and pressure—which is referred to as the human behavior model. A simulation framework suitable for multiple scenarios and prediction groups is proposed to predict the behavior of employees, and different scenarios are simulated to analyze the behavior of mine workers. Additional events (optimization of mining enterprise management system, safety culture, humanistic care, skills training, etc.) are added to the scene where employees' unsafe behavior has an increasing trend. The direct impact of additional events on employee attributes is fuzzy-assigned. We analyzed the impact of additional events on other attributes of employees and changes in employee behavior. Measures to reduce employee unsafe behavior are proposed from the aspects of improving the working environment, reducing work intensity, and strengthening skills training. Measures to prevent mine safety accidents are summarized from the aspects of safety culture construction and management reform.

2. Construction of SMAPP Model

The sentiment is people's attitude towards objective things and corresponding reaction behavior. Ortony, Clore, and Collins proposed the OCC model, which divides emotions into 11 pairs of basic emotions [23,24]. In employee emotion and management, Zhang Jian introduced five important employee emotion phenomena, namely, emotional intelligence, emotional work, occupational stress, emotion and creativity, and emotion and decision. This paper mainly refers to Wang Chunxue's research on the impact of emotions on safety sign recognition, and defines emotions as positive (happiness), neutral, and negative (sadness, anger, and fear), assuming that positive emotions promote the performance of safety behaviors [25].

Motivation is a kind of internal power, which affects the direction, intensity, and endurance of individual behavior. It is formed under self-regulation so that the internal needs of individuals and external incentives match. According to American psychologist Herzberg's theory of motivation–health care in 1959, motivation is divided into motivating factors and healthcare factors. Health factors mainly include policy and management, supervision, wages, colleague relations, and working conditions. These are non-work factors that, if satisfied, can eliminate dissatisfaction and maintain productivity, but do not motivate people to behave more positively. Motivating factors include achievement, promotion, development, etc. If these factors are satisfied, they can generate great incentives for people; if they are not satisfied, they will not generate dissatisfaction such as health factors. This paper defines motivation as progress, development, achievement, salary, and policy.

Ability is the degree to which an individual can perform a task or task as required. Ren Hao believes that a person's ability includes IQ, EQ, creativity, and moral quotient; Stephen believes that ability can be divided into intellectual ability and physical ability. Intellectual ability mainly includes language understanding, logical reasoning, understanding and expression, vocabulary use, associative memory, imagination, etc. Physical abilities are mainly strength, vitality, endurance, and coordination. According to the existing research, abilities are divided into physiological, cognitive, and technical levels, as well as learning, creativity, and social abilities.

Personality mainly refers to the relatively stable characteristics that affect people's behaviors. According to John Holland's personal–job fit theory, personality is divided into six parts [26]. According to Hippocrates' humoral dominance theory, personality is divided into four parts: bilious, sanguine, mucous, and melancholic. In this paper, according to the big five personalities of the ocean theory of personality, personality is defined as openness, neuroticism, conscientiousness, extroversion, and agreeableness. See Figure 1 for the manifestations of each type of personality.

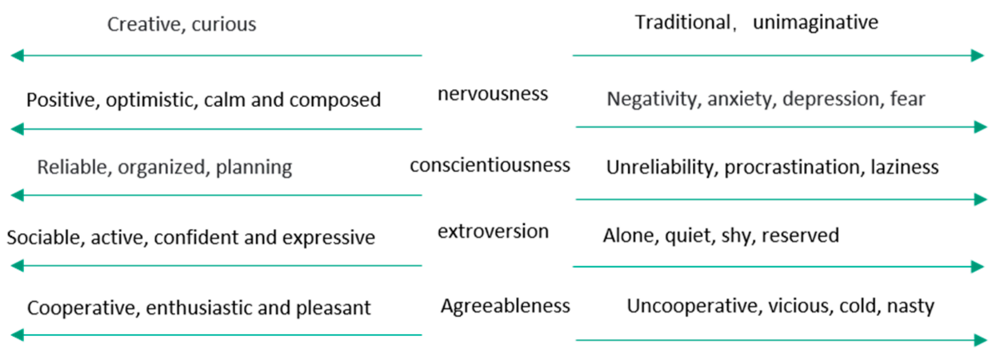

Figure 1. Big Five personality.

With the quickening pace of society, today, most people live under high pressure. While the right amount of stress is good for people's performance, excessive stress can certainly take a toll on people's physical and mental health. There are many reasons for people's stress. Su Yong divided stress into four parts: task-related, role-related, interpersonal, and working conditions [27]; or, simply stated: work, family, society, relationships, and health.

The human behavior model is established according to emotion, motivation, ability, personality, pressure, and the corresponding secondary influencing factors selected, as shown in Figure 2.

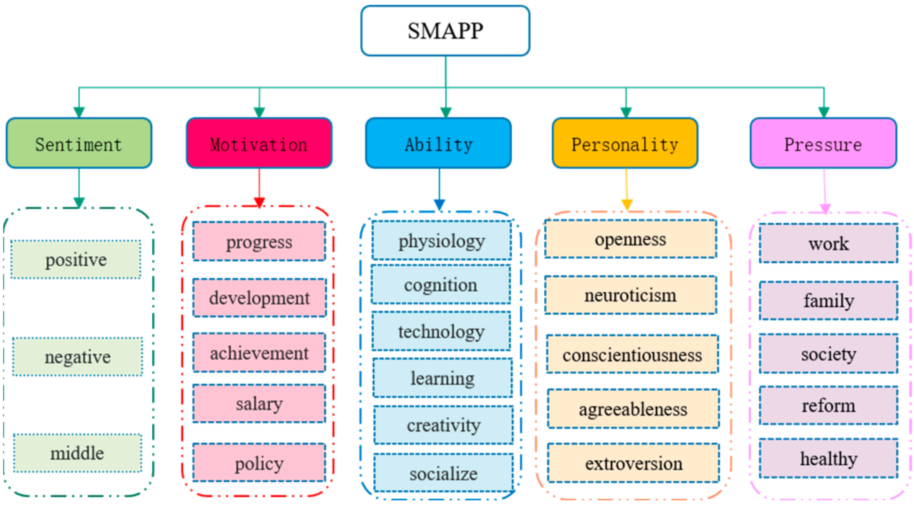

Figure 2. Human behavior model.

3. Build SMAPP Model Simulation Process Framework

In the aspect of the realization of human model simulation, there are three main methods. The first is a mathematical method, using mathematical formulas to predict human behavior, but this traditional simulation method can only get a simplified description of the whole system. It does not fully emphasize the complex hierarchical structure of the system, and sometimes it is difficult to extract formulas [28]. The second model is a rules-based system, which is a mature and widely used approach, as we only need to extract the interaction between different attributes and describe it in the form of rules [29]. Thirdly, agent-based modeling (ABM), seeks the simplest explanation for the observed complex system, modeling individuals such as people, organizations, and enterprises as agents. Agents have their state and rules of behavior. Through the behavior and interaction of micro-agents, sudden phenomena, dynamic equilibrium, and nonlinear results can be reproduced to deduce the macroscopic phenomena and operation results of the system [30]. There is no universally recognized definition of an agent. Currently, the cognitive architecture BDI (belief–desire–intention) model [31] is widely used in agent modeling (generally, it is believed that the thinking state of an agent includes belief, desire, and intention) and is too rational for describing complex and changeable human beings. For example, ACT-R believes that the cognitive process of human beings requires the participation of different modules, which correspond to the physiological structure of the human brain. The modules work independently and are coordinated by the central production system, and it is understandable to take rule-based reasoning as its core part to predict the output [32]. In this paper, the simulation framework of the SMAPP model is built based on rules; see Figure 3. The specific process is as follows:

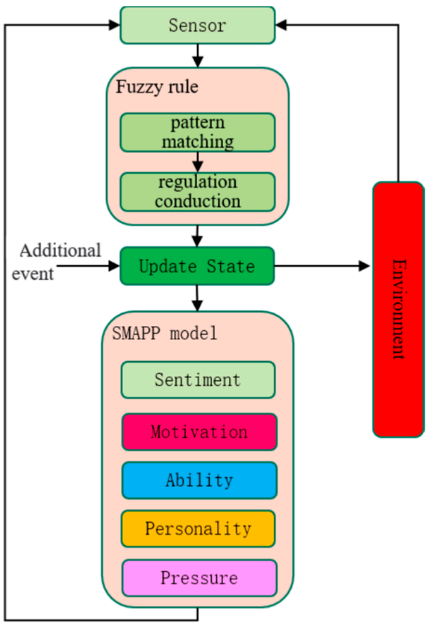

Figure 3. SMAPP model simulation process framework.

(1) The sensor obtains the SMAPP model attribute factor and environment status value at the same time, and fuzzy processing the status value of the attribute factor. In this paper, the fuzzy states of factors are defined into five types: very high, high, medium, low, and very low corresponding score intervals are shown in Table 1;
(2) According to the state of SMAPP model factors and environment, the fuzzy rules are mapped to build rules that conform to the synergistic influence between all factors. According to the existing research results, the mutual and interactive influence relationship between 24 attribute factors in the model is studied, and 1071 rule statements written in Python language are constructed to record, save and execute the mutual and interactive influence relationship between attribute factors under different state values;
(3) Execute these rules to update the state of SMAPP model factors and environment. During the execution of model rules, five update states are defined: sharp increase, increase, maintain, decrease, and sharp decrease; and the corresponding increments are 3%, 1%, 0, −1%, and −3% of the original parameter values, respectively [33]. Due to the complexity and uncertainty of people, random variables of −1 to 1 are added during the execution of model rules;
(4) Accidents often occur in the actual work, so additional events are added during the execution of the model rules. If an emergency occurs, SMAPP model factors and environment state can be updated directly;
(5) Enter the first step or end the simulation. With the implementation of the rule, the state of people and the environment is constantly updated. The number of updates is denoted as variable "T". Then, new rules are created to change the state of people or environment, such as conditions related to "T". When T = 72, it reduces (unsafe behavior); that means that the unsafe behavior decreased after 72 runs of the rule, probably as a result of improved skills and cognition with learning.

Table 1. Corresponding score interval of fuzzy state.

Fuzzy State	Very High	High	Medium	Low	Very Low
Value	>90	70–90	40–70	20–40	<20
Level	I	II	III	IV	V

Different application scenarios have different definitions of environment. To verify the simulation results of the model on unsafe behaviors, the environment is defined as a task, and three attributes are defined for it. The first is Difficulty, which is divided into five levels as before, but with different names: Very Hard, Hard, Medium, Easy, and Very Easy. The second property is the status value; it records the output value of the task, used to reflect the performance of the employee, and will affect the state of the employee. The third is unsafe behavior, which is consistent with the corresponding score of fuzzy state in Table 1 above, and divided into five levels: extremely unsafe (more than 90 points), unsafe (70–90 points), generally safe (40–70 points), safe (20–40 points) and very safe (less than 20 points). In the unsafe behavior of mining operations, "T" represents the unit of time in weeks.

According to the simulation architecture of the SMAPP model, Python language rules are used to describe the relationship between different attributes. For example:

if (isHigh(self.management) and isHigh(self.ability)):
self. progress = ActionUtil.increase (self. progress)
if (isHigh(self.openness) and isHigh(self.sentiment)):
self.creativity = ActionUtil.increase(self.creativity)
if (isVeryLow(self.promotion) and isVeryLow(self.extraversion)):
self.positive = ActionUtil.highDecrease(self.positive)
if (isVeryLow(self.promotion) and isLow(self.extraversion)):
self.positive = ActionUtil.highDecrease(self.positive).

The condition of the above rule is the state of the person and the environment, and the execution part is to change the state value in five update modes. The rule contains all possible states related to unsafe behavior in mine operations. The synergetic influence relationship of the SMAPP model is shown in Figure 4. The output of different factors is represented by different colors: purple for stress, green for sentiment, yellow for personality, red for motivation, blue for ability, light blue for safety tasks instead of the external environment, and black lines for human output. The different colored lines indicate the influence of factors on other factors, such as extraversion promoting sociability, with a yellow line going from extraversion to sociability. Ability will affect the individual's progress but will also affect the sense of achievement; there is a blue line pointing to progress and sense of achievement; and emotion will affect people's creativity and directly affect individual behavior (unsafe behavior). There is a green line pointing to creativity and unsafe behavior; motivation will promote individuals to improve their technical level; and a red line pointing to technology.

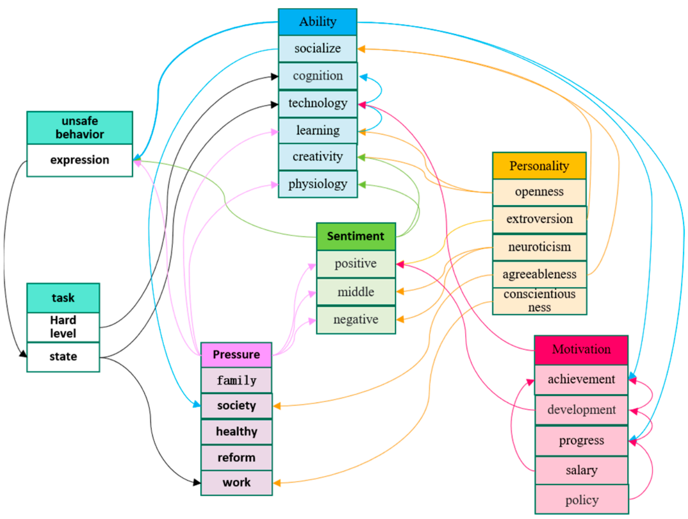

Figure 4. Synergistic influence diagram of SMAPP model attribute factors.

4. Simulation of Miners' Behavior Based on the SMAPP Model

A. Simulation of miners' behaviors under different scenarios

According to the SMAPP model and its simulation framework, we simulate three scenarios for mine production employees. (1) Level III for employees with 60 points in ability, emotion, and personality. (2) Weak ability, do not want to learn and change, and mood, personality, and ability of 30 points for the poor performance of the staff corresponding to Grade V. (3) Poor behavior becomes excellent behavior. First, the behavior was set to 30 points. In the 30th week, additional events were added, and its motivation and emotion were set to 80 points to represent the change of the person. Like a person who wants to learn, eager to make changes in real life. The specific results are as follows:

(1) The personality, emotion, motivation, and ability of the employees were set as 60 points; that is, the corresponding level III employees. Regardless of the environment and organizational changes, the employees were simulated according to the corresponding fuzzy rules of the SMAPP model simulation framework. The horizontal axis represented the times of the implementation and updating of the rules, and the vertical axis represented the ability, achievement, motivation, pressure, emotion, and unsafe behavior trends, respectively. From Figures 5–10, it can be seen that the ability of level III employees increases with the increase in training times and the enhancement of their subjective learning awareness. Among them, the first change is the individual's learning ability, and the last change is the individual's social ability. With the improvement of ability, personal emotions will become more positive, while work motivation will also be greatly improved, and personal pressure will also decrease as emotions become more positive. Therefore, the probability of unsafe behavior of employees at work will be reduced, thus ensuring the safe production of mines;

(2) The employee's ability, motivation, and emotion score are set at 30 points, indicating that the person has weak ability, poor mood, and subjective reluctance to study and work; the corresponding level is V. Trends in competence, motivation, stress, emotion, and unsafe behavior are shown in Figures 10–14. From Figures 10–14, it can be seen that when the individual's comprehensive ability is weak and the subjective learning awareness is not high, and they do not actively ask for them to change, and the organizational environment and the policy family, and other conditions do not change, their job motivation opportunities will decline and, at a lower level, and their negative emotions will increase. With time, when the personal ability is getting worse and worse, work pressure increases greatly, and the score is five times as much as in the beginning. Therefore, the probability of unsafe behavior of employees at work will increase exponentially, which will have a greater impact on mine safety production;

(3) If an employee is a person with low ability, emotion, and motivation at the time of entry, but with the occurrence of additional events such as marriage and family changes, accident experience training, management system, and promotion policy changes, they realize that they need to learn and improve their ability to change the status quo, and their work motivation and positive emotion become high [10,12,34]. In the simulation rules, the ability, personality, and emotion of employees are first set as low (30 points, corresponding to Level V in this paper), and then events are added (for example, training, improvement of working environment, optimization of the control system, an increase in salary, etc.), the corresponding value of learning, emotion, and motivation of employees was set as high at the 30th update (80 points, corresponding to level II in this paper), and the results were shown in Figures 15–19. It can be seen from Figures 15–19 that, due to employees' low ability, emotion, and motivation at the beginning, the overall quality of individuals is relatively low. In the case of certain subjective learning awareness and other external factors, their personal stress and unsafe behavior do not immediately decrease but will increase slightly. However, with continuous learning and the occurrence of additional events, the technical level and cognition of employees are also increasing, their emotions are in a positive state

for a long time, and the pressure is also reduced. Therefore, the unsafe behavior of employees gradually decreases with the increase in ability, motivation, and emotion and the decrease in pressure, to ensure the safe production of mines.

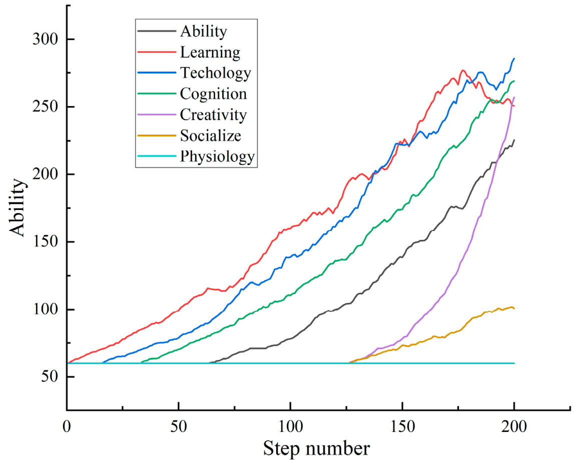

Figure 5. Ability trend curve of employees level III.

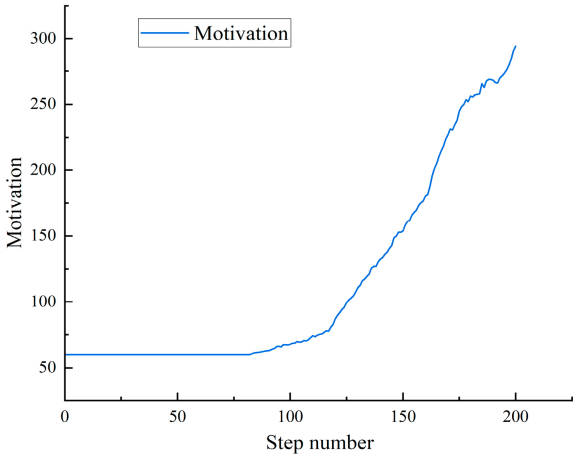

Figure 6. Motivation trend of employees level III.

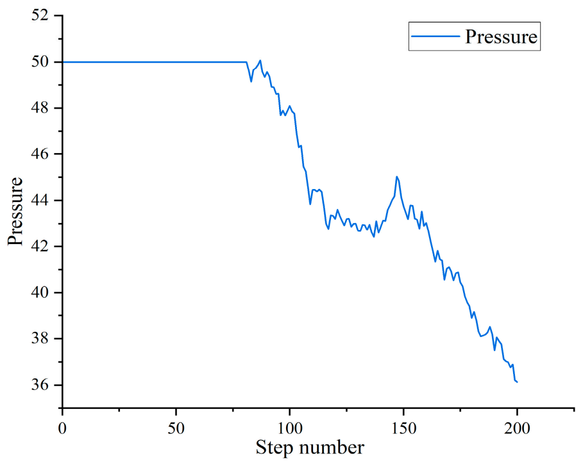

Figure 7. Stress trend of employees level III.

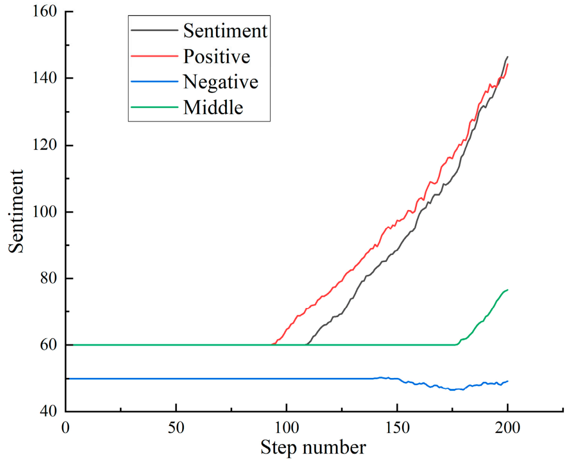

Figure 8. Emotional trend curve of employees level III.

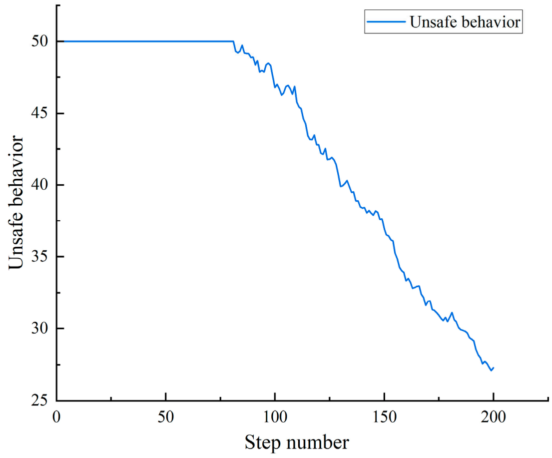

Figure 9. Unsafe behavior trend of employees level III.

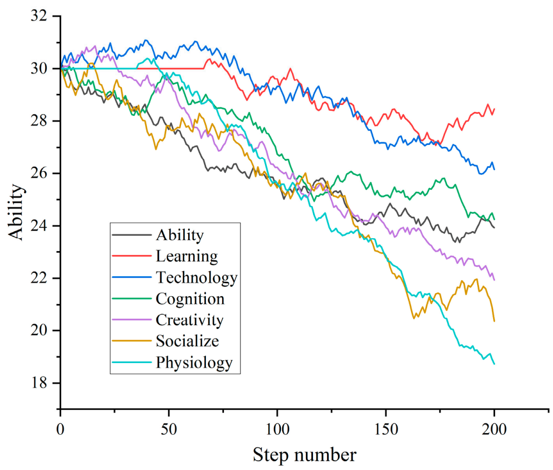

Figure 10. Ability trend curve of employees level V.

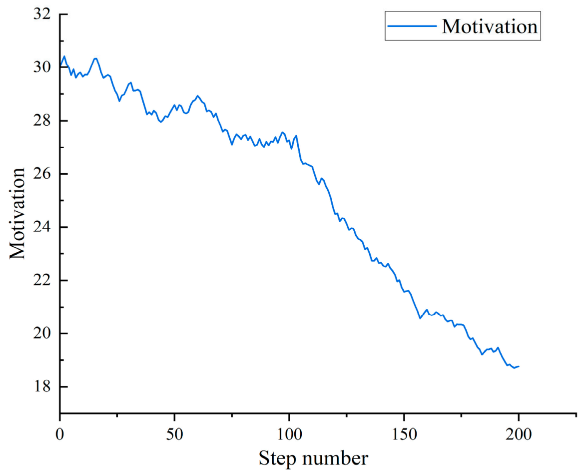

Figure 11. Motivation trend of employees level V.

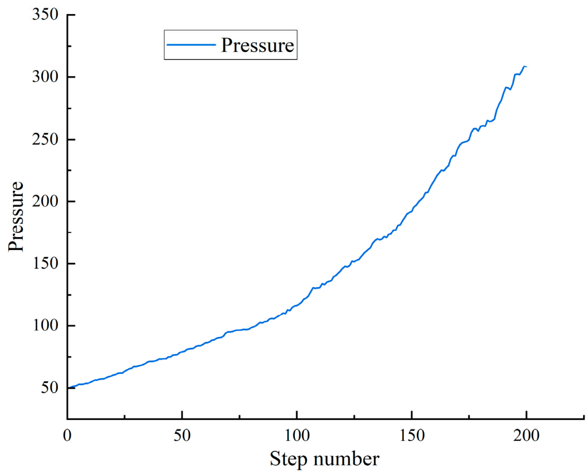

Figure 12. Stress trend of employees level V.

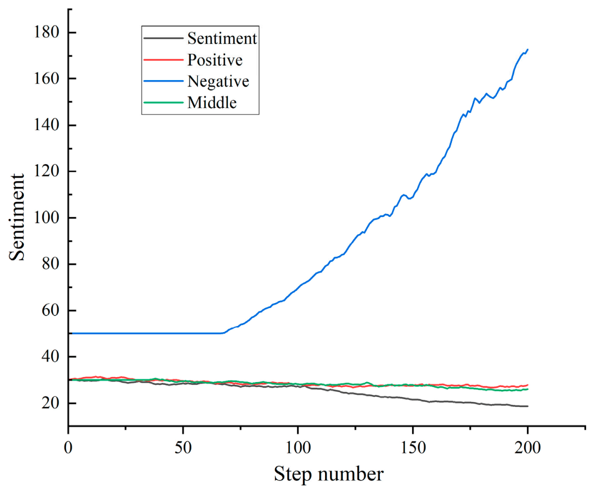

Figure 13. Emotional trends of employees level V.

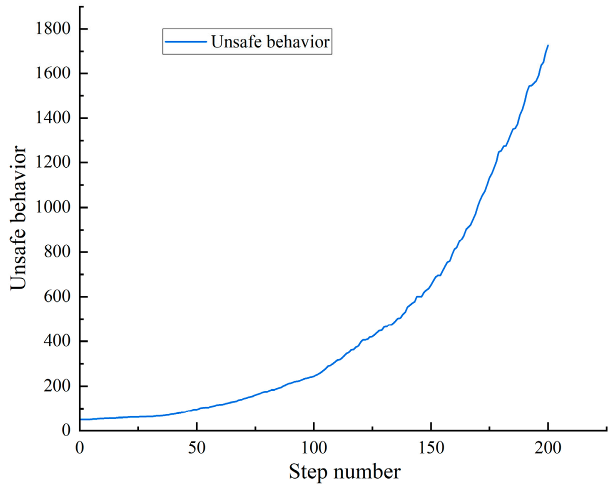

Figure 14. Unsafe behavior trend of employees level V.

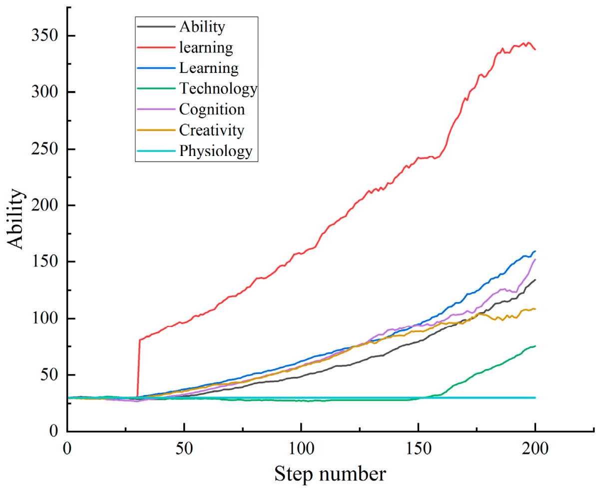

Figure 15. Ability trend of employees from level V to level II.

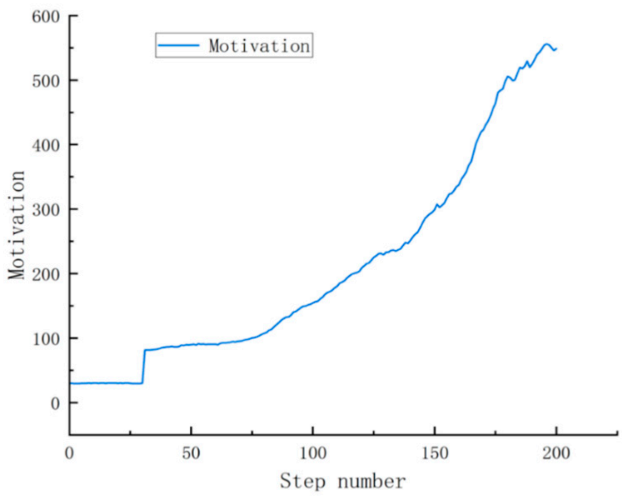

Figure 16. Motivation trend of employees from level V to level II.

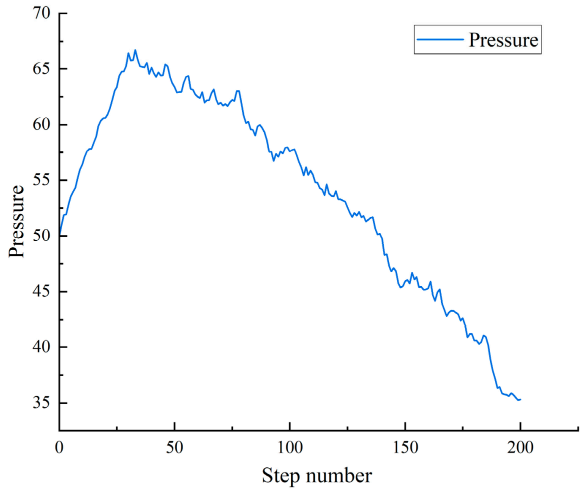

Figure 17. Stress trend of employees from level V to level II.

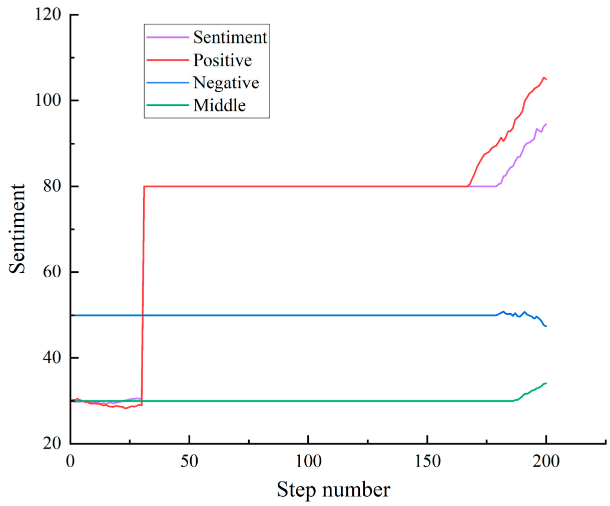

Figure 18. Emotional trend of employees from level V to level II.

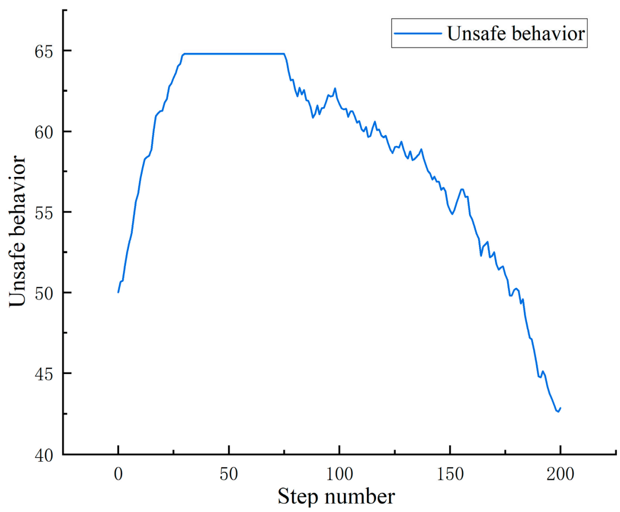

Figure 19. Unsafe behavior trend of employees from level V to level II.

B. Analysis of unsafe behaviors of miners and preventive measures

Through the simulation results, it can be seen that employees' emotions, motivations, abilities, personalities, and pressures directly or indirectly affect employees' behavior (unsafe behavior). The higher the scores of emotion, motivation, ability, and personality, the less unsafe behavior; the greater the pressure, the more unsafe behavior. Additional events such as employee family happiness, accident experience training, management system optimization, and promotion system improvement can change employee motivation, learning, and emotion, thus indirectly reducing employee unsafe behavior. The accident causation theory points out that human unsafe behavior is the direct cause of accidents. Therefore, reducing the occurrence of human unsafe behavior can avoid accidents to a large extent. Humans, machines, the environment, and management are indispensable. These four elements influence each other and promote each other, thus ensuring the smooth progress of mine safety production.

As a mining production enterprise where accidents occasionally occur, it must conduct questionnaire tests on employees before entry, after induction training, weekly, and after regular training, to timely understand the situation and changes in employees' sentiment, pressures, motivations, and abilities, and formulate corresponding improvement countermeasures for employees whose emotions and motivations are significantly reduced and pressures are significantly increased, thereby preventing a reduction of capacity and an increase in unsafe behavior. In terms of the preparation of the test questionnaire, the personality scale applicable to various enterprises was compiled by referring to the Big Five personality questionnaire; the mood and stress scale was compiled by referring to Li Guangli's miners' unsafe emotions questionnaire [17], Fan Wei's employees' mental resilience scale and emotion scale questionnaire [34], and Di Hongxi's employees' work stress questionnaire, and the ability scale was compiled according to the actual work needs and job types of enterprises [35]. The motivation scale was compiled by referring to the "1327" unsafe behavior control system of Bulianta Coal Mine [31] and Zhang Junjun's work motivation structure questionnaire of knowledge workers in the transition period [36].

According to the questionnaire test results (scores) of employees, the SMAPP model simulation framework was substituted for simulation to predict the changing trend of employees' unsafe behaviors, and corresponding measures were taken from the following aspects for employees with an increasing tendency of unsafe behaviors: (1) optimize the management system, develop a sound management system, promotion system, reward and punishment system, working environment, and other aspects to improve employees' job satisfaction or sense of achievement, so as to improve work motivation [37,38]; (2) strengthen the construction of corporate emotional safety culture, including emotional safety communication, emotional safety atmosphere, emotional safety measures, corporate identity, reasonable degree of safety regulations, etc., to improve the emotional stability of employees and reduce insecure emotions [39,40] (negative emotions); (3) pay attention to the training and assessment of employees' professional skills and safety skills, strengthen the training of employees' professional skills and safety skills (according to previous studies, they can be trained once a week), conduct assessment, and strictly carry out the work with certificates. Conduct regular tests on people with unsafe tendencies, and record the impact of different types of measures implemented on unsafe behaviors of employees. Because of the complexity and variability of employees, the trend curve model of various attribute factors of the SMAPP model will be studied and recorded in the future to reduce the unsafe behaviors of mine employees in a targeted way. Start from the main body of the accident to reduce the occurrence of mine accidents.

5. Conclusions

(1) The emotion, motivation, ability, personality, and stress were analyzed, and 24 attribute factors were selected to establish the SMAPP model. Analyze the mutual and interactive influence relationship of 24 attribute factors in the SMAPP model under different state values, and construct 1071 rule statements written in Python

language to record, save, and execute the mutual and interactive influence relationship of attribute factors under different state values. Build a simulation framework for multiple scenarios;
(2) According to the SMAPP model and its simulation framework, three scenarios of mine production employees are simulated in the programming tool written in Python language, and the employee behavior (unsafe behavior trend) under different scenarios is predicted. The simulation results are consistent with the existing research results, indicating that the SMAPP model and simulation framework are reliable under the set rules;
(3) Through the analysis of the simulation results, the higher the employee's emotion, motivation, ability, and personality score, the less unsafe behavior, the greater the pressure, and the more unsafe behavior. Through the model, the trend of unsafe behavior is predicted. From the aspects of improving employees' work motivation and job satisfaction, improving employees' emotional stability, reducing employees' stress and negative emotions, enhancing employees' professional skills, safety skills training, and implementing the certificate system, the preventive measures for unsafe behavior of mine production employees are put forward to prevent mine production safety accidents.

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