

## Article

# Analysis of Influencing Factors of Occupational Safety and Health in Coal Chemical Enterprises Based on the Analytic Network Process and System Dynamics

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**Abstract:** In the production process of coal chemical enterprises, there are factors such as dust, poisons, as well as toxic and harmful gases, which seriously restrict the safety and health of employees. It is urgent to strengthen research on occupational safety and health (OSH) of coal chemical enterprises. Research on the influencing factors is very important to improve the level of OSH in coal chemical enterprises. Therefore, this paper analyzed the factors affecting OSH of coal chemical enterprises from four aspects: “human–machine–environment–management”. Then, an influencing factor indicator system was constructed. The weights of the indicator were analyzed using the Analytic Network Process (ANP). On this basis, the primary and secondary indicators of the influencing factors were ranked. Subsequently, the weights of ANP were taken as the influence coefficient between variables, and the System Dynamics (SD) model of OSH control measures was established and analyzed. According to the weights of ANP and the results of SD simulation, management and control measures were proposed to provide theoretical support and method guidance for improving the level of OSH in coal chemical enterprises. Finally, the research results were experimentally applied to coal chemical enterprises. The research results of the paper will improve the level of OSH in coal chemical enterprises of both theoretical and practical applications.

**Keywords:** occupational safety and health; analytic network process; system dynamics; management and control measures; simulation

## 1. Introduction

As we all know, occupational safety and health (OSH) is an indispensable part of enterprise [1]. The OSH of enterprises (especially in high-risk industries) is a complex system. Complexity theory suggests that we see performance as an emergent property, the result of complex interactions and relationships. With inspiration from complexity theory, failures are seen as an emergent property of complexity [2]. The main research object of occupational safety and health is human. As a complex system, the human is affected by many factors, which are far beyond engineering specifications and reliability prediction [3]. In the complex system of nuclear industry, performance and safety culture play a key role in enterprise safety [4,5]. Schneider et al. proposed that in complex adaptive systems, leaders indirectly influence organizations through mediating variables of organizational identity and social movement [6].

On 5 April 2010, a series of explosions occurred inside the Upper Big Branch (UBB) mine in southern West Virginia. This accident reinforced the need for, and importance of, promoting a positive safety culture by routinely evaluating an organization's safety culture activities and initiatives and by making enhancements and adjustments to ensure that an organization remains proactive and appropriately focused on this important area [7]. Dutta drew on the culture-centered approach to dialogically articulate meanings of workplace risks and injuries, voiced by Bangladeshi migrant construction workers in Singapore [8].

In order to further study and analyze occupational safety and health, factors such as performance, cognition, motivation and safety culture need to be deeply analyzed.

Komljenovic et al. argued that the next level of safety performance will have to consider a transition from coping solely with workplace dangers, to a more systemic model taking organizational risks into consideration. A perspective that may be used in supervisory activities, self-assessments, and minor event investigations, is presented. When ingrained in an organizational culture, such perspective has the highest potential for continuous safety improvement [9]. The strategic approach for improving performance is to reduce human error and manage controls so as to reduce unwanted events and/or mitigate their impact should they occur [10]. Intuition and safety perception will affect the safety status of employees and even enterprises [11]. Kahneman et al. identified the cognitive and motivational biases that are relevant for decision and risk analysis. In addition, they describe some biases that are less relevant because they can be corrected by using logic or decomposing the elicitation task [12].

With the improvement of workers' awareness of safety and health, more and more companies are paying increasing attention to OSH. The influencing factors of OSH are various. Accurate and effective identification of influencing factors is the key to improve the level of OSH in enterprises.

Komljenovic et al. proposed a high level Risk-Informed Decision-Making framework in Asset Management that integrates risks extreme and rare events as part of an overall risk assessment and management activity. The research focuses on the methodology aimed at identifying, assessing and managing those risks in Asset Management [13]. Panikkar et al. employed a survey instrument predominately developed and administered by Teen Educators to assess occupational health risks [14]. Zytoon et al. studied the OSH conditions of young and aging fishermen compared to middle-aged fishermen in the small- and medium-size (SM) marine fishing sector [15]. Zhou et al. studied the occupational safety and health management methods as well as risk control technology associated with the coal mining industry, including daily management of occupational safety and health, identification and assessment of risks, early warning, and dynamic monitoring of risks [16,17]. Li et al. outlined the implications for the governance of occupational safety and health [18]. Chang et al. used a qualitative method-grounded theory-to collect code, and analyzed the data in order to understand the agencies' role in occupational accident education and hazard prevention for blue-collar foreign workers in Taiwan [19]. Hansen et al. provided insights into perceptions of potentially unsafe or uncomfortably hot working conditions that can affect occupational health and safety using information provided by the public and workers to the safety regulator in South Australia [20,21]. Anonymous authors in Korea reviewed the requirements for the advancement of occupational safety and health administrative organization and proposed measures to establish an Occupational Safety and Health Executive [22]. Wu et al. reviewed the history of regulatory system of occupational health and safety in China, as well as the current reform of this regulatory system in the country [23].

As one of the high-risk industries, the chemical industry has received substantial attention in its OSH. Mannan et al. used statistics to measure safety progress and determine patterns of injury, which will guide further improvements in chemical safety [24]. Hassim et al. did not only compare the existing methods, but also revealed the need of health assessment approaches for chemical process design that abide with the actual occupational health and industrial hygiene concept [25]. Khan et al. aimed to find the attributes of occupational injury among workers in the chemical industry and to enhance safety level. Injury data were collected and processed in terms of different variables, such as age, gender, skills, type of hazard, etc. [26]

Although OSH has been studied in a deep way, there are few studies on the dynamic evolution process of OSH. It is unfavorable to analyze the changing process and rules of the OSH level (especially in coal chemical enterprises). System Dynamics (SD) can simulate the interrelationships of factors and their changing processes in complex systems. Therefore, the evolution of the OSH level can be simulated using SD.

SD is an excellent way to understand a complex system, and there are examples of its use in risk assessment and safety management. Shin et al. developed a system dynamics (SD)-based model of construction workers' mental processes and safety attitudes [27]. Lu et al. studied replicator dynamics of the evolutionary model to make an optimization analysis of the behaviors of those interested parties and the adjustment mechanism of safety management policies and decisions, based on stability theory of dynamics system and phase diagram analysis [28]. Wu et al. established a system dynamics model of employee's work-family conflict in the construction industry, and conducted a simulation [29].

In order to make the simulation effect of SD better, it is necessary to quantitatively analyze the relationship between factors. Since the Analytic Network Process (ANP) can more accurately describe the network structure between objective things, it can better calculate the weight of each factor. Therefore, this paper uses ANP to optimize SD. Fang et al. used ANP to empirically analyze the interaction between network evolution decision, driving factors, and green innovation performance, and obtained the interaction relationship model of decision factors, driving factors, and green innovation performance [30]. Nima et al. investigated the applicability of ANP to security-based rank ordering of hazardous facilities such as chemical plants [31].

ANP and SD provide new ideas for the study of OSH in coal chemical enterprises. Based on the analysis of the influencing factors of OSH, this paper used ANP to analyze the weight of each influencing factor to find out the key factors and importance ranking. Then, the SD model of OSH was constructed, combining the results of the ANP analysis. With the influence of different factors, the OSH level of coal chemical enterprises was analyzed, and management and control measures proposed. Finally, management and control measures were applied to coal chemical companies to improve the status of OSH in coal chemical enterprises in practical applications.

## 2. Analysis of Factors Affecting OSH in Coal Chemical Enterprises

Based on the Chinese occupational safety and health standards, this paper analyzes the influencing factors of OSH of coal chemical enterprises from "human-machine-environment-management", according to the actual situation of coal chemical enterprises. As shown in Figure 1, the paper uses the Fishbone Diagram [32] to analyze the influencing factors of OSH in coal chemical enterprises.

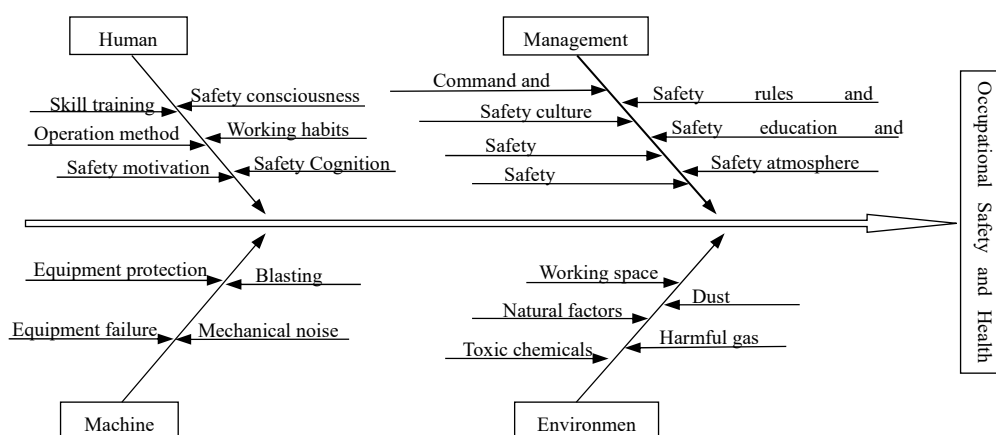


Figure 1. Fishbone diagram of occupational safety and health (OSH) influencing factors.

We concluded that the main human factors affecting OSH are skill training, safety consciousness, operation method, working habits, safety motivation, and safety cognition. Management factors

include safety culture, safety education and training, command and dispatch, safety rules and regulations, safety supervision, safety atmosphere, and safety performance. Machine factors include equipment protection, blasting, equipment failure and mechanical noise. Environment factors include natural factors, working space, harmful gas, dust, and toxic chemicals.

### 3. Analysis of the Indicator System of Influencing Factors

#### 3.1. Constructing an ANP Indicator System

According to the analysis of influencing factors, combined with the network structure and steps of ANP, the indicator system of OSH influencing factors of coal chemical enterprises can be divided into target layer and factor layer. The factor layer includes four primary indicators and 19 secondary indicators. By consulting experts and integrating all the factors, the OSH influencing factors indicator system of coal chemical enterprises (Table 1) is finally constructed.

**Table 1.** Occupational safety and health (OSH) influencing factors indicator system.

Target Layer	Factors Layer	
	Primary Indicators	Secondary Indicators
Occupational Safety And Health Level of Coal Chemical Enterprises	Human $H$	Skill training $H_1$
		Safety consciousness $H_2$
		Operation method $H_3$
		Working habits $H_4$
		Safety motivation $H_5$
		Safety cognition $H_6$
	Management $M$	Command and dispatch $M_1$
		Safety rules and regulations $M_2$
		Safety culture $M_3$
		Safety education and training $M_4$
		Safety supervision $M_5$
		Safety atmosphere $M_6$
		Safety performance $M_7$
	Machine $A$	Equipment protection $A_1$
		Blasting $A_2$
		Equipment failure $A_3$
		Mechanical noise $A_4$
	Environment $E$	Working space $E_1$
		Dust $E_2$
		Natural factors $E_3$
		Toxic chemicals $E_4$
		Harmful gas $E_5$

#### 3.2. Building an ANP Structural Model

ANP divides system elements into control layer elements and network layer elements. The network layer consists of all the elements that are affected by the control layer, and they present a network structure that interacts with each other.

##### (1) Control layer

The influencing factors of OSH affect employees' health perception, risk identification, and decision-making related to health. Therefore, in the control layer of the ANP structural model, OSH is regarded as the target, and health perception ( $R_1$ ), risk identification ( $R_2$ ), and health decision ( $R_3$ ) are taken as criteria.

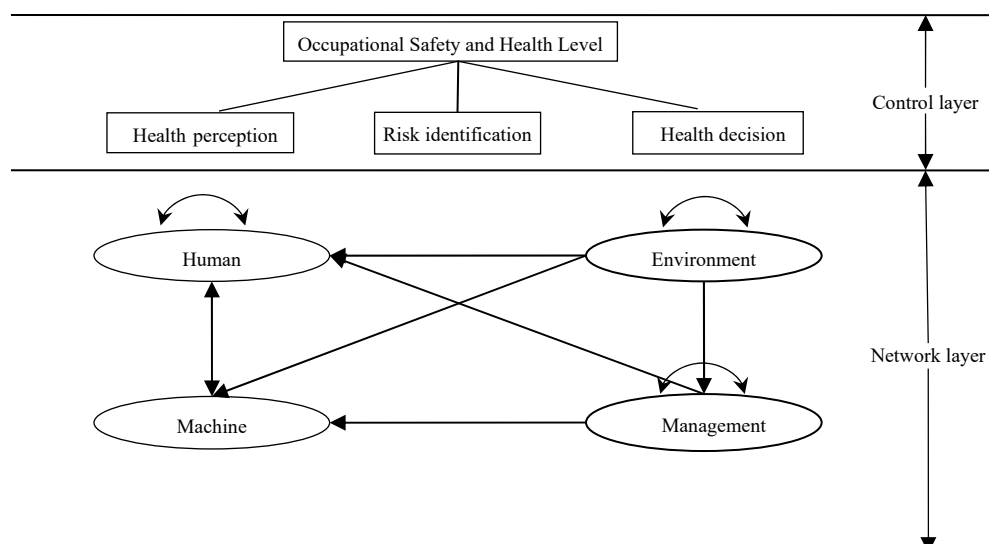
##### (2) Network layer

The factors in "human-machine-environment-management" are taken as element groups in the network layer. The network structure is constructed according to the relationship between the influencing factors of OSH (Table 1).

According to the relevant meanings of various influencing factors and expert opinions, the association of indicators is described. As shown in Table 2, “√” indicates that there is a dependency between the two. According to the association of indicators, the ANP structure model shown in Figure 2 is constructed.

**Table 2.** Association of influencing factors of OSH.

	$H_1$	$H_2$	$H_3$	$H_4$	$H_5$	$H_6$	$M_1$	$M_2$	$M_3$	$M_4$	$M_5$	$M_6$	$M_7$	$A_1$	$A_2$	$A_3$	$A_4$	$E_1$	$E_2$	$E_3$	$E_4$	$E_5$	$R_1$	$R_2$	$R_3$
$H_1$			√		√	√								√	√								√	√	√
$H_2$	√		√	√									√	√	√								√	√	√
$H_3$				√										√	√	√							√	√	√
$H_4$	√		√		√	√							√	√	√								√	√	√
$H_5$		√								√													√	√	√
$H_6$			√										√										√	√	√
$M_1$	√	√	√	√				√			√	√											√	√	√
$M_2$	√	√	√	√						√	√	√											√	√	√
$M_3$	√	√	√	√							√	√		√									√	√	√
$M_4$	√	√	√	√					√		√	√	√										√	√	√
$M_5$	√	√	√	√							√	√											√	√	√
$M_6$	√	√	√	√					√	√													√	√	√
$M_7$		√		√	√	√			√						√								√	√	√
$A_1$			√	√									√										√	√	√
$A_2$			√	√												√	√		√				√	√	√
$A_3$			√	√													√						√	√	√
$A_4$			√	√									√					√					√	√	√
$E_1$			√	√							√					√	√		√			√	√	√	√
$E_2$			√	√							√		√										√	√	√
$E_3$			√	√							√												√	√	√
$E_4$			√	√							√												√	√	√
$E_5$			√	√							√												√	√	√
$R_1$	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
$R_2$	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
$R_3$	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√



**Figure 2.** Influencing factors of OSH Analytic Network Process (ANP) model.

### 3.3. Calculating Indicators Weights

Due to the complexity of the principle and process of ANP, and the fact that a lot of elements are involved in ANP, ANP proprietary software (Super Decision, Chinese Version, SUPER DECISION,

US) was used to conduct the calculation process. The Super Decision solves the problem that the ANP process is complicated and computationally intensive, and creates convenient conditions for the real application of the ANP model.

#### (1) Matrix consistency test

According to the expert's judgment on the importance of relevant factors, a judgment matrix of the relationship between all factors is constructed. It is generally accepted that the coefficient of the consistency test is less than 0.1 [33]. If it is calculated that the values of all submatrix consistency test results are less than 0.1, it indicates that the consistency test is passed. Figure 3 shows the results of the consistency test.

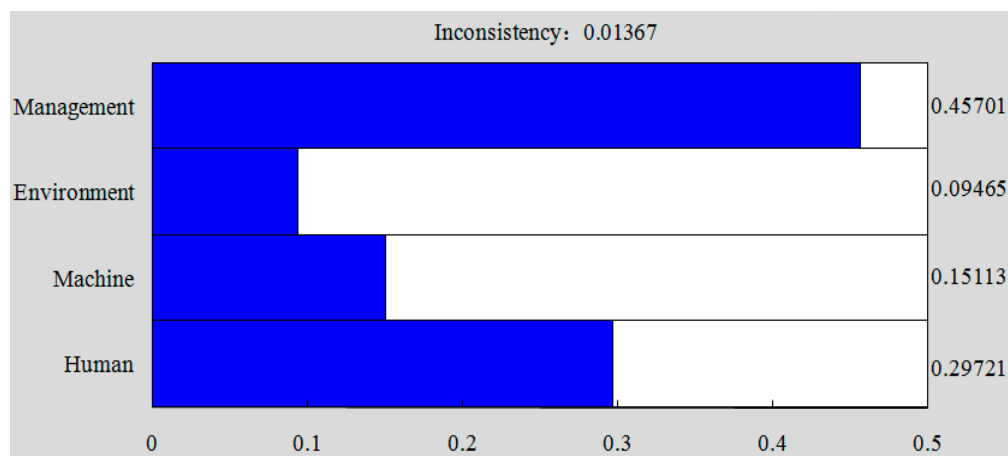


Figure 3. Consistency test results.

#### (2) Final ranking calculation

According to the calculation, the weights of OSH influencing factors can be obtained. The criteria in the control layer are ordered by weight: health decision (0.419), health perception (0.338), risk identification (0.243). It can be seen that health decision, risk identification, and health perception are the most direct factors affecting the OSH of employees. The weights of the primary and secondary indicators of the network layer for OSH are shown in Table 3.

Table 3. OSH influencing factor weights value.

Target Layer	Factors Layer				
	Primary Indicators	Weights of Primary Indicators	Secondary Indicators	Local Weights	Global Weights
Occupational Safety And Health Level Of Coal Chemical Enterprises	Human <i>H</i>	0.29721	Skill training <i>H</i> <sub>1</sub>	0.12232	0.019156
			Safety consciousness <i>H</i> <sub>2</sub>	0.18708	0.042015
			Operation method <i>H</i> <sub>3</sub>	0.14579	0.032208
			Working habits <i>H</i> <sub>4</sub>	0.20821	0.087636
			Safety motivation <i>H</i> <sub>5</sub>	0.15996	0.051537
			Safety cognition <i>H</i> <sub>6</sub>	0.17664	0.068462
	Management <i>M</i>	0.45701	Command and dispatch <i>M</i> <sub>1</sub>	0.08347	0.063433
			Safety rules and regulations <i>M</i> <sub>2</sub>	0.11327	0.051717
			Safety culture <i>M</i> <sub>3</sub>	0.19135	0.108972
			Safety education and training <i>M</i> <sub>4</sub>	0.14916	0.062035
			Safety supervision <i>M</i> <sub>5</sub>	0.15011	0.072954
			Safety atmosphere <i>M</i> <sub>6</sub>	0.13812	0.051462
			Safety performance <i>M</i> <sub>7</sub>	0.17452	0.081294
	Machine <i>A</i>	0.15113	Equipment protection <i>A</i> <sub>1</sub>	0.35131	0.038526
			Blasting <i>A</i> <sub>2</sub>	0.21106	0.011906
			Equipment failure <i>A</i> <sub>3</sub>	0.19032	0.018263
			Mechanical noise <i>A</i> <sub>4</sub>	0.24731	0.020889
			Working space <i>E</i> <sub>1</sub>	0.13527	0.007867
	Environment <i>E</i>	0.09465	Dust <i>E</i> <sub>2</sub>	0.18628	0.021728
			Natural factors <i>E</i> <sub>3</sub>	0.21415	0.013792
			Toxic chemicals <i>E</i> <sub>4</sub>	0.22420	0.035424
			Harmful gas <i>E</i> <sub>5</sub>	0.24010	0.038724

According to Table 3, it can be concluded that the primary indicators affecting OSH are ranked by Management, Human, Machine, and Environment in order of weight.

The secondary indicators of the Management factors are ranked by Safety culture, Safety performance, Safety supervision, Safety education and training, Safety atmosphere, Safety rules and regulations, Command and dispatch in order of local weight. The secondary indicators of the Human factors are ranked by Working habits, Safety consciousness, Safety cognition, Safety motivation, Operation method, Skill training in order of local weight. The secondary indicators of the Machine factors are ranked by Equipment protection, Mechanical noise, Blasting, Equipment failure in order of local weight. The secondary indicators of the Environment factors are ranked by Harmful gas, Toxic chemicals, Natural factors, Dust, Working space in order of local weight.

The secondary indicators are Safety culture, Working habits, Safety performance, Safety supervision, Safety cognition, Command and dispatch, Safety education and training, Safety rules and regulations, Safety motivation, Safety atmosphere, Safety consciousness, Harmful gas, Equipment protection, Toxic chemicals, Operation method, Dust, Mechanical noise, Skill training, Equipment failure, Natural factors, Blasting, Working space in order of global weight.

Using ANP to rank the indicators affecting OSH by weight, a reference was provided for the development of OSH management and control measures for coal chemical enterprises. In the formulation of measures, the indicators that rank ahead of the weight are taken into account.

#### 4. Simulation Analysis of OSH Management and Control Measures

##### 4.1. Building an SD Model

###### (1) Establishing a variable set for SD simulation

According to the influencing factors of OSH and the results of ANP calculation, combined with the characteristics of SD simulation, the variables to be studied are divided into state variables, rate variables, auxiliary variables, and constants [34]. As shown in Table 4, the contents in parentheses indicate the names of variables in the SD model.



**Table 4.** System Dynamics (SD) simulation variable set.

Variable Type	Variable Name
State variables	OSH level (OSH_Level), Human factors level (H_Level), Machine factors level (A_Level), Environment factors level (E_Level), Management factors level (M_Level)
Rate variables	OSH level increment (Increment_OSH), Human level increment (Increment_H), Machine level increment (Increment_A), Environment level increment (Increment_E), Management level increment (Increment_M)
Auxiliary variables	Safety culture (M <sub>3</sub> ), Working habits (H <sub>4</sub> ), Safety supervision (M <sub>5</sub> ), Command and dispatch (M <sub>1</sub> ), Safety education and training (M <sub>4</sub> ), Safety rules and regulations (M <sub>2</sub> ), Safety atmosphere (M <sub>6</sub> ), Safety consciousness (H <sub>2</sub> ), Harmful gas (E <sub>5</sub> ), Equipment protection (A <sub>1</sub> ), Toxic chemicals (E <sub>4</sub> ), Operation method (H <sub>3</sub> ), Dust (E <sub>2</sub> ), Mechanical noise (A <sub>4</sub> ), Skill training (H <sub>1</sub> ), Equipment failure (A <sub>3</sub> ), Natural factors (E <sub>3</sub> ), Blasting (A <sub>2</sub> ), Working space (E <sub>1</sub> ), Safety motivation (H <sub>5</sub> ), Safety cognition (H <sub>6</sub> ), Safety performance (M <sub>7</sub> )
Constants	Strengthening safety education and training (C <sub>1</sub> ), Improving incentives (C <sub>2</sub> ), Strengthening safety supervision and inspection (C <sub>3</sub> ), Improving the hierarchical management system (C <sub>4</sub> ), Building a corporate safety culture (C <sub>5</sub> ), Correcting bad operating habits (C <sub>6</sub> ), Job standardization management (C <sub>7</sub> ), Improving the safety atmosphere (C <sub>8</sub> ), Establishing employee access system (C <sub>9</sub> ), Optimizing the working environment (C <sub>10</sub> ), Improving man-machine matching (C <sub>11</sub> ), Increasing safety and health investment (C <sub>12</sub> ), Strengthening the ventilation (C <sub>13</sub> ), Increasing personal protective equipment (C <sub>14</sub> ), periodic physical examination (C <sub>15</sub> ), Periodic maintenance equipment (C <sub>16</sub> ), Adding dust removal equipment (C <sub>17</sub> ), Strengthening health inspection in the workplace (C <sub>18</sub> ), Setting hazard identification (C <sub>19</sub> )

## (2) Establish the SD model for OSH management control measures

In order to make the SD model more reliable, it is necessary to combine the weight analysis of ANP to establish the quantitative relationship between variables. Their quantitative relationship is shown in Equations (1)–(5).

$$OSH = 0.29721 \times H + 0.45701 \times M + 0.15113 \times A + 0.09465 \times E \quad (1)$$

where, *OSH* is Occupational safety and health level, *H* is Human factors, *M* is Management factors, *A* is Machine factors, *E* is Environment factors.

$$H = 0.12232 \times H_1 + 0.18708 \times H_2 + 0.14579 \times H_3 + 0.20821 \times H_4 + 0.15996 \times H_5 + 0.17664 \times H_6 \quad (2)$$

where, *H*<sub>1</sub> is Skill training, *H*<sub>2</sub> is Safety consciousness, *H*<sub>3</sub> is Operation method, *H*<sub>4</sub> is Working habits, *H*<sub>5</sub> is Safety motivation, *H*<sub>6</sub> is Safety cognition.

$$M = 0.08347 \times M_1 + 0.11327 \times M_2 + 0.19135 \times M_3 + 0.14916 \times M_4 + 0.15011 \times M_5 + 0.13812 \times M_6 + 0.17452 \times M_7 \quad (3)$$

where, *M*<sub>1</sub> is Command and dispatch, *M*<sub>2</sub> is Safety rules and regulations, *M*<sub>3</sub> is Safety culture, *M*<sub>4</sub> is Safety education and training, *M*<sub>5</sub> is Safety supervision, *M*<sub>6</sub> is Safety atmosphere, *M*<sub>7</sub> is Safety performance.

$$A = 0.35131 \times A_1 + 0.21106 \times A_2 + 0.19032 \times A_3 + 0.24731 \times A_4 \quad (4)$$

where, *A*<sub>1</sub> is Equipment protection, *A*<sub>2</sub> is Blasting, *A*<sub>3</sub> is Equipment failure, *A*<sub>4</sub> is Mechanical noise.

$$E = 0.13527 \times E_1 + 0.18628 \times E_2 + 0.21415 \times E_3 + 0.2242 \times E_4 + 0.2401 \times E_5 \quad (5)$$

where, *E*<sub>1</sub> is Working space, *E*<sub>2</sub> is Dust, *E*<sub>3</sub> is Natural factors, *E*<sub>4</sub> is Toxic chemicals, *E*<sub>5</sub> is Harmful gas.

On the premise of ensuring the correctness of the simulation results and improving the simulation speed, the simulation error is set through repeated testing, simulation and debugging. The coefficients



of the above five equations, that is, the weight error  $e_1$  of ANP is 0.00001. The error  $e_2$  in the system dynamics composed of Equations (1)–(5) is 0.000005, that is, when the value of the state variable of the system differs 0.000005 from the previous time, the system stops simulation.

Based on Equations (1)–(5) and Table 4, combined with the characteristics of SD common software AnyLogic (8.3.3, The AnyLogic Company, Chicago, IL, US), the SD model of OSH management and control measures is established. The SD model is shown in Figure 4. The symbol meaning in Figure 4 can be referred to Table 4.

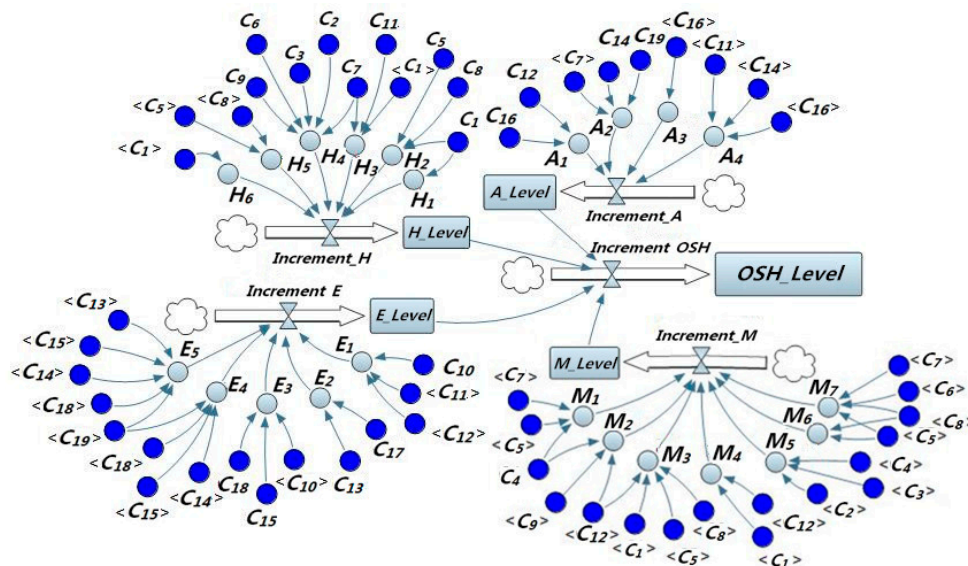


Figure 4. Management and Control Measures System Dynamics (SD) Model.

### (3) Determining simulation parameters

In the paper, the simulation time is set to 24 months and the simulation step is set to 1 month. The weights obtained by ANP are used as the influence coefficients between variables to construct a functional relationship of them. Combined with the nature of the variables, the functional relationship, and the actual requirements of the model, the initial values of the constants and state variables are finally determined after repeated adjustments and experiments. In this paper, the initial value of the constant is set to 0, that is, no control measures are taken. The initial value of the state variable is set to 0.3.

## 4.2. Simulation Analysis

### (1) Initial state simulation

In the initial state, the model shown in Figure 4 is simulated, and the simulation results are shown in Figure 5.

As can be seen from Figure 5, in the initial state, the overall OSH level is on the rise, but the increase is not large, and the maximum value is around 0.35000. There is a sharp increase for the first 6 months; from the 7th month to the 9th month, the increase is slower; from the 10th month to the 24th month, where there is only a small increase. It shows that under the current safety conditions, the coal chemical industry will have an increase in OSH levels, but in the end it will remain at a lower level.

### (2) Simulation of a single measure

The paper simulates OSH management and control measures by changing constants. On the basis of the initial state simulation, the value of the constant is increased to simulate the change of OSH level after coal chemical enterprises adopt certain measures.

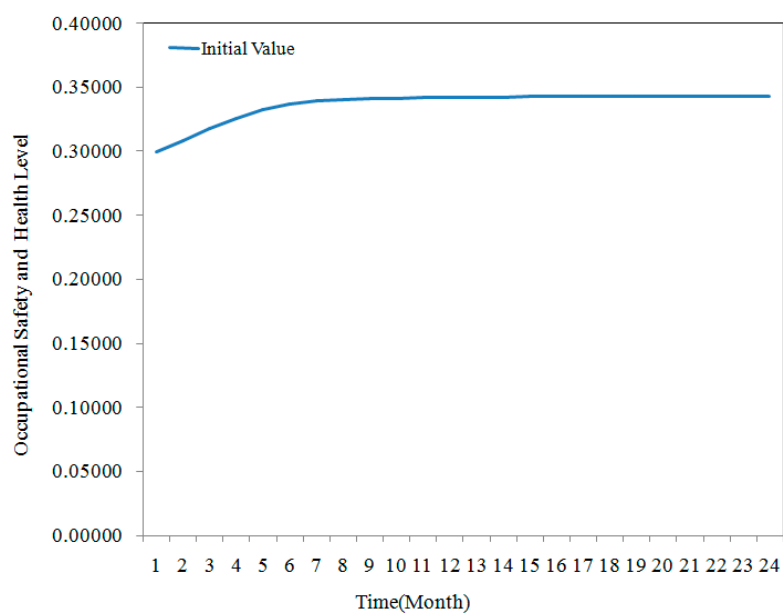


Figure 5. OSH level initial state SD simulation.

Figure 6 is a simulation trend of measures to enhance management. It can be seen that after the implementation of many management measures, the OSH level has increased significantly compared with the initial value, between 0.60000–0.85000. The effect of management measures from large to small is Safety culture, Safety supervision, Safety education and training, Safety atmosphere, Safety rules and regulations, Command and dispatch, Safety performance.

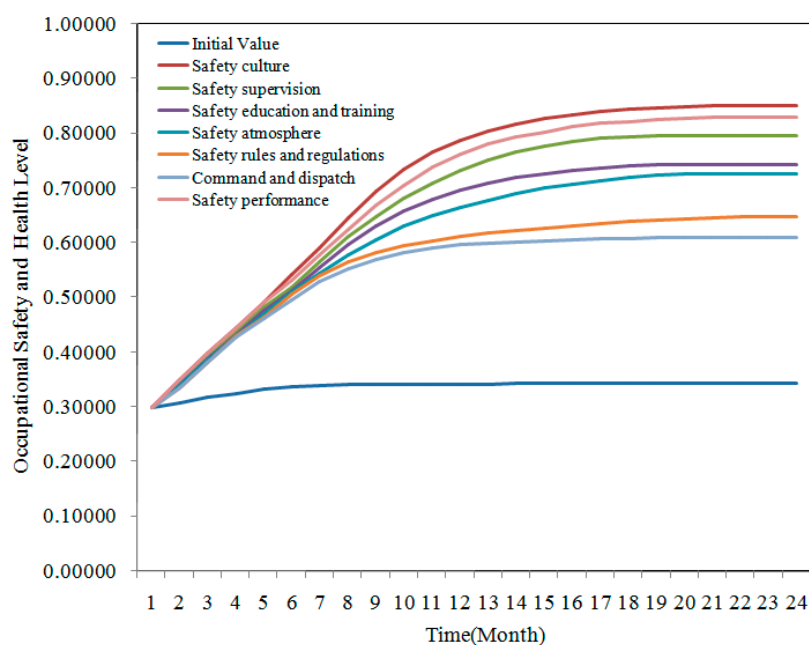


Figure 6. SD simulation of management factor measures.

It can be seen from Figure 7 that after the implementation of human measures, the OSH level has increased significantly compared with the initial value, and finally reached somewhere between 0.55000 and 0.80000. The effect of human measures from large to small is Working habits, Safety consciousness, Safety cognition, Safety motivation, Operation method, Skill training.

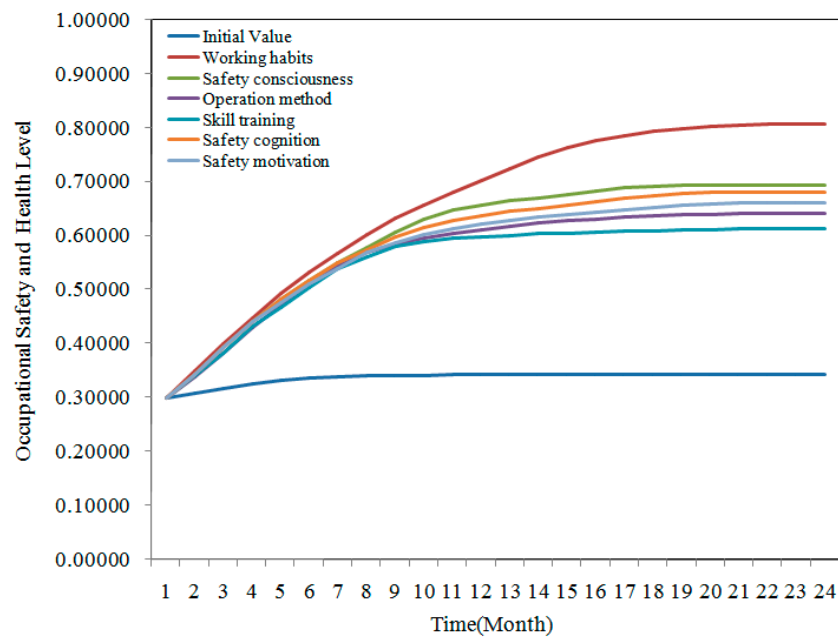


Figure 7. SD simulation of human factor measures.

Figure 8 is a simulation trend of measures to enhance mechanical aspects. It can be seen that after the implementation of the measures, the OSH level has increased significantly compared with the initial value, and is finally between 0.60000 and 0.80000. The effect of machine measures from large to small is Equipment protection, Mechanical noise, Blasting, Equipment failure.

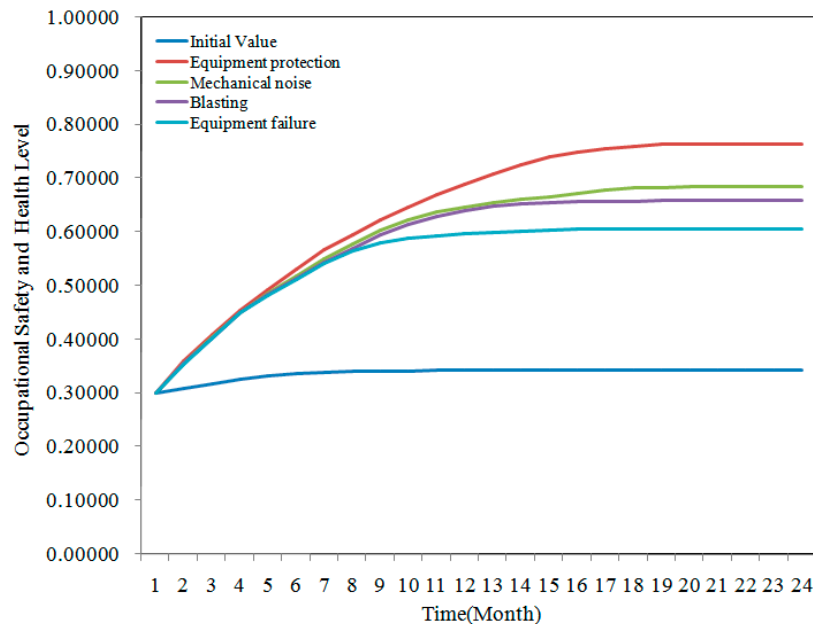


Figure 8. SD simulation of machine factor measures.

It can be seen from Figure 9 that after the implementation of the measures, the OSH level has increased significantly compared with the initial value, and finally reached somewhere between 0.50000 and 0.80000. The effect of environment measures from large to small is Harmful gas, Toxic chemical, Natural factors, Dust, Working space.

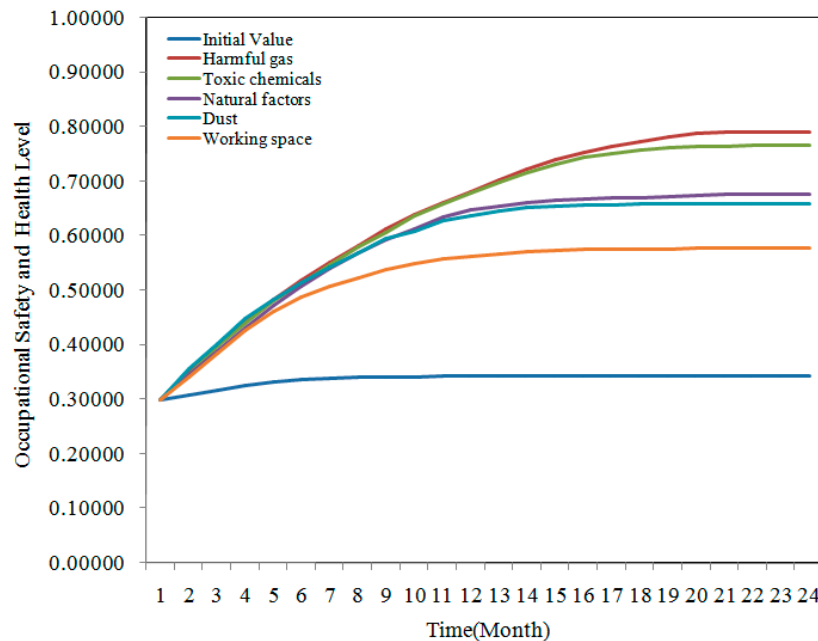


Figure 9. SD simulation of environment factor measures.

As can be seen from Figures 5–9, after taking different measures, the OSH level has increased at varying degrees, and the effect is obvious. It should be noted that although the OSH level has improved, it has not exceeded 0.85000. In order to explore more effective management and control measures, the paper will discuss in depth the implementation effect of combined measures.

### (3) Combined measure simulation

The combined management and control measures refer to the comprehensive use of a variety of means to improve the OSH, and ultimately achieve the purpose of effectively improving the level of OSH. This paper proposes combined management and control measures from Human, Machine, Environment, Management, etc. The simulation results are shown in Figure 10.

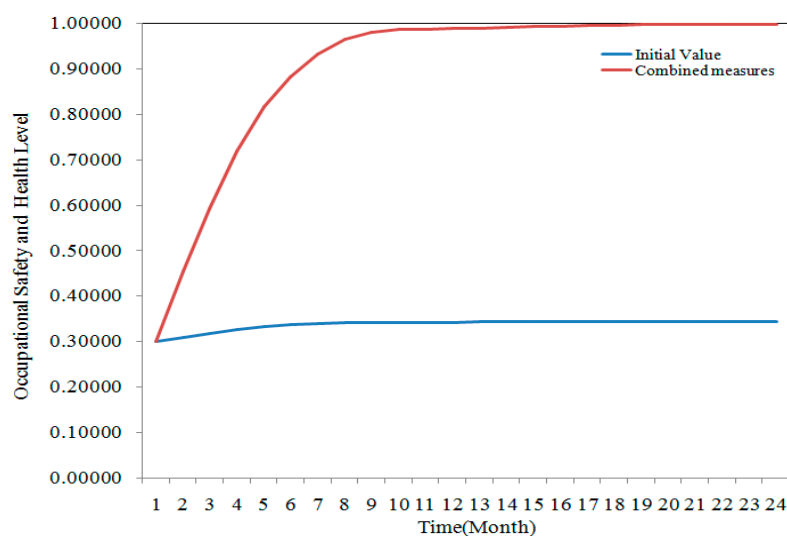


Figure 10. SD simulation of combined measures.

It can be clearly seen from Figure 10 that the OSH level under the combined measures rose rapidly in the first 6 months. After the 7th month–10th month of evolution, it gradually stabilized and finally reached 0.99699. It shows that the combination of measures is more effective, and is an easier way to improve the OSH of enterprises.

#### 4.3. Practical Application Research of Combined Measures

According to the ANP and SD analysis, referring to the Interim Provisions on the Occupational Health Supervision and Management of Workplaces and other relevant regulations, we took Hongxing Company as the research object. Taking into account the actual situation of the company, OSH management and control measures were formulated to protect the long-term healthy development of the company.

The production plant of Hongxing Company has a steel-structured double layer structure. At present, there are batch workshops, production workshops, packaging workshops, and hot air furnace workshops. The production and operation of each workshop are normal. The company mainly produces silica, the specific process is shown in Figure 11.

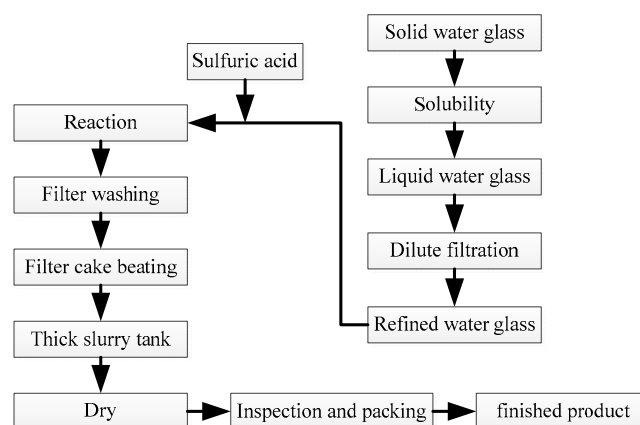


Figure 11. Process flow chart.

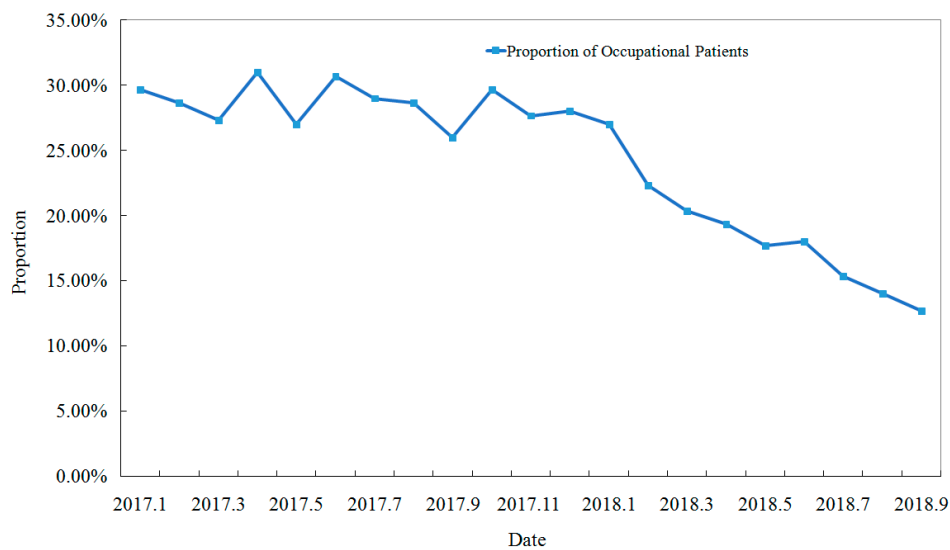
According to the actual operation of the company, as well as the design of the plant and the process flow, the plant layout is re-arranged with reference to the requirements of the combined management and control measures. The reaction device for dispersing harmful gases is placed on the second floor of the plant, and the slurry pump and other equipment that generate noise and vibration are placed at the bottom of the plant, and effective sound insulation and vibration reduction measures are taken. The pipeline for conveying sulfuric acid has the properties of sealing, pressure resistance, corrosion resistance, etc. and it does not pass through an auxiliary room where the worker often stays or passes.

The effect of the control measures was further verified by analyzing the proportion of occupational patients in Hongxing Company in 21 months. As shown in Figure 12, a chart showing the change in the trend of occupational diseases in the company from January 2017 to September 2018.

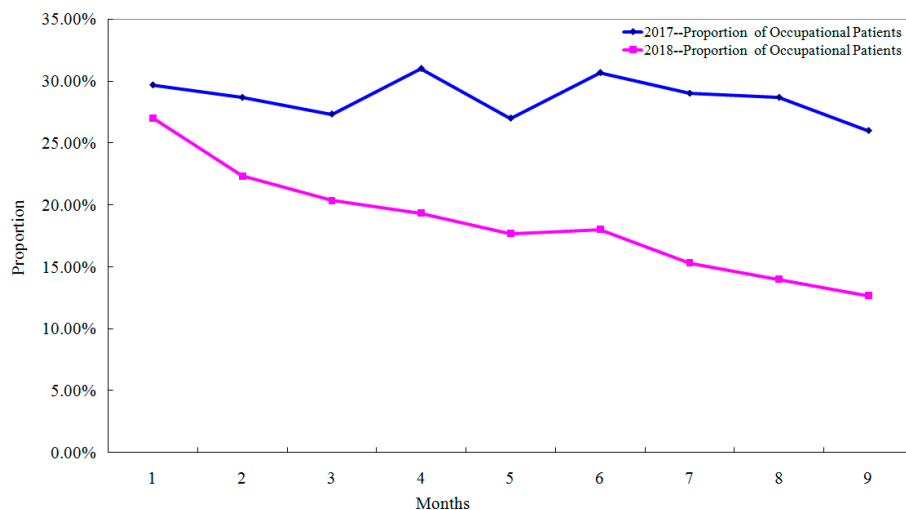
As can be seen from Figure 12, the proportion of the company's monthly occupational patients in 2017 is 28.33%. At the beginning of 2018, after the implementation of the management and control measures, the proportion of the occupational patients fell to 27.00%. It shows that management and control measures have begun to take effect. From January 2018 to September 2018, the proportion of occupational patients in the company drops rapidly, from 27.00% to 12.67%. It demonstrates that the control measures are effective.

In order to analyze the proportion of occupational patients before and after the implementation of management and control measures more clearly, the paper compares the proportion of occupational patients in the same month in 2017 and 2018, as shown in Figure 13.

As can be seen from Figure 13, the proportion of occupational patients decreased significantly in the same month of 2018 and 2017, and this trend became more and more obvious over time.



**Figure 12.** Trends in the proportion of occupational patients in Hongxing Company from January 2017 to September 2018.



**Figure 13.** Comparison of the proportion of occupational patients in the company in the same month of 2017 and 2018.

According to the trend of the proportion of occupational patients in Figures 12 and 13, it can be seen that after the company implemented the measures, occupational diseases were effectively controlled, and the OSH level significantly improved.

## 5. Conclusions

Based on the actual situation of coal chemical enterprises, this paper analyzed the influencing factors of OSH in coal chemical enterprises by combining ANP and SD, and simulated the combined management and control measures to further reduce the number of occupational patients in coal chemical enterprises and improve their OSH level. The main conclusions are as follows:

(1) The influencing factors of OSH in coal chemical enterprises were analyzed from four aspects of Human, Machine, Environment, and Management respectively, using the Fishbone Diagram.

(2) ANP was used to analyze the weights of the influencing factors. The results indicate that the primary indicators affecting OSH are Management, Human, Machine, and Environment, according to weights. The global weights of the secondary indicators indicate that the weights of factors such as

Safety culture, Working habits, Harmful gas, Equipment protection, Toxic chemicals, Dust, Mechanical noise are large, which are the key factors for the formulation of management and control measures.

(3) The SD model of OSH management and control measures was constructed. It was found that through simulation, the effect of adopting combined management and control measures was better than that of implementing a single measure.

(4) The research results of the paper were experimentally applied to the coal chemical company—Hongxing Company. It can be seen from the statistics that the combined management and control measures have effectively reduced the proportion of the company's occupational patients and improved the company's OSH level.

The research results of the paper provide a theoretical basis and application direction for the research of OSH management and control technology in coal chemical enterprises. In the future, the research results of this paper will continue to be promoted to other similar enterprises to improve the OSH level of the whole industry.

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