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Research on Safety Incentive Model of Coal Miners and Strategy Analysis

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ABSTRACT

Based on the safety incentive theory and safety incentive mode, the system dynamics model of safety incentive for coal miners is established, and the simulation of the model is provided. The research shows that the effect of improving reward measure and environmental conditions are the most significant. According to the influence to the safety incentives, other measures are in the following order: technical equipment, safety culture, enterprise goals and punishments. The safety incentive strategy of coal miners is put forward with the simulation results.

Keywords: Safety, Behavior, Incentive, Miners, System dynamics, Simulation, Strategy.

1. INTRODUCTION

A large number of statistics shows that more than 80% of coal mine accidents are related to workers' unsafe behaviors(Chen Hong, Song Xuefeng, 2006). Workers' unsafe behaviors are caused by many factors, such as psychology, physiology, environmental, etc. According to the related theories of organizational behavior, people's behavior is dominated by the motivation. Moreover, people's inner desire and motivation is inspired by incentive. So the research of incentive can help us find the effective way to guide the safety behavior of workers.

Since 1920s, many experts and scholars in the world have made researches on the incentive, and put forward different theories of incentive. Generally, these theories are divided into three categories (Shi Jutao et al., 2003; Li Jizu, 2009): Content-based Motivation Theory (e.g. Hierarchy of Needs Theory, ERG Theory, Two-factor Theory), Behavior Transforming Incentive Theory. (e.g., Frustration Theory, Attribution Theory) and Process Incentive Theory (e.g. Equity Theory, Expectation Theory, Goal-Setting Theory).

Many Chinese experts and scholars have also studied the safety incentive. Li Hongxia (2001) studied the safety incentive system, and put forward three types of safety incentive methods: Educational effect, Economic effect and Power effect. On the basis of motivation theory, Huang Mingxia (2006) described the incentive methods in safety management, such as work incentive, achievement incentive, criticism and encouragement incentive, training and education incentive. Mao Xiaoxin (2013) put forward the positive incentive scheme of safety

behavior, and it was discussed from material incentive and spiritual incentive. Liu Haibin et al. (2015) established the incentive mechanism of coal mine safety production based on the research of unsafe behavior. Combining with three types of incentive theory (Content-based Motivation Theory, Behavior Transforming Incentive Theory and Process Incentive Theory), Zhang Lili (2008) put forward the incentive mechanism of safety production management. Liu Ying and Shi Shiliang (2009) constructed the coal mine safety behavior incentive system.

The studies of the safety incentive is on theoretical level, and some are still in the period of experience. There are few studies on specific employee safety incentive mode. Moreover, there are few quantitative analysis of employees' behavior and psychology . In view of this, based on the theory and method of system dynamics ,the incentive model of coal miners safety behavior is researched, and to seek the strategies and effective ways to control the unsafe behaviors of coal miners.

2. SAFETY INCENTIVES AND SAFETY BEHAVIOR IMPROVEMENT

Safety incentive refers to inspiring people in the system reasonably, and guiding and controlling the behavior of people to make sure that their behavior meets the safety standard (rules), with the integrated use of management, economics and other modern scientific principles and methods. The aim of safety incentive is to prevent system from accidents and disasters, and to ensure that system is at an acceptable safty level. It ensures not only the individual safety but also the safety of the

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organization (enterprises), environment and society (Liu Ying and Shi Shiliang, 2009).

In the process of development enterprise should guide the employees' behavior by incentive method. According to the source of need, the incentive method can be divided into material incentive and spiritual incentive (Liu Haibin et al., 2015). The former refers to the bonus, salary, welfare and other material incentives while the latter refers to the corporate goals, leadership, interpersonal relationships, group cohesion, job satisfaction, etc.

At present, coal miners' safety awareness is improved by material incentive factors such as rewards, compensation and punishment. These incentives may have a good effect in a short time, but the enthusiasm of the workers will be changed alongside the disappearance of the reward or punishment. So the enthusiasm of the workers cannot be sustained. In addition, it is difficult for coal mining enterprises to make appropriate safety incentive measures to reduce the unsafe behavior of employees, so as to achieve the proleptic incentive effect. Therefore, in this paper, the safety incentive mode of coal miners is studied by the system dynamics simulation.

3. SD SIMULATION OF SAFETY INCENTIVE MODE

System dynamics (SD) is a science that scientific theory of system science and computer simulation are integrated to study system feedback structure and behavior. It is used to study and deal with complex system problems by qualitative analysis and quantitative analysis (Zhong Yongguang et al., 2012). The commonly used system dynamics software are STELLA/iThink, Vensim, Powersim, Anylogic, etc. Vensim is the most widely used among them. In this paper, Vensim will be used for the research.

3.1 Establishment of the stock flow chart of safety incentive mode

According to the actual situation of coal mine safety management, the safety incentive model of coal miners is analyzed and established. The stock and flow chart of safety incentive model of coal miners is established with "Safety performance level" as the measure of safety incentive effect (As is shown in Figure 1).
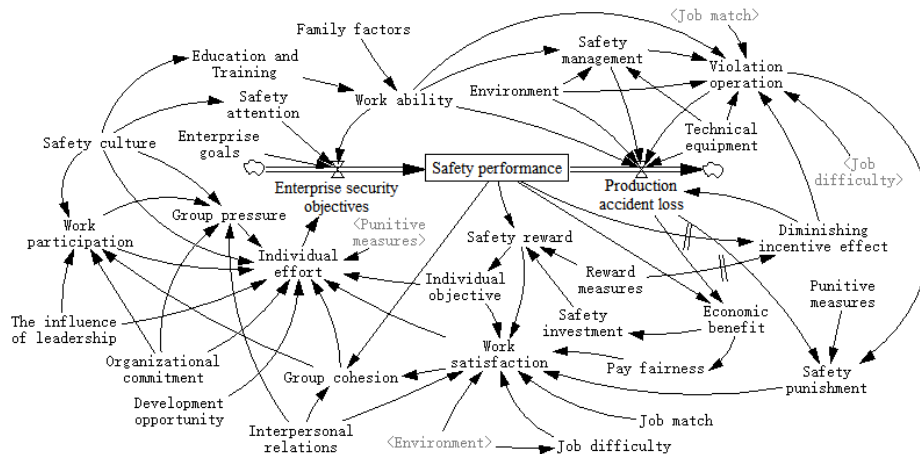

Fig.1: Stock and flow diagram of coal miners' safety incentive model

Table 1 Set of SD simulation variable

Variable type	Number	Variable name
Level Variables	1	Safety performance
Rate Variables	2	Enterprise security objectives, Production accident loss
Auxiliary Variables	18	Work participation, Job difficulty, Individual effort, Group cohesion, Group pressure, Individual objective, Safety work satisfaction, Safety reward, Safety investment, Pay fairness, Safety punishment, Economic benefit, Violation operation, Safety management, Work ability, Education and Training, Diminishing incentive effect(Zheng Guoduo. 2005), Safety attention
Constant	12	Family factors, environment, Technical equipment, Safety culture, The influence of leadership, Organizational commitment, Development opportunity, Job match, Interpersonal relations, Reward measures, Punitive measures, Enterprise goals

The mode includes level variables, rate variables, auxiliary variables and constants (Zhong Yongguang et al., 2012) (As is shown in Table 1). The constant in Table 1 is the standard or the desired goal which is set by the system, and the initial value is determined by the author and the coal mine enterprise experts.

3.2 Determination of parameters of SD model

The determination of the parameters in the SD mode is mainly about the weight coefficient of the independent variable to the dependent variable. In this paper, the parameters are determined by AHP and expert estimation (Tian Shuicheng et al., 2014; Wu Liping, 2006; Wang Lianfen, Xu Shubai, 1990).

Due to space reasons, take safe working satisfaction and its related variable, for example, to introduce the determination of weight coefficient. The variables related to safety job satisfaction(L) are: individual objective (a_1), interpersonal relations (a_2), safety punishment (a_3), safety reward (a_4), job match (a_5), job difficulty (a_6), environmental (a_7) and pay fairness (a_8), so the set of variables is: $U=\{a_1,a_2,a_3,a_4,a_5,a_6,a_7,a_8\}$. Three engineers who engaged in safety supervision in coal mine enterprises were invited to discuss with the author. So the judgment matrix is established by expert evaluation and the scaling method of 1-9 Grade(Wu Liping, 2006). It is:

$$A = \begin{bmatrix} 1 & 4 & 1/3 & 1/5 & 5 & 3 & 1/7 & 1/7 \\ 1/4 & 1 & 1/5 & 1/7 & 1/2 & 1/3 & 1/7 & 1/8 \\ 3 & 5 & 1 & 1/3 & 5 & 3 & 1/2 & 1/4 \\ 5 & 7 & 3 & 1 & 5 & 4 & 1/2 & 1/3 \\ 1/5 & 2 & 1/5 & 1/5 & 1 & 1/2 & 1/6 & 1/7 \\ 1/3 & 3 & 1/3 & 1/4 & 2 & 1 & 1/5 & 1/6 \\ 7 & 7 & 2 & 2 & 6 & 5 & 1 & 1/2 \\ 7 & 8 & 4 & 3 & 7 & 6 & 2 & 1 \end{bmatrix};$$

In the study, the consistency test and sensitivity analysis of the judgment matrix A are made. Result shows that the maximum eigenvalue of the matrix is: $\lambda_{\max}(A) = 8.6486$, and the eigenvectors is: $W_A=[0.145,0.047,0.238,0.385,0.063,0.093,0.500,0.717]^T$. The consistency index is: CI=0.09266, CR=0.06571; Both CI and CR are less than 0.1, so the consistency passed test.

The weights are calculated by the AHP: W= {0.073, 0.023, 0.111, 0.172, 0.032, 0.047, 0.22, 0.323}.

Given judgment matrix A with a small perturbations, the perturbation matrix is B.

$$B = \begin{bmatrix} 1 & 1 & 2/3 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 4/5 & 2/3 & 1 & 1 \\ 3/2 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 2/3 & 1 \\ 1 & 5/4 & 1 & 1 & 1 & 3/4 & 1 & 1 \\ 1 & 3/2 & 1 & 1 & 3/4 & 1 & 1 & 1 \\ 1 & 1 & 1 & 3/2 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

The matrix C is a Hadamard product of A and B. (Wang Lianfen, Xu Shubai, 1990)

$$C = \begin{bmatrix} 1 & 2 & 2/9 & 1/5 & 5 & 3 & 1/7 & 1/7 \\ 1/4 & 1 & 1/5 & 1/7 & 2/5 & 2/9 & 1/7 & 1/8 \\ 9/2 & 5 & 1 & 1/3 & 5 & 3 & 1/2 & 1/4 \\ 5 & 7 & 3 & 1 & 5 & 4 & 1/3 & 1/3 \\ 1/5 & 5/2 & 1/5 & 1/5 & 1 & 3/8 & 1/6 & 1/7 \\ 1/3 & 9/2 & 1/3 & 1/4 & 3/2 & 1 & 2 & 1/6 \\ 7 & 7 & 2 & 3 & 6 & 5 & 1 & 1/2 \\ 7 & 8 & 4 & 3 & 7 & 6 & 2 & 1 \end{bmatrix}$$

Result shows that the maximum eigenvalue of matrix C is: $\lambda_{\max}(C) = 8.810$ .and the eigenvectors is: $W_C=[0.138,0.044,0.255,0.366,0.062,0.094,0.523,0.703]^T$. Compared with the maximum eigenvalue and eigenvector of matrix A, the change is small. The weight set of matrix C is: W'= {0.063, 0.020, 0.117, 0.168, 0.028, 0.043, 0.239, 0.322}, Compared with the weight set of A, the ranking of each factor does not change, and the numerical difference is very small. According to the above algorithm, given A with different small perturbations, and the results are stable. So, it is considered that the sensitivity of the judgment matrix A is within the acceptable range.

Therefore, the weight set obtained from the judgment matrix A is reasonable. So the relation on safe working satisfaction is:
L=0.073a$_1$+0.023a$_2$+0.111a$_3$+0.172a$_4$+0.032a$_5$+0.047a$_6$+0.22a$_7$+0.323a$_8$

3.3 SD simulation and result analysis

After the parameters of the SD model are determined, Vensim is used to simulate the model on the basis of the stock and flow chart. The simulation period is set to 72 months, the simulation step is set to 1 month, and the initial value of safety performance is set to 10, so as to analyze the long-term trend of safety incentive effect in 6 years.

The main positive feedback loop in the model is: Safety performance→Safety reward→ Individual objective→ Safety work satisfaction → Individual effort → Enterprise security objectives → Safety performance. The main exogenous variables that affect the positive feedback loop are: Enterprise goals, Safety culture, Environment, Reward measures, and Punitive measures. The main negative feedback loop is: Safety performance→ Diminishing incentive effect→ Production accident loss→ Safety performance. The main exogenous variables that affect the negative feedback loop are: Environment Reward measures and Technical equipment. In addition to the simulation of the original model, the effect of exogenous variables on safety performance is studied by changing the initial value of 6

exogenous variables in turn, and the 6 exogenous include these: Enterprise goals, Safety culture, Environmental conditions, Reward measures, Punitive measures and Technical equipment. The simulation is divided into 3 groups

In the first group of simulation, the research obtained the level of safety performance through the SD simulation by increasing the initial value of one of the exogenous variables 1 units, and the initial value of the other exogenous variable remain unchanged. The second group and third group were increased separately by 2 units and 3 units. Comparing the simulation results of the three groups, it is found that the trends of the safety performance are the same. Table 2 shows the average value of safety performance of 72 months.

Table 2: Average value of the safety performance

	Original model	Reward measures	Technical equipment	Environment	Safety culture	Enterprise goals	Punitive measures
First group	49.708	55.365	53.510	55.339	52.764	51.784	49.957
Second group	49.708	62.764	57.311	60.709	55.819	53.860	50.205
Third group	49.708	72.732	61.112	66.601	58.875	55.936	50.454

Second group of simulation was selected for further analysis. The simulation results of the second groups are shown in Table 3, and the change trend of safety performance can be see from Figure 2.

The simulation results of the original model can be seen from Figure 2 and Table 3. The safety performance increased gradually from start to 30th month, it shows that the positive feedback loop plays a leading role in the model, that is, the safety incentive factors in the model play an incentive role

and lead to the growth of enterprise security objectives, which promote the level of safety performance. It reaches the minimum value at 54th month, and then it showns an upward trend to 72th month, but it does not reach the maximum value in 30th months. It shows that the negative feedback loop plays a leading role, that is, the incentive effect of safety incentive is weakened in the model and the loss of production accidents increases, which leads to the decrease of safety performance level.

Table 3: SD results of simulation

Time (month)	0	6	12	18	24	30	36	42	48	54	60	66	72
Original model	10.000	25.321	37.700	49.281	57.518	72.888	55.466	60.588	54.567	35.770	45.541	64.555	71.866
Reward measures	10.000	25.742	40.331	56.215	69.295	94.040	73.439	81.781	74.742	44.477	57.134	85.282	100.014
Technical equipment	10.000	28.324	43.044	56.445	66.068	83.595	64.156	70.102	63.357	42.068	53.208	74.866	83.199
Environ-ment	10.000	29.762	45.612	59.937	70.250	88.910	68.341	74.702	67.557	44.935	56.794	79.845	88.717
Safety culture	10.000	27.706	41.979	55.186	64.615	82.040	62.457	68.305	61.527	40.274	51.350	72.898	81.185
Enterprise goals	10.000	26.918	40.593	53.412	62.523	79.552	60.221	65.889	59.210	38.374	49.199	70.268	78.369
Punitive measures	10.000	25.512	38.046	49.776	58.117	73.686	56.036	61.223	55.123	36.082	45.979	65.239	72.645

It can be known from Figure 2, Table 2 and Table 3 that, with the initial value of the reward measures increases, the safety performance level increased significantly. It shows that the reward

measures are most sensitivities. The safety performance level increases the smallest after increasing the initial value of the punishment measure, and it shows that the punishment measure is

the least sensitive. The safety performance also increases after increasing initial value of the enterprise goals, safety culture, environment and technical equipment. It shows that these incentives can effectively improved safety behavior of coal miners. So the safety incentive effect of variables can be obtained by SD simulation. The sequence according to the effect of the incentive factors is as follows : reward measures, environment , technical equipment, safety culture, enterprise goals and punishment measure.
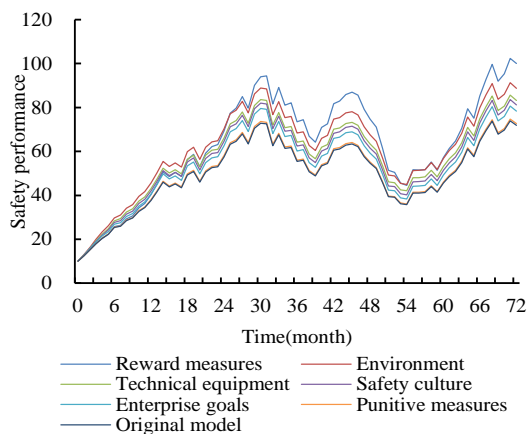

Fig. 2: Trend of simulation result

As it mentioned above, the judgment matrix A passed the sensitivity analysis, and the result is relatively stable after a small perturbation. Accordingly, simulation is made by reducing the weight of compensation rationality, and remaining the ranking of the weight coefficient, the simulation result is shown in Figure 3.
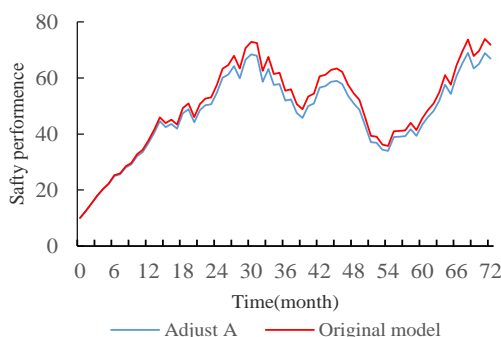

Fig. 3: The simulation results after adjusting weights

It can be seen that the trend of simulation result does not change too much. According to the same method, the simulations are provided after adjusting

other variables, and the trend of simulation result also does not change too much. It shows that the model is stable and the parameters are quite reasonable,and the conclusion is reasonable and credible.

4. SAFETY INCENTIVE STRATEGY OF COAL MINE WORKERS

According to the SD simulation results, the following strategies are put forward to inspire coal miners and to promote their safety behavior

1) To combine material incentive with spiritual incentive. SD simulation results show that reward and other material incentive measures,safety culture, development opportunities, enterprise goals and other spirit incentives can improve the safety performance of enterprises. Therefore, it should be taken to create a good development opportunities for the miners and other measures should be taken to enhance the level of spiritual motivation, and to promote miners safety behavior effectively with the help of the material incentives.

2) To establish a fair and reasonable system of rewards and punishments. Simulation results show that the reward measures to improve the safety performance is the most sensitive, and its incentive effect is more significant than that of punishment measures. Therefore, coal mining enterprises should implement positive reinforcement in the safety management, be cautious to use negative reinforcement, and establish a fair system of rewards and punishments. To give reasonable rewards and punishments to miners

3) To improve coal mine's environment and technical equipment. The simulation result shows that, in the early stage, improving environment can lead to the fastest growing safety performance, technical equipmen also works out. Therefore, coal mining enterprises should improve the environmental and technical equipment of coal mines, so that miners have a safe and comfortable working environment, and miners' enthusiasm for production safety can be improved.

4) To establish a harmonious and effective enterprise safey culture. Enterprise safety culture can make all employees operate voluntarily, avoiding unsafe behaviors. It is initiative technical measure in the enterprise security management, and it should be vigorously promoted in the coal mine enterprise.

5) To establish a reasonable enterprise security objectives. Coal mining enterprises should consider the employee's individual needs, completing ability and enterprise's actual situation , etc, develop a clear and reasonable security goals,and guide the miners complete the security objectives voluntarily and actively

6) Strengthening the pertinence of safety incentive. Because of different characteristics of coal coal enterprises and each employee, safety incentive should be targeted, and different incentive measures should be taken according to different production systems or post, so as to guide the safety behavior of miners.

5. CONCLUSIONS

1) The system dynamics model of safety incentive system for coal miners is established, which can be used to simulate and analyze the safety incentive effectively.

2) SD simulation results of safety incentive model for coal miners show that the effect of reward measures and environment is the most significant. According to the influence to the safety incentives, other measures are in the following order: technical equipment, safety culture, enterprise goals and punishments.

3) The safety incentive strategy for coal miners is put forward, which can provide reference for the establishment of safety incentive system and safety management of coal mining enterprises.

6. ACKNOWLEDGEMENT

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