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Fatal gas accident prevention in coal mine: a perspective from management feedback complexity

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Abstract

In order to reduce fatal gas accidents in coal mines in China so as to lessen miner injuries and economic losses, this paper describes a system analysis of fatal gas accidents in coal mines. From management complexity to system dynamic perspective, causes of fatal gas accident are discussed and the approaches to prevent accident are studied. Time delay and feedback effect of organization safety commitment in the system are simulated. The research shows that the time delay and feedback bring up complexity in the coal mine system. With causing mechanism analysis in the process of incident, the authors provides kinds of suggestions for coal mine administrator in decision-making from system dynamics perspective to preventing the fatal accidents, which is helpful in reducing fatal gas accident of mining industry in China.

Keywords: coal mine; fatal gas accident; feedback complexity; system simulation

1. Introduction

China has become one of the largest coal producer and consumer in the world. The increasing coal production provides amounts of energy for China’s rapid development. As a kind of main energy, coal plays an important role in the energy consumption of China. The coal mine industry makes contributions to China’s economy development. However, the great losses and bad effect induced by fatal accidents in the coal mine production always seems improper in China’s creating a harmony society. China, in particular, has the largest number of coal mining-related deaths in the world. Compared with other main coal producers in the world, China does not work well in the safety management.

Table 1. Mine gas explosion disaster in recent years in China

<table>
<thead>
<tr>
<th>Mine of Province</th>
<th>Time</th>
<th>Death Toll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunlan Mine of Shanxi Province</td>
<td>2.22.2009</td>
<td>74</td>
</tr>
<tr>
<td>Yuanxinyao Mine of Shanxi Province</td>
<td>12.6.2007</td>
<td>105</td>
</tr>
<tr>
<td>Liuguantun Mine of Hebei Province</td>
<td>12.7.2005</td>
<td>108</td>
</tr>
<tr>
<td>Fukang Mine of Xinjiang Province</td>
<td>7.11.2005</td>
<td>83</td>
</tr>
<tr>
<td>Sunjiawan Mine of Liaoning Province</td>
<td>2.14.2005</td>
<td>214</td>
</tr>
<tr>
<td>Xishui Mine of Shanxi Province</td>
<td>3.19.2005</td>
<td>72</td>
</tr>
<tr>
<td>Chenjiaxian Mine of Shanxi Province</td>
<td>11.28.2004</td>
<td>166</td>
</tr>
</tbody>
</table>

Table 1 shows part of the death toll of fatal coal mine gas explosion accidents in China in recent years. The frequent accidents in the coal mine industry attribute to the natural conditions and coal production condition and safety management level. On the one hand, the geology conditions of coal mines in China are much complicated and most of them contain methane in the mining

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seams. On the other hand, the property of the coal mine in China is various. And the supervision seems not effective. However, the low administration level is considered the main reason for the frequent accidents.

According to the systematic theory, the factors in the system are connected and affected with each other. The occurrence of an event will induce series of reactions. In the coal mine production activities, the supervisors always try to reduce the number of accidents by controlling the initial event that can trigger accidents. The single cause orient perspective and methodologies are emphasized instead of system cause in accident analysis. In the official report of most coal mine accidents in China, the worker’s violation behaviours and worse ventilation management and management confusion appeared frequently. What is the mechanism behind these and why does it do? This paper will give some system analyses with a system dynamics simulation.

2. Related literature

Unlike preliminary researches who focus on the study of single factor or casual event analysis to the accident, current work stressed more on the system complex casual study. Recent researches like systemic views of risk and accident causation viewed accidents as emergent phenomena that arise from the variability of organizational, group and individual performance, with roots in processes at each of those levels. In all of these approaches to study accident cause, the need to consider the role of human and organizational error is clear [1-3]. For example, studies have found that the most important factor in the occurrence of accidents is management commitment to safety and the basic safety culture in the organization [2].

Other researchers (e.g. Cooke, 2004 and Leveson, 2004) have used the System Dynamics approach to describe the dynamics of organizations. For example, Cooke (2004) developed a system dynamics model of the Westray mine disaster. In his causal loop model of the accident, the interactions between safety and non-safety factors (e.g. productivity) are presented. Another example of utilizing the System Dynamics approach for safety is the Systems Theoretic Accident Model and Processes (STAMP), developed by Leveson [4]. Based on STAMP, safety can be shown as a control problem and managed by a control structure developed for a socio-technical system. Accidents can be studied using this model, identifying which safety constraints were ignored or violated and why the controls imposed were insufficient. Yu et al. (2004) also use a system dynamics approach to assess the effects of organizational factors on nuclear power plant safety [5]. On the basis of these research works, with organizational management and personal safety commitment analysis, this paper involved gas explosion related factors in the whole system which included gas concentration, ventilation and temperature fire source to give a simulation of coal mine system.

3. Research boundary and method

A coal mine system seems to be a more dangerous place with its safety affected not only by complex geologic structure, methane and coal dust, rock burst and groundwater but also by mining machines faults and miners’ unsafe behaviors. Furthermore, the coal and methane outburst actually is a complex physical phenomenon which still is not understood and mastered completely. The complexity of the system brings up the variability of the coal mine system safety. In China, the coal mining industry was held as the most dangerous department. Nevertheless, most of the gas accidents can be avoided or reduced with proper approaches.

The research boundary is a coal mine site and the time boundary will be one year. The coal mine system includes supervisors, miners, the machines, production environment and other related factors. It is assumed that the number of miner is constant and there is no significant affect event which would change the system safety from the outside of the coal mine system.

There are kinds of hazards in the mine production process. The variations of these hazards are not only affected by their physical characteristics but also by the miner’s behaviors. This paper focuses on the organization behavior factor and unsafe behavior of miners according to the importance of the factors in the system. The simulation time is 52 weeks (one year) in the model.

System dynamics is a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems. It is an approach to understanding the behaviors of complex systems over time. What makes using system dynamics different from other approaches to studying complex systems is the use of feedback loops and stocks and flows. These elements help describe how even seemingly simple systems display baffling nonlinearity [6].

4. Simulation and analysis

4.1. Model construction and analysis

Coal mine system is a complex socio-technical system that includes the physical facilities, the social interactions of the people involved, the information system, and so on. Both the effects from outside and the disturbance from inside may induce an accident by events chain. One task of the safety management is to prevent it to avoid the accident [7]. Mainly, the immediate causes of coal mine accidents are unsafe behavior and unsafe conditions of machines and environment in the production activities. The gas (Methane) explosion accident depends on the methane viscosity, high temperature fire source and plenty of oxygen. Methane is likely to explode between its lower explosive limit of 5% by volume and its upper explosive limit of 16% by volume. There is always plenty of oxygen in the underground mine. So the methane and the fire source become the key factors. In this paper, we assumed the initial value of gas concentration factor as 0 in the beginning of simulation.
According to the mechanism of gas accident and the process of mine production, the system dynamic model was constructed after analyzing the system and the related factors. With system dynamics modeling approaches, the feedback and the formulation were analyzed and built [8]. The coal mine safety dynamic system is modeled by using feedback (causal) loops, stock and flows (levels and rates), and the non-linear flows created by interactions among system components. In the view of system dynamics, behaviors over time can be explained by the interaction of positive and negative feedback loops. The models are constructed from three basic building blocks: positive feedback or reinforcing loops, negative feedback or balancing loops, and delays. Positive loops (called reinforcing loops) are self-reinforcing while negative loops tend to counteract change. Delays introduce potential instability into the whole system [9-10].

The incidents causes of the coal mine are affected not only by physical factors but also by human behaviors in the working activities and the interaction between these factors. Among the hazardous factors, the human related is the main reason that affected the system safety just as in the current literatures [11-13]. As in practice, the safety of a coal mine system is attributed to the organization’s management commitment to safety. The miners also have their personal commitment to safety. The personal commitment to safety of a coal mine can be seen as an emergence of miner’s personal commitments and behaviors. With system dynamics modeling method, the system dynamics model of a coal mine was constructed as Fig. 1. by the system dynamic modeling software Vensim PLE version 5.4.

As shown in Fig. 1, the stock of management commitment to safety increases by a rate variable, the change in management commitment to safety with a feedback loop. The change in management commitment to safety decreases by time to change management commitment and target management commitment to safety. Target management commitment to safety increases by maximum management commitment to safety and pressure to change management commitment to safety. The miners’ personal commitment to safety responds to pressure from management commitment to safety, their relative experience, and so on. In the model, the gas concentration factor was constructed because the gas concentration in the real system was more difficult to illustrate, as well as temperature fire source factor. In the model, the gas explosion mechanism was constructed in a simple way according to the gas accident mechanism. The occurrence of gas accident was affected by gas concentration and high temperature fire source, which were also affected by human behavior.

In the system dynamic simulation model, the initial simulation time is 0 week; the final time is the 52 week. The time step is one week. For this is a simulation, we substituted the accident as incident in this paper. The organization and the miners both have their commitment to safety, includes normal commitment to safety and maximum commitment to safety. The value of normal commitment to safety of management and miners were both set to 80% and the maximum value were set to 120%. The unit for average incident rate is incidents per week. The equations and initial value of other variables were all assigned before running the simulation.

It is known from the stock and flow chart in Fig. 1 that there is no initial event in the safety system. All the events in the system are connected with other events in chains. Most researches considered human as the key element in the safety management and some psychological and behavior experiment were done on it. In this study, we stress more analysis on the react between mines and the management. The natural hazards like gas outburst and rock burst are correlated with the geological structure of the coal mine. It is difficult to describe the occurrence of them even in the engineering.
4.2. Simulation result discussion

After running the simulation, the result of each variable can be obtained from the software output. All the variables can be calculated in the simulation time. The average incident rate of simulation period was obtained from the software in Fig. 2. As shown in Fig. 2, the average incident rate rose gradually in first half phase and declined in the second phase, which means in the start of the coal mining production, the incident rate was low and rose gradually. With the tunneling of the coal mine, more gas concentration appeared, incident rate may rise without proper control measures. According to the Iceberg theory of accidents, the rise of minor accidents may be the premonitory warning of fatal gas accidents. In this situation, the supervisors should take measures to control the gas concentration and unsafe behavior of miners otherwise more losses and injuries may occur. Actually, the rising incident rate would bring more pressure on safety management and the qualified supervisors would take actions to resolve the problem for there is a negative feedback loop.

![Fig. 2. Average incident rate](image1)

![Fig. 3. Management commitment to safety with personal commitment to safety](image2)

A major determinant of the commitment to safety is miner’s personal commitment and behaviors. The level of both supervisors and miners’ personal commitment to safety may fluctuate. Time is needed for supervisors and miners to change the safety commitment and then influence their behaviors. Actually, all the decisions have time delay in practice. This means current management measures will work in the future time. For example, the management commitment to safety of the coal mine had a delay effect on the personal commitment to safety in Fig. 3. Besides, the personal commitment seems have more fluctuation compares with management commitment to safety. That’s because personal decision has low cost and high effectiveness. Also it means that a small change in management commitment to safety may bring up greater fluctuation on personal commitment to safety. Because management commitment can manifest itself through job training programs, management participation in safety committees, consideration of safety in job design, and review of the pace of work. For example, people working for a supervisor that never mentions safety perceives that safety is unimportant; as a result, they will not place a strong emphasis on safety (Hofmann & Stetzer, 1996) [14]. Therefore, the management commitment and measures should be persistent to achieve a better safety level.

It is shown that a small change of management commitment to safety will bring bigger reaction to average incident rate in the same direction, either rise and fall. And this reaction has been delayed in the time. As to the supervisors of a coal mine, it is import from them to realize that time delay effect and the fluctuation of personal commitment to safety in decision making process. Lower management commitment to safety, lower safety compliance, and lack of emergency management, poor communication and coordination are always appear in lots of accidents in China. The simulation results showed that the personal commitment to safety goes by the obvious opposite direction to average incident rate, which means that a coal mine’s safety is directly affected by the miners’ commitment to safety and their behaviors. The miners are the main body of the safety target. Therefore, the physiological and mental state of the miners should be cared in the organization. A little looseness in management commitment may become a bad signal for miners to reduce their personal commitment to safety. So it is an important method to increase the coal mine’s safety by keeping a high management commitment to safety. Also there should be measures on miners to reduce their unsafe behaviors. Such measures by management reflect personal commitment and involvement, which in turn appears to influence miner’s behavior. Therefore, it is important for an organization to lead a high management commitment to safety.

![Fig. 4. Average incident rate with management commitment to safety](image3)
The average incident rate is a sign of the coal mine safety level. The management commitment was the dominant factor in the system, which is the function of the time to change management commitment and target management to safety. In the long run, the safety level of the system will rise and fall around its equinoctial level. In this research, the time to change management commitment was discussed in the system dynamic model sensitivity analysis. In the model simulation, the time to change management commitment was assigned value of 13 weeks, 10 weeks, 7 weeks, 4 weeks, 3 weeks, 2 weeks, 1 week orderly for each running. The simulation results were showed in Fig. 4. It is shown that the average incident rate of the coal mine increased and cycle of fluctuation become shorter, which is harmful to the safety management of a coal mine. Good safety management policy or system is one that emphasizes not only effective but also consistent. That means in practical safety management the persistency of safety policy and system is much more important.

The simulation results suggest that the coal mine average incident rate shows more sensitivity to the time to change management commitment to safety. Therefore, in the practice safety management, the supervisors should keep the consistency of the management commitment to safety in the coal mine safety management system completely, increasing the miner’s personal commitment to safety to reduce their unsafe behaviors and setting up the long effect mechanism against hazardous factors.

5. Conclusion

The simulation model in this paper is just a coal mine system focus on safety which mentions less on other coal mine operation factors. However, the model and simulation results in this paper are meaningful to China’s coal mine’s safety management. It is concluded that the time delay and feedback effect should be considered in the coal mine safety decision making. The management commitment to safety should not be changed frequently and a consistent management commitment to safety is needed. The miners should be seen as the main body of coal mine safety. The average incident rate reflects the safety level of the system and highly correlated with the management commitment to safety. And the supervisors should pay more attention on it to prevent fatal gas accidents. Management commitment and leadership can make a difference in achieving sustainable results in coal mine accident prevention by enhance the coal mine safety management level.

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