A Logical Model and Simulation of Production System Accident-causing Mechanism

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ABSTRACT: *Human, machine, environment, management are the most important fur factors in the Accident-causing mechanism, and this idea has been accepted by all of us. But the relationship of the four factors, that is how the four factors mutual influence and lead to accidents, is not very clear. This will lead to difficulty in generating calculation model. This study considers these four factors in the accident formation process are not in a hierarchy. Human, machine and environment are accident triggered and in the basic layer, management belongs to the second level. Based on this idea, this paper establishes a logic calculation model for the accident-causing mechanism, and the status simulation method is used to calculate the model. The simulation results show that, the model for mechanism is explained more clearly on the accident. According to the model and simulation results, some measures controlling accidents are put forward at last.*

Keywords : Accident-causing Mechanism, Production system, Safety model, Status Simulation, Logic model

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1. Introduction

Production safety is one of important problems that the industry engineering concentrates on. Accident-causing mechanism [1,2] is a mechanism model which is summarized from many typical accidents. These mechanisms reflect the law of incidents, and provide theoretical proofs to instruct the improvement of practical security work. Accidents analyses demonstrate that incidents always happened with comprehensive factors. But the existing accident-causing theories [3-15] have not thorough mechanism to explain how the dangerous factors influence each other. The literature [10,11,14] researched typical accident-causing theories include Heinrich's accident-causing chain theory, Management error theory, Energy accidental release theory, Mainly due to human error accident model, Two kinds of hazard theory, Orbit intersecting theory and Reason's complex system accident-causing model. The weakness of the viewpoints was point out and criticized.

Accidents-causing theory problem plagued me for long term in the research of coal mine accident prevention system [16,17]. After analyzing many cases, I developed this view: In accordance with the composition of production system to distinguish human, machine, environment and management factors are not on one level. Human, machine, environment factors are must factors in the production system, but management factor is not. The management factor is organizational factor in the production system. Management is not in the same level as the other three factors. Management factor is an important cause of production accidents rather than direct cause. Based on this idea, the influence of human, machines, environment and management factors on the system is researched in this paper, and a model is established systematically. Logic unit structure is adopts to simulate the various risk factors' composite state. The simulation results show that model can better explains the system's accident occurrence mechanism. According to this model, the author puts forward the production system's accident control method.

2. The Complex Man-Machine-Environment System Accident Model

The analysis of lots accident shows that the complex human-machine- environment system accidents has following characteristics:

1. Potentiality and Necessity: Accidents often happen suddenly, and the factors that leading to the accidents, so-called "hidden danger" or potential risk has already existed. So it is reason that security risks are due to the system's imperfection, which is embedded in the system properties. Hidden danger will emerge and cause an accident with the passage of time.

2. Randomness and Contingency: The complex system is developing in a turbulent and chaotic environment. The final output status of the system is shown as random events depending on the initial condition.

3. Causality and Correlation: The accidents in complex system perform as the results of many factors continually causing and affecting each other, it performs a coupling relationship rather than an individual effect on the system, such as suppress and promote each other.

2.1 Machines and Environment Factors: Machines and environment factors belong to material factors in the system. The machine design is not perfect due to various factors. Moreover, with the evolution of system, machine in use will produce new hidden accident danger for its maintenance and designed lifetime. Environment is another important "material" factor, especially for some system that directly changes natural environment such as mining industry. Complex transform of time and space lead the environment become a dynamic and important hazard. It should be noted that without the human factor involved, material factors cannot constitute a system and the accident won't happen.

2.2 Human Factors: The human factor is the important part in the accident-causing theory. Early accident-causing theory involved people but tended to make uniform analysis about it. In the massive accident analysis process, we find that the people in the complex production system can be divided into two kinds: one is the concrete producer, or operators, they are the main force in producing, and having direct interaction with machines and environment. These men are the major factor leading to accident and then straightly suffer from it. Such personnel's influence on the accident finally performs in their reactions and executions. Another one is the manager. The manager's task is to manage and supervise operators, machine and environment, their abilities impact on the occurrence of accident significantly. It is more suitable to classify their behavior and effect as management factor when we study them. In this paper, the human mentioned without explanation refers to the operators only.

Surry-Anderson model points out that if human are able to identify dangers in the circumstances and correctly take corresponding measures, the danger will be controlled or be extinct, on the contrary, the danger will become impending or even be an accident that cause injury. Research based on human cognitive and behavior also suggests that difference in individual people can affect the accidents. Different individual, in the circumstances with hidden danger, will lead to different results, cause an accident or avoid it. People with highly sense of dangers can adopt preventive measures to avoid accidents. Furthermore, individual difference in observation, knowledge, understanding of machine and environment, and the ability of handing emergency, play a decisive role in occurrence. In the study, the author finds that the individual difference among operators are due to the inherent differences in character, psychological quality, physical trait, perception and comprehension. In Accident Tendency theory, the people who tend to cause accident are the ones that can't meet the system's needs very well in the inherent aspects. Meanwhile, the same operator will show different abilities in dealing with accidents, which depends on health condition, emotion and social random events during different time. So, it will be clearer to divide the research into two parts, inherent character and timely condition.

2.3 Management Factors: Management factors are particular factors in human-machine-environment system. Heinrich's Accident-causing Theory argues that management factors play an important part in causing accidents. Bird's Accident-causing Sequence Theory and Edward Adams's Accident-causing Chain Theory consider that management factors are the root of accidents. The accident model of the Orbit-intersecting Theory tends to take accidents as the result of human's action interacting with machine defect in management. But, the interaction of people with material is the necessary requirement for the production system, it is not proper to consider management factors lead the interaction. Management is essentially an organizational technology, but not the necessary elements for production system. Operators, equipment and environment, the three constitu tive give the system certain ability in production.

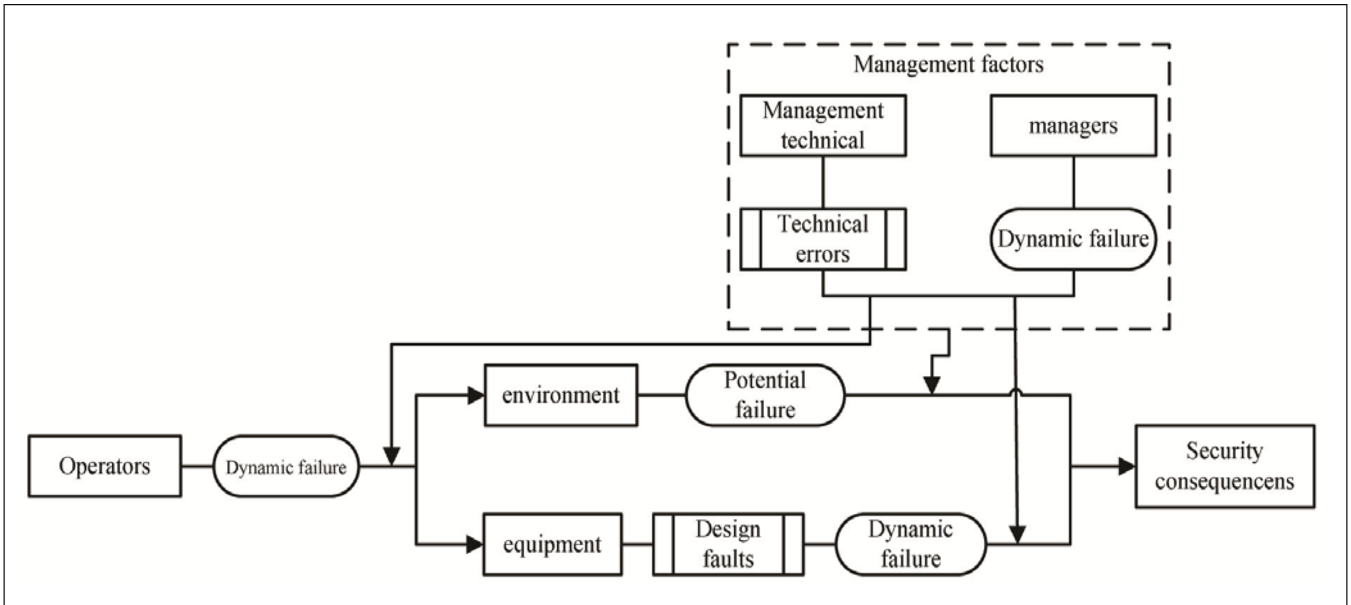

Figure 1. Production System Accident-causing Model

Combined with system theory, we think that management factors are actually the control unit of the system, the significance of which is to avoid accidents and make the system execute designed functions better. Management factors work on the original system by designing management technique and implement. Like human and machines factor, management factor is flawed, which is the important reason that the accidents cannot be totally avoided. According to the above analysis, the complex production system's accident-causing model is established as Fig.1.

3. Model Stimulation and Analysis

Define U_s as the system's output status. According to the above analysis, U_s's status is decided by the following equations:

$$\begin{cases} U_S = (U_H \otimes U_{Mh}) \otimes [(U_D \otimes U_{Md}) \oplus (U_E \otimes U_{Me})] & (1) \\ U_H = U_{Hi}(x_1, x_2, \cdots x_m) \otimes U_{Ht}(y_1, y_2, \cdots y_n) & (2) \\ U_D = f(m_1, m_2, \cdots, m_q, t) & (3) \\ U_E = f(n_1, n_2, \cdots n_p, t) & (4) \end{cases}$$

In the above equations: U_H, U_D and U_E represent the status of human, machines or device, and environment, U_{Mh}, U_{Md} and U_{Me} respectively mean the management factor of human, device and environment. U_{Hi} represents the inherent characteristics of the operators, while U_{Ht} represents timely status of the operators. x, y, m and n respectively are the influence factors of various status. $\otimes$ and $\oplus$ are the generalized coupling operator.

In the process of the system operation, represents two statuses that causing or avoiding accidents. Define "0" as the status causing accident and "1" as the avoiding accident status. The system's actual coupling operator is of great complexity. In order to meet the needs of this study, this paper use logical operator to simplify them on the basis of the system operation rules.

3.1 Simulation of Self-Organizing Condition System

The system without management factors is called the self-organized status production system. According to accident- causing model equations, we can establish self-organizing production system model (see Fig. 2). Fig. 3 gives the model's simulation result.

From the simulation true value table, we can see that the system under the self-organizing condition can finish certain production functions ,but this status may cause accidents at the probability of 9/16.That is to say, in the self-organizing condition, the probability of causing an accident is even higher than the random events of flipping a coin. From the simulation true table, we can also know that the security of the self-organizing condition system depends largely on the security of the operators. When there is 0 in the U_{Hi} channel and U_{Ht} channel, named when the inherent characteristic or real time performance has default, only both the U_D channel and the U_E channel display "1", named to ensure the environment and the machine in the security state, can ensure the safety of the system. In the system when U_H is defective, the probability of an accident is up to 75%. This figure is greatly close to the documentary statistics data for mining human error data, which not only shows that human plays important role in the system, but also shows a big deficient in the safety quality of China's coal miners and the safety management Meanwhile, the last four status in the simulation table illustrates that when the safety of operators themselves is very high, will help effectively control of the system.

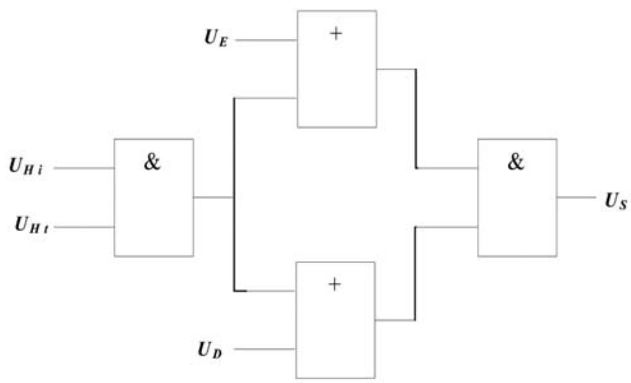

Figure 2 .The Production System Model in Self-organization Condition

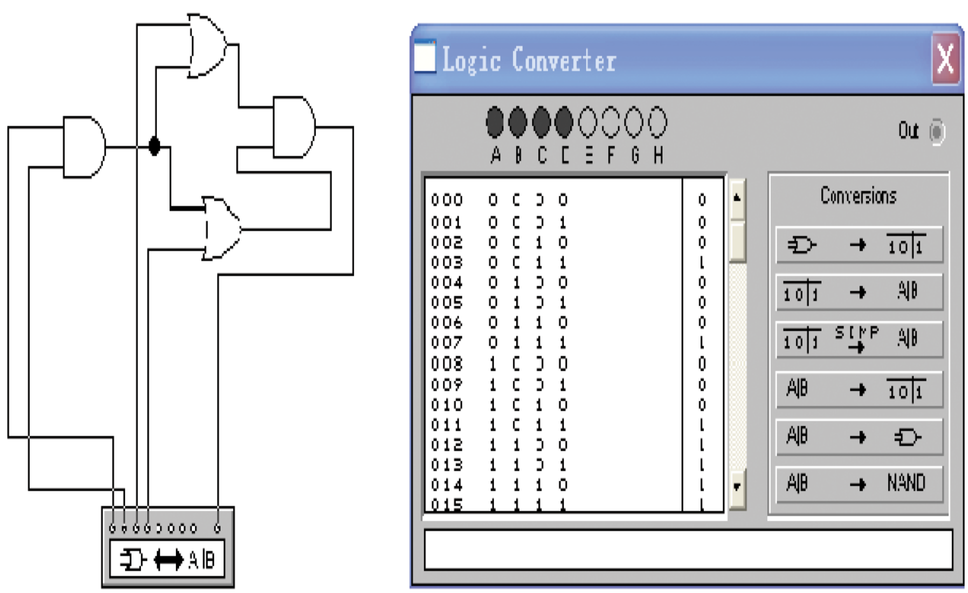

Figure 3. The Simulation Results of Self-organization Condition System

3.2 Simulation of System Introducing Management Control

In the natural condition, the safety status probability of operators can reach is only 25%, and the actual one may even lower. In order to improve security of system, the management factor must be introduced to control operator's insecurity status. With the implement of correct and effective management, the security of the operators subsystem will get guaranteed, the security will increase to 62.5%.Similarly, for environment and equipment, we introduce management factor to monitor and inspect the hidden trouble behind them, and take the corresponding preventive measures (Fig.4).

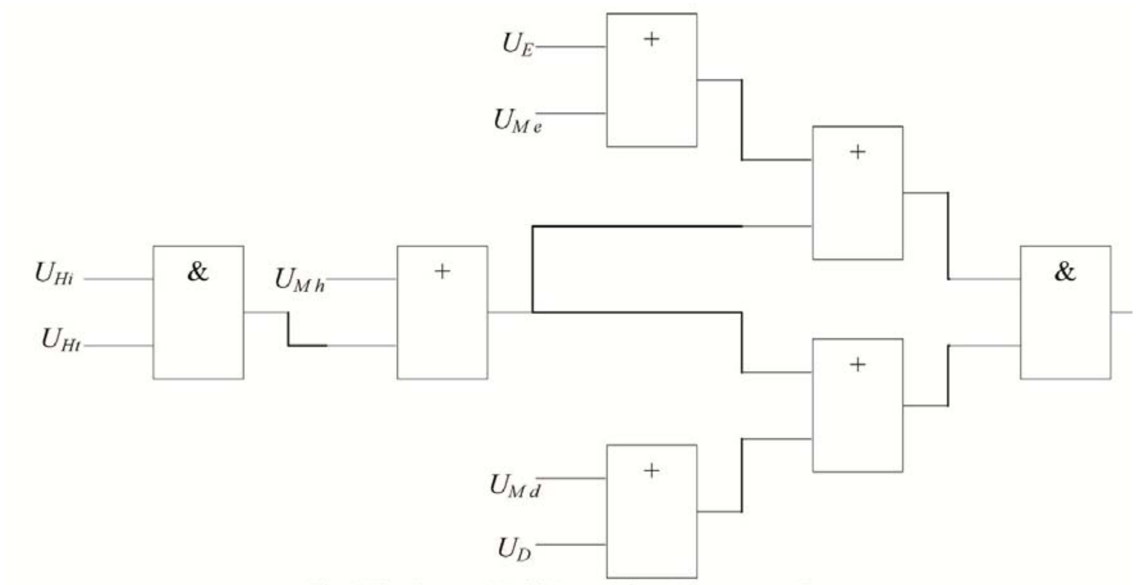

Figure 4. The System Model Introducing Management Factor

From the logical structure can be seen, the simulation results of Fig.4 show that this model can produce 128 combinations status, among which 21 may lead to an accident and 107 statuses will be not. That is to say, the status leading to an accident accounts for 16.4%.The security of the system has greatly improvement compared to the self-organization condition system.

3.3 The Accident-causing Mechanism Analysis Introducing of Management Factors

The table 1 shows the causing accident status of model introducing Management Factor. From table 1, we can see that the causing accident status of system all appeared in the operator with security defective and lacking of correct and effective management. Meanwhile, between machine and environment factors, there is at least one factor which is in unsafe status and lacking of correct and effective management.

We use the true value "1" to deform the system model showed in the Fig. 4. So the system status can be expressed as below.

$$U_S = (U_{Hi} * U_{Ht}) + (U_E * U_D) + (U_E * U_{Md}) + (U_D * U_{Me}) + (U_{Me} * U_{Md}) + U_{Mh} \tag{5}$$

It is clear that to make the system in the safety status in which system's output shows"1", either the operator or the machine and the environment has high security, or using the management means shields another unsafe factor or operator under the status of guaranteeing environment or machine factor in the security condition, all of these can provide a new way for us in the system's security control.

Combination of the above analysis, we can draw the following conclusions:

1. Management Factor is the Most Important Factor to Inhibit the System Accidents in Production System: The effective management of human, machines and environment in the original production system may largely guarantee the security of the system. Conversely, management confusion or management absence will make the original security risk of the system losing protection barrier, so that accident rate will increase greatly.

2. The Operator's Reliability has Big Influence on the Security of System: As the security of operators is decided by inherent character and timely status, therefore, we can manage operators from the following several aspects: a) Design corresponding professional suitability personnel selection system to reject operators whose inherent characteristics do not conform to works. b) Establish mechanism to identify operator's bad timely state. c) Play great emphasis on the training mechanism of operator. Group activities organization can be used to enhance security of the operators.

No.	System of its own state				Management status			U_S
	U_{Hi}	U_{Ht}	U_D	U_E	U_{Mh}	U_{Md}	U_{Me}	
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	1	0	0
3	0	0	0	1	0	0	0	0
4	0	0	0	1	0	1	0	0
5	0	0	0	0	0	0	1	0
6	0	0	1	0	0	0	0	0
7	0	0	1	0	0	0	1	0
8	0	1	0	0	0	0	0	0
9	0	1	0	0	0	1	0	0
10	0	1	0	1	0	0	0	0
11	0	1	0	1	0	1	0	0
12	0	1	0	0	0	0	1	0
13	0	1	1	0	0	0	0	0
14	0	1	1	0	0	0	1	0
15	1	0	0	0	0	0	0	0
16	1	0	0	0	0	1	0	0
17	1	0	0	1	0	0	0	0
18	1	0	0	1	0	1	0	0
19	1	0	0	0	0	0	1	0
20	1	0	1	0	0	0	0	0
21	1	0	1	0	0	0	1	0

Table 1. System State of Causing Accident

3. Machine and Environment is the Dangerous Source in System. More attention should be paid on the management of machines and environment. We should take seriously of the machine design defect, the daily maintenance and working status's inspection. For environment, the important thing is the dynamic monitoring work. This will help to control the system's bad status in time.

4. Comparative Study With Other Accident Causing Theory

The comparison of this accident-causing model with others, we can more clearly see the advantages of the model.

• **Comparison With Accident Chain Model:** The accident chain model is the classical theory of the accident causing model. Representative of these model include Heinrich accident causing model, Boulder accident causal chain theory and Adams's accident causal chain theory. Literature [10,11,14] pointed out, the contribution of Heinrich's Domino theory is established the important concept of accident cause "chain of events" firstly, but it describes the cause of the accident chain relationship too absolute and simple. The fact is, in front of the dominoes fell, the behind may fall, may not fall. This new model is clearly explained this concept. As can be seen from the calculation, the system may still be safe when there are defects in factors. The new model can explain the fact better.

Bode accident causal chain theory and Adams's accident causal chain theory suggests that effective control of unsafe behavior and machines can avoid the occurrence of accidents; This theory emphasizes the importance of management factors.

Literature [10,11,14]point out The limitations of the theory lies in that it neglect the role of equipment in the cause of the accident, without considering the operator personal factors, such as negligence, omissions and errors, and exaggerated the role of management. In the new model, the conclusion which management factor is the most important factor to inhibit the system accidents can be drawn also. And the role of human, the environment and equipment are included.

• **Comparison With Accidental Energy Release Model:** The accidental energy release is based on the view of accidental energy transfer Leads to accidents. This method has the superiority in the classification theory of casualty statistics. However, it is difficult to be applied for Immeasurability. The new model can calculate the system state by logic operation.

• **Comparison with Human Cognitive Reliability (HCR) Model:** Literature [10, 11,14] pointed out general human error model, such as Thurley model, Haier model, Vigrissr Wirth and Laurence models, have put more emphasis on human error, and Ignore safe physical conditions in systems. The dialectical relationship between people and objects are not clear analysis. The model in this paper also pay attention to the safety of human, the environment and equipment, and it can get the conclusion that safe environment and equipment can also guarantee the system safe.

• **Comparison with the Track Crossing Accident Theory:** Track crossing accident theory thought that prevent accidents should avoid cross subjects and objects in dangers, which is inconsistent with the actual production. Therefore the theory cannot effectively guide the prevention accident in enterprise. The new model indicates that the cross is necessary relations of production system, The accident prevention measures may also be derived from this model.

• **Comparison with the Complex Causal Accident Model:** Complex system causal model of Reason consider the organization errors is mismanagement, the concept of this definition makes management errors (such as how are mistakes form, how to act on the system) more complicated.

In this model, the management mistakes will focus on the supervision and management of human and material, mainly to undertake monitoring and blocking dangerous in system, which has more clear definition of management.

From the above discussion can be seen that the new model has integrate and optimize the original model, so the new model has more advantages in guiding the accident prevention.

5. Conclusions

Accident-causing theory is the basic theory to conduct work safety. Based on the existing accident-causing theories and ideas, this paper has re-examined the influence of man, machines, environment and management factors in a systemic view, and a model has re-constructed to explain the production accident.

(1) The new model redefines the dialectical relationship between the four factors (human, machine, environment and management) influencing the accident, presents the accident causing levels. That is, the human, machine and environment are the direct causes of production accidents, which is in the basic layer of accident triggered. The management factor is not a direct factor of causing accident, which is in the control layer. But management factors are important factors to prevent the production system of accident. Management factors can make the system reliability enhance greatly.

(2) This model can be used to make simulation and calculation by logical means, which provides convenience for the analysis of system fault state. The simulation results also provide a way for establishing accidents prevention system. There are 6 ways can be found from equation (5).

1. Qualified personnel (workers) can be used to ensure the system security.

2. Using technical reform to eliminate the hidden dangerous source in environment and mechanical while ensure the system security.

3. Increasing the mechanical supervision when environmental hazard sources are little danger also can achieve the objective of system safety.

4. Strengthen the supervision and management of environmental risk source in the case of small mechanical hazards.

5. Strengthen the supervision and management of environmental and mechanical danger at the same time.

6. Strengthen the supervision and management of operational staff. Compared with other models can be seen, the model can interpret the mechanism of system accident better, which has more advantages in analysis of accident causing problems.

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