Analyzing chemical accident based on six-hierarchy accident analysis model

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Abstract. This paper briefly reviews the limitations of traditional accident analysis methods used in complex technical system accidents. By constructing the six-hierarchy accident analysis model, the accident causal factors are divided into two parts: the social system and the technical system, and the two parts subdivided into six hierarchies. By analyzing the communication and the control between the various hierarchies, the accident analysis steps of the complex social technology system based on the six-hierarchy accident analysis model are established to discover the deep-seated causes of the accident.

1. Introduction

Currently, the most common accident analysis model decomposes an accident into multiple event sequences that change over time, which typically include several types of component failures, human failures, and events associated with energy release. For simple accidents we can find out the incident chain of accidents based on the accident causation chain, and take protective barrier to cut off the event chain, which play a role in preventing accidents. However, with the progress of science and technology, modern production systems become more complicated and systematic. Society, organization, personnel and other factors merged with the modern production system gradually, thus forming a complex social technology system, such as: chemical plants, nuclear power plants and railway operating systems.

Accidents of the complex social technology system are different from accidents of the traditional mechanical system. Although components of complex social technology system meet performance requirements, it is still possible to have a security incident. In other words, although components of the system operate reliably, interaction between components may also make the system into a dangerous state [1]. Hierarchies of the organization can interpret the model of the complex social technology system. Each hierarchy imposes constraints on its lower hierarchy, thereby achieving the effect of controlling the lower hierarchy. In this paper, the six-hierarchy accident analysis model is established under the premise of considering the system theory, and the accident analysis of a chemical accident is carried out.

2. Six-hierarchy accident analysis model

2.1. The establishment of the model

This paper puts forward a six-hierarchy accident analysis model under the premise of considering social factors and organizational factors. The model divides accident causes into six hierarchies, i.e., behavior restriction, job control, safety supervision, company culture, industry supervision and safety
laws, as shown in Figure 1. These factors correspond to the social system and technical system of complex social technology system. The corresponding result is presented in Table 1.

![Figure 1. Six-hierarchy accident analysis model](image)

| Types of complex social technology systems | Factors of six hierarchies                          |
|-------------------------------------------|---------------------------------------------------|
| social systems                            | safety laws and industry supervision              |
| technical systems                         | company culture, safety supervision, job control, and behavior restriction |

In the process of running the system, the higher hierarchy imposes constraints on the lower hierarchy, thereby achieving safe operation of the system. The process of accident analysis is from the lower hierarchy to the higher hierarchy step by step, and accident causes of each hierarchy and the control failure between hierarchies are found. As can be seen from Fig. 1, safety laws and industry supervision are at the top of the model, which are the root causes of accidents. Company culture and safety supervision are located in the middle of the model, which are the indirect causes of accidents. Job control and behavior restriction are at the bottom of the model, which are the direct causes of accidents. In the current accident analysis, the analysis of technical system hierarchy is more, the analysis of social system hierarchy is less. However, the social system factors are also important to prevent accident in the complex social technology system. The study of social system factors can help to identify weak links in the system, so as to prevent accidents effectively.

2.2. Interlayer connection

Through the step-by-step analysis of the system, interlayer connection and control are particularly important. It needs to establish the interlayer connection channels in the structure of the system safety control, including reference channels and measurement channels [5]. The reference channel is a kind of downward channel, whose the higher hierarchy provides the lower hierarchy with safe constraint instructions and information. The measurement channel is a kind of upward channel, whose the lower hierarchy provides the higher hierarchy with feedback information. These channels are presented in Figure 2.

[Diagram of interlayer connection channels]
2.3. Interlayer control

It's necessary to understand the control process between the different hierarchies in applying the six-hierarchy accident analysis model. Constraints and feedbacks between different levels maintain its dynamic balance. The higher hierarchy receives the feedback information of the lower hierarchy by controller, and determines whether needs to take corrective actions. The lower hierarchy accepts the control instructions of the higher hierarchy to meet the safety requirements of the higher hierarchy. In the production process, the controller can be either a manual controller or an automatic controller. Both of them can determine which control behavior is required by understanding the state of the current controlled process, and estimate the impact of different controls on the current state. The typical control process is presented in Figure 3.

3. Steps of analyzing accidents with six-hierarchy accident analysis model

3.1. Creating event chain

The event chain can describe the entire physical process of the accident and identify the basic information related to the accident. Although the information can’t reflect the deep cause of the accident, they are the basis of the accident analysis. The event chain is often a timeline based on the time and logical relationship of the accident, which express the physical process of the accident.

3.2. Defining systems and hazards related to the accident

When analyzing an accident, it needs to define the system accident according to the specific event. There is no specific standard for the definition and classification. It often requires subjective judgment through the actual situation and experts in the field. For example, in the case of a chemical raw
material leakage accident, the various production systems in the plant are defined as a system. And residents around the plant, that is, public health are defined as a system. After the system is defined, it is possible to identify the hazards and put forward relevant security constraints.

3.3. Analyzing the physical process of the accident

After establishing the event chain and defining the system, it is possible to analyze the physical process of the accident and identify the running status of the controller, then analyze the physical failure of the system and abnormal communication to determine the direct cause of the accident.

3.4. Analyzing factors of each hierarchies and the control structure between hierarchies

After determining the direct cause of the accident, reasons of the accident are determined step by step according to the six-hierarchy accident analysis model. Its purpose is to find out what factors led to the physical failure of the system, then understand behaviors of various hierarchies in the social technology system safety control structure and control errors of various hierarchies.

4. Case analysis of chemical accident

In order to illustrate the application of the six-hierarchy accident analysis model, this paper analyzes Binyuan “8·31” serious explosion accident in Dongying city, Shandong Province and determine the accident causes of each hierarchies [6].

4.1. Brief process of the accident
The workshop workers discharged dinitrobenzene materials of the nitrification re-separator to the ground. Dinitrobenzene was discharged from high to the first floor in the condition of the presence of such strong oxidants as sulfuric acid, nitric acid and nitrogen dioxide, and then they burned under the impact force. The fire baked nearby the nitrification machine, pre-washer and other equipment, whose dinitrobenzene materials temperature rose and exploded. The accident eventually led to 13 deaths, 25 people were injured, and the direct economic loss was 43.26 million yuan.

4.2. Event chain of the accident
(1) On August 28th, 2015, the chairman of the company approved the nitrification device to take the feeding test.

(2) From 15:00 on August 28th to 24:00 on August 29th, the nitrification device took the feeding test, its temperature fluctuated greatly due to failure in the nitrification machine temperature control system, instability in the cooling water control and failure in the valve control. Eventually it run unstable and stopped.

(3) 16:38 on August 31st, the company organized to feed once again.

(4) From 16:47 to 22:45 on August 31st, temperature of the 5# nitrification machine fluctuated greatly, and up to 95 ℃. (The normal temperature is 60-80℃.)

(5) From 21:27 to 22:45 on August 31st, temperature of the 4# nitrification machine fluctuated greatly, and up to 96 ℃. (The normal temperature is 60-70℃.)

(6) The workers used industrial water to water the shell of the 4 # and 5 # nitrification machine. Meanwhile, the central control room increased the quantity of circulation cooling water. At this moment, the second layer of the nitrification device had a lot of smoke. The nitrification machines were stopped under the suggestion of experts. And experts decided no longer to start the nitrification machine at that night.

(7) The workers stopped feeding the nitrification machine until 22:24 on August 31st, the temperature of the nitrification machine tended to be stable at 22:52 on August 31st.

(8) In order to prevent dinitrobenzene of the nitrification re-separator (X1102) from coagulating, the workers inserted into the observation hole of the nitrification re-separator with the hose and tried to suck out dinitrobenzene in the way of siphon but failed.
(9) The workers unloaded the flange on the discharge pipe (DN50) of the nitrification re-separator and opened the valve of the discharge pipe. The dinitrobenzene materials of the nitrification re-separator leaked from the flange, where smoked the white smoke, and then turned yellow, red, and finally become brown red.

(10) After two minutes of the feeding, a worker saw the flame between the pre-washer and the nitrification re-separator and ran outside with the other four workers.

(11) 23:18 on August 31st, the nitrification device exploded.

(12) The government organized rescue.

(13) 4:00 on September 1st, the site command organized experts to analyze the accident situation and made the emergency plan rapidly. Then the site command mobilized 70 experts who major in chemical, environmental protection, fire and police and 9 rescue dogs to search the accident site. The site command also organized experts who major in health care, police and forensic to identify the DNA. As of September 5th 12:00, the site command identified all the identity of victims.

4.3. Defining systems and hazards related to the accident
According to the six-hierarchy accident analysis model, it’s necessary to divide the system related to the accident into two parts: the technical system and the social system. The technical system is mainly the operation of the chemical equipment, which is controlled by the chemical plant. It includes the control behavior and the management behavior of the chemical process. The main implement bodies of the social system are the government agencies and the industry associations, which are responsible for the formulation, the publication, and the supervision of laws. The safety control structure which is composed of two systems is presented in Figure 4.

4.4. Analyzing accident causes of technical system

4.4.1 Hierarchy of behavior restriction.
The workers violated the operation. The workshop workers discharged dinitrobenzene materials of the nitrification re-separator to the ground. Dinitrobenzene was discharged from high to the first floor in the condition of the presence of such strong oxidants as sulfuric acid, nitric acid and nitrogen dioxide, and then they burned under the impact force. The fire baked nearby the nitrification machine, pre-washer and other equipment, whose dinitrobenzene materials temperature rose and exploded.

4.4.2 Hierarchy of job control.
The head of workshop ordered the adventure work. After the third stop of feeding test, the head of workshop forced workers to unload the flange on the discharge pipe of the nitrification re-separator and open the valve of the discharge pipe. The dinitrobenzene materials of the nitrification re-separator leaked from the flange.
4.4.3 Hierarchy of safety supervision.
The safety management agencies and personnel of enterprise didn’t meet the requirement of Law of the People's Republic of China on Safety Production. Their safety management system and safety production responsibility system was not sound. Their workers didn’t have the safety training. They didn’t make the standardized process operating methods and safety operating procedures. They didn’t have the normal operational records and shift records.

4.4.4 Hierarchy of company culture.
The company had a weak sense of safety laws and safety consciousness in the process of enterprise management. They disregarded the national laws, and their responsibility for safe production was not fulfilled. The company had lots of serious violations in the project construction process and trial production process.

4.5. Analyzing accident causes of social system

4.5.1 Hierarchy of industry supervision.
According to the report of accident investigation, the relevant departments responsible for the safety supervision and management were not responsible for the safety supervision. The government departments involved in the accident include Lijin Prefectural Safety Bureau, Dongying Municipal Safety Bureau, Lijin Prefectural Public Security Bureau, Lijin Prefectural Fire Bureau, Lijin Prefectural Bureau of Hosing and Urban-Rural Development. The local government was not responsible for the safety supervision, including Diaokou Township Government, Lijin Prefectural Government and Dongying Municipal Government.

4.5.2 Hierarchy of safety laws.
In order to prevent the chemical accidents, the state and local governments have issued the relevant laws, regulations and documents such as Law of the People's Republic of China on Safety Production, Law of the People's Republic of China on Fire Protection, Notice of Shandong Provincial Government General Office on "8 • 22" Explosion Ignition Accident in Shandong Runxing Chemical Technology Co., Ltd. However, the relevant departments and company did not follow the requirements of policy strictly in the implementation of the policy. It’s another cause of the accident.

4.6. Analyzing control structure between hierarchies
In the complex social technology system, the key link between hierarchies is control and feedback. In this accident, the control process from higher hierarchy to lower hierarchy was also the case. The defects of control and feedback occurred in the whole process of the accident according to the report of accident investigation. Each hierarchy had different degrees of error, and ultimately the accident occurred. The control structure between hierarchies is presented in Figure. 5.
5. Conclusions

This paper presented the six hierarchies of accident causes and its control structure between hierarchies by constructing the six-hierarchy accident analysis model for complex social technology systems. The factors in the technical system are the direct causes of the accident, and factors in the social system are the root causes of the accident. It is the important methods to prevent safety accidents by taking corresponding restraints on all kinds of accident causes.

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