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In order to effectively prevent coal mine accidents, we selected the most serious type of accident in coal mines—gas explosions—as the research object. Based on the accident causation model (24Model), we propose an action path and analysis steps of accidents caused by different employees in the organization. A gas explosion coal mine accident was analyzed using the 24Model and the proposed action path, and 12 unsafe actions, 3 unsafe states, 4 habitual behaviors, 10 safety management systems, and 10 safety cultures were obtained. Case analysis results show that by using the 24Model and path analysis the proposed effect can help employees to clearly identify the cause of the accident, to better understand the logical relationship with the causes of the accident, improve the effectiveness of training, and effectively prevent similar accidents. The 24Model and the proposed path can be used to comprehensively analyze the reasons for and help to effectively prevent coal mine gas explosion accidents.



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# The Accident Path of Coal Mine Gas Explosion Based on 24Model: A Case Study of the Ruizhiyuan Gas Explosion Accident

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**Keywords:** coal mine; gas explosion accident; safety management; accident prevention; 24Model; action path

## 1. Introduction

According to 2016 statistics, China is the largest producer and consumer of coal in the world [1]. Therefore, preventing coal mine accidents is a critically important aspect in China's research on safety science. According to accident reports released by the National Coal Mine Safety Administration from 2007 to 2016 [2–11], gas explosions are the most serious type of accident in coal mine production. Based on the information provided in these reports, there were 63 major gas explosion accidents with a totally casualty count of 1443 persons in this time period. These accidents accounted for 35% of all major coal mine accidents and 40% of casualties (Figure 1). As such, preventing gas explosion accidents should be a key concern for improving coal mine safety. In this paper, the accident with the most onetime casualties in the 10-year period was selected for analysis. Accident cause analysis is the basis of accident prevention, since the method shows whether the effects of accident prevention are reliable. Therefore, the choice of the analysis method is critical to the results [12]. Currently, accident prevention research has focused on the lack of systematic cause analysis methods and analysis tools, resulting in accident analyses being incomprehensive or unspecific, so the effect of preventing accidents needs to be strengthened [13]. In order to provide a more comprehensive and clearer analysis of accident causes, this paper provides a systemic accident causation model for effective control to improve accident prevention.

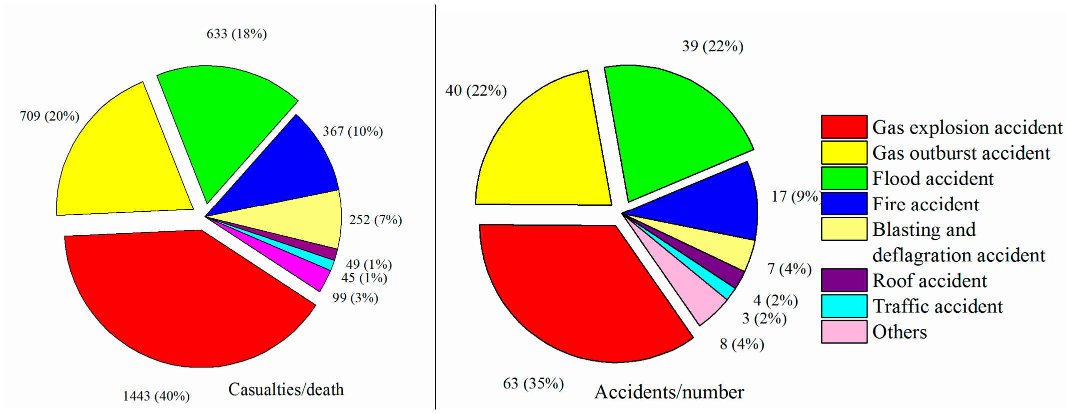


**Figure 1.** Classification statistics of major accidents in China during 2007–2016. Data from the accident reports released by the National Coal Mine Safety Administration from 2007 to 2016 [2–11].

## 2. Analysis Method

### *2.1. Traditional Accident Causation Model*

Accident causation modeling reflects the patterns of certain types of accidents [14] based on the explorative research results of many typical accidents and the accumulation of safe production experience. As the production environment evolves, a variety of accident causation models have emerged internationally and more than a dozen are currently in use [15].

In 1919, Greenwood and Wood [16] used statistical models, such as the Poisson distribution, to analyze many casualty accidents, and proposed the "incident tendency of accidents". Heinrich [17] proposed the domino model in 1931, which describes an accident as a series of discrete events that occur in a particular chronological order. In 1990, Reason [18] proposed the relationships between unsafe acts, unsafe conditions, safety supervision, and organizational behavior among accident causes, and created the epidemiological accident model known as the "Swiss cheese" model, which was widely used. Additionally, some analysis models consider accidents caused by human error in relatively simple systems, such as fault tree analysis and cause-consequence analysis [19]. In 1997, Rasmussen [20] divided accident causes into six levels and proposed an accident analysis method called AcciMap. Leveson [21] proposed the Systems-Theoretic Accident Model and Processes (STAMP) in 2004. This model, which is based on a systemic perspective, considers safety as a control issue based on the thought that accidents occur due to inadequate control and the absence of safety-related constraints [22,23].

The previously described models, while still popular, do not produce adequate results when used to analyze the causes of coal mine gas explosion accidents [24]. For example, although AcciMap [20] establishes a causal analysis method, the subjectivity of the factors selected in the analysis of the cause is obvious, and individual behaviors and organizational factors are not well distinguished, which is not conducive to statistical analysis of a large number of accidents [25]. Since they include unclear indicators and unspecified definitions when analyzing accident causes, these methods struggle to separate multiple causes. This results in a lack of logic and difficulty generalizing the findings. In this work, an accident causation model (24Model) is used as the theoretical basis for the analysis of gas explosion accidents. Some industries have already used the 24Model in accident analysis and prevention. For example, Suoxiao studied the capsizing of the Eastern Star ferry using 24Model analysis of the five factors that led to the accident and proposed appropriate preventive measures [26], Xueyujingyang used the 24Model to analyze personal and organizational factors that lead to aviation accidents [27], and Zhanghu used a 24Model analysis of ammonia leakage accident causation factors in food enterprises [28]. Thus, 24Model is already a more mature accident causation model in both theory and practice.

### 2.2. Development of 24Model

Developed in 2005, the 24Model looks to behavioral science for the philosophy of accident prevention [29]. Since its inception, the model has undergone four theoretical development stages. Based on behavioral science, the first version of the model proposed a structured safety management model for organizations. This model relied on the idea that safety culture, safety structure, and safety methods within organizations produce intermediate results such as safety knowledge, safety awareness, and employee habits. These characteristics jointly engender results such as employee behavior, the safety status of the facility, and the safety performance of the organization [30]. The second iteration of the model clarified that the goal of the theory is accident prevention and the research object is the accident itself. This version of the model was established based on a large number of safety accident case studies together with Stewart's accident causation chain [31]. The second iteration represented a new, modern accident causation chain—the behavioral safety 24Model (Figure 2)—where 2 indicates the organizational and personal levels and 4 indicates the four stages: safety culture (root causes), safety management system (radical causes), habitual behavior (indirect causes), and onetime behavior (direct causes) [32]. At this point, the basic framework of the 24Model was formed. The third version of the model considers the personal, psychological, and physiological effects of the accident-inducing person, as well as that of supervision outside the organization. After reintegration, inadequate safety knowledge, low safety awareness, poor safety habits, psychological factors, physiological factors, safety supervision, and other factors are all listed as direct causes of unsafe acts [33]. The fourth version improved upon three aspects of the third model to produce a more reasonable logical structure and a simpler overall structure (Figure 3) [34]. These aspects are as follows: (1) "Poor safety psychology" and "poor health and physiology" were classified into the habitual behavior cause. (2) The scope of external causes of the organization was expanded to include the organization's superior authority, government and various regulatory authorities, suppliers and their services, the genetic and growth environment of the members, and social, political, economic, and cultural factors. (3) The action path of "unsafe conditions" was added.

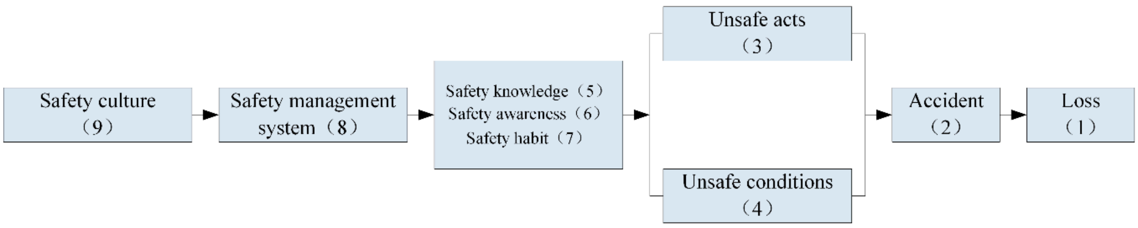


**Figure 2.** Behavior-based 24Model [33]. Reproduced with permission from [Fu, G.], [Studies on the Structure of Safety Science]; published by [Safety Science Publishing: Beijing, China], [2015].

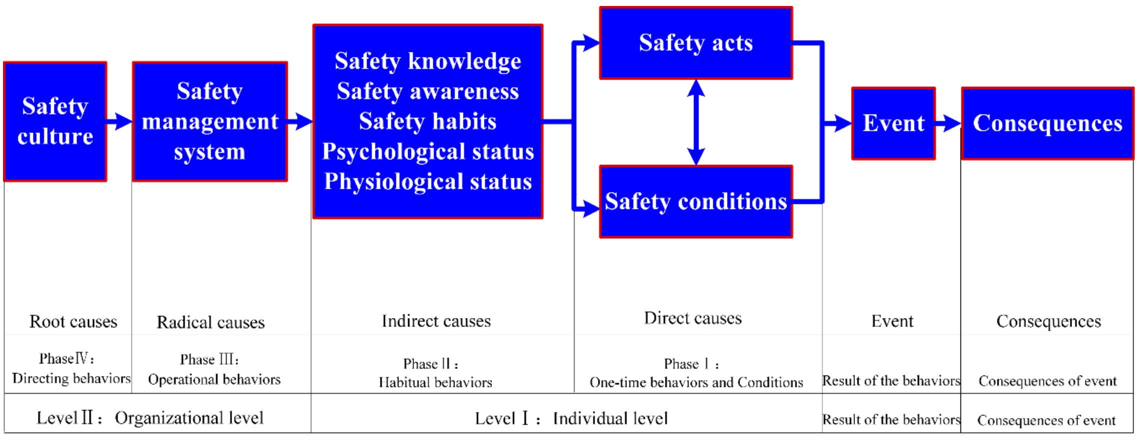


**Figure 3.** 24Model [35].

The most important aspect of the fourth iteration of the model is that it proposes a general analysis method for accident causes. This method emphasizes that the action path of unsafe acts should be determined. The action path refers to the influence object and influence mode of different employees' actions within the organization. For example, an employee's unsafe act can affect one or more causes in the model. Therefore, starting from the direct cause of the accident, the logical relationship of the 24Model can be traced back to several influence paths, each of which has a different effect on the occurrence of the accident. At present, scholars use the 24Model to analyze the causes of coal mine gas explosion accidents [36–38], but there is no detailed action path analysis. We therefore analyzed the impact path and relationship of an actual accident in detail. Figure 4 [35] shows the influence that the various causes in the model had on the accident and Figure 5 shows the interpretation of the influence path in the causes.

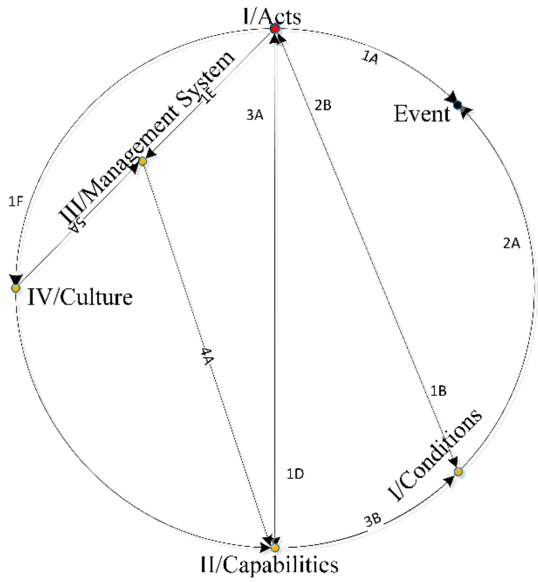


**Figure 4.** Process of reasons affecting accidents [35]. Reproduced with permission from Gui and Ren, [24Model (Version 5)]; published by [Fifth edition 24Model, http://blog.sciencenet.cn/blog-603730-1083115.html], [2017].

Take two of the action paths as an example for explanation. As shown in Figure 5, there are nine action paths that produced an unsafe act. Path 1A represents the case in which an unsafe action directly triggers an accident. Thus, its influence object is the "accident" and the influence mode is "activation". Similarly, path 1B1 shows the situation where an "unsafe condition" is directly caused by an unsafe act, where the influence object is "unsafe condition" and the influence mode is "activation".

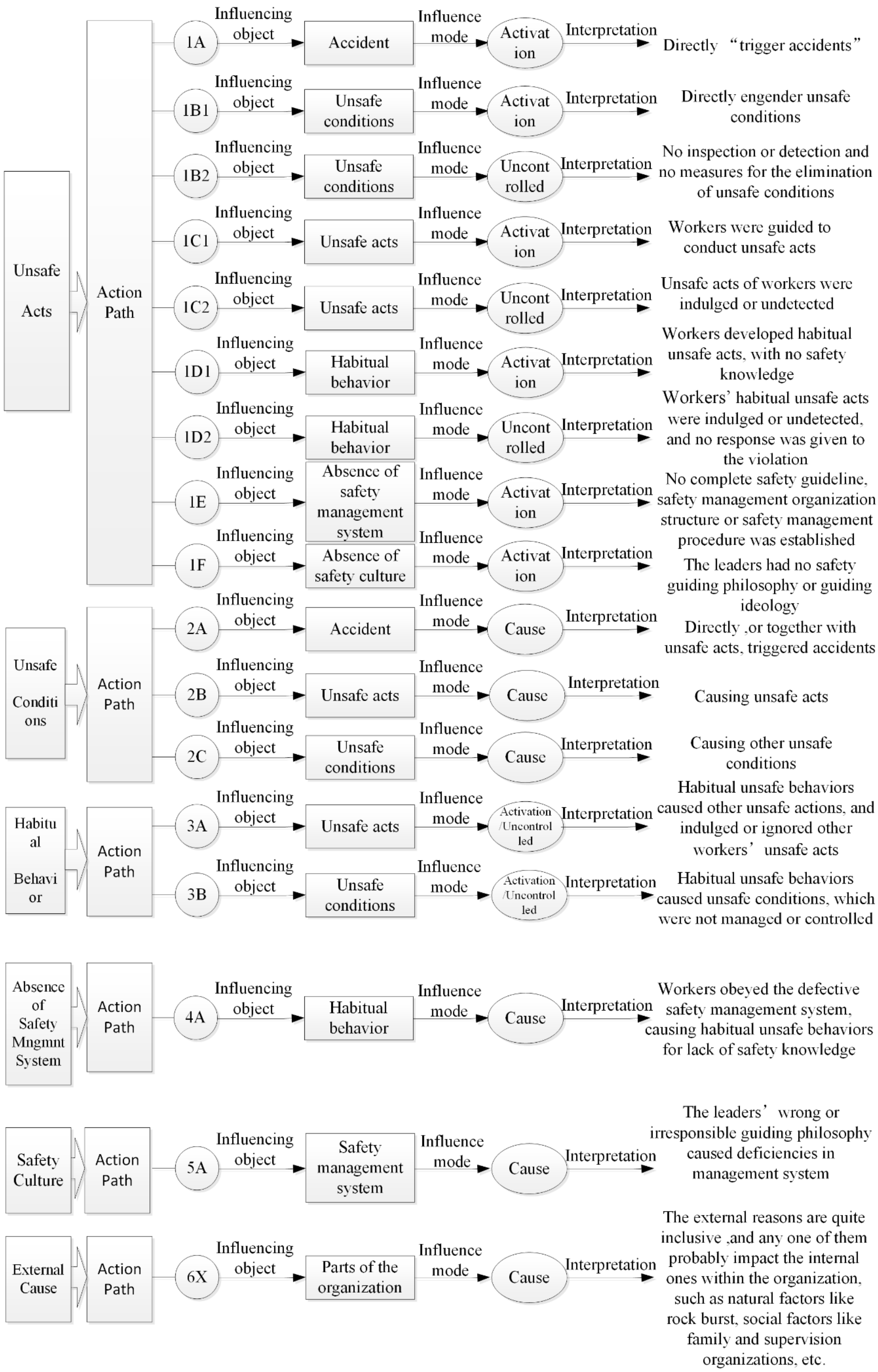


**Figure 5.** Target and path of reasons affecting the accident.

### 2.3. Specific Definition of 24Model

The forward path of the accident causation model is the occurrence mechanism of the accident. The reverse path is the path of accident investigation and analysis. Accident analysis should start from the accident itself, including the internal organization or the direct cause (unsafe acts, unsafe conditions), the indirect cause, the radical cause (safety management system), and root cause (safety culture) of the event and matter related to the accident.

(1) Identification of unsafe acts. Unsafe acts that have a direct or important relationship with an accident can occur at or before the time of the accident. Therefore, no matter when an unsafe act occurs relative to the accident, if it has an important impact, it is called an unsafe act and needs to be identified during analysis. The person performing the unsafe act is generally first-line staff in the wrong operation, but can be a manager in the organization as well. The model is based on the thought that as long as it is performed by an individual (staff at any level within the organization), their action has a direct or indirect impact on the accident and should be identified.

(2) Identification of unsafe conditions. The physical state refers to the state of objects, such as materials, tools, facilities, and places. The scope of the state as referred to here is relatively wide. For example, an object violates the standards set by the state or the locality, or it does not violate the regulations but promotes the occurrence of an accident. After risk analysis and empirical judgment, the physical state is considered highly risky, which is considered an unsafe condition.

(3) Habitual behavior causes. The main habitual behavior causes are:

(a) Safety knowledge: the knowledge related to the occurrence of accidents or unsafe acts. For example, in the case where it is not possible to be directly determined, it is possible to decide whether or not a person was equipped with safety knowledge from other relevant information.

(b) Safety awareness: the degree of emphasis on the source of danger and the ability to eliminate it.

(c) Safety habits: the habits in daily work, that is, the usual practice.

(d) Safety psychology: the working state of employees under conditions of fatigue, mood swings, distraction, and judgment errors.

(e) Safety psychology: employees' working state in poor physical conditions such as illness or pain.

(4) Safety management system. A safety management system is a set of system documents, including the safety policy (a centralized form of safety culture, guidelines for safe work habits), the organizational structure of safety management, and safety management procedures [39]. The absence of a safety management system is understood as the management staff designing unsafe acts in the system, and therefore some of the employees' unsafe acts have no correct system to follow. 24Model regards the implementation of the safety management system to be a human action.

(5) Safety culture. Generally, safety culture refers to the source and specific content of the attitude of the organization toward safe work implementation, also called a philosophy. In the model, 32 safety culture items are proposed, with guiding behaviors reflected in the safety management system.

## 3. Accident Analysis

### 3.1. Gas Explosion Accident of Ruizhiyuan Coal Industry Co.

At approximately 11:15 p.m. on 5 December 2007, a major gas explosion occurred in a coal mine of the Ruizhiyuan Coal Industry Co. in Zuomu Township, Hongdong County, Linfen City, Shanxi Province, China. There was a staff of 128 persons in the coal mine at the time of the accident. After the accident, 37 persons were improperly sent down to the mine for rescue; in total, 18 persons were injured and 105 were killed, with a direct economic loss of 42.75 million yuan. The mine was a low-gas mine, with an easy-to-fire coal seam for self-ignition. The ventilation mode was a central side-by-side extraction type, with a total air intake of 1444 $m^3$/min and a total exhaust air volume of 1533 $m^3$/min, with one stope face and two heading faces. Through the use of false sealing, posterns, and fake drawings, surpassing-layer and cross-border mining continued during the shutdown period, using over-capability and extra staff. The accident occurred in coal seam #9, which was barred from mining. After the investigation, the accident process was assumed to have occurred as described. The accident occurred in a windless operation spot where a wealth of gas was accumulating to the explosion limit. Workers did not check the gas concentration before blasting. The flame from the blasting triggered a gas explosion and coal dust was involved. Subsequently, the accident was not reported in time as required. Additionally, a blind rescue was conducted, during which rescue personnel did not wear professional rescue equipment, resulting in a secondary accident.

### *3.2. Accident Analysis Steps*

#### 3.2.1. Organizational Carving Up

Shanxi Ruizhiyuan Coal Industry has its own management responsibilities and independent administrative structure. It was taken as the accident organization for the internal cause analysis.

According to the 24Model analysis, all unsafe acts that are directly or significantly related to the accident are analyzed, with the influence path, influence object, and mode of unsafe acts discussed. The results are shown in Table 1. In this section, we analyze actions on the part of company personnel.

A. Team staff. The members of the mine team were the operators for the specific operations. Their job responsibilities played a decisive role in their actions during the accident.

The direct cause of the accident was caused by the blasters, and the sparks were the "triggering" actions that directly caused the accident (Table 1, path 1A). Article 347 of the Coal Mine Safety Regulations stipulates that "the system of three inspections for one blasting must be implemented." The blaster did not act in accordance with this stipulation and thus was the direct cause of the gas explosion accident.

The gas inspector did not check the gas concentration before loading the explosives and before the explosion. This was not the direct cause of the gas concentration exceeding the limit, although it was the reason that the problem could not be found in time and prevented. Therefore, it is the unsafe condition (Path 1B2).

B. Management staff. Suedung and Rasmussen [40] mentioned that, in the social-technical model, the company's management is provided by a charter management company, and the management organization regulates the employees' work behavior through the work plan. As such, the top-down line management ensures employee work safety. The management staff in the accident organization includes direct and mine-level staff. The mine-level management authority regulates employee behavior through rules, regulations, and operational procedures. The direct management authority issues and inspects the implementation of specific work plans in accordance with the system and the charter. However, the direct management team also participates in forming the safety management system together with the mine-level management authority. Because the responsibilities of the two groups overlap, unsafe acts often result, so they are analyzed together.

The mine-level management staff is organized in the following way. The corporation manager and the legal representative undertake comprehensive work on the mine. The mine manager and the chief engineer are responsible for the technical management work, and they are the first responsible persons for safe mining production. The administrative deputy mine manager controls the use of underground fire products and logistics, whereas the deputy mine manager for production safety is responsible for underground coal production, technology, mining, and safety management.

**Table 1.** Analysis of employees' unsafe acts in the organization of Ruizhiyuan coal mine.

| Unsafe Act | Action Maker | Staff Level | Action Path | Influencing Object | Influence Mode | Interpretation |
|---|---|---|---|---|---|---|
| Violated blasting | Blasters on duty | Shift employees | 1A | Accident | Activation | Ignition source in this accident was blasting flames from violated blasting, igniting transfinite gas accumulated on windless working face, resulting in gas explosion |
| | Blaster | Shift employees | 3A | Unsafe actions of blasters on duty | Activation | In normal operation, blasters habitually violated rules and regulations, so they did as usual on accident day |
| Unchecked gas concentration | Gas checkers on duty | Shift employees | 1B2 | Unsafe conditions | Uncontrolled | Gas checkers did not check gas concentration before blasting, so gas concentration limit could not be detected in time |
| | Gas checkers | Shift employees | 3A | Unsafe actions of gas checkers on duty | Activation | Gas checkers habitually did not check gas concentration before blasting as usual on accident day |
| | Gas checkers | Shift employees | 3A | Unsafe conditions | Uncontrolled | Gas checkers habitually skived off work |
| Regulations on management of firework products and blasting operation rules | Mining team | Direct management staff | 1E | Absence of safety management system | Activation | Company did not formulate instructions for blasting operation or relevant knowledge training for blasters, so they had no knowledge or skills in blasting, and were even given wrong information; thus, they were not equipped to detect and eliminate potential risks in blasting; over time, blasters develop habitual violation |
| | Production safety deputy head | Mine-level management staff | 1E | Absence of safety management system | Activation | |
| Absence of safety training on blasters | Mining team | Direct management staff | 1D1 | Habitual unsafe action of blasters | Activation | |
| Directed or condoned violations of workers' behavior | Mining team, team leader, safety inspection department | Direct management staff | 1D1/1D2 | Bad habits of unsafe actions of blasters | Activation/ Uncontrolled | In normal operation, blasters developed habitual violation of regulations in long-term usual practice |
| | Team leader | Direct management staff | 1C2 | Unsafe actions of blasters on duty | Uncontrolled | At occurrence of accident, wrong guidance and indulgence of blasters' violated operation emerged |
| Absence of gas inspection system | Ventilation team | Direct management staff | 1E | Absence of safety management system | Activation/ Uncontrolled | Mine leaders illegally conducted work in closed areas and little emphasized gas prevention and treatment in working environment |
| | Production safety deputy head | Mine-level management staff | 1E | Unsafe actions of blasters on duty | Uncontrolled | Absence of gas inspection system provided little knowledge and skills related to gas inspection, and even incorrect information; thus, gas inspectors gradually developed an operation mode of habitual violation |
| Absence of training on gas inspectors | Ventilation team | Direct management staff | 1D1 | Habitual unsafe actions of gas inspectors | Activation | Absence of gas training for gas inspectors provided little knowledge and skills related to gas inspection, and even incorrect experience, and further made them unable to detect and eliminate gas concentration over limits; thus, they gradually developed an operation mode of habitual violation |
| Usual absence of gas detector | Team leader, ventilation team, safety inspection department | Direct management staff | 1D1/1D2 | Habitual unsafe actions of gas inspectors | Activation/ Uncontrolled | Ventilation team had inadequate gas detector and did not implement check system before descending the well, so workers did not bring gas detectors or have gas inspectors give real-time monitoring and reporting of gas concentration |
| | Team leader | Direct management staff | 1C2 | Unsafe actions of gas inspector on duty | Uncontrolled | No gas inspectors were designated for inspection |

**Table 1.** *Cont.*

| Unsafe Act | Action Maker | Staff Level | Action Path | Influencing Object | Influence Mode | Interpretation |
| --- | --- | --- | --- | --- | --- | --- |
| Wrong ventilation system design | Ventilation team | Direct management staff | 1E | Absence of safety management system | Activation | Workers were organized to illegally work in closed area with no consideration of inappropriate ventilation system, resulting in no effective air volume on working face and frequent work under over-limit gas conditions |
| | Production safety deputy head | Mine-level management staff | 1E | Absence of safety management system | Activation | |
| Implementation of inappropriate ventilation system | Ventilation team | Direct management staff | 1B1 | Unsafe conditions | Activation | |
| Absence of methane sensor | Ventilation team | Direct management staff | 1B2 | Unsafe conditions | Uncontrolled | No methane sensor was set for the blind alley on coal seam #9, so gas concentration on the working face could not be monitored |
| No measurement of air volume | Ventilation team | Direct management staff | 1B2 | Unsafe conditions | Uncontrolled | No special air measurer was designated to measure air speed, air volume, etc., in the well |
| Violation of establishing false closed walls and fake drawings | Production technology Section coal mining technician | Direct management staff | 1E | Absence of safety management system | Activation | Mine leaders required workers to illegally operate in the well and formulated fake drawings to evade supervision, resulting in occurrence of the accident |
| | Production safety deputy head | Mine-level management staff | 1E | Absence of safety management system | Activation | |
| Ignorance of closed walls and fake drawings | Production technology Section coal mining technician | Direct management staff | 1B1 | Unsafe conditions | Activation | |
| Failure to implement system of mine leadership shift in well | Mine leaders on duty | Mine-level management staff | 1C2<br>1B2<br>1D2 | Unsafe act<br>Unsafe conditions<br>Bad habit of unsafe actions | Uncontrolled<br>Uncontrolled<br>Uncontrolled | Mine leaders failed to find or ignored underground hazards, such as violated blasting, absence of gas check, inadequate air volume, lack of methane sensor, and so on; this can be interpreted to mean that implementation failure of "mine leadership to bring staff into the well" system would increase accident risk |

The direct management staff responsibilities are as follows. The head of the ventilation team is responsible for the gas and ventilation management of the mining face. They act to ensure that the gas concentration of the working face does not exceed the limit and that the air volume is reasonable. The head of the production technology department is responsible for the production and technical work, ensuring sealing of the working face and providing underground drawings and other information. The team leader of the mining team is responsible for training the blasting workers to ensure that the blasters work safely in the operational procedures. The head of the ambulance team is responsible for organizing rescue work after an accident and ensures that the rescuers are working in safe conditions and are equipped with complete equipment for the environment. The security inspection department is responsible for inspecting and supervising the worksite of the working face, supervising the personnel who are in the well, and ensuring the compliance of the workers and the safety of the physical location. The shift squad leader is responsible for the safe production of the working surface in coal mines.

The unsafe acts of management staff are described in this analysis. The head of the excavation team (direct management staff) and the deputy mine manager for production safety (mine-level management staff) did not formulate procedural documents (path 1E), such as blasting operation procedures and instructions, nor did they provide sufficient safety training for the blasters. During daily blasting operations, the team leader, the security department (direct management staff), and the shift leader (mine-level management authority) misdirected and condoned the employees' illegal blasting behavior (here, "employees" refers to those who were at work that day).

The leader of the ambulance team (direct management staff) and the shift head (mine-level management staff) blindly organized a rescue (1E), with the rescue personnel wearing no professional mine rescue equipment. In order to quickly and effectively handle mine incidents, to protect the lives and safety of workers and national resources, and to reduce property losses, miners mastering self-help techniques and high-level organization of teams being equipped with advanced equipment to perform rescue work are very important [41].

The head of the ventilation team (direct management staff) and the deputy mine manager for production safety (mine-level management staff) were responsible for the design of the defective working face #9, in which the ventilation system provided no air to the working face. The ventilation team implemented the wrong ventilation system design.

The coal mining technicians (direct management staff) of the production technology department and the production safety deputy mine managers (mine-level management staff) constructed fake closed walls and fake drawings to deceive superior leaders (1E). This exceeded the limits of mining and evaded safety supervision, causing trouble for investigators.

The head of the ventilation team (direct management staff) and the deputy mine manager for production safety (mine-level management staff) did not develop and implement a strict gas inspection system (1E). Since the mine is a low-gas mine and coal dust is explosive, inadequate attention was paid to this issue. The ventilation team did not prepare enough gas detectors and did not check whether the workers in the well were wearing them (1C2). They also did not require gas inspectors to provide real-time monitoring and reporting of gas concentrations in the well (1C2). Coal mining face #9 was not set with a methane sensor for real-time warning (3E). The ventilation team did not record air measurements. Thus, air speed and air volume were not regularly measured (3E) for the various wind locations in the well, frequently resulting in no air or breeze operation. This can cause the gas concentration to exceed the limits, and the failure to monitor the gas concentration created the unsafe state.

The head of the security inspection department (direct management staff), the mine manager, and the chief engineer (mine-level management staff) did not establish a sound safety management structure. There was no supervision for underground operations, no full-time safety inspection personnel, and no safety inspection system, and the work still proceeded under these conditions.

Mine-level management staff did not implement the system which into underground working with staff, and so they ignored the many hidden dangers in the mine.

After the accident and investigations, the corporate managers and the head of the mine (mine-level management staff) were found to have engaged in long-term illegal production and overexploitation, which violated the regulations on coal mine construction provided in the Coal Mine Safety Regulations. The administrative deputy mine manager (mine-level management staff) did not establish regulations on the use of pyrotechnics. Although this unsafe act had no direct impact on the occurrence of this accident, it was extremely risky and could have easily caused or worsened accidents.

### 3.2.2. Cause Analysis of Unsafe Conditions

Unsafe condition 1: Through the analysis, it was found that the ventilation team implemented the wrong ventilation system design (1B1), causing the effective air volume of the #9 coal mining face to be insufficient, resulting in employees working in a windless environment. This was the direct cause of insufficient airflow along the working face.

Unsafe condition 2: The windless state in the working face made it impossible to discharge the excess gas, resulting in local gas concentration that exceeded the limit along the working face.

Unsafe condition 3: The banned coal mining face #9 was insufficiently sealed. A closed wall was used to prevent gas, fire protection, and coal dust. In this accident, the air leakage from the closed wall caused a large amount of coal dust to be ignited in the gas explosion, greatly expanding the size of the accident.

Simultaneously, inadequate gas detectors in the well, broken methane sensors on the working face, and fake drawings used to deceive leaders were all unsafe conditions, which, although not the cause of the gas accumulation, blocked its timely detection and posed potential safety hazards (Figure 6).

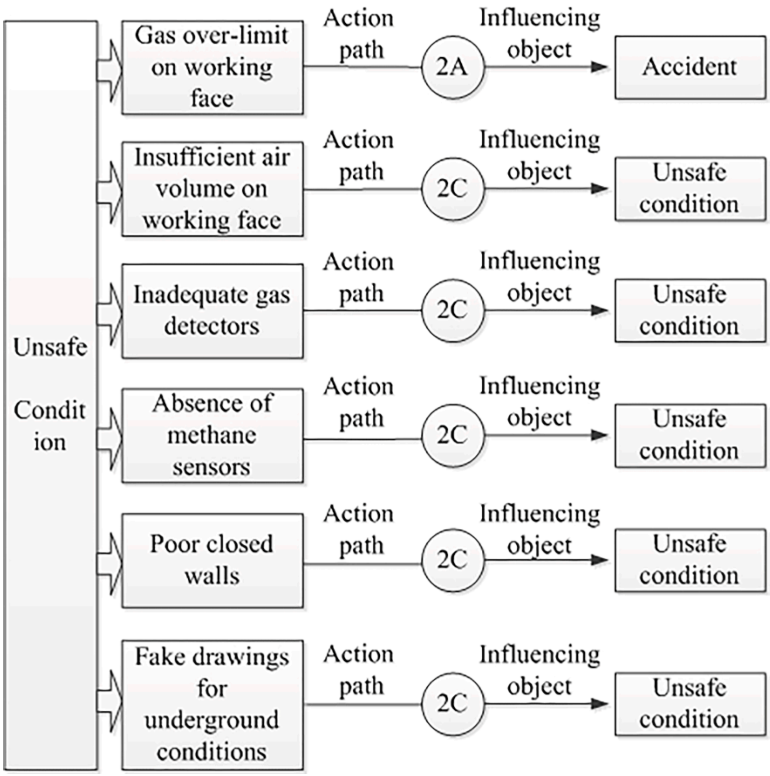


**Figure 6.** Analysis of unsafe conditions.

### 3.2.3. Cause Analysis of Habitual Behaviors

According to the report, it was not accidental that the team members violated the operation rules. Rather, in daily blasting operations, the blasters habitually violated the operation instructions. It was frequently seen that the gas inspectors did not carry portable gas detectors and did not check the gas levels. Therefore, the unsafe acts of the team members in this accident were habitual violations common to routine work. These gradually became habitual unsafe acts (3A).

Several factors contributed to this habitual violation. There were no procedural documents, such as blasting operation procedures and instructions, for the mine well. Additionally, there was no safety training provided to the blasters. As a result, the blasters lacked relevant knowledge and experience in blasting operations and did not have the relevant skills (insufficient safety knowledge). Figure 7 lists the safety knowledge deficiencies of the employees. Due to the lack of relevant knowledge, the blasters lacked the ability to detect or eliminate risks in daily blasting operations (low safety awareness). The wrong commands and the blasting behavior violations on the part of the team leader enabled the blasters to ignore the safety of the blasting operation, thus forming unsafe working habits (poor safety habits). The habitual operation violations of the blasters coupled with the collusion of the management staff caused the blasters to omit the necessary process (poor safety mentality). In general, under the combined effect of these factors, the blasters had a culture of habitual violations. Similarly, the formation of habitual violations of the gas inspectors was primarily due to the influence of management staff.

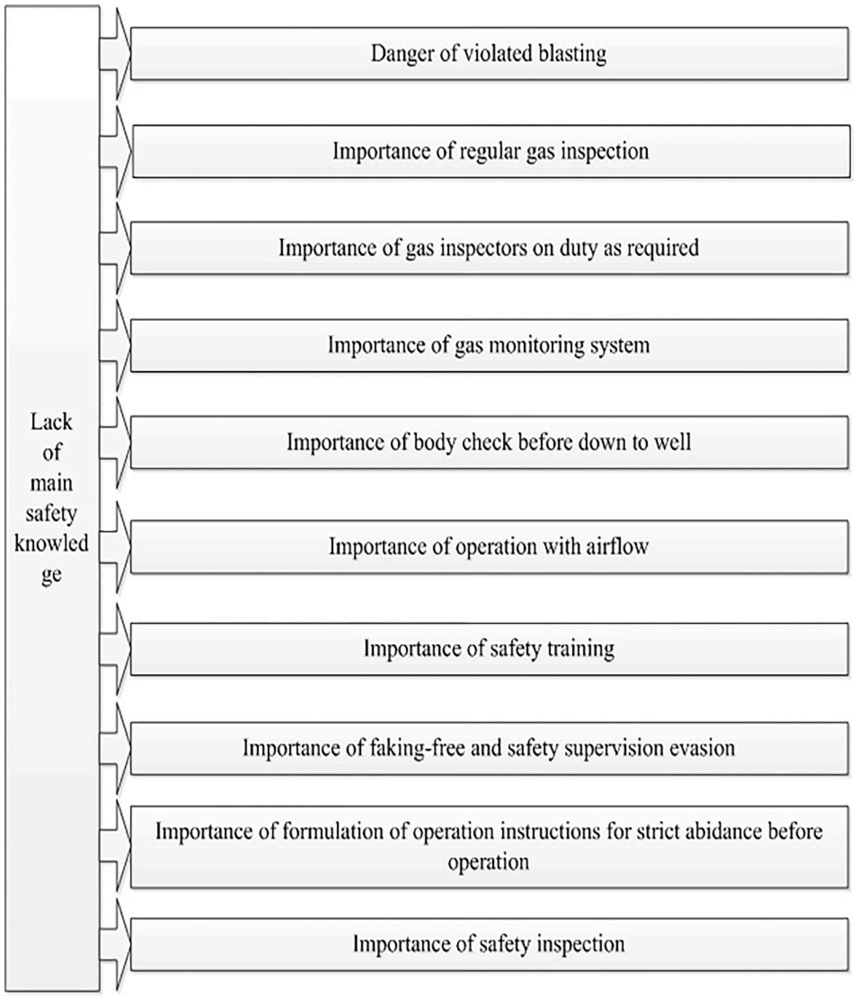


**Figure 7.** Main safety knowledge deficiencies manifested by employees.

### 3.2.4. Analysis of Reasons for Safety Management System

In the accident analysis, the complete absence of a safety management system was discovered from the above-mentioned unsafe acts by the management staff. Specifically:

(1) Deficiency of a safety policy: There was no clear and specific safety policy.
(2) Deficiency of a safety management organizational structure: There were no special safety management agencies or full-time security personnel.
(3) Deficiency of safety management procedures: There was no implementation of a safety inspection system, no "mine leadership to bring staff into the well" system, no safety training system, an incorrect ventilation system design, no special operation personnel management system, no implementation of blasting procedures, and no pyrotechnics management regulations.

### 3.2.5. Absence of a Safety Culture

Safety culture is a concept largely embodied in the establishment of a management system. In the accident analysis, the following safety culture deficiencies were found:

(1) The importance of safety and actual safety are mainly determined by safety awareness and understanding of personnel with safe production. The mine authorities did not establish a safety policy, indicating that management leaders did not believe that safe production and awareness were important or necessary in order to provide a safe environment.
(2) The degree of integration of safety into management, the understanding of responsibility by management staff, and the formation mode of safety systems ensured that there was no basic understanding of safety management or awareness of safety system formation. This resulted in the absence of a basic safety management system.
(3) The degree of emphasis on safety of the enterprise department, the degree of employee participation in safety, the lack of adequate facilities, and the degree of safety training all contributed to the accident. The departments at the management level did not assign specific personnel to be responsible for safe production, and they did not ascertain the use of the wrong design, resulting in operation by workers with no safe production awareness. The workers used equipment purchased by management personnel that had no regular maintenance management, causing a large number of safety hazards. The mine leadership possibly considered it unnecessary to provide safety training and so the safety training system was ignored.

## 4. Results

This paper provides a detailed analysis of a gas explosion accident, finding the direct causes, indirect causes, radical causes, and root causes of the accident. It also describes how the various causes specifically affected the accident. After comparing with the analysis results in the actual accident report published on the official website [42], this paper includes all the causes, but with more logical and practical value for accident prevention. In the accident report, the causes are simply divided into direct and indirect causes, but the different types are not categorized. This complicates distinguishing the causes and proposing corresponding countermeasures. In addition, the analysis method used in this work focuses on the influencing processes and action paths of causes of the accident, so that the occurrence and development of the accident can be more comprehensively understood in order to effectively prevent future accidents (Figure 8).

| Cause type | Cause |
| --- | --- |
| **Direct Causes** | **Causes of unsafe act:** |
| | 1 Violated blasting by blasters |
| | 2 Absence of gas concentration check by gas inspectors before blasting |
| | 3 Team leaders' violated guiding and indulgence of the violated blasting |
| | 4 No instructions for pyrotechnics usage and underground blasting operation |
| | 5 No training for blasters and gas inspectors |
| | 6 No operation rule for gas inspection |
| | 7 No adequate gas detector, no requirement on reporting of gas inspection |
| | 8 Wrong ventilation system designs, no timely measurement of air volume on working face |
| | 9 No methane sensor on working face |
| | 10 Violated closed wall design ,fake drawings |
| | 11 No complete safety management organization ,safety inspection system or safety training system |
| | 12 No implementation of the "mine leadership to bring staff into the well" system, hindering hazard investigation |
| | **Causes of unsafe conditions:** |
| | 1 Insufficient airflow on working face |
| | 2 Gas concentration exceeding the limit |
| | 3 Poor closed walls, fake drawings |
| **Indirect Causes** | 1 With no relevant operation knowledge, blasters and gas inspectors had no related skills, but even wrong experience and little safety knowledge |
| | 2 The lack of safety knowledge caused absence of ability to detect or eliminate operation-linked risks |
| | 3 The daily violated operation, if not corrected, made workers develop habitual violations |
| | 4 The fluke mind of workers made them have unsafe mental states |
| **Radical causes** | **Deficiency of safety policy:** |
| | 1 No specific safety policy |
| | **Deficiencies of safety management structure:** |
| | 1 No special safety management organization |
| | 2 No professional safety inspectors |
| | **Deficiencies of safety procedures:** |
| | 1 No safety inspection system |
| | 2 No "mine leadership to bring staff into the well" system |
| | 3 No safety training system |
| | 4 Wrong ventilation system design |
| | 5 No management system for special operation personnel |
| | 6 No blasting operation instructions |
| | 7 No pyrotechnics management regulations |
| **Root Causes** | **Deficiencies of safety culture:** |
| | 1 Importance of safety |
| | 2 Safety lies in safety awareness |
| | 3 Recognition of safety by production subjects |
| | 4 Integration degree of safety into management |
| | 5 Understanding of management staff |
| | 6 Formation mode of safety system |
| | 7 Responsibility degree of corporate department |
| | 8 Participation degree of staff |
| | 9 Satisfaction of facilities |
| | 10 Demand degree of safety training |

**Figure 8.** Accident analysis results based on 24Model.

## 5. Conclusions and Suggestions

Based on the 24Model of accident causation, we proposed that different paths of employee movement within the organization can enhance the analysis of the logical relationship between causes of an accident. To prove the method's feasibility and practicality, 24Model was adopted to analyze a gas explosion accident step-by-step.

(1) In this analysis, the 15 unsafe acts included three unsafe acts with potential safety hazards that did not affect the accident, so there were 12 unsafe acts causing the accident. 6 unsafe conditions, three of which were not involved in the explosion but were potentially safety hazards, 4 habitual behaviors, 10 safety defects in the management system, and 10 deficiencies in the safety culture that induced the accident were found.

(2) The results of the case analysis were compared with those in the actual accident report on the official website, and we found that the accident causes analyzed in this paper are included in the report, but in a way that is more logical and practical for accident prevention.

(3) Case training is an effective safety training tool. By looking at this case as an example, the the analysis results of the gas explosion accident can be clearly actioned. Employees can clearly identify the causation factors of the accident through various modules and grasp the interrelationships among factors such as people, materials, and management systems, so that similar violations can be avoided in daily work.

(4) The logic of the cause analysis and induction of 24Model are easy to understand, making the model useful for teaching first-line workers with a low education level.

(5) Creating a safety checklist using the causes of previous accidents provides a tool to check for the risk of gas explosion accidents in coal mines.

(6) By uncovering the lack of employee and manager safety knowledge, corresponding knowledge training and management system construction can be provided to prevent future gas explosion accidents.

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By using the results of the 24Model coal mine gas explosion accident causation factor analysis, the information for each module provides the cause from very specific analysis. When using 24Model to analyze other accidents, it is possible to find the causes of unsafe actions and physical states of employees according to the order of direct cause, indirect cause, root cause, and root cause in the model, according to unsafe acts and conditions. Based on this, we drew an accident causes analysis flow chart (Figure 9). The indirect causes, and then the cause of the indirect cause, can be determined based on the radical causes and the root causes of the loophole. Accurate analysis of each part of the cause of the accident can be based on various reasons: to improve the management loopholes in a targeted manner and to prevent accidents from top to bottom.

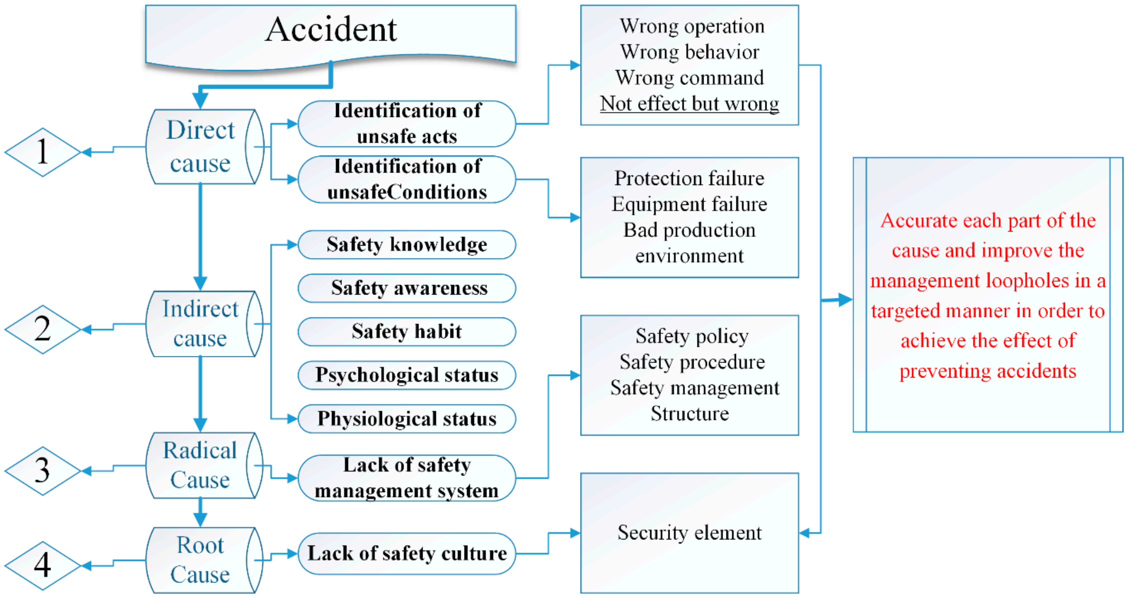


**Figure 9.** Accident causes analysis flow chart.

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