Analysis of key unsafe acts in major and particular major gas explosion accidents

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Abstract. In recent years, the average annual coal mine industry will occur from 6 to 7 a one-time death of more than 10 gas explosion accident, and the cause of the accident is caused by people's unsafe act, so analysing the unsafe act of the gas explosion accident is the key way to prevent this kind of accident. Based on the 24Model, this paper analyses the unsafe operation of all the major and particular major gas explosion accidents in the past 10 years, and the frequency of triggering accidents. The results show that: illegal operation occurred in a total of 24 unsafe movements, grouped into 4 categories, occurred 141 times in 63 incidents, The "Unchecked gas" act is the highest frequency of triggering accidents, the frequency of triggering accidents is 23% of all unsafe operation acts; illegal behaviour occurred in a total of 24 unsafe movements, grouped into 4 categories, frequency of 155 times, where "illegal or no placement ventilation set" appears to be the highest frequency, 15% of the total frequency ratio; a total of 28 unsafe actions in violation of command, grouped into 4 categories, the frequency is 198 times, "ultra-layer cross-border theft" is this type of unsafe action if the most times, frequency ratio is 14%. Provide scientific basis for preventing gas explosion accident in coal mine.

1. Introduction
Being the major source of energy in many countries across the world [1].Coal has an estimated production of 15 billion tons in recent five years (The trend chart in Fig1), and in China, coal provides around 60% of the total energy and annual coal production in 2016 was around 3.7 billion tons [2].This is also followed by safety issue concerning coal mining to which higher importance is attached by the society [3]. The accidents in mining industry can be roughly divided into five categories, namely gas explosion, coal and gas outburst, roof collapse, water leakage, and fire accident [4]. Among them, gas explosion is a kind of mining accident that may result in high mortality and tremendous loss [5]. A review of the mining accidents in recent years reveals that almost all the accidents involve unsafe acts of employees, and none of them is caused by technical factors. This reflects the unsafe acts control and management in mining enterprises is quite problematic [6]. Therefore, to analysis the unsafe acts in the cause is an indispensable part in the prevention against gas explosion.
Based on the domestic mining accident analysis reports over the years provided by State Administration of Coal Mine Safety, the author analyzed all the major or above gas explosion accidents arising during 2007-2016, computed the unsafe acts, occupations of the triggering staff, and critical unsafe acts, and collated all the 63 major gas explosion accidents over the past decade in the hope to provide a scientific basis for the drafting of preventive measures against mine gas explosion accidents.

![Figure 1. Trend map of coal production in recent years [2]](image)

2. Analytic tool
Since the Swiss Cheese Model proposed by Reason in 1990, such models as accident-cause model for sociotechnical system by J. Rasmussen and STAMP model by Nancy G. Leveson have been widely applied by the scholars and businesses both at home and abroad [7]. Nevertheless, this paper chooses accident-cause 24 model to analyze the accidents on the basis of the logic and operability therein. The team initializing the model had made several revisions to it according to the previous work until a relatively complete accident-cause model gets established and widely applied. In addition to the strong operability, the accident-cause 24 model is also developed with coal mine field as the research object so that the accident analysis here can be more specific. The accident-cause model well defines accident, source of danger, and all sorts of causes (including all the unsafe behaviors and physical states), proposes the idea that all the accidents can be attributed to the artificial unsafe acts, and demonstrates both executive level and common employees can be the initiators of unsafe work [8]. By referring to the definition of unsafe act in 24 model, the author set to find all the unsafe acts in the study cases herein and locate the critical ones as per the frequency of occurrence. All the unsafe acts mean the acts of unsafety arising from the whole accident. The unsafe acts in one accident are composed of several acts of unsafety [9].
3. Classification of unsafe acts

Classification of unsafe acts is conducive to more effective prevention of accidents and elimination of all the unsafe acts in a category can prevent the occurrence of an accident of such category.

Identification of unsafe acts in 24Model is based on three aspects: (national, industrial, and organizational) rules and regulations, cases of accidents, and risk evaluation. Unsafe acts can be also divided into non-conforming acts, conforming but accident-triggering acts, and conforming but highly risky acts, or further subdivided into unsafe operation, unsafe action, and unsafe commanding (see Table 1) [10]. Analysis of unsafe acts for gas explosion is limited to an organization. This paper tries to analyze the non-conforming acts in accordance with the coal mine safety regulations released in 2016 by the state as well as a series of rules and regulations drafted within the enterprises. Non-conforming act means the employee commits any unsafe act by violating the coal mine safety regulations during the work; conforming but accident-triggering act means the employee triggers an accident but violates no rules or regulations during the work, and the conforming but highly risk act can be assessed as per the rules and regulations, cases of accidents and risk evaluation.

| Name                      | Non-conforming                  | Conforming but accident-triggering | Conforming but highly risky |
|---------------------------|---------------------------------|------------------------------------|-----------------------------|
| Unsafe operation          | Non-conforming and unsafe       | Conforming but accident-triggering | Conforming but highly risky |
| Unsafe action             | operation                       | operation                          |                             |
| Unsafe commanding         | Non-conforming and unsafe       | Conforming but accident-triggering | Conforming but highly risky |
| Judgement basis           | (National, industrial, and      | Rules and regulations and          | Rules and regulations,      |
|                           | organizational) rules and       | cases of accidents                  | cases of accidents,         |
|                           | regulation                      |                                    | risk evaluation             |

4. Analysis of unsafe acts during a gas explosion accident

4.1. Statistics of unsafe acts

Altogether 63 major and particularly major gas explosion accidents in past decade are selected from 2007-2016 An Analytic Report of Coal Mine Accidents [11] [12] [13] [14] [15] [16] [17] [18] [19] [20] across the Country and set as the research object of the present paper. The aforesaid accident-cause 24Model is employed to carry out statistics of unsafe acts contained in the samples.

A preliminary analysis of the causes of those 63 major gas explosion accidents during the ten years suggests there are altogether 76 unsafe acts that are committed for 494 times cumulatively. When focusing on the analysis of unsafe acts, the author combines mineral mining staff in GB/T6565-2009 Classification and Codes of Occupations [21] with previous research [22] by dividing the mining staff to be decision makers and production workers and the latter to be fireman, coal diggers, gas inspectors, security inspectors, and supporting workers. However, due to lack of definite criteria for occupations classification in coal mine industry, the occupations and acts summarized in this paper don’t strictly echo with each other. In accordance with Coal Mine Safety Regulations (2016), 76 unsafe acts are determined and classified by names. The classified names of unsafe acts are proper for the expression in operation site and can facilitate the accident prevention work (see Table 2).

1) There are 24 non-conforming unsafe acts, including “lack of three inspections for one detonation”, “use of non-conforming blasting substances”, and “massive non-protected working in gob”, initiated by fireman, underworking digger and bricklayer, coal digger, initiating and explosive articles administrator, filling and recovery worker, hydraulic supporting staff, pit detector, and gas inspector. Those 24 non-
conforming acts are further divided into 4 categories by the author according to coal mine safety regulations, namely “non-conforming blasting”, “non-conforming roof caving”, “incomplete security inspection” and “non-standard operation of electrical equipment”.

(2) Twenty-four unsafe acts are concluded from the non-conforming acts, including “making false report to superior”, “concealing data from methane sensor”, “non-standard setting or lacking of ventilation facilities”, “omitting pre-mining body search” and divided into four categories: “evading security supervision”, “disordered ventilation system management”, “failure in performing equipment and facilities inspection” and “risky operation”. The initiators of such acts include mine ventilation worker, mine electrical anti-explosion worker, and materials purchaser.

(3) As for non-conforming commanding, there are 28 unsafe acts, including “lack of comprehensive firefighting system”, “lack of integrated outburst-proof system”, “no rescue agreement”, “illegal cross-layer or -boundary mining”. Such acts are usually initiated by the decision-makers in a business, such as president and manager. Those 29 unsafe acts are categorized into four kinds: “lack of comprehensive mine production system”, “lack of first-aid and rescue services”, “improper staffing and management”, and “illegal production”.

### Table 2. Identification table for unsafe action of 63 major and particular major gas explosion accidents

| Non-conformance                                                                 | Staff                          | Category                        | Items in Coal Mine Safety Regulations |
|--------------------------------------------------------------------------------|--------------------------------|---------------------------------|---------------------------------------|
| Lack of “three inspections for any blasting”                                    | Fireman                        | Non-conforming blasting          | Article 347 and 350                    |
| Lack of interlinked-three system                                               | Roadway digger and brick-layer Miner |                                |                                       |
| Improper exploder operation                                                    | Initiating and explosive articles administrator |                               |                                       |
| Use of illegal blasting article                                                |                                |                                 |                                       |
| Unsealed shot hole                                                             |                                |                                 |                                       |
| Massive non-protected working in gob                                           | Filling and recovery worker     | Non-conforming roof-caving       | Article 101 and 278                    |
| Improper unsealing                                                             | Hydraulic supporting staff      |                                |                                       |
| Improper sealing                                                               | Pit detector                    |                                |                                       |
| Failure in clearing the float coal                                            |                                |                                 |                                       |
| Lack of gas inspection                                                         | Gas detector                    | Incomplete security inspection   | Article 4 and 451                      |
| Lack of potential risk detection                                              | Gas outburst-proof worker       |                                |                                       |
| Untimely elimination of roadway ponding                                       | Security inspector              |                                |                                       |
| Lack of electric gas detector                                                 | Supporting staff                |                                |                                       |
| No overhauling of roof support                                                |                                |                                 |                                       |
| Live overhaul                                                                  | Electric inspector              | Non-standard operation of electrical equipment | Article 161 and 443 |
| Unauthorized change of miner light structure                                   | Miner light administrator        |                                |                                       |
| Unauthorized starting of faulty conveyor                                       | Chain conveyor operator         |                                |                                       |
| UnAuthorized opening of air door | Power supply administrator |
|----------------------------------|----------------------------|
| Unauthorized power disconnection or connection | |
| Unauthorized starting or stopping of draught fan or blower | |
| Operation of non-explosive-proof tricycle | |
| Non-conforming operation of welding gun | |
| Non-conforming operation of electric coal drill | |
| Non-conforming operation of coal rake | |

| Drawing falsification | Engineering technician |
|-----------------------|------------------------|
| Making false report to superior | Mine surveyor |
| Concealing of data from methane detector | |
| Failure in recording off-limit gas value | Evading security supervision |
| Setting of false number of underground worker | |
| Lack of monitoring and positioning systems in guard room | Article 492 and 493 |

| Non-standard or lack of ventilation facilities | Mine ventilation administrator |
|-----------------------------------------------|-------------------------------|
| Ventilation through air door | Disorderly ventilation system management |
| Use of non-standard ventilator | Article 139 and 142 |
| Lack of ventilation system drawing | |
| Lack of local fan use instructions | |

| Our-of-repair explosive-proof facilities | Electrical explosive-proof inspector |
|-----------------------------------------|-------------------------------------|
| Non-overhauled blower | Shaft repairman |
| Insufficient gas sensor | Security apparatus supervisor |
| Out-of-repair steel wire rope of scraper | Product security performance inspector |
| Out-of-repair monitoring and testing systems | |
| Failure in performing equipment and facilities inspection | Article 435 |

| Entering dangerous site | General worker |
|-------------------------|----------------|
| Risky operation | Article 13 and 265 |
| Unsafe commanding                | Self-rescuer administrator | Materials purchaser | Mine dust-proof administrator | Outburst-proof administrator | Mine dust detector | Mine inspector | Lack of comprehensive mine production system | Article 70 |
|---------------------------------|---------------------------|---------------------|-------------------------------|-----------------------------|---------------------|----------------|---------------------------------------------|------------|
|缺乏全面的消防安全系统          |                           |                     |                               |                             |                     |                |                                              |            |
|缺乏综合防突系统                  |                           |                     |                               |                             |                     |                |                                              |            |
|缺乏综合防尘系统                  |                           |                     |                               |                             |                     |                |                                              |            |
|缺乏生产图                           |                           |                     |                               |                             |                     |                |                                              |            |
|缺乏地面气抽泵                     |                           |                     |                               |                             |                     |                |                                              |            |
|不足2个安全出口                   |                           |                     |                               |                             |                     |                |                                              |            |
|无救援协议                        |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|无应急预案                        |                           |                     |                               |                             |                     |                |                                              |            |
|缺乏自我救援                       |                           |                     |                               |                             |                     |                |                                              |            |
|故意迟报或隐瞒事故               |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|非标准化救援指挥                 |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|未及时撤离                       |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|缺乏地下作业人员                  |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|特殊操作员未取得合格证件           |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|超量地下作业人员                 |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|无班前会议                       |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|无劳动合同                       |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|缺乏安全教育和培训                |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|无保安工程人员                     |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|缺乏标准化工程人员                |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|不合格的工作人员和管理               |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|无照开采                          |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|转包生产                          |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|越层越界采矿                      |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
|非法生产                          |                           |                     | Mine rescue staff             | Lack of emergency rescue     |                     |                |                                              | Article 18 and 19 |
Unauthorized change to production system
Non-standard mine closing
Unauthorized production recovery during suspended production
Production through illegal power connection or stealing
Incompetent managing staff
Underground work without being supervised by mine leader

4.2. Analysis of key unsafe acts

4.2.1. Summary of key unsafe acts. In accordance with the case study and classification of unsafe acts above, we can summarize the frequency of those unsafe acts. The importance of such acts can be judged as per their triggering frequency. Those with higher triggering frequency are usually called “key unsafe acts”. The accidents can be better prevented if we can analyse the triggering frequency of each unsafe act and find out the key unsafe acts.

The frequency ratio of every unsafe act is provided in Fig. 2a. Among the 63 major gas explosion accidents occurring between 2007 and 2016, there are 24 non-conforming unsafe acts which can be categorized into four kinds at the frequency of 141. “Incomplete security inspection” occurs most frequently among all the non-conforming acts with the frequency being 49, in which “non-conforming blasting” occurs for 37 times. Incomplete security inspection incorporates “no gas inspection”, “no potential risk inspection”, “untimely elimination of roadway ponding”, “no gas interlocking”, and “no overhauling of roof support”, and other two categories of unsafe operation occur for 55 times. The key unsafe act in non-conforming operation is “incomplete security inspection work” which is against Article 4 in Coal Mine Security Regulations. According to the article, the operators must abide by security check mechanism and potential risk detection, governance and reporting systems. The highest frequency of such unsafe act can be attributed to the negligence of security inspection mechanism and prevailing “empiricism” among security inspection staff. To prevent the occurrence of this act, it is necessary to draft security inspection rules on the basis of relevant rules and regulation and demand strict compliance among the employees and provide related training for the employees to strengthen their awareness of security on the other hand. The key unsafe act in the category of non-conforming operation is “incomplete security inspection work”.

Altogether 24 unsafe acts of four categories are included in the non-conforming action at the frequency of 155. Among them, “risky operation” occurs most frequently for 49 times which account for 10% of all the frequencies. It is inclusive of “entering dangerous site”, “omitting pre-mining body search”, “omitting pre-mining registration”, “no methane alarm apparatus”, “no self-rescuer”, “entering mine with open fire”, “smoking during underground work” and “purchasing disqualified initiating and explosive articles”. The second most frequently occurring unsafe act in this part is “failure in performing equipment and facilities inspection” at the frequency of 47 times and the acts of other 2 categories occur for 59 times in all. Both entering a dangerous site and untimely evacuation in case of a fire accident belong to “risky operation”. These are against Article 265 in Coal Mine Safety Regulations according to which when any sign of a fire accident is discovered, it is a must to stop the work immediately,
evacuate all the workers, and block the dangerous zone. The occurrence of this kind of unsafe acts is primarily caused by the employees’ failure in taking effective and prompt measures when encountering such danger. In addition, the team leader also fails to organize an evacuation of workers in front of such a danger and develops the habit of committing such unsafe acts. Higher mortality may be caused due to the unawareness of the danger among the employees. To prevent such unsafe acts, the team leaders and general workers should be offered training about “risky operation”, and rehearsals of similar scenes can be scheduled. When any sign of a fire accident is detected and it is decided that the accident is out of control, the team leaders can instruct the workers to escape from the scene, block the site, and lead all the workers in other areas to evacuate in a good order. The key unsafe act in non-conforming action is “risky operation”.

There are 28 unsafe acts incurred by non-conforming commanding and they can be divided into 4 categories. They occur for 198 times in total. The act with highest frequency (89, 18%) is “illegal production”, under which there are such unsafe acts as “unlicensed exploitation”, “subcontracted production”, “beyond-capacity mining”, “cross-layer or -boundary mining”, “unauthorized change to production system”, “non-standard mine closing”, “unauthorized production recovery during suspended production”, “production through illegal power connection or stealing”, “incompetent managing staff” and “underground work without being supervised by mine leader”. It is followed by “improper staffing and management” at the frequency of 68 (14%). The total frequency of other two categories, namely “lack of emergency rescue” and “lack of comprehensive mine production system”. Illegal production is forbidden in Article 1 and 3 in Coal Mine Safety Regulation which explicitly specify that safety production permit system should be performed in the coal production, and those without such permit should not be engaged in the coal production activities. The mine owner is either unaware of the danger of unlicensed mining or leaves the things to chance by arranging employees to conduct risky production for maximization of profit. In accordance with the Regulations, the mine owner or administrator should take the work with permit and regularly accept security training, and those obeying no such rules shall be forbidden from undertaking the job. “Illegal production” is identified as the key unsafe act in this category.

4.2.2. Detailed analysis of key unsafe acts. As shown in Fig. 2b, (1) when non-conforming operation is concerned, 32 of 63 accidents (23%) in question are caused by “lack of gas inspection” followed by “lack of three inspections for any blasting” (15, 11%), “improper sealing” and “lack of potential risk inspection” (11, 8%), “lack of interlinked-three system” (9, 6%), “use of illegal blasting article”, “live overhaul” and “non-conforming operation of electric coal drill” (7, 5%), and other 16 non-conforming operation acts (29% in total).

(2) As for non-conforming action, “non-standard or lack of ventilation facilities” occurs in 23 of 63 accidents (15%) and becomes the most key unsafe act in this category, followed by “out-of-repair explosive-proof facilities” (17, 11%), “insufficient gas sensor” (14, 9%), “out-of-repair monitoring and testing systems” (13, 8%), “entering dangerous site” and “lack of self-rescuer” (12, about 8%), and other 18 non-conforming actions (41% in total).

(3) In the category of non-conforming commanding, it is evident that the frequency ratio of “cross-layer or -boundary mining” is 14% which is highest in all 28 unsafe acts. The remaining list goes as follows: “special operator without due license” and “unauthorized production recovery during suspension” (22, 11%), “no security training and education” (21, 11% or so), “insufficient underground staffing” (17, 9%), and the remaining acts (46% in total).
Improper roof caving
Non-conforming blasting
Inadequate security inspection
Unauthorized operation of electrical equipment
Evading security supervision
Disorderly ventilation system management
Failure in performing equipment and facilities inspection
Risky operation
Lack of complete mine production system
Lack of emergency rescue
Improper staffing and management
Illegal production

Figure 2. *a* Percentage distribution of unsafe acts frequency in 63 major and particular major gas explosion accidents
5. Conclusion

(1) There are altogether 76 unsafe acts in 63 major gas explosion accidents during 2007-2016 and the total frequency is 494. Among them, 24 unsafe acts can be categorized into non-conforming operation at the frequency of 141 times and “no gas inspection” is identified as the key unsafe act at the frequency of 32 (23%).

(2) Non-conforming action incorporates 24 unsafe acts with a total frequency of 155. Among all those unsafe acts in this category, “non-standard or lack of ventilation facilities” is identified as the key unsafe act that occurs in 23 of 63 accidents and accounts for 15% of all the non-conforming actions.

(3) In non-conforming commanding, there are 28 unsafe acts with accumulated frequency reaching 198 times. Among them, “cross-layer or -boundary mining” is determined as the key unsafe act that occurs in 28 accidents (14%).

(4) Those key unsafe acts are initiated by different people in a mining enterprises with “no gas inspection” usually by underground gas inspector, “non-standard or lack of ventilation facilities” by mine ventilation administrator and “cross-layer or -boundary mining” by decision-makers such as president or manager.

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