



# Accident-causing mechanism in coal mines based on hazards and polarized management



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## ABSTRACT

Hazards are elements that could cause harm or loss and are sources of risk. This paper classifies hazards associated with coal mining. Specifically, hazards are categorized into root hazards and status hazards, and the status hazards are further divided into unidentified status hazards and identified status hazards, and the identified status hazards include controlled and uncontrolled status hazards. It also explores in some detail the relationship between hazards, accidents and accident-causing mechanisms. The accident-causing mechanism of “three layer of defense” is proposed based on root hazards and status hazards definition and classification, including control criteria, control measures, and rectification measures, which demonstrates that the uncontrolled status hazards and unidentified status hazards are the two main accident-causing sources. The paper then ideas of polarized management of hazards as a means of maximizing the identification of the root hazards and their corresponding status hazards, minimizing out of control probability of the identified status hazards, and minimizing accidents probability caused by the uncontrolled status hazards. Finally, the polarized management methods of hazards are put forward respectively, which include root-status hazards identification, formulation of control criteria and control measures, and rectification measures.

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## 1. Introduction

Underground coal mining is recognized as one of the riskiest operations worldwide (Lama and Bodziony, 1998; Sari et al., 2004, 2009; Duzgun and Einstein, 2004; Duzgun, 2005; Grayson et al., 2009; Maiti and Khanzode, 2009; Paul, 2009; Shahriar and Bakhtavar, 2009; Khanzode et al., 2011; Nieto et al., 2014). Underground coal miners are exposed to hazards well in excess of those who working in most other occupations (Mahdevari et al., 2014). In underground coal mines there are a considerable number of hazards which include specialized equipment, high temperatures, humidity, rock stresses, coal and silica dusts, and harmful gases. These underground coal mining hazards have the potential to trigger accidents that can lead to injuries, multi fatalities and/or major asset losses unless risk control measures are implemented that effectively manage them.

Currently, there are quite a few definitions of hazards in the literature (Chen, 1995; Health & Safety Commission, 1976; Health and Safety Executive, 1999; He and Tian, 2000; Sperber, 2001;

Baun et al., 2006; McCoy et al., 2006; Jeong et al., 2008; Keckojevic, 2009; Aven, 2010, 2011, 2012, 2013; Liu et al., 2011; Chen et al., 2012; Feng and Wang, 2013; Liu and Li, 2014). For example, in OHSAS 18001 (2007), defines hazards as the roots or conditions which could lead to injury or illness, property damage, environmental damage, or combination of these states; Hazards are things that have the potential to cause harm and/or damage (ISO Guide 73:2009; AS/NZS ISO 31000, 2009). Besides, Tian (2001) proposed the “Theory of Three Types of Hazards” which classifies hazards into the following three types of dangerous sources. The first is accidental discharge of energy or a dangerous substance. The second refers to unsafe factors (e.g., safety equipment failure, individual unsafe behavior, etc.) causing invalid function which fails to restrict the first type hazards. The third consists of institutional mistakes (e.g., culture, regulations, etc.), organizers’ unsafe actions and mistakes, etc. The consequence of an accident is determined by the first dangerous sources. The occurrence or possibility of an accident depends on the second dangerous sources. The third type is the essential reason for the occupational hazards’ occurrence, which is also the potential reason for the former two (Tian et al., 2007). In addition, the Mining Hazards Database sponsored by the Queensland Government was compiled by assessing the hazards that could exist in each coal mining activity or element, including five accessible sections – General Mining Hazards,

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Surface Mining Hazards, Underground Mining Hazards, Alerts by Hazard, and Hierarchy of Controls. The original data mainly came from multidisciplinary teams of mineworkers, mine management, inspectors of mines, and where relevant experts from other fields. Besides the Mining Hazards Database, the Minerals Industry Risk Management Gateway (MIRMGate) developed by the University of Queensland is a portal to a comprehensive library of information related to hazard and risk management in the mining, minerals processing and quarrying industries ([www.MIRMGate.com](http://www.MIRMGate.com)). MIRMGate provides direct access to online resources sourced from Australian and global minerals industry bodies, including companies, industry associations and regulatory bodies. The above researches provide a promising theoretical support for improving risk management in coal mines. However, the current studies of hazards do not address or clarify the misunderstanding or confusion about the internal relations of hazards, risks, and accidents, which can undermine the ability to discern objects of risk management and perform effective risk management activities. Therefore, to help address the gaps in the research, this paper classifies the hazards deeply in coal mines and differentiates their relationship with accidents and then explores accident-causing mechanism based on the above hazards classification, and puts forward the polarized management of hazards finally.

The remainder of this paper is organized as follows. In Section 2, we categorize the hazards into root hazards and status hazards in coal mines. In Section 3, we mainly differentiate and analyze the relationships between hazards and accidents and then explore the accident-causing mechanism in coal mines. In Section 4, we apply the accident-causing mechanism to control of the roots of accidents, namely put forward polarized management of hazards. Finally, we conclude this work in Section 5.

## 2. Hazards classification and definition

In this study, the hazards are defined as the roots that could cause harm or loss and are sources of risk, which is consist with the definition in ISO Guide 73. Hazards are categorized into root hazards and status hazards. Root hazards are the root cause of accidents in coal mine, which are objective and inherent in the underground coal mining and production process regardless of being identified or not. They are further classified into people, machine, environment, and institution. Specifically, the root hazards from people refers to working positions in coal enterprise, such as coal mining machine driver, gas monitor, and coal digger, the root hazards from machine refers to all the machinery and equipment, such as coal mining machine, scraper chain conveyer, and hydraulic support, the root hazards from environment refers to natural geological conditions and working environment, such as methane, groundwater, and coal and silica dusts, and the root hazards from institution refers to organization structure, safety culture, rules, regulations, etc. (Li and Song, 2007; Li, 2009, 2010; Liu et al., 2011; Liu and Li, 2014).

The status hazards are the unsafe conditions or unsafe behaviors that can release or allow a root hazards to trigger an accident. Status hazards are related to root hazards. For example, status hazards of relating to people mainly refer to human's unsafe behavior, such as a status hazard might be improper gas emission monitoring from gas drainage worker, or unreasonable ventilator installation from ventilator worker. Status hazards of machine mainly refer to machine's unsafe status, such as air duct leakage and unqualified detonator. Status hazards of environment mainly refer to environment's unsafe status, such as coal spontaneous combustion and high gas concentration in heading face. Status hazards of institution mainly refer institutional deficiencies, such as unreasonable organization structure and shortage of drainage worker.

These status hazards have the potential to cause harm and/or damage. Furthermore, the status hazards are further divided into identified status hazards and unidentified status hazards, and the same applies to the root hazards namely identified root hazards and unidentified root hazards.

Risk control management of safety in coal mines should be established on the basis of the identified root hazards and their corresponding status hazards. If the identified status hazards are further divided, they can be divided into controlled status hazards and uncontrolled status hazards (status hazards which have gone out of control). Controlled status hazards refer to the situation where the root hazards are managed within normal and safe operating parameters. On the contrary, the uncontrolled status hazards refer to the situation where the root hazards could be operating out of safety control criterions, which are operating conditions that could trigger accidents under some conditions. An illustration of the above classification of hazards is shown in Figs. 1 and 2.

## 3. Accident-causing mechanism based on hazards

### 3.1. Relationships between hazards, risk and accidents

There exists a misunderstanding or confusion on the concepts between hazards, risks, and accidents, resulting in difficulty to discern objects of risk management and perform effective risk management activities. Therefore, it is crucial to differentiate and analyze the relationships between hazards, risks, and accidents. The hazards are the roots that could cause harm or loss and are sources of risk. Risk is the effect of uncertainty on objectives caused by variability and specific uncertain events. It is often measures in terms of consequence and likelihood. Hazards are the prerequisites for risks. Risks can be associated with hazards that can cause accidents that can impact objectives or opportunities that can lead to benefits that can impact objectives. When all the hazards are safely controlled, there is no risk except residual risk. Conversely when certain hazard is out of control, namely there is an uncontrolled status hazards then there is an unacceptable level of risk. The goal is to implement sufficient controls so that the residual risk of the hazards resulting in accidents is reduced to a tolerable/acceptable level. The uncontrolled status hazards are the status hazards which have gone out of control and are the direct causes of accidents under some conditions.

In order to provide basis of accident-causing mechanism, the relationships between the hazards and accidents is studied in-depth. As demonstrated in Fig. 1, the status hazards consist of the identified status hazards and unidentified status hazards. Firstly, because of the limited knowledge of human, the identification of status hazards exist blind area, namely exists the unidentified status hazards which are directly in a status of non-defense. Consequently, the unidentified status hazards are the biggest threats. Therefore, comprehensive and in-depth identification of status hazards, namely eliminating the blind areas, is paramount in avoiding accidents. Secondly, control criterions and control measures should be setup to manage the identified status hazards. The control criterion is the control of hazards to what extent can eliminate the risk of hazards, which can be formulated according to relevant state criteria, industry criteria, and manufacturer criteria. The control measures are methods or means to achieve control criterions. If the identified status hazards meet the control criteria, they are called controlled status hazards which do not have the potential to trigger accidents as shown in Fig. 3. If the status hazards do not achieve the control criterions, they are considered uncontrolled status hazards which result in out of control operations that could potentially trigger acci-

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