Evidence-Based Approach to Mine Safety, Health and Environment Integrity

Zhongxue Li¹, Shuaiqi Wang¹, Wenguang Li² and Yiqing Zhao^{1*}

¹ Department of Mineral Resources Engineering, University of Science and Technology Beijing, Beijing, China

² Blekinge Institute of Technology, Karlskrona, Sweden

Abstract: Faced with the serious managerial situations and diverse conditions and needs for mine safety, occupational health and environmental stewardship in Chinese mining communities, an evidence-based approach is proposed for the management of mine safety, health and environment integrity. By the proposed approach, tangible and effective scientific evidence should be collected and accumulated, and the authenticity, accuracy and applicability of the evidence should be assessed to form an evidence-based approach for characterizing mine safety, health and environmental hazards and risks from multidimensional perspectives. The results are then used to formulate diverse safety, health and environment functional requirements. In an evidence-based approach, the evidence is combined with the professional experiences and the actual economic and technological situations, availability and affordability of a mine. This approach is helpful to establish scientific, reasonable, acceptable and effective solutions for identifying and mitigating hazards and improving the level of mine safety, health and environment integrity of mining operations.

Keywords: integrity, evidence-based approach, risk characterization, functional requirements

1. Introduction / Background

In recent years, economic reforms have opened China's economy so that Chinese society has rapidly modernized. Along with this advancement, the exploitation and utilization of mineral resources continues to be active and the scale of mining production continues to increase, which has created a deterioration in resource reserves and as well as the general condition of mining technology. There are many hazards and safety problems in mine production and occupational health as well as in the community environment in China's mining industry. These problems threaten the security of China's mines and present serious obstacles and challenges to the industry and the government. According to the statistics from the State Administration of Work Safety Supervision, there were 50,500 mine safety incidents in China between 2001 and 2013, which consisted of 31,439 coal mine safety accidents and 19,061 non-coal mine safety accidents, resulting in 30 deaths (Qin 2014). At the same time, mineral dust and radioactive material from mine production processes have increased the morbidity rate of silicosis and cancer in mining workers.

In short, there is a wide variety of safety, health and environmental dangers present in this patch work of mines. Based on the current grim status of mine safety, worker health and environmental quality, and a host of other issues, an evidence-based study is proposed herein that will help to attain the objectives of mine safety, which will be based on practical requirements.

Safety Integrity Management (SIM) is a discipline that was first introduced in the 1970s. It has gained increased interest as the scale of industrial mechanization and

automation has increased, which has resulted in an increase in the frequency of production accidents in equipment and process industries. Increased attention to SIM has resulted because of functional safety and the impact of programmable industrial control systems, large-scale equipment and special equipment, etc. The theory and practice of safety integrity management have been applied to various industries by the Health and Safety Executive (HSE), the American Petroleum Institute (API), American Society of Mechanical Engineers (ASME), National Institute for Occupational Safety and Health (NIOSH) and Mine Safety and Health Administration (MSHA) (Li et al 2017).

Safety integrity theory has also been used in China's oil and gas fields, as exemplified by the oil and gas safety standards SY/T 6621-2005, SY/T 6648-2006 and SY/T 6714-2008, which adopted the RBI safety integrity theory (NEA 2016). The analysis of failure, construction of case base, the identification technology of the risk factors and potential dangers, risk assessment technology, detection technology, fault diagnosis technology, disaster assessment technology, etc., have also been widely applied in China's industries and have produced good results (Sammarco 2002).

This reported study promotes systematic and multi-dimensional analyzes of hazards of accidents and the problems of risk prevention by introducing the concept of safety integrity to the system of safety and disaster risk prevention and control. This will lead to the establishment of the framework for the theory and methodology of mining safety, health and environment integrity, which will include engineering technology systems, laws and regulations and a supporting environmental system. The product will promote

* Corresponding Author: Y.Q. Zhao, zyq@ustb.edu.cn, phone: +86 18500225299

intrinsic safety in mines, eliminate hazards, and reduce the risk of accidents.

2. Evidence-based Mine Risk Characterization

2.1 Benefits of evidence-based approach

In order to effectively reduce the safety, health and environmental risks in a mine, and decrease the incidence of mine accidents, miner health damage and environmental damage, it is necessary to find a scientific, reasonable method for mine integrity management by collecting, summarizing, analyzing and applying the best and most appropriate scientific data to solving these problems (Baxter et al 2008). As is well known, there are many problems in mine production management, including management personnel, that is tasked with decisions concerning mine construction and production which are based on personal experience and cost (Farley et al 2009). However, many safety, health and environmental conditions contain unknown dangers, because of incomplete and unreasonable data. The use of an evidence-based approach to mine safety, health and environment integrity can reduce or even eliminate mine hazards, and health and environmental risks through evidence-based management. In addition, when an accident occurs, the necessary control measures can be adopted to prevent further incidents based on the guidance provided by the data. In addition, using this verifiable evidence, the relevant responsible party, or parties in the case of mutual prevarication, can be found which will improve the level of management in the mining enterprise (Li et al 2017).

2.2 Evaluation of the evidence

Permission from the relevant parties in a mining company is needed to obtain the necessary scientific and reasonable safety, health and environmental information for this system. Since each mine is unique, it is difficult to obtain sufficient, high quality evidence on the safety, health and environment in each mine to establish a general mine integrity management system. Therefore, this evidence-based management study has endeavored to obtain the best factual evidence concerning mine safety, health, and environmental integrity, while taking into consideration the actual economic situation and the profitability of each mine (Schalock et al 2014).

The evaluation of the evidence in mine integrity management is the basis for the system. Evidence-based integrity management employs the most effective and reasonable evidence based on laws, regulations, case analysis, and related research reports, among other sources. The composite evidence from different sources has varying significance and authenticity. For example the evidence from the laws and regulations is more reliable than research reports, and direct evidence is more reliable than indirect evidence. According to the classification of medical evidence, the evidence for mine safety, health and environment integrity is divided into the following three levels (A. rules and regulations; B. research literature; C. others), which is shown in Table 1 (Zhang et al 2012).

At the top of the hierarchy are the data and information obtained from rules and regulations, followed by the evidence gleaned from research reports. The evidence taken from rules and regulations are less biased than the information from obtained from other sources (Nold and Bochmann 2010). The narrower the triangle in the table is, the smaller the bias of the evidence is, and the stronger the credibility of the evidence is.

Table 1. Grading of information and data used in mine integrity management.

Evidence grades in mine integrity management		Bias	Evidence
A	1. National laws		
	2. Various legislations		
	3. Industry standards and department regulations		
B	1. Systematic and high-quality summary		
	2. Data statistics and analysis		
	3. Contrastive study of multiple cases		
	4. Successful practice experience		
C	1. Multiple expert opinions and reports		
	2. Safety, health and environment accident case		

2.3 Mine risk characterization and evaluation

In order to obtain an analysis of mine safety, health and environment integrity, hazards need to be identified and assessed. The hazards originate in a number of areas such as the tailings system, mining subsystems and perforation process among others. These risks are assessed using the available most reasonable scientific data and professional experience in the mine based on a feasibility study. The life cycle of a mine includes planning and design, construction and installation, construction operations, acceptance and trial production, closure maintenance, ecological reconstruction etc. These various stages are all part of the risk feasibility assessment.

In the process of conducting a mine risk feasibility study, it is necessary to obtain an in depth understanding of the resources, geological conditions, production processes and environmental factors of the mine. At the same time, consideration must be given to the potential side effects of these factors on mine production safety, the health of workers and residents, and the environment. It is possible to alleviate potential risks by using an alternative design or technology, which can be found from the evidence of national laws, regulations, literature searches, research reports, expert reports and other sources. The list of hazards for each mine is compiled using an evidence-based identification system. Decision-making processes and results at each stage of the project are documented. The cost of the risks are assessed and controlled. Pre-risk analysis is adjusted according to the specific situation.

In the plan and design stage of the mine, it is necessary to systematically analyze the mine's design to determine all the safety, health and environmental risks in all the processes required in mine production. Evidence-based hazards identification and risk assessment are needed to determine the necessary prevention and control measures. In the mine construction, installation and operation phase, it is inevitable that a review will be required using evidence assembled for the construction program and prevention and control of risk identification, analysis and evaluation methods. In the stage of mine acceptance trial production, the entire process of risk management will be reviewed as a supplementary assessment. The next step is a review of the previous assessment to ensure that all the required actions and preventive measures are implemented.

In the stage of mine production operation, it is necessary to ensure that all of the mine equipment is constructed and installed according to the design requirements. Implementing the mine construction project will ensure that the design requirements are satisfied. At the stage of pit maintenance, reuse and ecological reconstruction, scientific and valid data are needed to assess a number of related issues, including, the risk of equipment evacuation, closure of the spot and dump, removal of buildings, reuse, secondary risks, spot reclamation and ecological reconstruction, closure of other facilities, community concerns and other related issues.

In the life cycle of a mine, the dormant, dangerous and active hazards of safety, health and environment are identified using the best available scientific evidence from technological system, human behaviour system, institutional system and man-machine interacting system. The level of risk of a mine-related system is determined by a risk assessment of that system based on the accepted level of risk for the safety, health and environment, and according to specific needs for the safety, health and environment integrity, the corresponding level of integrity is determined. Based on the scientific data obtained from the national laws and regulations, literature search, research reports, expert reports, etc., while taking into consideration the actual economic situation and the profitability of each mine, the appropriate system decisions are made. The necessary accident prevention and control measures are used through evidence-based intervention to eliminate risks and prevent safety accidents, health hazards, environmental impacts.

3. Mine safety, Health and Environment Integrity

The safety, health and environment integrity in mine production can be defined as the ability of the equipment and technology processes, personnel and management practices and the man-machine environment to properly implement or achieve the expected results, effect or function, under the defined conditions. This focuses on the specific mine production activities and processes, as shown in Figure 1. Safety, health and environment integrity do not mean that all risks are eliminated, but rather it is determined what integrity level of safety, health and environmental quality are acceptable based on the risk to the acceptable

limits of safety, health and environmental quality. Once this has been established, effective measures can be used to reduce or control the risks to the acceptable range for the technology, economy and society (IEC 1998).

Figure 1. Mine safety, health and environment integrity and its components.

3.1 Technology and system integrity

The equipment and technical process status of mine production activities and processes include geological mineral conditions, electromechanical equipment, artificial facilities, energy materials and other conditions (Li et al 2017). The hazards in these entities include unfavorable geological mineral conditions, lack of safety equipment or failure, aging, overloaded operation, poor materials, improper protection, uncontrolled release of energy of electromechanical equipment and so on. Through a systematic and comprehensive collection of evidence and the evaluation and classification of evidence, the necessary prevention and control measures can improve the technical status, and effectively eliminate the existing safety, health and environmental risks, and improve the level of the integrity of mine system by the use of the most scientific and reasonable evidence.

3.2 Human behaviour and system integrity

The psychology and behavior of people, especially in on-site operations and management personnel who control the production activities and processes affect production safety. Consequently, prevention and reduction of unsafe behavior can effectively improve the level of the safety, health and environment integrity of on-site operations. Evidence-based integrity management requires the collection of comprehensive, reasonable scientific evidence from all available sources to help classify mine safety, health and environment. The classification of the evidence is shown in Figure 1 and includes A-level evidence that has little bias and is highly reliable, with B-level and C-level evidence falling in next. In the practice of production, if a mine manager is not highly competent, application of high quality evidence in developing a risk management plan may not be sufficient to minimize safety, health and environment risks in the mine. In this case, corresponding safety, health and environment integrity steps should include, continued safety education and training, identification of related safety, health and environment hazards and identification of

workers who flaunt the safety rules; The process for monitoring safety violations should be bolstered and any rule violations or deviation from standard procedures should be corrected promptly. All staff should participate vigorously to ensure that the mine is operating in a controlled condition. Reward and punishment should be employed to associate employee behavior in the best interests of mine.

3.3 Institutional specification and system integrity

Effective regulations, specifications, standards, guidelines, signs, procedures of production safety, environment protection and human health are an important aspect of the safety, health and environment integrity of an institutional specification system. Institutional specifications for the safety, health and environmental integrity of the mine involve improving the safety, health and environmental regulations. It should be confirmed that all levels or professional regulations, norms, rules, standards, guidelines, procedures, signs, and procedures can be implemented effectively. This certification is a most important source of the evidence that forms the basis for the management system. A high target for mine safety, environment protection and personnel health is compiled based on the practical considerations of the workplace and the risk factors of the conditions and behavior. Integrity management measures need to be institutionalized and standardized, according to the life cycle of project design, construction, production, operation stages or the process of drilling, blasting, loading and other operation links, the operating procedures.

3.4 Man-machine interaction and system integrity

Most of the man-machine environment conditions in the mining industry are relatively poor. The adverse climate conditions and man-machine environment (including high pressure, intense heat, high humidity, space limitation) can lead to equipment failure or personnel failure (including landslides, roof collapse, water flooding, spontaneous combustion, falling, heatstroke). Either of these two events will result in safety, health or environmental accidents or disasters. It is necessary to compile associated evidence concerning the man-machine environment factors in specific areas and conduct a systematic and quantitative analysis of the resulting data using statistical methods such as meta-analysis. These subsequent analyses will determine the integrity of man-machine environment system and will allow the necessary measures to be adopted to meet safety, health and environmental needs. Evidence-based integrity measures include monitoring and controlling, forecasting and alarming, signs setting, ventilation, defending and protecting, emergency response mechanism, etc. (Li et al 2017).

3.5 Framework of mine safety, health and environment integrity

Based on the life cycle of a mine, the search range and search method for the evidence are determined from the technical process systems, the human behavior, the

institutional specification and the man-machine interaction system. Highly reliable A-level data can be obtained for these systems from the State Administration of Work Safety (SAWS), Ministry of Environmental Protection (MEP), the local environmental protection departments, Mine Safety and Health Administration (MSHA) and the Health and Safety Executive (HSE), etc. In addition, B-level and C-level evidence can be obtained from statistical data, comparative analysis of multiple cases and successful practical experience. The reasonable and scientific evidence is then used to identify the dormant, dangerous and active hazards of the safety, health and environment from the four systems in a mine.

Through the risk assessment, the risk level of safety, health and environment related systems can be determined. Then, according to the specific needs of these entities, the level of integrity that these entities can achieve can be assessed. In order to make the proper decisions based on the scientific and reasonable evidence available from laws, regulations, literature searches, research reports, expert reports and other ways, and it is important to combine the scientific evidence with the available professional experience and the actual economic situation and affordability to formulate the appropriate mine protocols. Employing evidence-based intervention together with a safety check list, the safety, health and environment integrity of mines can be objectively determined. If this system produces the desired results, it can be used as a practical guide and as new evidence emerges, that can be included in the system database to further improve the system. If the results of the implementation of the system are poor, then the evidence and the system itself will be reevaluated and implemented again with new evidence until the desired results are achieved. The required preventative measures will be used to gear the system to various levels of safety, health and environment integrity, in order to eliminate hazards and prevent accidents, and it will improve the level of mine safety, health and environment integrity and the overall management of the mine.

4. Conclusions

There are hundreds of mines in China, distributed over the entire country. Because these mines have very different types of resources, technology, regional economies and management and labour qualifications, there is a wide variety of safety, health and environmental risks throughout mining industry.

The scientific and effective evidence of mine safety, health and environment integrity is collected and divided into three grades. The decision-making in mine management was guided by the best evidence.

In an effort to provide some control over these hazards, an evidence-based and mine life cycle oriented safety, health and environment integrity management system was proposed to analyze the safety, health and environmental risks and the issues of risk prevention and disaster control from technical process system, personnel behaviour system, institutional specification system and man-machine

environment system, through a systematic, scientific, and multi-dimensional approach. This can help to improve mine safety, health and environment integrity, and ensure the effective protection of mine production safety, the health of mine workers and mine community residents and the mine environment.

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