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Highlights from the literature on risk assessment techniques adopted in the mining industry: A review of past contributions, recent developments and future scope

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ABSTRACT

In this paper a comprehensive review is presented of risk assessment techniques adopted in the mining industry worldwide; those techniques applied in other hazardous industries and potential techniques which are robust, mature and holistic and can be implemented for the Indian mining industry in future to enhance workplace safety are also presented. Findings from the review are indicative of the fact that socio-technical complexity of industrial systems has increased. Recent developments in the area of risk management highlight the need for implementation of the latest robust techniques of risk assessment in the mining sector. In consideration of the present scenario, the development of a model for risk analysis having an interface between hazard identification and risk assessment, along with an interface between risk assessment and accident causation to predict if an accident will occur under given conditions, has become dire necessity. This will increase hazard awareness and enable mine management to select and prioritize problem areas and identify safety system weaknesses in both underground and surface mining. This will ultimately help decision makers, risk analysts and safety managers make a major contribution in the development of workplace safety with a near-to-zero accident rate.

1. Introduction

Minerals constitute the backbone of economic growth of any nation and India has been eminently endowed with this gift of nature. Many minerals, namely oil, gas, coal, copper, lead–zinc, gold, iron, manganese, limestone and bauxite, all of which have high commercial value, are extracted in India. The life cycle of a mine consists of exploration, mine development, mine operation, decommissioning and land rehabilitation [1–5]. Mines are normally classified as metalliferous or non-metalliferous, and further subdivided into opencast or underground mines. Extraction of the mineral is fraught with innumerable dangers; mining has always been a hazardous profession, and in 1985 the government of India initiated steps to formulate legislative measures for the safety of workmen. In 1897, the first major disaster in mining occurred in the Kolar goldfields, killing 52 persons, to be soon followed by the Khost coal mine disaster in Baluchistan (now in Pakistan), killing 47 persons [1–4]. These disasters hastened the process of formulation of safety laws and as an outcome to this the first Mines Act was enacted in 1901 [1–4]. Risk assessment has now been made a requirement of the Occupational Health and Safety Act 2000 (Sections 7 and 8).

Risk assessment is the process of evaluating the risk(s) arising from a hazard(s), taking into account the adequacy of any existing controls, and deciding whether or not the risk(s) is acceptable (OHSAS-18001). A hazard is any situation, substance, activity, event or environment that could potentially cause injury or ill health (OHSAS-18001). Risk combines three elements: a potential event, with probability of its occurrence, and severity of consequence (OHSAS-18001). The following steps constitute the process of risk assessment (Report on Health and Safety Management System (RHSMS)): proper identification of the hazard, to know who is at risk, to understand the possible measures that can be taken to treat the hazard, minimise its impact in the workplace, to maintain the measure adopted for the future. This assessment will help decision makers to frame the mitigation plan and practice, so that a healthy workplace with near to zero accident rate can be developed. The flow chart for the research methodology is shown in Fig. 1.

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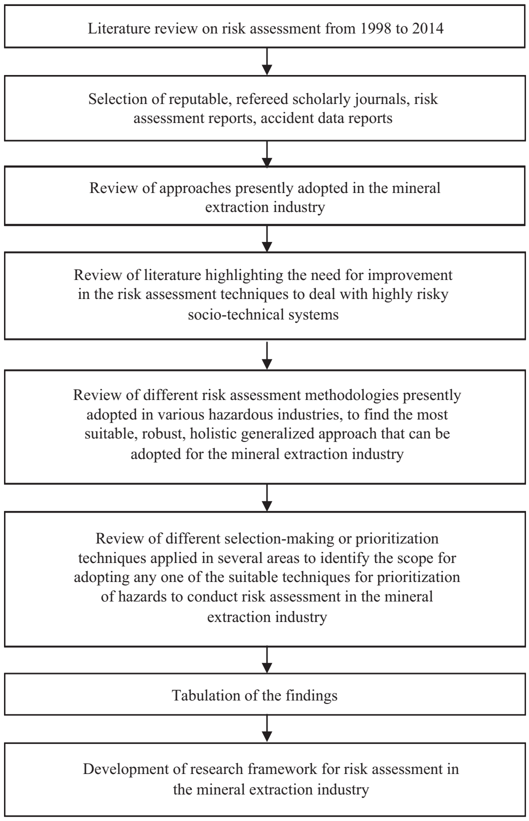

Fig. 1. Flow chart for research methodology.

2. Review of approach and techniques adopted in the mining industry for risk assessment (1992–2012)

In the Indian mining industry, one of the classical approaches, known as the Rapid Ranking Method (RRM), is widely adopted [6–8]. This technique gives a mathematical index *R* which is computed, based upon the following criteria: consequence of severity, exposure and frequency of occurrence. This approach is considered as one of the most robust and mature tools for risk assessment in the mineral industry. The technique discussed above is perception-based and therefore contains vagueness in the outcome at times because of biased opinions of experts participating in the process. Many other approaches have been adopted to deal with the lacunas of the traditional approach, which are further explained in this section. Mine Safety and Health Administration (MSHA) and Current Population Survey (CPS) data were examined to identify mining equipment related injuries. This study provides information concerning the mining equipment which was mostly involved in, or contributed to fatalities and injuries and the age group of workers with different levels of experience and related proneness to accidents [9]. A systematic risk analysis was undertaken to categorise injuries in US mining operations. The categories were: 'fatalities', 'Non-Fatal Days Lost (NFDL)' and 'No Days Lost (NDL)'. A risk matrix was produced which showed that there existed a serious level of fatalities and NFDL and a moderate level of NDL, therefore continuous effort to develop control strategies is required [10]. Incident rates and lost work time are very important indicators for evaluating safety and health performance. With the help of data on lost workdays, risk is being analysed to make comparisons between lower and higher risk operations for the period under study. In this study the problem related to unavailability of the denominator data was solved by examining the consequences of injuries and comparisons were made between disparate operations. The Beta distribution is adopted to model the losses and compare safety performance of metalliferous and non-metalliferous mines [11]. In another study, international evaluation of injury rates in coal mining is being carried out and comparisons are being made between risk and compliance-based regulatory approaches to see if a risk-based regulatory system may be associated with improvement in employee safety. To make the comparison, analysis of annual Lost-Time Injury (LTI) rates for bituminous coal mines in the US and two Australian mines is being carried out and generalised estimating equations have been developed to analyse the rate of change of Incident Rate Ratios (IRR) of LTIs among coal mines [12]. The Human Factor Analysis and Classification (HFACS) approach is being used in Australian coal mines to analyse safety data to evaluate preconditions associated with the mishaps so that in future such conditions can be controlled or avoided [13]. Several factors were identified to predict the presence of failures, including inadequate supervision, organisational climate, inappropriate operations, team resource management, etc. with application of the above technique so that, in future, attention should be paid to these associations to develop accident countermeasures. In open pit mining, working conditions are complex, more workers are involved in ore extraction, natural conditions are poor and the contour mining environment further enhances the complexity of working conditions. In such a working scenario, the application of an intrinsic safety approach can reduce the danger considerably by reducing the probability and severity of accidents [14]. The concept of organisational alignment is being introduced for the enhancement of workplace safety [15]. Frontline workers and managers were interviewed to check how much they were aligned with a set of new safety principles recently introduced by their company. The results were indicative; the records of above average and below average safety records were compared and it was found that workers with above average safety records more strongly aligned with safety principles. The risk assessment system is developed for mining industry specifically to control chemical exposure and its ill effects [16]. The factors considered for the development of the new framework for risk assessment for synthetic chemicals used in the mining industry are: selection of hazardous property categories, the method for scoring the hazardous properties of the chemicals considered, the assessment of data quality, etc. To monitor recurring hazards in the underground coal mining industry an important measure is suggested to be taken into consideration, namely, Time Between Occurrences (TBO). This measure could be modelled in the same way as Time Between Failures (TBF) is modelled in reliability studies. The model includes Weibull-distribution based hazard rate functions, Poisson distribution based cumulative risk functions and Weibull-distribution based control charts. This study also suggested that, along with planned inspections for hazard identification, a control chart scheme should be developed and employed for continuous monitoring and control of the hazards [17]. The Safety Element Method (SEM) is being adopted to improve the safety management system and the results, after its implementation in four Norwegian mines, were compared and were found to be satisfactory [18]. In SEM, subjective assessment played a vital role. The accident records maintained by the company, interview results, and questionnaire were reviewed. These internal assessments gave acceptable safety results, proving the method to be a valuable approach towards safety improvements. Mining injury surveillance data derived from MSHA (Mine Safety and Health Administration) is being used for the assessment of severity of injuries of operators and contractor employees [19]. This data is being analysed using a negative binomial regression model. The logarithmic mean injury rate is expressed as a linear function of the following indicators: namely, non-coal contractor, metal operator, non-metal operators. Mean injury rate for the indicators shown above is calculated based upon the relative year starting with 1983 as the base year. The mean injury rate for surface mining and underground mining for various minerals for all the indicators is