Title: **Impact of occupational hazards and individual characteristics in workers' injuries at Continuous Miner worksite**

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Abstract

Occupational injuries have a significant impact on individuals and their families in terms of economic consequences, and physical and emotional well-being. Moreover, they result in interrupted production and low morale among the workforce. According to recent estimates by the International Labor Organization, around 374 million non-fatal injuries and 2.78 million fatalities occur due to work-related accidents and occupational diseases each year. Asia is reported as the epicenter of occupational injuries and death, with a share of 65% of the global total. Rapid industrial growth in developing nations such as China and India has played a significant role in occupational health and safety issues in Asia. Triggered by industrialization and population growth, energy demand is also increasing worldwide. In the current scenario, coal is the prime source of energy for developing nations as well as many developed countries. As a result, demand for coal is growing, and so is the coal mining industry.

The Indian coal mining industry is shifting towards fully mechanized underground mining methods to fulfill the growing energy demand as coal reserves near the surface (ideal for surface mining) are depleting fast. As continuous miner technology is appropriate for the Indian geo-mining conditions, it is most favored among the highly mechanized system of underground mine workings. It is being implemented in India at a growing rate as part of India's drive to mechanize the coal mining sector. Continuous miner technology is also being used by the underground mining sector in the USA, Australia, and South Africa in different capacities and continuously proved to be an efficient technology for coal production and mine development over the last three decades.

Implementation of highly mechanized technology reduces the manpower and the number of exposed workers; however, engineering solution is not enough to prevent occupational injuries at the workplace. Statistics from countries like the USA, Australia, and South Africa, countries that are using continuous miner technology,

reveal that injury occurrences are still considerably high despite technological upliftment. Therefore, it is crucial to evaluate the injury occurrences at continuous miner worksites in India, identify their most potential predictors, and formulate safety interventions to mitigate the predictors.

A suitable methodology was developed for this study to evaluate continuous miner technology from the perspective of occupational safety and injury epidemiology. A very few studies have investigated continuous miner worksite injuries methodically. Also, most previous studies analyzed these injuries through classification-based and bivariate approaches. There is a scarcity of literature exploring the relationship between risk factors and occupational injuries at a continuous miner worksite in a multivariate situation. The present study developed a scientific methodology to address this research gap. The methodology has two verticals, one is macro-level analysis, and another is micro-level analysis. The macro-level analysis was carried out to establish causal relationships between prominent risk factors and occupational injury at continuous miner worksites using a matched case-control study design. The micro-level analysis was carried out to establish the association between operation hazards and occupational injuries related to primary machines at continuous miner worksites through a cross-sectional study design. Also, the present study provides a framework for identifying, selecting, and prioritizing safety interventions based on macro-level multivariate analysis outcomes (causal factors). The injury data for this study were collected for two-year period (2015 and 2016) from three continuous miner worksites located in the central part of India. These mines belonged to the same company and were located at the same geological formation. The case study mines employed a total of 883 workers at continuous miner worksites, and the average production per year per mine was 0.45 million tons during 2015 and 2016.

For this study, analytical epidemiological approaches were selected for data analysis based on the literature on injury epidemiology. For macro-level analysis, case and control groups were identified as per matched case-control study design to assess the effect of 12 hypothesized risk factors (individual factors and occupational hazards). 135 cases were matched with 270 controls (matching criteria: age and occupation; matching ratio: 1:2), so a total of 405 workers (135 case-control pairs) participated in this study. The bivariate analyses of the risk factors were made using the Mantel-Haenszel test. The conditional logistic regression model analyzed the hypothesized risk factors in a

multivariate situation. Results show that injuries were multifactorial. 8 risk factors out of 12 had significant crude odds ratios (OR). Multivariate analysis revealed that among 8 factors, 7 factors remained significant. Among individual factors, big family size (≥6 members), no formal education, and presence of disease had significant adjusted odds ratios (ORa) of 4.08 (95% CI: 1.65–8.29), 2.06 (95% CI: 1.65–8.29), and 2.94 (95% CI: 1.65–8.29), respectively. Among occupational hazards, statistically significant hazards were the following: hand tools-related hazards (ORa 3.69, 95% CI: 1.65–8.29), working condition-related hazards (ORa 3.11, 95% CI: 1.49–6.49), continuous miner-related hazards (ORa 1.95, 95% CI: 1.01–3.77), and shuttle car-related hazards (ORa 6.95, 95% CI: 3.02–15.99). Furthermore, the effect of age of the workforce on the causal relationship between risk factors and injury was examined. Dataset was divided into two age groups, workers aged ≤39 years and >39 years, for multivariate analysis using conditional logistic regression. Multivariate results reveal that the risk factors differed between the two age groups. For individual factors, big family size (ORa 2.07, 95% CI: 1.01–5.17), presence of disease (ORa 5.35, 95% CI: 1.81–1581), and poor safety perception (ORa 2.19, 95% CI: 1.01–5.34) were significant for ≤39years age group; whereas the >39years age group workers were at risk due to big family size (ORa 9.83, 95% CI: 2.94–32.80) and lack of education (ORa 2.20, 95% CI:1.01–5.34). Regarding occupational factors, among the ≤ 39years age group workers, only shuttle car-related hazards (ORa 4.72, 95% CI:1.57–14.17) were found to be significant, while among the >39years age group workers, significant ORa were found for hand tools-related hazards (ORa 5.56, 95% CI:1.52–20.31), working condition-related hazards (ORa 4.28, 95% CI:1.47–12.47), and shuttle car-related hazards (ORa 14.24, 95% CI:3.07– 66.08).

For micro-level analysis, a cross-sectional study design was adopted and exposure to different machine operation-related hazards was captured through a questionnaire. A total of 156 workers were randomly selected from the pool of workers working with or around the individual machines. Among 156 workers, 51 were found to be injured by one of the three machine types. The bivariate chi-square test was conducted to determine the association between different operational hazards and injuries from machines. Logistic regression was used to assess the association in the multivariate situation. Multivariate analysis results show that machine-related injuries were significantly associated with ‘Tramming operation-related hazards’ of shuttle car

operation (ORa 2.57, p<0.05, 95% CI: 1.09-6.03). Also, 'PPE-related hazards' (ORa 2.29, p<0.1, 95% CI: 0.97-5.41) and 'Bolting operation-related hazards' of roof bolter operation (ORa 3.01, p<0.1, 95% CI: 0.99-9.19) were close to significant.

The final step of the study was the identification, selection, and prioritization of safety intervention to mitigate causal risk factors for injury occurrences at continuous miner worksites. Multiple safety interventions were identified for causal factors obtained from macro-level multivariate analysis, and the best intervention for each factor was selected based on experts' opinion scoring. Finally, each safety intervention was prioritized based on the importance of the corresponding causal factor and the effectiveness of the intervention in mitigating the effect of the same causal factor. Prioritization of safety intervention could be helpful in building a more effective safety intervention strategy under budget and resource constraints.

This study developed an integrated methodology based on epidemiological practices consisting of descriptive, analytical, and prescriptive analysis to evaluate injury data from continuous miner worksites. This methodology can further help improve safety practices carried out by mine management and the industry. The types of analyses presented in this thesis may enable the mine safety personnel to identify the causal factors for occupational injury, detect significant hazards, and focus on prioritized safety interventions to control and eliminate them. Specifically, the following areas have been addressed in this thesis: (a) evaluation of the role of individual factors and occupational hazards in the occurrences of injuries at continuous miner worksites, (b) the effect of age disparity on the causal relationship between risk factors and injury occurrences, (c) detection and assessment of hazards related to primary machines at the continuous miner worksites, and (d) identification, selection, and prioritization of safety interventions based on the importance of cause it is related to and the effectiveness of the intervention.

Keywords: Continuous Miner, Epidemiological study, Occupational injury, Risk factors, Safety intervention.