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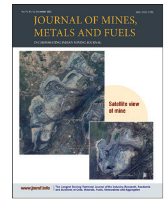

Role of Human Factors and Ergonomics in Indian Mining Industries

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Abstract

The human body and its mechanical functions are considered important factors in human factors and ergonomics (HFE) studies. It occupies a central place in man-machine system design. An anthropometric mismatch of a few centimetres in machine design can increase postural stress during operation. Therefore, some of the anthropometric design aspects might be critical to the operator, which can impact performance, the operator's safety, and work availability. Moreover, the presence of ergonomic stress factors in the working environment makes the workplace miserable for continuous work. To control the risk factor's effect, mining industries could benefit from the adaptation of the HFE technique in the fixation of a reasonable workload, control of the heat stress effect, and implementation of scientific rest-pause scheduling.

Keywords: *HEMM, HFE, Mining, Risk Factors*

1.0 Introduction

In mining, ample numbers of stress and risk factors are present in daily operation[1] of underground and opencast mining. Over the decade, safety analysis in mining is taking place as a core area of research as numbers of accident reports have been registered. Reports of musculoskeletal disorders (MSDs) and other occupational injuries are coming out[2,3] in significant numbers. In Indian mines, stress generation of miners has been found with loss of performance[4]. Therefore, employers and supervisors are planning to implement the best possible or reasonable precautions in the form of Human Factors and Ergonomics (HFE) to protect the health and safety of workers. There are several HFE guidelines and risk measurement techniques present that could provide guidance and examples of reasonable precautions. An analysis of HFE is required in managing principal risks to Occupational Health and Safety (OHS). Although the focus is on the application of ergonomics in mining, insignificant research has been done in this field to understand man-machine interfaces.

Moreover, only a few companies and institutions in India have the technical capability and proper knowledge to manage HFE issues. In every mining operation, whether it is opencast or underground mining, Heavy Earth Moving Machinery (HEMM) and other types of mining machinery play a pivotal role in keeping the mines running to meet the demand of production. In spite of its huge role in daily mining, it is seldom thought about the applicability of machine design to increase human efficiency along with reducing the chances of developing musculoskeletal disorders (MSD) and other types of bio-mechanical hazards.

The introduction of various types and sizes of machines in the market and its allied negative outcome

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for mining operations has drawn the attention of many engineers and ergonomists. It is also important for the operator's efficiency and safety during the operation of those machines. According to the HFE disciplines, there is a need to specify the type of people to operate these machines, based on ergonomic standards[5]. Different HFE standards provide a methodology for the application of HFE in the context of anthropometric design and its implementation with the goal of risk reduction and safeguarding operator and machine. With this context of understanding, anthropometry is defined by the measurement of size and the proportions of the human body[6]. Moreover, HFE can be defined as the study of people in the working environment. The application of HFE modifies the work to fit the worker, not the other way around. The HFE is also defined as the study of the work process in a given set of environments, while the main goal of the HFE is to eliminate the effect of risk factors during work. In another way, HFE is an applied science concerned with designing and arranging job tasks in line with someone's capabilities so that the highest level of efficiency and safety can be achieved. Therefore, the present article aims:

To discuss beneficiary goal points of implementing HFE in mining.

To discuss the analysis technique of different mining ergonomic stress factors.

2.0 History of HFE Development and Current Practices

The HFE had been recognized for the first time in European industrial development during the 1950s, when it was under serious consideration for industrial applications, emphasizing the acquired data of work physiology, biomechanics, and anthropometry for the design of workstations. However, the strategy of implementing HFE in Europe was developed long after giving thrust on the systems approach, design, performance and well-being goals[7], especially; application in offices[8]. Unlike European industries, the developmental process of HFE in the U.S.A. had emerged as a must have discipline after World War II. Many problems were identified during military operations involving sophisticated equipment such as airplanes, radar, sonar stations, and tanks. Physical ergonomics was first developed to combat the effects of heat stress in the United States of America. It was also found from research analysis of Korean War data that the killing of aeroplane pilots during training was higher than in actual wartime conditions. This surprising finding led a base to review the design of airplanes as well as procedures and strategies in operation for implementing HFE research[9] to avoid further accidents.

In India and other developing Asian countries, the development of HFE is still very slow. In comparison with the developed countries like UK, USA, Australia, Canada, and the European Union, the HFE study has not been given proper stress or taken as a mandatory provision in the Indian industry. As a counter to the HFE research in developed countries, several roadblocks have been found in India. Very few employers and concerned people know about the exact benefits and requirements of HFE research in the industry. Furthermore, confusion about the domain between a behavioral study and HFE is also found very common in Indian industry people. After a long wait, in the Coal Mine Regulation (CMR) 2017, the first rules and regulations of HFE have come, and the study of HFE in the mining industry is made mandatory for the employer by the Ministry. It is proved as a good step for the Ministry to ensure the miner's safety after remaining under safety amendments since the year 2010.

3.0 Goals and Beneficial Output of Hfe Research in Industry

The main beneficial outputs of HFE are as follows:

- HFE is the science of designing the workplace according to the capabilities and limitations of the worker. A poor design causes fatigue and injury to workers, which leads to a loss of productive hours.
- Deals with physical factors within the environment that harms the musculoskeletal system. The HFE deals with themes such as repetitive movement, manual handling, workplace/job/task design, uncomfortable workstation height, and poor body positioning.
- HFE includes information on safety and health issues while working a shift continuously.
- HFE generates the idea of proper job scheduling based on human functional anthropometry and humanizing work and working environment in the industry to reduce human errors and rate of injuries.
- It can generate a concept of Ergo-model applicability to help managers and work management choose and

select the right person in the right place. It can also enhance the realization and application of knowledge in the industry as a human resource or safety officer.

- The HFE study helps to learn how to select the correct ergonomic risk assessment tool for the jobs. Proper implementation of HFE solutions can make employees more comfortable and injury-free; therefore, it will increase the productivity of an industry.

4.0 Record of Safety

Although some safety provisions have already been introduced in the current coal mine regulations, still there is enough scope for improvement. In comparison with the U.S.A. and Spain, report of death and other allied safety issues in Indian mine is (Table 3) higher in number. The comparison with other industries like construction, the report of safety is poor (Tables 1 and 2) in mining.

Table 1. Comparison of lost days (Pearson coefficient = 0.86) for injuries between construction workers and mining workers in Spain, 2000-2010

	Construction		Mining			
Year	**Lost days**	**Workers**	**Lost days**	**Workers**	**OR***	**95% CI****
2000	5,190,830	1,850,200	358,293	63,400	2.01	1.99 - 2.03
2001	5,541,976	1,913,200	392,993	63,300	2.07	2.05 - 2.09
2002	5,591,298	1,913,200	341,636	63,300	1.85	1.83 - 1.86
2003	5,364,382	1,984,500	319,601	63,200	1.87	1.85 - 1.88
2004	4,831,552	2,253,200	256,627	59,600	2.01	1.98 - 2.02
2005	5,289,392	2,357,200	235,812	60,300	1.74	1.72 - 1.75
2006	5,493,238	2,542,900	201,271	66,500	1.40	1.38 - 1.41
2007	5,800,105	2,697,300	210,109	50,100	1.95	1.93 - 1.96
2008	4,048,106	2,468,300	164,888	51,900	1.94	1.91 - 1.95
2009	3,262,380	1,911,500	141,053	43,400	1.90	1.88 - 1.92
2010	2,884,399	1,680,000	123,845	41,200	1.74	1.68 - 1.83
Mean	4,373,348	2,142,864	249,648	56,927	1.51	1.50 - 1.52

*Lost days in mining/Mining workers/ lost days in construction/Construction workers.

**CI: Confidence interval[10].

Table 2. Comparison of the incidence rate of accidents (per 100 000) of fatal injury accidents between workers of construction and mining sectors in the U.S.A. and Spain during 2010[10]

	U.S.A			Spain				
	Deaths	**Workers**	***IR**	**Deaths**	**Workers**	***IR**	**RR****	**95% CI**
Construction	751	5,645,000	13.3	134	1,680,000	8	1.66	1.39 – 2.00
Mining	172	694,000	24.8	7	41,.200	17	1.45	0.68 – 3.10

*IR = Incidence Rate.

**RR = Relative risk

Table 3. Fatal accident rate comparison of India and USA[11]

Year	**Accidents per million tons of production per year**		**Accidents per million man-hours per year**	
	India	U.S.A.	India	U.S.A.
1989	0.722	0.077	0.112	0.05
1990	0.638	0.071	0.105	0.04
1991	0.587	0.068	0.103	0.04
1992	0.644	0.060	0.118	0.04
1993	0.541	0.055	0.103	0.04
1994	0.484	0.049	0.099	0.04
1995	0.468	0.050	0.103	0.04
1996	0.383	0.040	0.089	0.04
1997	0.380	0.030	0.091	0.04

5.0 Analysis Technique of Stress Factors

There are different standard HFE measurement techniques for the measurement of HFE problems and risk factors related to work. Some well-known methods are mentioned here under:

5.1 Analysis of Rest-Pause

Resting time calculation for a static or dynamic job is determined using the Spitzer formula[12]. The equation (Eq. no. 1) of Spitzer is shown below:

$$R = (\frac{E}{4} - 1) \times 100 \quad (1)$$

Where,
R = resting time as the percent of working time and
E = the energy expenditure during work, kcal/min.

5.2 Analysis of Thermal Comfort

Thermal comfort analysis for the stressful environment is analyzed through equation no 2. The American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE) standard 55-2004 elaborates on the use of an equation for predicted mean value (PMV) calculation[13]. It is generally used to determine the scale of thermal comfort in the workplace.

$$PMV = (0.303e^{-2.100M} + 0.028) \times [(M-W) - H - E_c - C_{res} - E_{res} \quad (2)$$

Where,
PMV = Predicted mean vote
M = Metabolic rate (W/m^2)
W = Effective mechanical power (W/m^2)
H = Sensitive heat loss
E_c = Heat exchange by evaporation on the skin
C_{res} = Heat exchange by convection in breathing
E_{res} = Evaporative heat exchange in breathing

5.3 Analysis of Heat Stress

Direct measurements of environmental parameters such as black globe temperature, dry bulb temperature (DBT), wet bulb temperature (WBT), and air velocity are done to measure heat stress. Subsequently, measured derived parameters are mean radiant temperature (MRT), air vapor pressure (AV_p), wet bulb globe temperature (WBGT), and Discomfort index (DI). Estimations of DI, operating temperature (T_o), and mean radiant temperature (MRT) are done from the following equations [Eq. No 3,4 and 5][14]. The measured values are used as an index to demonstrate ambient working conditions.

$$\text{Discomfort Index (DI)} = 0.5T_W + 0.5T_O \quad (3)$$

$$T_O = 0.5(T_a + MRT) \quad (4)$$

$$MRT = (1 + 0.22V^{0.5})(T_g - T_a) + T_a \quad (5)$$

Where,
T_w = Wet bulb temperature,
T_a = Ambient temperature,
T_o = Operating temperature,
MRT = Mean Radiant temperature,
T_g = Black globe temperature and
V = air velocity (m/min)

The combined effect of environmental stress factors are shown through heat stress indices wet bulb globe temperature (WBGT). Scientists Yaglou and Minard have given the formula of WBGT, which is well established hereunder[15] [Eq. no 6]:

$$WBGT = 0.7\ WBT + 0.3\ Tg \quad (6)$$

Where,
WBT = Wet Bulb Temperature
T_g = Globe Temperature

6.0 Discussion

In developing countries, most likely overpopulated countries, the HFE study is not yet taking core research interest as unawareness related to the new subject still exists. Additionally, the availability of a large unemployed workforce is also a prime factor in the slow developmental process. It is observed in several studies that, in Indian mining, workers should be given proper workload according to their given set of working environments[16]. Some of the researchers working in the field of HFE application for Indian mining and mineral industries have already demonstrated[17] different stress factors' effects on workers' safety. A possible coexistence of injury and stress factors has been observed in Indian mining operations. Stress factors like heat stress, humidity, vapour pressure, and inadequacy of air current[18] portray a significant contribution towards ill health, reduced work rate or productivity, and muscle fatigue in shifts.

Moreover, in India and other developing Asian countries, most of the machinery operations in mining are designed to be compatible with the continuous nature of the job. The existence of a stressful environment, postural issues, and job stress are common phenomena in mining. Implementation of HFE models can provide better synergy between HEMM and other mining machinery operators and machines. Subsequently, the HFE measuring techniques could act as a tool for the analysis of different industrial stress factors in the work system, along with providing essential remedial measures.

7.0 Conclusion

HFE application is required for every industry where interaction between workers and stress factor exists. Subsequently, several HFE-centric initiatives like proper training, fixation of individual-centric workload for a continuous job and ergonomic intervention in machine seat and cabin design as per the guidelines of new coal mine regulations 126 and 215 of 2017 need to be implemented. Regular monitoring of work stress factors including an adaptation of suitable control measures should be undertaken to bring down stress effects in the industry. Moreover, implementation and giving more emphasis on HFE rules and regulations could give better results in the future.

8.0 References

1. Dey NC, Dey SC, Sharma GD. Importance of ergonomic application for the improvement of coal productivity in mines. Proceedings of the 17th Coal Operators' Conference. 2017; pp. 306-313.
2. Dey NC, Sharma GD, Dey S. An ergonomic study of health of drillers working in an underground coal mine with adverse environmental conditions. MGMI Trans. 2015; 111:58–65.
3. Donoghue MA. Heat illness in the US mining industry. American Journal of Industrial Medicine. 2004; 45(4):351-356. https://doi.org/10.1002/ajim.10345
4. Dey SC, Dey NC, Sharma GD. Occupational Malfunctioning and Fatigue Related Work Stress Disorders (FRWSDs): An Emerging Issue in Indian Underground Mine (UGM) Operations. Journal of the Institution of Engineers (India): Series D. 2018; 99(1):103-108. https://doi.org/10.1007/s40033-017-0149-9
5. Woodson WE, Tillman B, Tillman P. Human factors design handbook: information and guidelines for the design of systems, facilities, equipment, and products for human use. McGraw-Hill, New York, United States. 1992; 10036.
6. Salvendy G, McCabe GP, Sanders SG, Knight JL, McCormick EJ. Impact of personality and intelligence on job satisfaction of assembly line and bench work - an industrial study. Applied ergonomics. 1982; 13(4):293-299. https://doi.org/10.1016/0003-6870(82)90070-9
7. Dul J, Bruder R, Buckle P, Carayon P, Falzon P, Marrasn WS, Doelen B. A strategy for human factors/ergonomics: developing the discipline and profession. Ergonomics. 2012; 55(4):377-395. https://doi.org/10.1080/00140139.2012.661087
8. Shackel B. Ergonomics in information technology in Europe - a review. Behaviour and Information Technology. 1985; 4(4): 263-287. https://doi.org/10.1080/01449298508901808
9. Helander M. A guide to human factors and ergonomics. Crc Press. 2005; 8 p. https://doi.org/10.1201/b12385
10. Felipe-Blanch JJ, Freijo-Alvarez M, Alfonso P, Sanmiquel-Pera L, Vintro-Sanchez C. Occupational injuries in the mining sector (2000-2010). Comparison with the construction sector. Dyna. 2014; 81(186):153-158. https://doi.org/10.15446/dyna.v81n186.39771
11. Hinge S, Ambhore N. Review of an Underground Conveyor using Composite Materials. International Journal of Current Engineering and Technology. 2015; 5(2):1287-1291. http://inpressco.com/wp-content/uploads/2015/04/Paper1221287-1291. pdf (Accessed 11.01.2020)
12. Tiwari PS, Gite LP. Evaluation of work-rest schedules during operation of a rotary power tiller. International Journal of Industrial Ergonomics. 2006; 36(3); 203-210. https://doi.org/10.1016/j.ergon.2005.11.001
13. Nicol JF, Humphreys MA. Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and buildings. 2002; 34(6):563-572. https://doi.org/10.1016/S0378-7788(02)00006-3
14. Epstein Y, Moran DS. Thermal comfort and the heat stress indices. Industrial health. 2006; 44(3):388-398. https://doi.org/10.2486/indhealth.44.388
15. Dimiceli VE, Piltz SF, Amburn SA. Estimation of black globe temperature for calculation of the wet bulb globe temperature index. In Proceedings of the World Congress on Engineering and Computer Science, October 19 - 21, 2011, San Francisco, USA. 2011; pp. 19-27.
16. Dey NC, Nath S, Sharma GD, Mallick A. Environmental impact on physiological responses of underground coal miners in the eastern part of india. Journal of Human Ergology. 2014; 43(2):69-68.
17. Sharma GD, Dey S, Dey NC. Rationalising postural demand of side discharge loading machine operators with respect to musculoskeletal pain and discomfort in underground coal mines in India. International Journal of Human Factors and Ergonomics. 2016; 4(1):60-72. https://doi.org/10.1504/IJHFE.2016.076573
18. Dey NC, Dey S. Effective utilization of man shift through sustainable workload testing for underground mining machine operators. An ergonomic based man-machine interface approach. New Trends in Production Engineering. 2019; 2(1):394-403. https://doi.org/10.2478/ntpe-2019-0042