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Risk Assessment of Coal Processing Plant: An Ergonomic Perspective

Rohit Gupta
Indian Institute of Management
Sambalpur, India
rohitism12@gmail.com

Abstract

With the increase in focus on productivity and technological intervention in coal processing, workers' health is impacted. Although, conscious workers, stringent labour regulations, and expected long term benefits have forced production facilities to focus not only operational performance but also workers' overall health. But due to higher focus on general industrial safety and slow impact on workers' health, Human Factors and Ergonomics are given lesser focus in coal processing plants. As Human Factors and Ergonomics concerns of workers have slow impact, so workers are left with lesser focus of management on elimination or mitigation of risks relates to Human Factors and Ergonomics. But considering long terms impact of Human Factors and Ergonomics on workers' health and social commitment is forcing organizations to gauge Human Factors and Ergonomics risks and develop- counter measures. Therefore, this study aims to identify, prioritize the Human Factors and Ergonomics risks in a coal processing plant and provide management a comprehensive analysis to enable them to eliminate or mitigate the risks and improve workers' overall safety and health and remain competitive in long term.

Keyword
Risk; Coal processing; Ergonomics; HFE; Productivity.

1. Introduction

Organizational health, safety and Environment are threatened by coal processing units in various ways and become quite harmful if relevant, on-time and effective control measures either to eliminate or reduce the impact are not taken (Singh and Gupta, 2020). Coal Processing at a coal washery comprises different activities segmented mainly into maintenance, operations, logistics, transportation, material handling, office work. The priority to improve safety and reduce impact on environment has become one of the top priority of organizations due to increased awareness of workers, Employee wellbeing centric approach from management (Singh and Gupta, 2020) customer sensitivity for brands' orientation for employee and social wellbeing, stricter regulations & reporting by government organizations like DGMS (Directorate General of Mines Safety), CPCB (Central Pollution Control Board), SPCBs(State Pollution Control Boards) and many more related to industrial safety and hazard control authorities (Smith et. al., 2022).

But as Ergonomics has, most of the time, slow and long-term impact so it gets less attention in the industry to be tackled with. As the factors responsible for musculoskeletal disorders are not easily identifiable; their quantification is even more difficult (Kolus, et. al, 2023). Due to slow impact, even workers do not realise the severity of ergonomic unsafe practices and they remain lesser concerned. But the impact of ergonomic factors on health of workers can't be ignored due to the visible and long-term impacts.

Although rapid automation and mechanization has reduced and even eliminated many manual jobs but there are still lots of manual jobs which are part of plant operations (Panagou, et. al., 2024). These jobs are performed by same people for long time some time for years. These jobs have most of the repetitive actions impacting physical, Reduction or elimination of risk requires the focused attention and having countermeasures for respective risks. With high number of risks, difficulty in identification, monitoring of exposure, quantifying the impact on people makes it imperative to prioritise the risks according to impact, severity, frequency of exposure (Khan and Ahmad, 2019). This will make management, authorities to place countermeasures systematically to reduce or eliminate the risks.

Competitive working environment are escalating more pressure on SMEs to align their business strategies in such a way, that synergistically improves operational and Worker's performance (Nagaraj and Jeyapaul, 2018). So are challenging condition in big established companies also due to various jobs done manually.
This study tried to analyse the DI Pipe manufacturing plant with Human Factors and Ergonomics (HFE) approach by incorporating ergonomics concept it into a VSM technique. Basically, this study addresses the following research objectives:
RO1: To identify lean & HFE indicators to analyse the DI Pipe manufacturing.
RO2: To incorporate HFE indicators into VSM.
RO3: Identify the critical activities of DI Pipe manufacturing based on the calculated risk.
The rest of the research paper is organized as follows: Section 2 presents a literature review based on lean and HFE. Section 3 includes the overview of the DI pipe manufacturing. Section 4 presents a brief outline of research methodology. Section 5 briefly explains the case study. Section 6 includes the data collection. Section 7 presents the results & discussion on the findings. The last section highlights managerial implications and conclusion.

2. Literature Review

This section aims to understand the theoretical background of work practices in coal processing plants and its impact on Worker's health and safety. In addition, this section also identifies HFE categories and their measuring indicators with the help of reputed peer-reviewed journals' studies.

2.1. Background of HFE in Coal Processing plants

Human factors and ergonomics are essential considerations in the design, operation, and maintenance of coal processing plants (Behera and Mohanty, 2021). Human factors refer to the study of how people interact with technology, equipment, and processes, while ergonomics is concerned with designing workplaces, tools, and equipment to optimize human performance and well-being.

In coal processing plants, human factors and ergonomics play a crucial role in ensuring the safety, efficiency, and productivity of the workforce (Behera and Mohanty, 2020). Coal processing plants involve a wide range of tasks, including loading and unloading coal, operating heavy machinery, monitoring, and controlling process parameters, and handling hazardous materials (Kesavachandran and Nandakumar, 2019). Each of these tasks requires careful consideration of human factors and ergonomics to minimize the risk of accidents and injuries, reduce fatigue and stress, and improve overall performance (Jain and Gupta, 2021).

In a coal processing plant, the activities related to Maintenance, Operations, material handling, Transportation, Monitoring, Human interaction, Human Resource Management etc impact HFE (Jain and Gupta, 2021). Although focus now a days is not much on HFEs due to higher focus general safety in daily activities. Human resources engaged in these activities normally are deployed for longer durations and they perform jobs on daily or regular basis (Das and Datta, 2017) Due to repetitive nature of these activities HFEs are impacted in mostly mild way. The risks associated with HFE come with the processes of Coal Plant itself but due to lack of awareness of long-term impacts there and more focus on general safety HFE impacts were ignored. The studies have been done by researchers for the impact of HFEs in coal processing plants.

2.2. Identification of HFE indicators to access the human factor risk level

HFE focuses on Man-machine interactions which is assessed from multiple perspective such as engineering, design, technology, science & management (Karwowski 2005). Previously, various research papers have analysed and discussed how HFE domain optimize worker's output and efficiency and leads to overall organization performance (Karwowski 2005; Karwowski 2012). Ergonomic interventions play a major role in improving the workers' output and performance of an organization. These interventions consist of automated workstations, improved design of tasks as well as tools, efficient design layouts etc. Ergonomically designed workstations and tasks leads to risk reduction of MSDs issues, workers' injuries, absenteeism rates. These improvements also increase the operational performance of the organization. Larson and Wick (2012) investigated that implementation of ergonomically designed workstations decreased the MSDs issues and improved workers' productivity.

Rathore et., al, (2020) examined the relationship between physical risk factors (e.g., awkward work posture, forceful exertion, and repetitive task) and the prevalence of MSDs symptoms among the glass artware workgroup. Similarly, many studies have examined the association of psychosocial (job satisfaction, mental workload, job stress, psychological strain), managerial (supervisor support, communication system, co-workers support, and reduction of resources) and work design risk factors (job clarity, job autonomy, job rotation) with the prevalence of MSDs issues among the workers. These risk factors are considered in our study as HFE categories to measure the risk level in Coal processing plant, as shown in Figure 1.

Some of the factors were also taken from health and safety experts (safety professionals) through personal interview. Discussion was done with plant managers, safety professionals, engineers, and shopfloor workers to find out HFE factors specific to the coal processing activities. Most of the factors remain common across coal processing plants due to similarity of process and technology used across plants. But there are some factors which become specific to a plant depending upon the work culture, size, leadership, management attitude of the company. We will discuss the factors affecting HFE of workers of a coal processing plant.

3. HFE Risk Factors

The detailed description of HFE risk factors categories and their measuring indicators are presented in Figure 1.

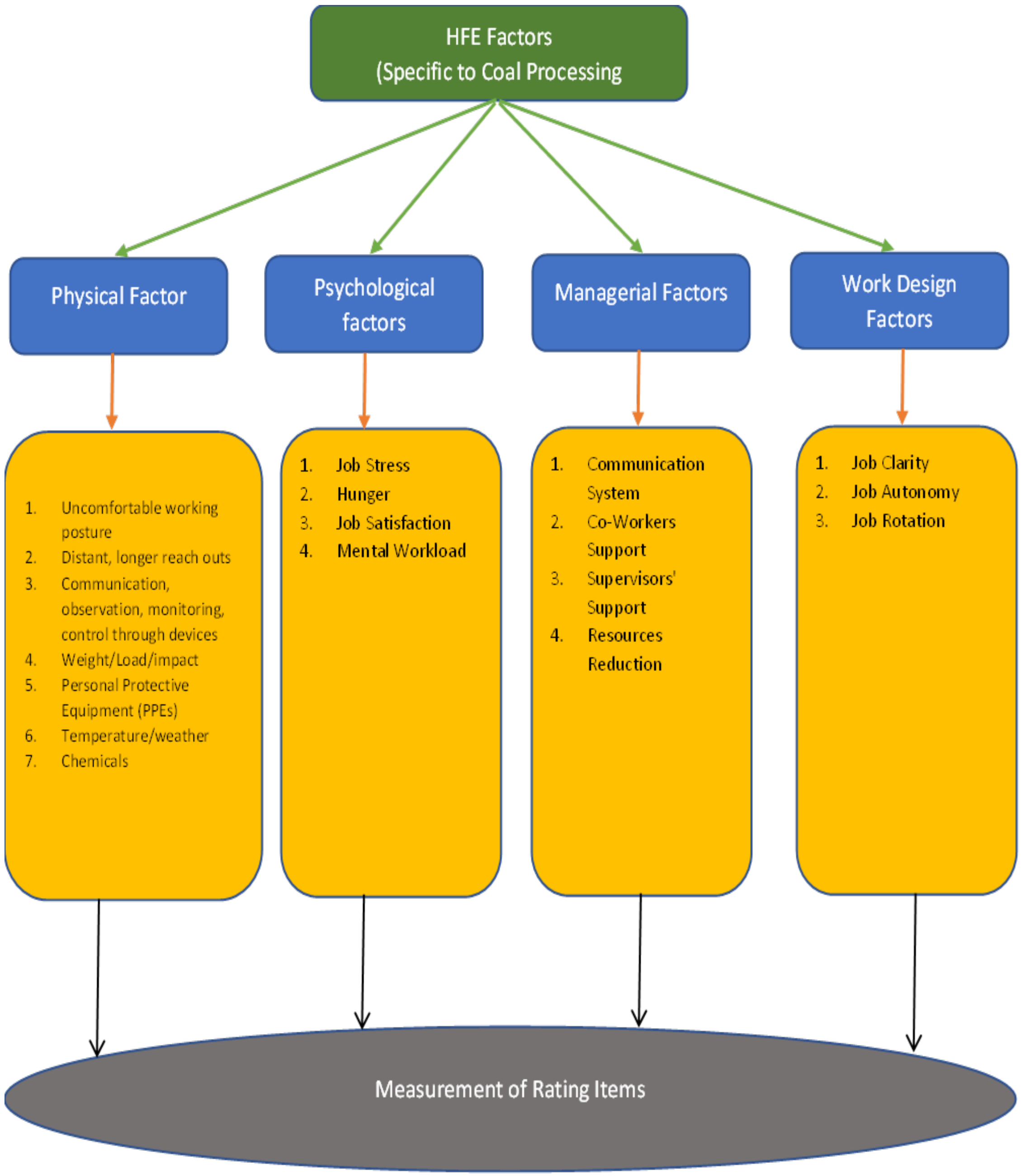

Figure 1. HFE Factors and their Indicators considered in this study

4. Research Methodology

In the first step a comprehensive hierarchy of all the risks which may affect the coal processing plant has been developed. This is done by thoroughly studying the considered chain of coal processing comprising all existing activities and identifying potential loopholes. Inputs from previous research and experts in the coal processing plant are used. These are then analysed for overlaps and categorised using similar characteristics. This exercise should be repeated whenever a major change is made in the chain process. The second step in the process involves assigning weights to the criteria according to their importance. AHP is used for this purpose and expert views are taken as input. The weights are calculated for primary factors, sub- factor. The enough number of experts to be considered to reduce the bias, errors. The terms or words used to define risks are to be explained properly and feedback from experts to be taken to ensure the context understanding of considered risks.

4.1. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a Multi Criteria Decision-Making (MCDM) methodology that helps individuals and organizations make complex decisions by breaking them down into smaller, more manageable parts. AHP was developed by Thomas L. Saaty in the 1970s and has since been widely used in fields such as business, engineering, and social sciences. The AHP process involves breaking down a decision into a hierarchy of criteria and sub-criteria, which are then ranked by their importance to the overall decision. The process involves pairwise comparisons, where each criterion is compared to every other criterion in terms of its relative importance. These comparisons are done using a scale of numerical values from 1 to 9, with 1 indicating that the two criteria are equally important and 9 indicating that one criterion is much more important than the other.

Once all pairwise comparisons have been made, the AHP algorithm calculates the relative weights of each criterion and sub-criterion, based on the consistency of the comparisons made. The process also involves calculating a consistency ratio to ensure that the pairwise comparisons are logical and consistent (Table 1). The final result of the AHP process is a set of weights for each criterion and sub-criterion, which can be used to make an informed decision. AHP is a useful tool for complex decision-making because it allows decision-makers to break down a decision into smaller, more manageable parts, and to consider multiple criteria and sub-criteria simultaneously. In this study AHP has been applied to calculate weight of Primary Factors, sub-factors or HFE and criteria for root factors evaluation. The pairwise comparison matrices have been formulated for Primary factors, Sub-factors and Evaluation Criteria for root factors(risks).

The responses were taken from experts in these pairwise comparison matrices to get relative importance of factors. These relative importance matrices have been used to calculate the relative weights of the factors over other. Saaty scale (Aczel and Saaty 1983) is used for relative importance and their conversion into values. The sample questionnaire is attached in appendix.

Table 1. Scale for Pairwise Comparison

Degree of Importance	Definition	Values
EI	Equal Importance	1
MI	Moderate importance for one over other	3
SI	Strong Importance	5
VSI	Very Strong Importance	7
ExI	Extreme Importance	9

5. Data Collection, Analysis & Results

5.1. Data Collection

Apart from study of previous research on HFE in related Coal Washery and related industry, safety experts, plant managers, workers of coal processing plants in India were interviewed to get the HFE factors. The experts were provided with questionnaire (Table 2). The questionnaires were formulated to receive responses in form of paired comparison matrices for primary factors, sub factors and risk evaluation criteria while for root factors response were received in form of ordinal scale impact (Not applicable, very low, low, intermediate, high, very high). Responses were received from 10 experts in form of paired comparison matrices. The responses were converted into values by scale 1,3,5,7,9 for paired comparison matrix for AHP analysis. The scores from each expert were used to get the geometric mean which is used as single score for analysis in AHP. Hence, geometric mean of 10 values from 10 experts have been used for analysis for each respective factor for evaluation criteria risk factors.

Table 2. Response from one expert

Criteria	Degree of Importance																	Criteria
	Extreme Important		very Strong Importance		Strong Importance		Moderate Importance		Equal Importance		Moderate Importance		Strong Importance		very Strong Importance		Extreme Important	
	Ex I		**VS I**		**SI**		**M I**		**EI**		**M I**		**SI**		**VS I**		**Ex I**	
Physical					√													**Psychological**
											√							**Managerial**
																	√	**Work Design**
Psychological					√													**Managerial**
														√				**Work Design**
Managerial													√					**Work Design**

5.2 Analysis and Results

Combining the responses from 10 experts into one final matrix with geometric mean of all 10 responses (Table 3).

Table 3. Group decision making matrix

	Physical	Psychological	Managerial	Work Design
Physical	1	1.93	1.87	0.82
Psychological	0.52	1	2.33	1.84
Managerial	0.54	0.43	1	1.69
Work Design	1.21	0.54	0.59	1

Table 4. Weights & Rank for primary factors

Primary Factor	Weight	Rank
Physical	0.32	1
Psychological	0.29	2
Managerial	0.19	4
Work Design	0.20	3

From above Table 4, it is observed that importance level of factors is Physical > Psychological > Work Design > Managerial i.e., Physical factors being most important and managerial the least important. Similarly rank of other sub-factors of Physical category based on their weights is as follows in Table 5:

Table 5. Weights & Rank for Physical factors

Physical Factors	**Weights**	**Rank**
Uncomfortable working posture	0.21	1
Distant, longer reach outs	0.15	3
Communication, observation, monitoring, control through devices	0.12	5
Weight/Load/impact	0.18	2
Personal Protective Equipment (PPEs)	0.15	4
Temperature/weather	0.08	7
Chemicals	0.10	6

Considering only Physical factors and comparing them for importance gives us following rank-
1.Uncomfortable working posture > 2. Weight/Load/impact > 3. Distant, longer reach outs > 4. Personal Protective Equipment(PPEs) > 5. Communication, observation, monitoring, control through devices > 6. Chemicals > Temperature/weather
Similarly rank of other sub-factors of Psychological category based on their weights is as follows in Table 6:

Table 6. Weights & Rank for Psychological factors

Psychological Factors	**Weight**	**Rank**
Job Stress	0.36	1
Hunger	0.14	4
Job Satisfaction	0.26	2
Mental Workload	0.24	3

Importance rank for psychological factors amongst themselves
Job Stress > Job Satisfaction > Mental Workload > Hunger
Similarly rank of other sub-factors of Managerial category based on their weights is as follows in Table 7:

Table 7. Weights & Rank for Managerial factors

Managerial Factors	Weights	Rank
Communication System	0.24	1
Co-Workers Support	0.21	2
Supervisors' Support	0.20	3
Resources Reduction	0.16	5
Time Pressure	0.19	4

Importance rank for managerial factors amongst themselves is as follows:
Communication System > Co-Workers Support > Supervisors' Support > Time Pressure > Resources Reduction
Similarly rank of other sub-factors of Work Design category based on their weights is as follows in Table 8:

Table 8. Weights & Rank for Work Design factors

Work Design Factors	**Weights**	**Rank**
Job Clarity	0.51	1
Job Autonomy	0.28	2
Job Rotation	0.21	3

Importance rank for Work Design factors amongst themselves is as follows:

Job Clarity > Job Autonomy > Job Rotation

6. Conclusion

With increasing pressure for productivity and technological intervention in all spectrums of work life, workers health is impacted in many ways. Coal processing being labour intensive jobs are normally considered to pose musculoskeletal risks over long time. But, with increasing automation and dependence over technology, workers are expected to perform more number of activities which are less of physical nature. These changed natures of jobs are also impacting mental health. So, considering other human factors along with physical one is necessary for coal processing and other related plants for better assessment of workers' overall health. Industries are focusing on overall health of workers to mitigate, reduce the risks and their impacts to remain productive, competitive and many a times statutory compliant.

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Appendix: AHP Questionnaire

Criteria	Degree of Importance																	Criteria
	Extreme Important		very Strong Importance		Strong Importance		Moderate Importance		Equal Importance		Moderate Importance		Strong Importance		very Strong Importance		Extreme Important	
	Ex I		**VS I**		**SI**		**M I**		**EI**		**M I**		**SI**		**VS I**		**Ex I**	
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