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Managing Multiple Hazards in the Workplace: Engineering and Technological Strategies for Assessing, Ranking and Prioritizing Safety and Health Risks in Heavy Metal Facilities

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Abstract

Assessing and prioritizing safety and health risks in heavy metal facilities, such as iron and steel factory facilities, is crucial due to the potential exposure to multiple hazards. Although there are existing tools for ranking single hazards in industrial settings to support safety and health programs, there is a scarcity of comprehensive tools for assessing multiple hazards. Having a unified tool to evaluate various hazards in different scenarios would enable effective prioritization of corporate resources and facilitate risk prevention, control, and management. This paper presents a framework based on various engineering and technological strategies to identify and assess workplace risks of multiple hazards, using a hypothetical iron and steel facility as a case study and a representative of the heavy metal industry. The framework incorporates essential elements from traditional risk assessments, such as the frequency of occurrence, databases of potential hazard exposure, injury rates, severity, days away from work, and, when applicable, the costs associated with injuries, including job and task reassignment.

After assessing and prioritizing the hazards, it is clear that exposure to toxic chemicals like acids and chromium, as well as dust such as silica, pose the highest risks. These hazards consistently ranked the highest across all measures, including U.S. OSHA-estimated costs for a single injury per year. While material handling does pose risks like lifting-related and sharp injuries, these incidents are not as prevalent in modern automated heavy metal industrial sectors. Overall, injuries and illnesses caused by material handling hazards do not rank as high as chronic illnesses resulting from exposure to chemical hazards. It is important to address chemical hazards to avoid potential future litigation and associated costs to companies.

In addition to chemical hazards, occupational noise, biological, and heat stress hazards can also lead to chronic illnesses. However, these hazards are typically less severe and can be prevented through effective safety and health programs, including monitoring and surveillance. We recommend a framework that combines various methods and strategies to effectively manage the risk and severity of multiple workplace hazard. This framework should be implemented in heavy metal and metallurgical industries, such as iron and steel industrial facilities, to ensure the safety and well-being of employees.

Keywords: Risk Management, risk ranking, multiple hazards, sharp injuries, prioritizing hazards

Introduction

Metal and metallurgical industries encompass a wide range of facilities, including heavy industry sites such as iron and steel manufacturing plants. The products produced by these facilities are used by a variety of consumers, including but not limited to those in the automobile, gas, and oil pipeline industries, as well as for domestic appliances and commercial applications.

There are at least 1,859 operating metal and metallurgical industries under the North America Industrial Classification System Code 33111. These companies include iron and steel facilities and employ approximately 100,000 workers, with an annual payroll of $7 billion and generating substantial revenue of nearly 90 billion dollars [1]. For these facilities to continue contributing to the economic base of the nation and making a profit, it is critical that they identify, evaluate, and mitigate occupational hazards and associated risks associated with the various unit operations in the industry.

Iron and steel processing facilities usually begin by importing or purchasing local steel bars as their primary raw material. These can include recycled iron and steel materials, which are processed on-site using the Electric Arc Furnace (EAF), Blast Furnace (BF), and Basic Oxygen Furnace (BoF). In addition to steel, facilities may use various chemicals such as zinc, hexavalent chromium, and hydrochloric acid for galvanizing, corrosion resistance, and oxide removal, respectively. It is crucial for these facilities to identify, evaluate, and mitigate any associated occupational hazards and risks to ensure the safety of their workers and maintain their contribution to the national economy.

These processes often involve transforming iron and steel slabs or ingots into finished goods such as steel sheets in steel rolling mills. These sheets can have varying widths or thicknesses ranging from 1000 mm to 2000 mm (40 inch-75 inches), and lengths between 220 mm-225 mm (8.7 inch-10 inches), depending on customer requirements. The specific gauges, sharpness, weights, and industrial applications also vary. Nonetheless, it is crucial to address potential hazards to ensure the safety of workers in such facilities.

The primary aim of this study was to comprehensively identify and examine the potential occupational hazards prevalent in the heavy metal industry, with a specific focus on iron and steel facilities. The objective was to establish task-based hazard characterization and ranking frameworks to assess the risks associated with multiple hazards, aiming to safeguard the well-being of employees, contractors, and staff, and ultimately promote a safe working environment for all individuals involved.

Materials and Methods

This study has utilized the framework and model (Fig. 1.0) of assessing and managing occupational hazards established by the American Industrial Hygiene Association (AIHA) [2]. The AIHA model involves several key activities, such as anticipating, recognizing, identifying, evaluating, controlling and managing occupational hazards [2]. Professionals charged with protecting worker health and safety, including safety engineers and advocates, rely on this model to ensure a continually improving workplace safety environment.

This methodology, in addition to incorporating other approaches and steps as described below (Fig. 1.0) is used in this case study.

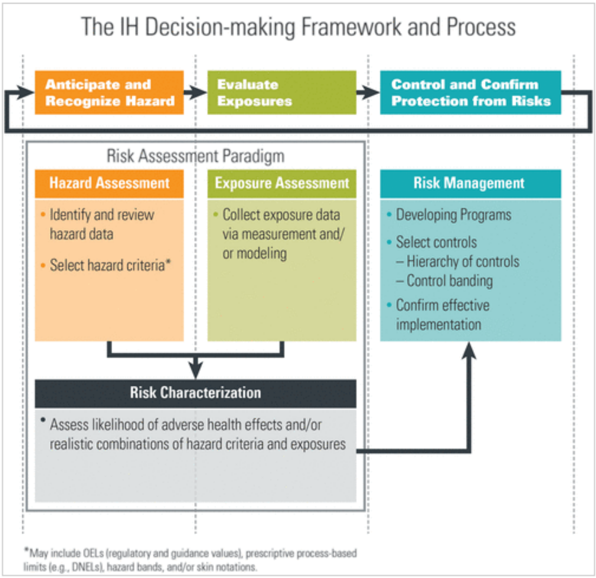


Figure 1.0: The AIHA Hazard Assessment and Risk Decision-Making Framework and Process (2)

(a) The initial stage of a comprehensive literature review holds great importance as it enables us to grasp the workflow, unit processes, and operations, ultimately allowing us to anticipate potential hazards.

(b) Furthermore, a one-day comprehensive walk-through audit was carried out as a secondary step to identify hazards and determine specific locations or unit operations where these hazards were present. This audit also aimed to assess the number of employees and contractors exposed to these hazards. The objective was to evaluate the likelihood and potential impact on workers' health and safety, both in acute and chronic terms. A walk-through survey methodology has been successfully employed in studying noise exposure in various iron and steel mill facilities (13). It is crucial to acknowledge that the severity and consequences of each hazard may vary across different units. Factors such as the number of affected employees, hours worked, and the extent of injuries and illnesses sustained by employees should be considered as primary factors in assessing the overall impact.

(c) The next logical progression after completing the one-day walk-through audit was to expand the duration of the tour to three days. This extended timeframe aimed to avoid any potential tunnel vision that may have arisen from a brief tour. To accomplish this, additional investigators were included in this step. During the facility tour, efforts were made to engage with workers through informal conversations, interviews, and surveys. This approach has proven effective in assessing workers' perceptions of noise-induced illnesses in other iron and steel mills (10-11). A sample of the questions asked can be seen in Figure 2.0 below. Additionally, this step involved the collection of hazard samples and the visual observation of work practices.

(d) To assess the identified hazards and potential risks to workers, property, and the environment, a risk ranking system was implemented in this study. This system was developed based on a comprehensive literature review. In the initial assessment, historical data was extracted from the U.S. Occupational Safety and Health Administration (OSHA) and the Bureau of Labor Statistics (BLS) databases. These records and events at a hypothetical iron and steel facility were reviewed to aid in ranking the hazards that occurred over a six-year period, from 2015 to 2022. The data provided insights into the probability of occurrence, hazard locations, types, and potentially serious incidents and fatalities (PSIF). Additionally, "Estimated Costs of Occupational Injuries and Illnesses and Estimated Impact on a Company's Profitability Worksheet" of the U.S. OSHA was used to estimate the potential economic implications of hazards and injuries (4). This approach is particularly relevant when looking to estimate costs associated with injuries sustained by number of employees per year for a hypothetical iron and steel facility in the event of injuries.

Figure 2.0: Sample Questionnaire for Assessing Employees' Perceptions of Hazards and Risks

1. How would you rank the following occupational hazards, from least hazardous to most hazardous?

Hazard/Injuries/Illnesses	**1 (Least Hazardous)**	**2**	**3**	**4**	**5 (Most Hazardous)**
Noise					
Ergonomics (material handling, lifting, improper tool design, etc)					
Heat Stress					
Hand safety, sharp injuries, cuts, abrasion, lacerations etc.					
Silica exposure, silicosis					
Acid mist exposures					
Hexavalent chromium exposures					
Slips, Trips and Falls (STFs)					

Results and Discussion:
Hazards were identified at the hypothetical iron and steel facility, as outlined in Table 1.0. A concise description of the corresponding rows and columns accompanies each hazard. Furthermore, the discussion includes examining the specific jobs, tasks, and unit operations where workers may potentially be exposed to these hazards (columns 2-3). When relevant, the impacts and risks to workers, the environment, property, and the public are also discussed, providing a comprehensive overview.

Table 1.0: Hazard Identifications from a Walkthrough Audit

Column 1		**Column 2**	**Column 3**
1A	**1B**		
1	**Hazard identified**	**Hazard-description-Work Tasks**	**Remarks**
	Material handling and *sharp Injuries* (hand-safety)	Workers handle carbon steel products that are as sharp as razor blades.	Ongoing research is focused on automating job tasks and operations. Additionally, tests are planned to evaluate the cut, abrasive, and puncture resistance of gloves.
2	Occupational **n*oise hazards (14)***		Hazard mapping is crucial to identify specific areas and tasks that pose a risk of Noise-Induced Hearing Loss (NIHL).
3	Material handling, repetitive activities and ***ergonomic hazard (14)***	Extended periods of work on overhead cranes, as well as tasks such as band-cutting or folding, and the responsibilities of control room operators, pose a heightened risk of musculoskeletal injuries. This risk is further compounded by the manual lifting of heavy objects (14).	Interactions with overhead computers and the continuous monitoring of steel-metal plates on conveyor belts have the potential to lead to back injuries, musculoskeletal disorders, and similar issues. This is particularly relevant in control rooms.
4	***Chemical hazards:*** exposure to silica dust	Employees, contractors and their workers may be exposed to silica dust during downtime or scheduled annual maintenance of furnaces, posing a potential risk to a considerable number of workers. Furthermore, there is a possibility of exposure to other inhalable agents such as fumes and dust.	Permanent company workers and contractors' employees and occasionally sub-contractors can be exposed for short durations and long-durations during the turn-arounds-or maintenance activities
5	***Chemical hazards:*** exposure acidic mists	Acid usage is prevalent in heavy metals industries particularly in iron and steel facilities, with hydrochloric acid frequently being employed for various purposes such as finishing and steel pickling processes. It is commonly used for the removal of oxides and scales on steel wires and strip steel, especially when stainless steel sheets are desired or when further processing is required.	Occasionally, sulfuric acid, hydro-fluoric acid and nitric used – acid mists for processing carbon steel or stainless steel. The impacts may go beyond work environment and create Hazardous Air Pollutants (HAPS) (3). Exposure job-tasks: pickling tanks, rinse tanks; and the handling of acid or acid-transfer stations

6	***Chemical hazards:*** exposure to hexavalent chromium	Exposure to hexavalent chromium can be significant during the chrome plating of steel rolls. The application of hexavalent chromium is aimed at achieving an improved strip surface and ensuring the desired product's cleanliness. Additionally, there is a risk of skin contact with acids and other substances in this process.	Lung cancer (a chronic illnesses) among workers exposed to hexavalent chromium. Other illness: sensitization, asthma, and dermal irritation.
7	***Physical hazards:*** Heat Stress and light hazards	Heat stress can occur in the proximity of the electric arc furnace (EAC) floor areas Contact with hot metallic surfaces (14) Risks from relative humidity and temperatures usually radiant heat (14) Lack of wind speed may have an impact on radiative, convectional and conduction heat transfer mechanisms	These hazards predominantly occur during the summer months when a considerable number of employees are exposed to work tasks that can induce heat stress. To address this issue, various options are available, including the implementation of large industrial fans, the provision of water stations, and the establishment of planned work regimens as administrative controls. It is worth noting that temperatures as high as 1600°C have been documented in the vicinity of furnaces (14). In certain heavy metal and metallurgical facilities, furnaces can generate glare, as well as emit ultraviolet (UV) and infrared (IR) lights, which can have an adverse effect on workers' eyes (14). There are instances where the light amplification by stimulated emission of radiation from the furnaces falls under class 3 or 4, necessitating the implementation of more stringent control strategies (14).
8	***Biological hazards:*** Exposure to mold, fungi etc	The occurrence of biological occupational hazards in heavy metal industries, in particular, iron and steel facilities, such as fungi (mold), bloodborne pathogens, bacteria, poisonous plants, and animals, is extremely rare to the point that they are generally overlooked.	Instances of mold growth are infrequently observed in the majority of heavy metal industries particularly in the iron and steel facilities, with exceptions being found in overhead cranes, particularly during wet months. Mold growth, as well as the potential occurrence of legionnaire disease (14), can also manifest in administrative offices and HVAC or water-cooling areas. However, the number of employees potentially exposed to these hazards may not be substantial enough to justify further analysis.

As outlined in the literature, "Hot Rolling Mills-Automatic Facilities" are commonly found in iron and steel facilities, representing typical operations. These unit processes often involve various activities, such as heavy lifting, crane tasks, yard management sections, furnace operations, and roller operations. Consequently, workers in these roles face potential exposure to a broad spectrum of occupational hazards (4). It is crucial to note that these hazards can lead to both severe, life-threatening injuries and non-fatal illnesses.

The U.S. Bureau of Labor Statistics (BLS) has identified a range of hazards present in iron and steel facilities, including materials handling hazards that can result in trips, slips, falls, and sharp injuries and illnesses (3). These types of injuries account for approximately 44% of recorded injuries in the general metal industry, including iron and steel facilities. Additionally, occupational noise poses a significant concern, with over 30 million Americans being exposed to excessive noise levels that can potentially lead to long-term noise-induced hearing loss (NIHL) (3).

Chemical hazards have been identified in iron and steel facilities, particularly in the context of steel pickling operations. More than 100 steel pickling facilities across the United States employ the use of acids to remove oxides and scales from raw materials such as iron and slabs for subsequent processing (3). The U.S. Environmental Protection Agency (EPA) has emphasized in one of their reports that emissions from iron and steel facilities can pose both occupational and public health hazards (3).

The exposure to acid mist is dependent on several factors, including the configuration of acid baths (surface area, volume, and temperature), the presence of local-exhaust ventilation systems, and the extent of stirring or agitation in the process. Consequently, workers are at risk of being exposed to acid mist, while emissions of hazardous air pollutants (HAPs), ozone-depleting substances (ODS), and greenhouse gases (GHGs) may also be released into the environment (3).

Material handling and ergonomic hazards are prominent in tasks involving lifting, while ergonomic hazards are also associated with screen monitoring activities in control facilities. These hazards can be effectively addressed through the implementation of science-based ergonomic programs, prioritizing the adaptation of job tasks to fit the capabilities and needs of workers, rather than expecting workers to conform to the job requirements. In this approach, it is essential to consider factors such as task frequency, awkward postures, and repetitive movements, as these can exacerbate ergonomic risks. It is important to acknowledge that these factors may vary across different unit operations within the heavy metal industries, particularly in the iron and steel facility, necessitating tailored solutions for each specific area. Assessing and ranking ergonomic hazards can pose challenges, especially when considering them alongside other hazards such as noise or heat stress, which tend to be concentrated in certain areas of the facility. Musculoskeletal disorders (MSDs), characterized by cumulative and chronic injuries to soft tissues, including muscles, tendons, ligaments, nerves, joints, and blood vessels, are common manifestations of ergonomic hazards. Conversely, acute injuries, such as cuts, abrasions from sharp objects, or immediate impacts from noise, are more readily noticeable.

In terms of occupational noise, the National Institute for Occupational Safety and Health (NIOSH) recommends a maximum allowable exposure limit of 85 dBA Time Weighted Average (TWA) over an 8-hour work period. According to NIOSH, at this threshold level, a cumulative exposure of 40 years in the workplace would result in an estimated 8% excess risk of developing Noise-Induced Hearing Loss (NIHL). This risk is significantly lower compared to the 25% excess risk associated with noise exposures at 90 dBA, which is the legally binding Permissible Exposure Limit (PEL) set by the U.S. Occupational Safety and Health Administration (OSHA) for an 8-hour TWA (9).

Limited area sampling data for noise exposure, as depicted in Fig. 3.0(a) for the control room and Fig. 3.0(b) for the hydraulic room where robotic machines are used for banding and debanding of iron and steel coils, indicate a range of noise levels ranging from approximately 66 dBA to 89 dBA. Although similar findings have been reported in other studies (10, 11), conducting personal monitoring to collect more representative exposure data can provide a more precise understanding of the risks associated with Noise-Induced Hearing Loss (NIHL) for employees.

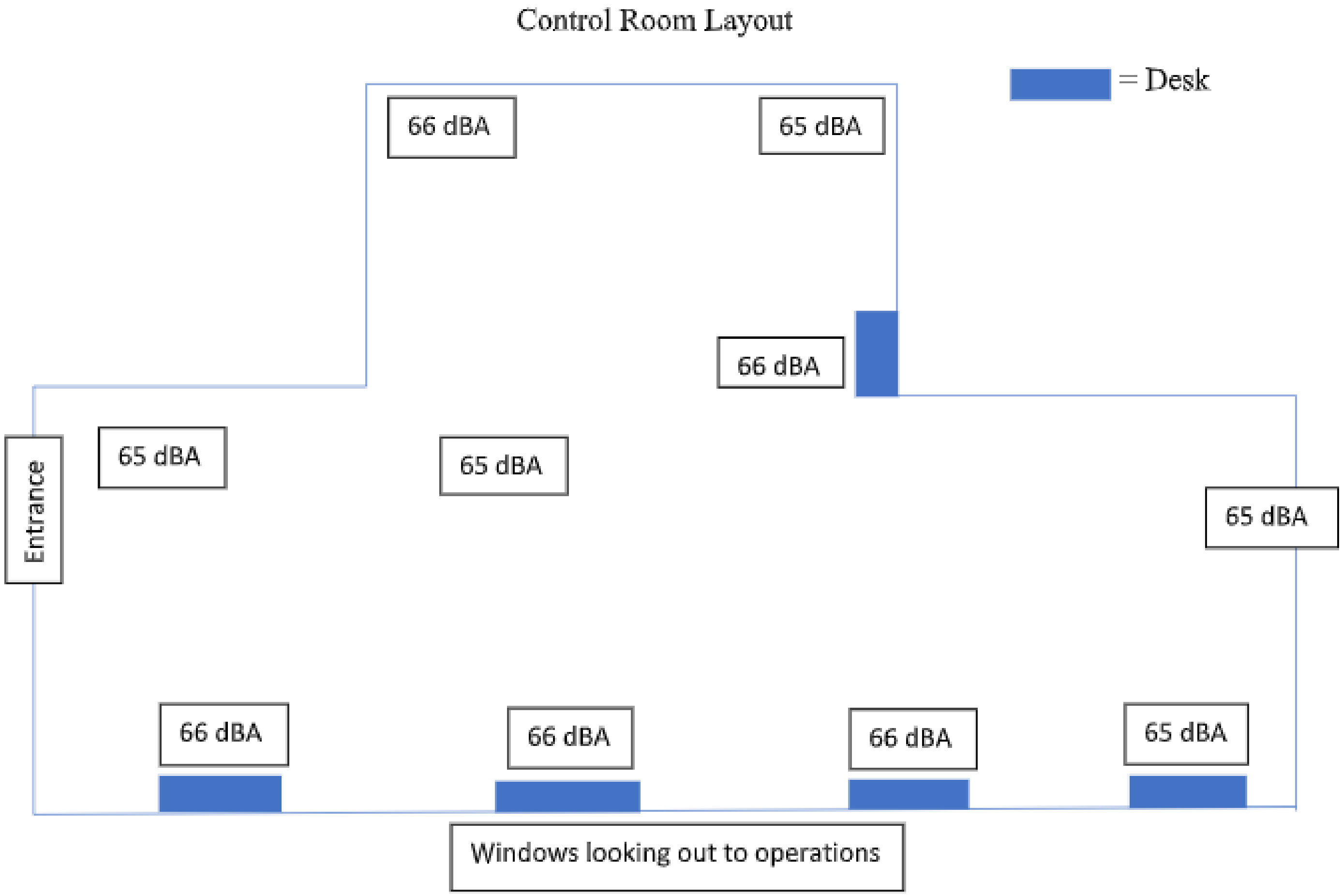


Figure 3.0a: Area Monitoring for Noise in the Control Room

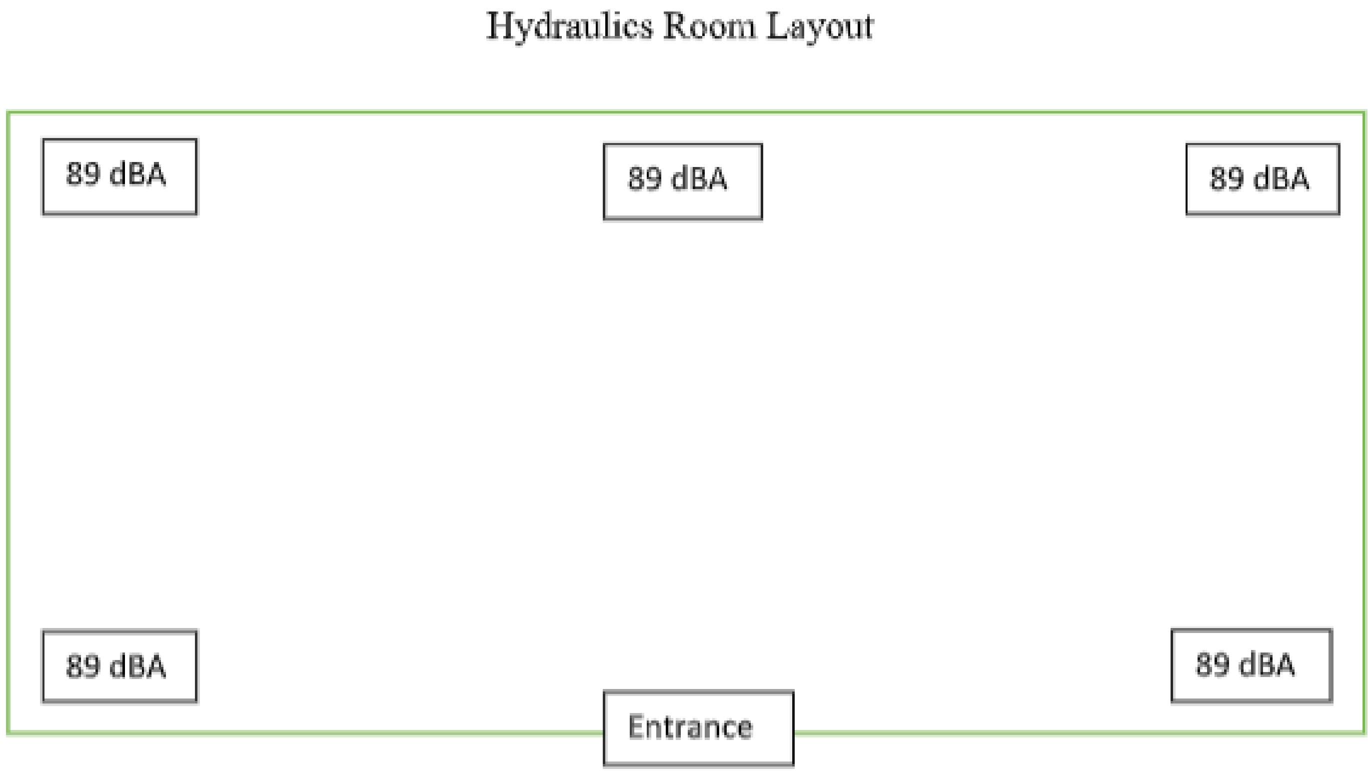


Figure 3.0b: Area Monitoring for Noise in the Hydraulic Room

In modern iron and steel facilities, particularly those workplaces equipped with robotic equipment and devices for quality control (QC) and quality assurance (QA) purposes, noise levels can be relatively high. In the specific iron and steel facility discussed here, the tasks of banding and debanding the iron and steel coils, for example, involved securing Outside Diameter (OD) and Inside Diameter (ID) bands to the coils. Traditionally, these tasks were performed manually in older iron and steel facilities, requiring significant labor and posing risks such as heat exposure, falls, ergonomic issues, lacerations, and cuts from sharp objects. However, with the advancement of robotic machines in modernized iron and steel facilities, these manual activities have been eliminated, mitigating the aforementioned hazards. Nonetheless, the introduction of robotic machines has introduced new challenges, particularly in terms of increased noise levels, necessitating the development of novel solutions to address this specific hazard.

Ranking of Multiple Hazards:

The ranking of multiple hazards has been approached in various ways in the literature, employing different strategies, schemes, and tools. Some methods involve computational models, while others utilize qualitative assessments (2, 7-8, 10). In cases where there is limited occupational exposure data, hazard banding, and certain cases, exposure control categories have been utilized (7-8, 2). Additionally, input from workers, including their personal perceptions and assessments of hazards, has been considered for ranking purposes (7-8).

For instance, when considering biological agents in combination with other hazards, some rankings have employed a five-step continuum for risk assessment, as illustrated in Fig 3.0(c) (7). This approach integrates workers' perceptions of the hazards and their potential threats to individuals as a valuable input for ranking and assessing risks associated with biological agents.

Figure 3.0c: A Continuum of the Five-Step Flexible Risk Assessment Method

For the successful operation of any industry, it is crucial to identify, address, and mitigate hazards that hinder their day-to-day functions. The iron and steel facilities are also implementing continuous improvement strategies to ensure safety. Safety and health professionals, along with workers, must consider several key factors when assessing hazards. These factors include the number of employees potentially exposed, the health effects such as fatal and non-fatal injuries and illnesses, as well as ecological and property damage. Additionally, the severity of the hazards, including the associated costs to the company and the need for job reassignment, are critical considerations. The likelihood, probability, and frequency of occurrence for specific hazards or combinations of hazards are also important factors to be evaluated.

To aid in the assessment process, these factors are tabulated and color-coded in Table 2.0 for each individual hazard or multiple hazards. For example, a hazard with a very high-risk score, indicating the need for immediate action, is designated as "unacceptable" and requires prompt assignment of responsibility for corrective measures. The scores for each hazard are combined and letter-coded, as illustrated in the example below using letters A to E (Table 2.0).

Table 2.0: Letter Coding System for Prioritizing Risks of Multiple Hazards

Letter Coding	Letter Description	Risk Ranking & Prioritization	Remarks	Action/Responsibility/Accountability
A	Low risk	0-2	Acceptable	Training/Coordinator
B	Medium risks	3-5	Low	Close Supervision immediate supervisor e.g.
C	Higher risks	6-8	Medium	Training/Coordinator
D	Higher risks	9-11	High	Senior Manager
E	Severe risks unacceptable	12 or higher	Unacceptable	immediate action required. Responsibility: senior manager

Probability of Occurrence of Occupational Hazards:

The probability of occupational hazards occurring is often studied using a ranking system that assigns probabilities or chances of hazards happening within different categories (0-1-2-3), sometimes referred to as hazard bandings (7-8). Here, we provide an illustration of these rankings for the absence or low occurrence, occasional occurrence, and frequency of occurrence of hazards, respectively.

1. The none hazard category refers to hazards that have never been experienced by a worker throughout their employment history.
2. The low hazard category indicates hazards that are likely to occur or affect a worker within a five-year period.
3. Occasional hazards are likely to occur or affect a worker within a one-year period.
4. Frequent hazards are those that occur or affect a worker during a shift of eight to twelve hours.

Ranking of Multiple Hazards using one Matrix

Ranking multiple hazards using a single matrix becomes essential due to variations in the number of workers potentially exposed to each hazard, resulting in different impacts on environmental properties and health. Conducting a literature review is crucial for developing a comprehensive matrix that enables the ranking of, and prioritizatin, these multiple risks. Further exploration of this theoretical subject is warranted.

Workers' Perception, Qualitative Views and Ranking of Hazards

The perception, qualitative views, and ranking of hazards by workers play a crucial role in assessing multiple hazards, especially when considering potential interventions (Table 3.0). Input from workers through interviews and surveys is essential for gaining valuable insights into the nature of these hazards

Table 3.0: Workers' Perception and Ranking of Occupational Hazards

Survey #	Noise	Ergonomics	Heat stress	Silica-exposure	Acid-mist	Chromium	Sharp-injuries	Others
Ranking and Prioritizing Hazards	5	5	4	5	5	5	4	3
	4	1	1	5	4	5	3	2
	2	3	1	5	5	4	3	2
	3	3	3	5	4	4	4	2
	4	3	5	5	4	4	1	2
	3	3	3	5	4	4	4	2

Assessment and Ranking of Costs and Economic Implications of Hazards

As part of the overall methodology used in this case study, an assessment and ranking of costs and economic implications of hazards to facilities are necessary. To provide a comprehensive view of potential risks, data was reviewed for potentially serious injuries and fatalities incidents (PSIF) as well as other incident records. This information was collected from databases covering a six-year period, from 2015 to 2022, and included near misses for potential acute injuries. Figures 4.0 and 5.0 provide our results as a visual representation of this data.

It may be necessary to conduct additional analysis of the data collected from these sources in order to facilitate future assessments of the ranking of occupational hazards. This analysis should account for various factors such as the employee/contractor involved, the type of hazard, and the location of the accident, incident, injury, or illness. Based on the figures provided, it is clear that impacts on equipment damage, injury, or illness, as well as reactive near misses, are valuable indicators to consider when ranking the risks associated with these occupational hazards.

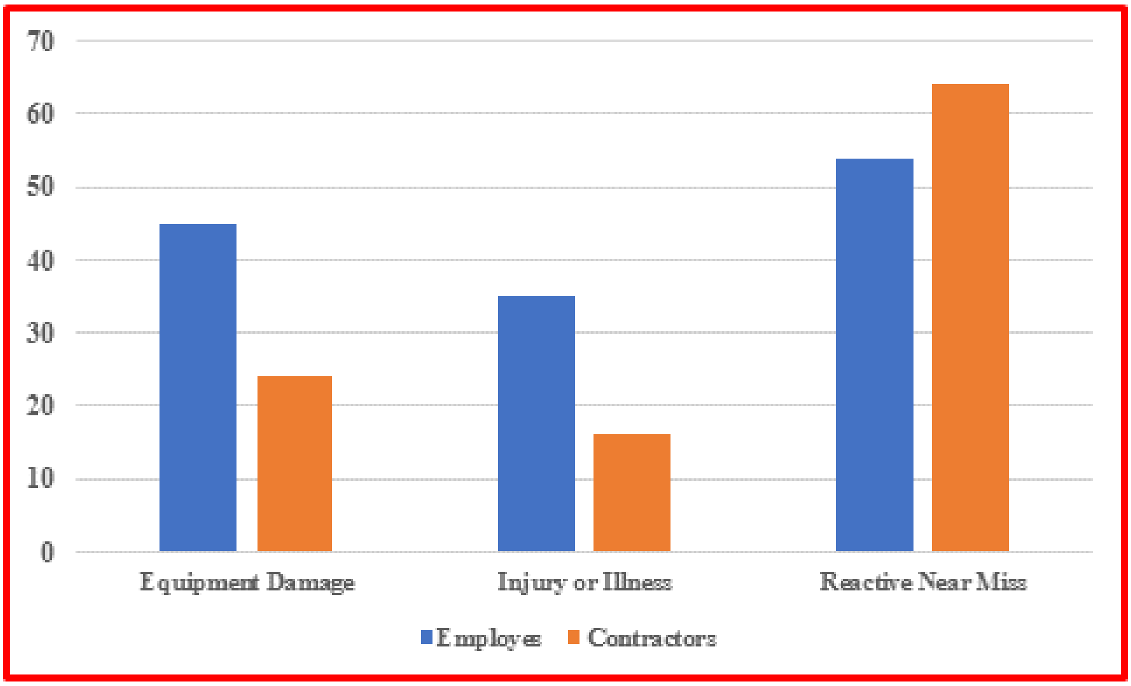
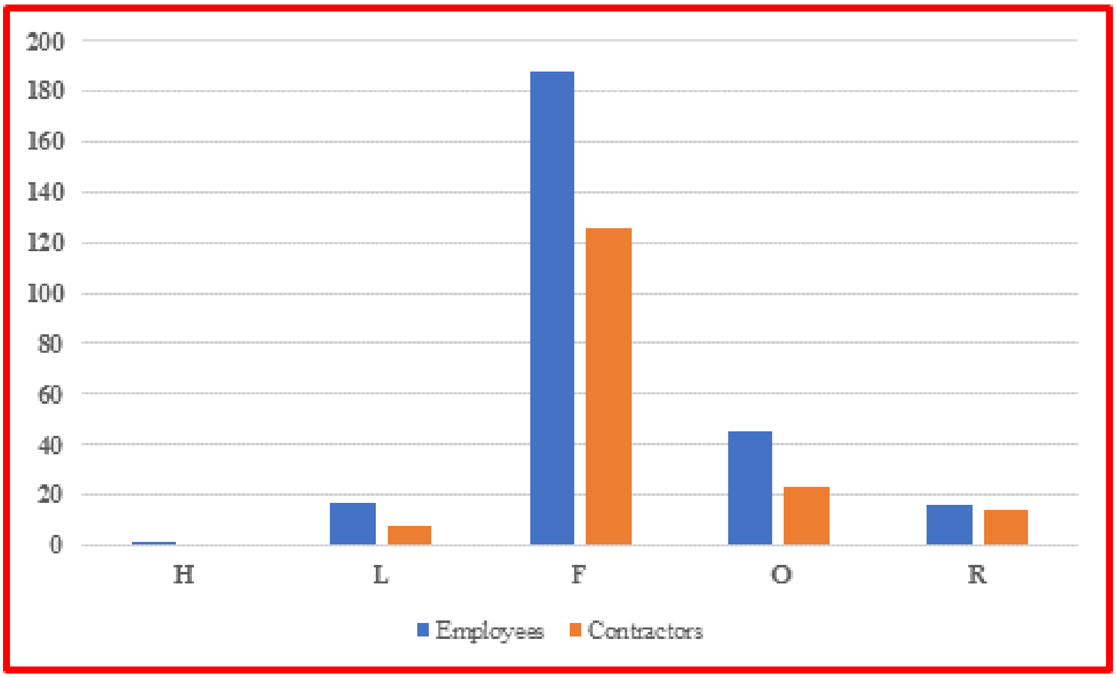


Figure 4.0: Potentially Serious Injury/Illness or Fatality (PSIF) Trends from 2015 to 2022



H:
H: L: Lost Workday Incident-OSHA Recordable **F:**
O: Medical Treatment Required-OSHA Recordable **R:** Restricted Work Incident-OSHA Recordable

Figure 5.0: Injury Data Trends from 2015 to 2022

The economic implications of the injury and illness data presented here may provide the appropriate ranking and prioritization of risks posed by each or multiple hazards from the perspectives of the company's profits, ecological implications and social responsibilities context. It is important to consider the impact on workers, the company's bottom line, and the supply chain when ranking the risks associated with multiple occupational hazards. The upstream and downstream factors are not considered in this analysis, but it is clear that impacts to equipment damage, injury, or illness, as well as reactive near misses, are valuable indicators to consider when ranking and prioritizing the risks associated with these occupational hazards. The U.S. Occupational Safety and Health Administration (U.S.OSHA) estimates one injury per year from chemical hazards, such as exposure to silica dust which may occur in the furnace areas of the iron and steel facilities, causing chronic illnesses such as silicosis and cancer, are ranked and presented in Fig 6.0.

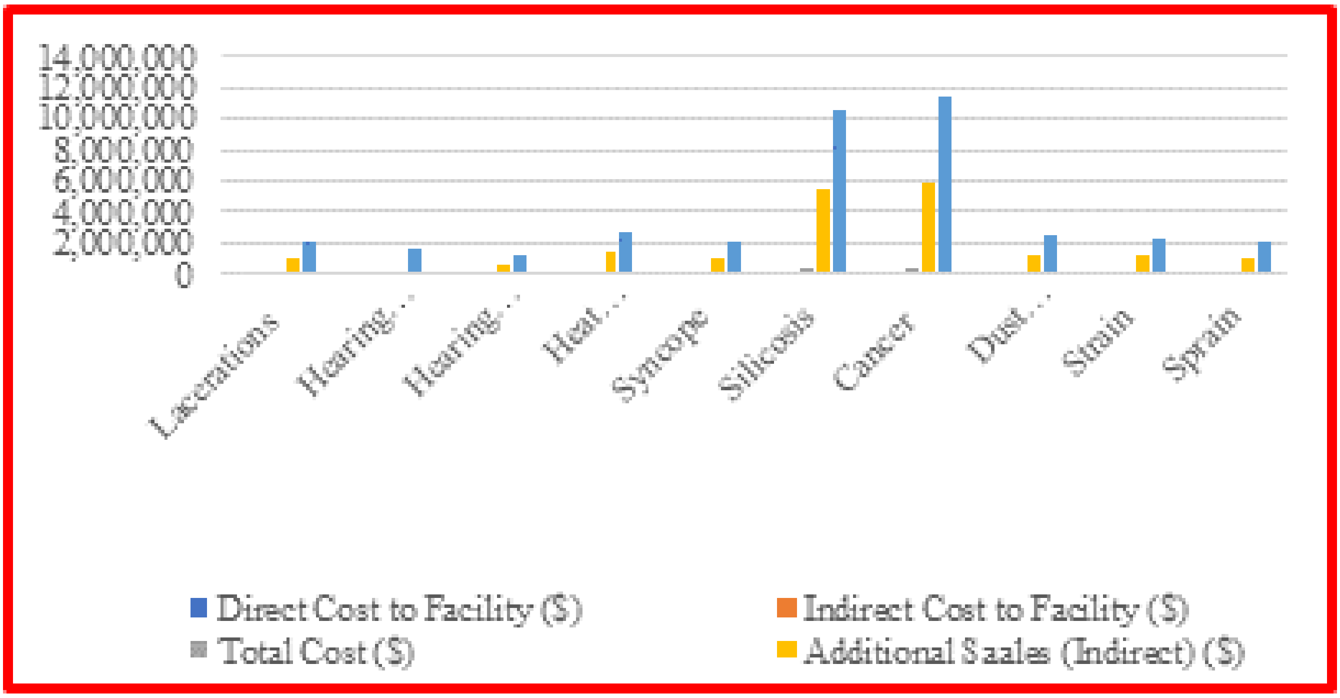


Figure 6.0: Ranking of Multiple Hazards Based on Company's Bottom Line
(Source: OSHA-https://www.osha.gov/safetypays/estimator)

Conclusion and Recommendations

This study is of significant importance as it contributes to the continuous improvement of safety and health programs for workers in workplace facilities, particularly within the heavy metal industry, exemplified by the iron and steel sector in this case study. The article employs multiple engineering and technology approaches and strategies, which enable a swift assessment of workplace hazard evaluations. Consequently, this facilitates the implementation of a successful safety and health program in iron and steel facilities by supporting line personnel. However, it is essential to acknowledge that the ultimate responsibility lies with top management to provide a clear vision and allocate resources to foster these proactive activities for the ongoing improvement of such safety and health programs.

When a combination of different methods for ranking and prioritizing risks of multiple occupational hazards is utilized, it becomes possible to address the risks more effectively from the perspectives of workers' health and safety, as well as ecological and property damage (7-8). While this study does not explore all available approaches, other tools like the U.S. federal government's ranking system, including the Federal Emergency Management Agency's (FEMA) Multi-Hazard (HAZUS-MH) risk assessment tools (1) and others, can also be employed to assess the inclusion of natural hazards or technological disasters in the overall scoring, ranking and prioritization of the risks.

In conclusion, we strongly recommend adopting a comprehensive approach by utilizing a blend of techniques, including assigning numerical scores and factoring in probabilities of occurrence along with severity of impacts, to determine the Hazard Ranking Value (HRV). This methodology provides a solid foundation for prioritizing various occupational hazards within the heavy metal industry, with a specific focus on iron and steel facilities, and has the potential to be applied to other industry sectors as well.

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final version of the manuscript are solely the author's responsibility.

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