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Identification of Potential Hazards in Metal Fabrication Works Using Hazard Identification, Risk Assessment and Risk Control (HIRARC) in the Manufacturing Industry

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Abstract

Metal fabrication works in the manufacturing industry are widely recognized as high-risk operations due to the involvement of hot work processes, heavy machinery, sharp materials, and manual handling activities. These conditions expose workers to various occupational safety and health hazards if not properly managed. This study aims to identify potential hazards, assess associated risks, and propose appropriate control measures for metal fabrication activities using the Hazard Identification, Risk Assessment and Risk Control (HIRARC) method. The study was conducted at the Universal Division, Factory 2 of PCA Group Sdn. Bhd., focusing on five major fabrication activities, namely manual welding, robotic welding, grinding, buffing, and the use of hand tools. A qualitative case study approach was utilized through direct site observations, photographic documentation, and the review of existing safety records. The identified hazards were evaluated using a qualitative risk matrix based on likelihood and severity, followed by the recommendation of control measures in accordance with the hierarchy of controls. The findings indicate that several fabrication activities present medium to high risk levels, particularly due to exposure to sparks, flying particles, electrical hazards, poor ergonomic postures, and inadequate personal protective equipment (PPE) compliance. The outcomes of this study provide a structured basis for prioritizing risk control measures and enhancing workplace safety practices in metal fabrication operations within the manufacturing industry.

1. Introduction

Metal fabrication plays an important role in the manufacturing industry by supplying structural components and mechanical parts for sectors such as construction, automotive, and infrastructure [1]. Fabrication processes typically involve welding, grinding, buffing, cutting, and the use of hand tools, which expose workers to high-risk working conditions due to hot work processes, sharp materials, heavy machinery, and manual handling activities. Workers in metal fabrication environments are exposed to multiple occupational safety and health hazards,

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including physical, chemical, mechanical, electrical, and ergonomic hazards [2]. Common risks include burns and flying particles from welding and grinding, inhalation of welding fumes, mechanical injuries from machinery and hand tools, and musculoskeletal disorders resulting from repetitive tasks and poor working postures [3]. If these hazards are not effectively managed, they may lead to occupational accidents, long-term health effects, production disruptions, and financial losses [4].

In Malaysia, workplace safety in manufacturing industries is regulated under the Occupational Safety and Health Act 1994 and the Factories and Machinery Act 1967, which require employers to identify hazards and implement appropriate risk control measures [5]. However, incidents related to metal fabrication activities remain prevalent due to inadequate hazard identification, insufficient risk assessment, and poor compliance with safety practices, particularly the use of personal protective equipment (PPE) [6]. This highlights the need for a structured and proactive risk management approach.

Hazard Identification, Risk Assessment and Risk Control (HIRARC) is a systematic method used to identify workplace hazards, evaluate risk levels based on likelihood and severity, and implement suitable control measures following the hierarchy of controls [7]. The application of HIRARC allows organizations to prioritize high-risk activities and improve occupational safety and health performance in high-risk environments such as metal fabrication workshops [8].

Therefore, this study applies the HIRARC method to identify potential hazards and assess associated risks in metal fabrication works at the Universal Division, Factory 2 of PCA Group Sdn. Bhd., focusing on manual welding, robotic welding, grinding works, buffing works, and the use of hand tools. The findings of this study aim to support the improvement of workplace safety practices and contribute to a safer manufacturing environment.

2. Methodology

2.1 Study Design and Location

This study utilized a qualitative case study approach to identify and assess occupational safety and health hazards associated with metal fabrication works. The study was conducted at the Universal Division, Factory 2 of PCA Group Sdn. Bhd., a manufacturing facility involved in metal fabrication and engineering operations. This approach allowed for direct observation of real working conditions and safety practices in a high-risk manufacturing environment.

Five major metal fabrication activities were selected for assessment due to their high-risk potential and frequent occurrence in daily operations. These activities included manual welding, robotic welding, grinding works, buffing works, and the use of hand tools. Observations were carried out during normal production activities to ensure that the findings were realistic and representative of actual workplace conditions. The observations were conducted over a defined four-week study period during routine operations to ensure consistent and representative assessment of metal fabrication activities.

2.2 Data Collection Method

Data collection was conducted using three qualitative methods which is direct site observation, photographic documentation, and review of existing safety records. Direct site observations were carried out to identify unsafe work practices, hazardous conditions, and worker exposure to potential risks during metal fabrication activities. These observations were performed repeatedly throughout the study period during normal working hours to capture typical workplace conditions. Photographic documentation was used to support visual identification of hazards and non-compliance with safety practices, particularly related to PPE usage.

In addition, existing safety records such as previous HIRARC documents, inspection checklists, and incident or near-miss reports provided by the Health, Safety and Environment department were reviewed. This review helped to identify recurring hazards as well as existing control measures implemented in the workplace.

2.3 HIRARC Implementation

The HIRARC method was applied to systematically evaluate workplace hazards. Hazard identification was conducted by examining each selected work activity to identify potential physical, chemical, mechanical, electrical, and ergonomic hazards.

Risk assessment was performed using a qualitative risk matrix based on the likelihood of occurrence and severity of consequences. The qualitative risk matrix used in this study is based on the principles of the HIRARC approach and is widely applied in industrial safety assessments to ensure a consistent and systematic evaluation of workplace risks. In this study, likelihood refers to the probability of a hazard occurring during routine metal fabrication activities, while severity represents the potential impact or consequence should the hazard occur, ranging from minor injury to fatality. The overall risk level was determined by combining the likelihood and severity ratings using a qualitative risk matrix, and the risks were categorised into low, medium, or high to support the prioritisation of appropriate risk control measures.

2.4 Data Analysis

The collected data were analyzed qualitatively using the HIRARC risk matrix to determine the overall risk level of each identified hazard. The analysis focused on identifying high-risk activities and prioritizing suitable control measures to reduce workplace risks and improve occupational safety and health performance in metal fabrication operations.

3. Results and Discussion

This section presents the findings of the HIRARC analysis conducted for metal fabrication works at PCA Group Sdn. Bhd. (Division Universal), Factory 2. The results are discussed in relation to the study objectives, which include hazard identification, risk assessment, and the determination of appropriate risk control measures. The HIRARC assessment covered five major metal fabrication activities: manual welding, robotic welding, grinding, buffing works, and the use of hand tools. The findings in this section reflect the overall hazard profile and risk levels identified across the assessed activities.

3.1 Hazard Identification for Metal Fabrication Works

Hazard identification was carried out for metal fabrication works to determine potential hazards associated with routine production activities. The hazard identification results for metal fabrication works, including the associated hazards, potential risk consequences, and existing control measures for each assessed activity, are summarized in Table 1.

Table 1 *Hazard identification for metal fabrication works*

No	Work Activity	Hazard	Risk Consequences	Existing Control
1	Manual Welding	Welding spark	Heat, fire and burnt, eye contact, sore eye, blind	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Ventilation fan **Admin Control:** Trained worker, Red card enforcement **PPE:** Apron, face mask N95, face cover/goggle, glove
2	Manual Welding	Toxic fumes and gases, bright light	Dazzled, mild headache	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Ventilation fan **Admin Control:** Safety poster **PPE:** Face shield, apron, leather glove
3	Manual Welding	Wound cable (open circuit)	Electric shock, fatality	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Proper wiring, regular maintenance **Admin Control:** Training on electrical hazards **PPE:** Insulated gloves
4	Manual Welding	Awkward posture, force movement	Back pain, muscle strain, tendonitis	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** N/A **Admin Control:** Ergonomic poster, safety induction, stretching **PPE:** N/A
5	Manual Welding	Gas cylinder	Leakage, toxic gas inhaled, fainted, death, fire, explosion	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Spark arrestor, cage with chain **Admin Control:** Housekeeping, pre/post inspections, ERT **PPE:** N/A
6	Manual Welding	Moving forklift	Hit by moving forklift, fatality, body injury	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** N/A **Admin Control:** Safety poster, SOP, supervision, trained operator **PPE:** Safety shoes

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Table 1 (continued) *Hazard identification for metal fabrication works*

No	Work Activity	Hazard	Risk Consequences	Existing Control
7	Robotic Welding	Welding spark	Heat, fire and burnt, eye contact, sore eye, blind	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Ventilation fan **Admin Control:** Trained worker, Red card enforcement **PPE:** Face shield, apron, leather glove
8	Robotic Welding	Toxic fumes and gases, bright light	Dazzled, mild headache	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Ventilation fan **Admin Control:** Safety poster **PPE:** Face shield, apron, leather glove
9	Robotic Welding	Wound cable (open circuit)	Electric shock, fatality	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Proper wiring, regular maintenance **Admin Control:** N/A **PPE:** Insulated gloves
10	Robotic Welding	Awkward posture, force movement	Back pain, muscle strain, tendonitis	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** N/A **Admin Control:** Ergonomic poster, safety induction, stretching **PPE:** N/A
11	Robotic Welding	Robotic movement	Cut, crushed, bruises, abrasion	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Safe distance barriers, emergency lockouts **Admin Control:** Trained operator, safety procedures **PPE:** N/A
12	Grinding	Rotating blade	Abrasion, bursting of wheel, cut, minor and major injury	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Blade cover **Admin Control:** Induction training, safety signage, monthly toolbox briefing **PPE:** Apron, face mask N95, goggle/face shield, glove, ear protection
13	Grinding	Dust, sharp steel particle	Eye injury, inhaled, cardiovascular disease, cancer	**Elimination:** Manual cutting where practical to avoid grinding **Substitution:** Use coated or dust-minimizing abrasives **Engineering Control:** Use portable dust collectors **Admin Control:** Housekeeping, job rotation, toolbox talks on inhalation risks **PPE:** N95 mask, safety goggles, long sleeves
14	Grinding	Noise	Impairment hearing, deaf	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** N/A **Admin Control:** Noise monitoring, Red card enforcement **PPE:** Earplugs
15	Grinding	Open circuit (wound cable)	Electric shock, fatality	**Elimination:** Reduce cable clutter by designating cable routes **Substitution:** Use cordless grinders where applicable **Engineering Control:** Proper wiring, regular pre/post checks **Admin Control:** Safe work procedure, regular inspections, cable tagging **PPE:** Electrical insulated gloves and dielectric boots

Table 1 (continued) *Hazard identification for metal fabrication works*

No	Work Activity	Hazard	Risk Consequences	Existing Control
16	Grinding	Awkward posture, long duration	Muscle strain, back pain	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** N/A **Admin Control:** Safety induction, ergonomic poster **PPE:** N/A
17	Buffing works	Dust, lead particle	Asthma, cancer	**Elimination:** Use of non-lead materials where possible **Substitution:** Replace lead-based components **Engineering Control:** Ventilation fan **Admin Control:** Housekeeping, training (safety induction), supervision enforcement **PPE:** Face mask (N95)
18	Buffing works	Prolonged use / vibration	'Reynaud's syndrome', white finger, carpal tunnel syndrome	**Elimination:** Limit unnecessary use of handheld buffing **Substitution:** Use anti-vibration tools **Engineering Control:** Vibration-dampening handles **Admin Control:** Job rotation, ergonomic exercises, work-rest schedule **PPE:** Anti-vibration gloves
19	Buffing works	Noise	Hearing loss, deaf	**Elimination:** Use quieter equipment **Substitution:** Replace tools with low-noise versions **Engineering Control:** Noise-dampening covers **Admin Control:** Scheduled noise monitoring, hearing conservation program, noise briefing, Red card enforcement **PPE:** Ear plugs
20	Use of hand tools	Cutter knife, cutting tools, pliers, cordless screwdrivers, plastering tools	Cut, stabbed, laceration	**Elimination:** Remove unnecessary use of sharp tools **Substitution:** Use safer tool designs (e.g., retractable knives) **Engineering Control:** Designated tool storage and holders **Admin Control:** Safe work procedures, supervision, trained workers, counseling for non-compliance **PPE:** Cotton gloves

3.2 Risk Assessment Results for Metal Fabrication Works

Risk assessment was conducted by evaluating the likelihood and severity of each identified hazard to determine the corresponding risk rating. The risk assessment results for metal fabrication works, including likelihood, severity, risk rating, and corresponding risk level for each identified hazard, are presented in Table 2.

Table 2 *Risk assessment results for metal fabrication works*

No	Work Activity	Hazard	Likelihood	Severity	Risk Rating	Risk Level
1	Manual Welding	Welding spark	1	4	4	Low
2	Manual Welding	Toxic fumes and gases, bright light	1	2	2	Low
3	Manual Welding	Wound cable (open circuit)	1	5	5	Medium
4	Manual Welding	Awkward posture, force movement	1	4	4	Low
5	Manual Welding	Gas cylinder	1	5	5	Medium
6	Manual Welding	Moving forklift	4	4	16	High
7	Robotic Welding	Welding spark	2	4	8	Medium

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Table 2 (continued) *Risk assessment results for metal fabrication works*

No	Work Activity	Hazard	Likelihood	Severity	Risk Rating	Risk Level
8	Robotic Welding	Toxic fumes and gases, bright light	1	2	2	Low
9	Robotic Welding	Wound cable (open circuit)	1	5	5	Medium
10	Robotic Welding	Awkward posture, force movement	1	4	4	Low
11	Robotic Welding	Robotic movement	2	4	8	Medium
12	Grinding	Rotating blade	4	3	12	Medium
13	Grinding	Dust, sharp steel particle	1	4	4	Low
14	Grinding	Noise	1	4	4	Low
15	Grinding	Open circuit (wound cable)	1	4	4	Low
16	Grinding	Awkward posture, long duration	1	4	4	Low
17	Buffing works	Dust, lead particle	2	4	8	Medium
18	Buffing works	Prolonged use / vibration	1	4	4	Low
19	Buffing works	Noise	1	4	4	Low
20	Use of hand tools	Cutter knife, cutting tools, pliers, cordless screwdrivers, plastering tools	4	3	12	Medium

3.3 Risk Control Measures for Metal Fabrication Works

Based on the risk assessment results, appropriate risk control measures were proposed in accordance with the hierarchy of controls to reduce the identified risks to acceptable levels. The recommended risk control measures, based on the hierarchy of controls, together with the revised risk ratings, are presented in Table 3.

Table 3 *Risk control measures for metal fabrication works*

No	Work Activity	Hazard	Recommended Control Measure	Revised (L)	Revised (S)	Revised Risk Rating (LxS)
1	Manual Welding	Welding spark	**Elimination:** N/A **Substitution:** N/A **Engineering Control:** Enclosed welding station **Admin Control:** More frequent training **PPE:** Face shield, N95 respirator, goggles, gloves, long-sleeve apron	1	2	2
2	Manual Welding	Toxic fumes and gases, bright light	**Elimination:** N/A **Substitution:** Use low-fume rods **Engineering Control:** Fume extraction hood **Admin Control:** Air quality monitoring **PPE:** N95 respirator	1	1	1
3	Manual Welding	Wound cable (open circuit)	**Elimination:** N/A **Substitution:** Use wireless welding systems **Engineering Control:** Use ground fault interrupters **Admin Control:** Cable inspection checklist **PPE:** Electrical-rated gloves	1	2	2

Table 3 (continued) *Risk control measures for metal fabrication works*

No	Work Activity	Hazard	Recommended Control Measure	Revised (L)	Revised (S)	Revised Risk Rating (LxS)
4	Manual Welding	Awkward posture, force movement	**Elimination:** N/A **Substitution:** Use robotic arm for repetitive tasks **Engineering Control:** Adjustable welding tables **Admin Control:** Stretching programs **PPE:** Back support belt	1	2	2
5	Manual Welding	Gas cylinder	**Elimination:** N/A **Substitution:** Replace with centralized gas supply **Engineering Control:** Automatic gas shutoff system **Admin Control:** Leak detection training **PPE:** Self-contained breathing apparatus for emergencies	1	2	2
6	Manual Welding	Moving forklift	**Elimination:** Restrict forklift access to welding area **Substitution:** Use a powered pallet jack instead of a forklift in the welding area **Engineering Control:** Forklift detection system **Admin Control:** Stop work in 3 m radius during forklift operation PPE: High-visibility vest	2	2	4
7	Robotic Welding	Welding spark	**Elimination:** Enclose robotic welding station **Substitution:** Use laser welding with less spark **Engineering Control:** Install spark deflector system **Admin Control:** Introduce restricted access zones **PPE:** Auto-darkening helmet, fire-resistant clothing	1	2	2
8	Robotic Welding	Toxic fumes and gases, bright light	**Elimination:** Use fume-free welding method **Substitution:** Use low-emission wire/electrodes **Engineering Control:** Fume extraction system **Admin Control:** Continuous air quality monitoring **PPE:** Respirator with appropriate filters	1	1	1
9	Robotic Welding	Wound cable (open circuit)	**Elimination:** Eliminate trailing cables using wireless system **Substitution:** Use self-coiling or retractable cables **Engineering Control:** Ground fault circuit interrupters (GFCI) **Admin Control:** Monthly cable inspection logs **PPE:** Electrical-rated gloves and dielectric boots	1	2	2
10	Robotic Welding	Awkward posture, force movement	**Elimination:** Redesign workstation layout for automation **Substitution:** Use robotic arms for repetitive/manual tasks **Engineering Control:** Adjustable workstations and chairs **Admin Control:** Implement job rotation to reduce strain **PPE:** Back support belt	1	2	2

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Table 3 (continued) *Risk control measures for metal fabrication works*

No	Work Activity	Hazard	Recommended Control Measure	Revised (L)	Revised (S)	Revised Risk Rating (LxS)
11	Robotic Welding	Robotic movement	**Elimination:** Fully enclosed robotic cells **Substitution:** Use collaborative robots with force sensors **Engineering Control:** Install safety interlock and enclosed robotic welding cells **Admin Control:** Install warning indicators for restricted access zones, regular retraining **PPE:** Cut-resistant gloves, safety boots	1	2	2
12	Grinding	Rotating blade	**Elimination:** Use alternative cutting methods (e.g., laser or waterjet) where possible **Substitution:** Replace with low-speed grinders or cut-off machines **Engineering Control:** Deadman switch and anti-kickback devices **Admin Control:** Red card policy, enforcement by HSE committee **PPE:** Cut-resistant gloves, impact-rated full-face shield	2	2	4
13	Grinding	Dust, sharp steel particle	**Elimination:** Use pre-cut materials to reduce grinding **Substitution:** Use dustless grinding tools **Engineering Control:** Local exhaust ventilation (LEV), dust collector **Admin Control:** Air monitoring, limit exposure time **PPE:** Respirator (N95 or P100), safety goggles	1	2	2
14	Grinding	Noise	**Elimination:** Relocate noisy work outside of general area **Substitution:** Use low-noise grinders **Engineering Control:** Acoustic barriers, sound dampening pads **Admin Control:** Limit duration of exposure, rotate tasks **PPE:** Noise-cancelling earmuffs	1	2	2
15	Grinding	Open circuit (wound cable)	**Elimination:** Eliminate trailing cables via cable retractors **Substitution:** Use battery-operated grinders **Engineering Control:** Ground fault interrupter (GFI) **Admin Control:** Cable checklist and tagging system **PPE:** Electrical insulated gloves and dielectric boots	1	2	2
16	Grinding	Awkward posture, long duration	**Elimination:** Automate repetitive grinding where feasible **Substitution:** Use adjustable-height workbenches **Engineering Control:** Ergonomic workstation setup **Admin Control:** Frequent breaks, rotation of job tasks **PPE:** Back support brace	1	2	2

Table 3 (continued) *Risk control measures for metal fabrication works*

No	Work Activity	Hazard	Recommended Control Measure	Revised (L)	Revised (S)	Revised Risk Rating (LxS)
17	Buffing works	Dust, lead particle	**Elimination:** Pre-clean materials to reduce buffing **Substitution:** Use alternative surface finishing methods **Engineering Control:** Install dust extraction system **Admin Control:** Medical surveillance, dust exposure tracking **PPE:** P100 respirator	1	2	2
18	Buffing works	Prolonged use / vibration	**Elimination:** Use automated buffing machines **Substitution:** Use ergonomically designed lightweight tools **Engineering Control:** Buffing stations with arm support **Admin Control:** Vibration exposure logging, training **PPE:** Anti-vibration gloves with wrist support	1	2	2
19	Buffing works	Noise	**Elimination:** Isolate high-noise equipment **Substitution:** Use low-decibel buffing tools **Engineering Control:** Acoustic panels or barriers **Admin Control:** Rotate workers to limit exposure **PPE:** Noise-canceling earmuffs	1	2	2
20	Use of hand tools	Cutter knife, cutting tools, pliers, cordless screwdrivers, plastering tools	**Elimination:** Use pre-fabricated materials to reduce manual cutting **Substitution:** Replace with round-tip tools where possible **Engineering Control:** Use of blade guards and safety grips **Admin Control:** Frequent inspection, refresher training **PPE:** Cut-resistant gloves	1	2	2

The findings of the HIRARC analysis demonstrate that metal fabrication works at PCA Group Sdn. Bhd. involve a broad range of hazards arising from manual operations, machine-assisted processes, and the use of tools and equipment. The identified hazards span physical, chemical, mechanical, electrical, and ergonomic categories across all assessed activities, including manual welding, robotic welding, grinding, buffing works, and the use of hand tools. This indicates that workers are exposed to multiple sources of risk throughout routine production tasks. Based on the risk assessment results, higher risk ratings were mainly associated with activities involving moving forklifts, gas cylinders, rotating blades, and robotic movement. These hazards present the potential for severe consequences, such as serious injury or fatality, particularly when control measures are inadequate or not strictly implemented. In addition, repeated exposure to dust, fumes, noise, vibration, and awkward working postures contributes to long-term health effects, highlighting the importance of addressing both safety-related and health-related hazards in metal fabrication environments.

The risk control measures proposed in this study were developed in accordance with the hierarchy of controls and aimed at reducing both the likelihood and severity of the identified hazards. The implementation of engineering controls, such as ventilation systems, machine guarding, safety barriers, and enclosed workstations, played a key role in lowering risk levels. These measures were further supported by administrative controls, including training, supervision, safety procedures, and monitoring, as well as the use of appropriate PPE. Overall, the HIRARC method systematically identifies hazards, prioritizes risks, and guides effective controls in metal fabrication, with reduced risk ratings highlighting the need for continuous monitoring, regular review, and consistent enforcement to sustain a safe working environment.

4. Conclusion

This study successfully achieved its objectives by applying the HIRARC method to metal fabrication works at the Universal Division of PCA Group Sdn. Bhd., Factory 2. Through systematic site observations, photographic documentation, and review of existing safety records, various hazards associated with manual welding, robotic welding, grinding, buffing works, and the use of hand tools were identified. The findings confirmed that workers in metal fabrication environments are exposed to a combination of physical, chemical, mechanical, electrical, and ergonomic hazards arising from routine production activities.

The risk assessment results revealed that several work activities present medium to high risk levels, particularly those involving moving forklifts, gas cylinders, rotating blades, robotic movement, electrical systems, and prolonged awkward working postures. These hazards have the potential to cause serious injuries, long-term health effects, or fatalities if not properly managed. The application of the HIRARC risk matrix allowed hazards to be prioritised based on their likelihood and severity, providing a clear basis for decision-making and targeted risk reduction. This demonstrates the importance of conducting structured and regular risk assessments in high-risk manufacturing environments.

The recommended risk control measures, developed in accordance with the hierarchy of controls, demonstrated the effectiveness of combining engineering controls, administrative controls, and PPE in reducing risk levels to more acceptable conditions. Engineering measures such as machine guarding, ventilation systems, and enclosed workstations were supported by administrative actions including training, supervision, safety procedures, and monitoring, with PPE serving as the final layer of protection. Overall, this study confirms that the systematic implementation of the HIRARC method is an effective approach for improving occupational safety and health performance in metal fabrication works and supports continuous improvement towards a safer and more compliant workplace.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

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