International Journal of Safety and Security Engineering
Vol. 14, No. 4, August, 2024, pp. 1039-1047
Journal homepage: http://iieta.org/journals/ijsse

Effective Critical Risk Management in Welding Operations for Mining: A Case Study on Incident Reduction

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https://doi.org/10.18280/ijsse.140403

Received: 5 February 2024
Revised: 9 April 2024
Accepted: 16 April 2024
Available online: 30 August 2024

Keywords:
risks, critical controls, incidents, accidents

ABSTRACT

The main objective of the research was to manage the critical risks to reduce incidents and accidents in the welding area of a mining contractor company for loading, hauling and transportation of minerals. The methodology used was quantitative and analytical-synthetic approach, with a non-experimental and descriptive design. The results obtained indicated that there were a total of 5 incidents and accidents in 2021 and 2022, while in 2023 it was reduced to 3, with the activity with the most incidents being: auxiliary welding work (4 incidents), followed by auxiliary mechanical work (3 incidents). The risk analysis revealed that 50% of the incidents had a low risk level, 40% high risk and only 10% medium risk. Spearman correlation analysis indicated a perfect correlation (ρ=1.00) between activities and associated risk levels. The critical controls implemented produced a 40% reduction in incidents and accidents, demonstrating their effectiveness in risk reduction. Finally, it was concluded that through the t-student statistical analysis showed a p-value of 0.000023, indicating that the implemented interventions were effective in reducing the frequency of incidents and accidents.

1. INTRODUCTION

Occupational accidents are a problem in many sectors, entailing high costs for companies [1, 2]. To prevent accidents, it is necessary to identify all the various critical risks in the work process and then control them with an adequate assessment [3]. The number and severity of accidents and incidents are crucial indicators when measuring corporate performance [4]. Risk identification and control is crucial to mitigate accident-related costs and to enhance system efficiency. Identifying critical risks and providing control measures is important to reduce accident costs and increase system efficiency. Among the benefits of critical risk management are reducing work-related injuries and illnesses, creating effective and efficient ways to perform work reducing compensation costs, and increasing worker productivity [5].

One of the accurate and systematic study methods to identify the potential risks of each job is the Job Safety Analysis (JSA) method, which recommends in the operation phase to identify and analyze the risks [6]. The Occupational Safety and Health Administration (OSHA) recommends that by performing a proper occupational safety analysis, many accidents and diseases can be prevented, and finally, take necessary measures of engineering control, training, personal protection, and executive instructions [7].

In mining activities are developed mostly of high risk, therefore, companies in this area seek to prevent the generation of accidents or incidents through the implementation of strict controls, in the same way the government implements laws in prevention of these, to ensure the integrity of the collaborators of the industry [8]. The constant growth of accident rates is closely related to the implementation of improvements in the safety management of employees, in this sense, companies are obliged to comply with the highest safety parameters [9, 10].

The mining contractor company currently provides earthmoving services to a mining company, through the rental of heavy equipment, located in northern Peru. The company carries out various complementary activities, such as welding to reinforce the bucket in the workshop and in the field, nail grinding, material cutting, among others, which involve compliance with isolation procedures and energy blocking, where there has been an increase in the number of incidents.

Many studies indicate that, to prevent incidents and accidents, the management of critical controls represents one of the most used and reliable methods to prevent this type of events [11]. According to the literature review, it was found that Vasques Orellana analyzed the effectiveness of controls on critical risks in the Chuquicamata Mining Project, introducing an indicator to improve prevention and management, achieving greater efficiency and speed in problem resolution. This approach reduced productive losses, ensured legal compliance, and improved the flow of information, where of 161 reported incidents, 43.4% are related to the project, 64% of these incidents are due to critical risk No. 10 (unsafe driving), and 3% to risk No. 5 (rockfall), adding up to 67% of total incidents, highlighting the relevance of risk controls previously identified as dangerous [12].

Studies such as Molino Rosas that managed critical risks to reduce fatal and disabling accidents in a mining unit, where by using descriptive statistics, it observed a decrease in the indicators of frequency, severity and accidentability during a period of 1 year, obtaining a frequency index of 3.6, a severity index of 60.4 and an accidentability index of 0.22 [13]. Likewise, Vidal Castañeda learned how the management of critical controls and safe work contributes to the prevention of undesirable events in a mining company in Peru, he mentioned about the relationship that Bowtie has with risk management and the safe work program, in a period of 4 years the frequency rate of lost time injuries per 1 million hours worked dropped to 1. 33 reducing by 13.7%, in the frequency rate of disabling injuries per million man-hours worked was 44, reducing by 49.4% and in the total frequency rate of recordable injuries was 2.44 which reduced by 47.4% [14]. Del Carpio Barriga investigated risk management at Unidad Minera Inmaculada, identifying 11 critical risks that accounted for 80% of accidents from 2018 to 2019, where 40% of corrective actions were not effective, implementing improved engineering controls and updating risk assessments, achieved 85% of the tasks were completed correctly, showing the effectiveness of the new management model. The remaining 15% noted areas for improvement, including protocol adjustments and the need to reassess unidentified risks [15].

Vasquez Rodríguez designed an optimal plan that guaranteed the control of the risks that could occur during the development of the wells-dewatering operation service and crane rental for Yanacocha mining, where he identified 29 risks, of which 16 are critical risks that require responses, 13 of these, the responses are oriented to mitigate them and 3 to eliminate them [16]. Paredes Honores also investigated the prevention of fatalities through the management of critical safety risks in a subway mine, whose results determined 09 fatality risks, called critical risk managed with priority, in addition these risks are present in 418 tasks, contributing to safety statistics and fatality prevention, since the indicators of frequency, severity and accident rate were reduced by 30%, 97% and 98%, respectively [17]. Nolasco Torres implemented planning and development strategies for the maintenance of the critical risk management of the company SMED PERÚ S.A.C. where he showed a significant decrease in compliance with actions by 97% to 80%, focused on planning strategies for the control of critical risks [18] and Palacios Huamán in his study minimized incidents and accidents through the identification, control, elimination and implementation of controls on critical risks, where the cause of accidents in 2016 in his company was falling rocks, implementing critical controls decreased by 50%, on the other hand, it was reduced by 10% in hauling and transportation, machine operation, blows with objects and splashing of chemicals, also reduced by 100% in causes such as material handling, blocking and labeling, in transit, floors, roads and access [19].

Studies related to safety management in the mining industry, Kainat and Shahzadi [20] in their research on safety and occupational health management in the mining industry indicated that companies operate in an environment of complex organizational, physical and technical relationships, where the safety approach in mining must incorporate both "hard" and "soft" perspectives on safety. Swedish companies have used these techniques to improve their safety records, also focusing on technical, organizational, and behavioral measures to improve safety. Cano et al. [21] in their study on the occupational safety and health management model for mining contracts, indicated that OSHMS allows establishing guidelines to prevent and mitigate accidents that may occur in mines and exploration areas. It indicated that an OSHMS model supported by tables will report the company's status and implementation process. Similarly, Thirumalai et al. [22] in their research on study and analysis of safety management system in granite mining industry using unconventional machining processes, was based on safety system in granite mines including employee health standards. It worked with a survey of 50 mine workers, where according to the analysis 60 % of the people want a safety management system. This analysis shows that 60% of the people want to follow safety protocols to avoid accidents and hazards in the granite mine. Also, 80% of the workers demand training facilities for safety management implementation. Finally, Wang and Li [23] in their research on coal mining process safety management, indicating that it is a high-risk operation, mining enterprises should strictly manage safety issues in daily production, handle and prevent safety accidents by the most advanced methods. For better work, employees should improve their own safety awareness, it will also improve the support of society and the state.

The research has the following structure: Section 2 describes the materials and methods used; Section 3 presents the results and discussions obtained; Section 4 summarizes the conclusions of the study; and Section 5 lists the bibliographical references used.

2. MATERIALS AND METHODS

2.1 Research design

The research was conducted under a non-experimental design, which means that the independent variables were not modified, but rather the phenomena were observed, identified, analyzed, and quantified as they occur in a natural environment. Regarding the depth of the research, it was classified as a descriptive design since it focused on describing and analyzing the main causes of accidents and identifying the most critical risks in the population [24]. In terms of its purpose, it is considered applied since its main objective was to specifically address the research problem [25].

2.2 Population and sample

The population studied included all the risks associated with the various activities performed by the contracting company. A probabilistic random sampling was used to select those risks that have caused the highest number of incidents and accidents, thus ensuring that the data are representative of the most significant hazards [26]. This sampling method strengthens the generalizability of the study results to similar situations within the industry.

2.3 Instrumentation and data collection

The research involved a review and documentary analysis of various resources, including internal reports of incidents and accidents, as well as the review of bibliographic sources related to the variables under study. Also, direct observation was used, this is due to the existence of a direct connection between the individual making the observation and the element being examined. Field recording was also used for the collection of information and subsequent analysis. Finally, a Spearman correlation statistical study was carried out.

The data collection instruments consisted of collection sheets, incident and accident reports and statistical tables for the analysis of the variables under study, analysis of accidents by unsafe acts and conditions, personal factors, and work factors.

2.4 Methodology of analysis

For the analysis of the collected data, a quantitative approach was used to quantify accidents and incidents in the welding area. The Spearman correlation was used to verify the relationship between the associated risks and the activities. Spearman's correlation, also known as Spearman's rank correlation coefficient, is a non-parametric measure of statistical rank correlation that evaluates the strength and direction of the association between two variables classified by order. It is applied to data that do not follow a linearity relationship, but rather a monotonic relationship, either increasing or decreasing. Its coefficient, represented by the Greek letter (ρ), ranges from -1 (perfect negative correlation) to 1 (perfect positive correlation), with 0 indicating no correlation [27, 28]. The formula for calculating Spearman's correlation is:

$$(\rho) = 1 - \frac{6\sum d^2}{n(n^2-1)} \tag{1}$$

where, (ρ) is the Spearman correlation coefficient, d is the difference between the corresponding x-y order data and n is the number of data pair.

2.5 Procedure

The research procedure was developed according to a detailed plan, which is presented in the form of a flow chart in Figure 1. This plan included specific steps for data collection, statistical analysis, and interpretation of results.

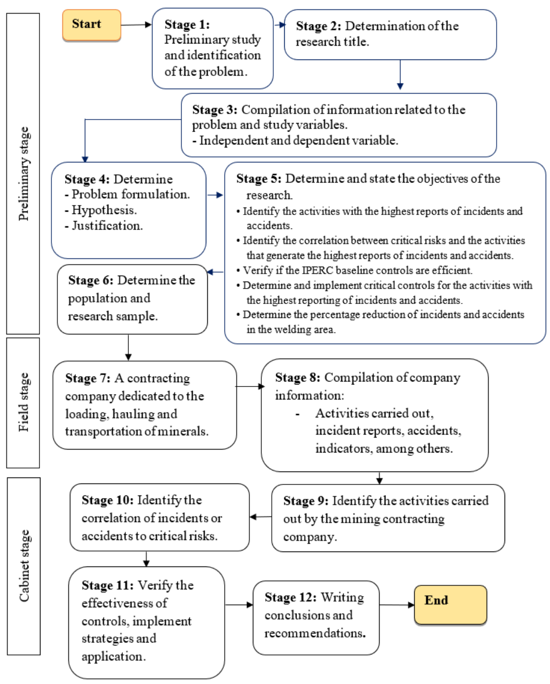

Figure 1. Flow chart of the investigation

2.6 Work in the welding area

The mining contracting company has yellow line vehicles (excavators, front loader) of the Volvo brand, due to the tasks carried out by these equipment, continuous wear of certain parts is observed, which leads to the execution of welding tasks. These tasks include activities such as reinforcing buckets, welding adapters, cutting plates, among others.

The bucket reinforcement strengthens the bucket used on front loaders and excavators. It is carried out by welding 1" and 2" plates, pips, segments, or additional reinforcements in critical areas that are exposed to high wear, the objective is to increase the resistance and durability of the bucket (see Figure 2) [29].

Figure 2. Excavator bucket wear and reinforcement

Adaptor welding (front loader and excavator): Adapters are components that connect work attachments such as grapples to buckets. Welding adapters involves securing these adapters to the main structure (bucket) of the equipment (see Figure 3) [30].

Figure 3. Adapter welding

Figure 4. Nail highlighting

Plate cutting is a task that involves the use of cutting tools, such as torches or plasma machines. Plate welding consists of joining the cut plates to the bucket through a process of heating and melting the metal to cover or replace parts of the bucket that are worn or damaged, such as the edge, bottom, and sides.

Nail grinding involves reinforcing worn nails to give them a second life, which is done to restore the equipment's optimum performance and ensure that it can continue to perform digging and loading tasks effectively (see Figure 4).

3. RESULTS AND DISCUSSIONS

3.1 Incident and accident statistics

According to the Figure 5, the total number of work-related incidents and accidents were 5 in 2021 and 2022, and 3 in 2023. This shows a decrease of 40% in the last year. Of the 5 incidents and accidents that occurred in 2021, 2 were incidents, 1 was hazardous, 2 were minor accidents and none were disabling or fatal. In 2022, there were 3 incidents, none were dangerous, and 2 were minor accidents. In 2023, there were 2 incidents, 1 hazardous incident.

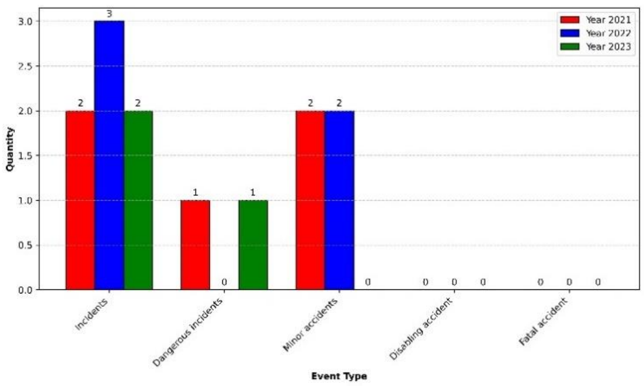

Figure 5. Number of incidents and accidents per year

Incidents and accidents in 2021 were generated by activities such as loading material with a front loader (1), auxiliary welding work (3), including: reinforcement of excavator bucket in the field (1), underpinning of nails (1) and scribing and material clearance (1). They were also generated by mechanical auxiliary works (1), for a total of 5. In the year 2022 the incidents and accidents were generated by pushing material with loader (1), auxiliary works with front loader such as wall conformation (1), auxiliary welding works such as: reinforcement of excavator bucket in the field (1) and nail strengthening (1) for a total of 2, mechanical auxiliary works such as assembly and disassembly of components (1), for a total of 5. In the year 2023, incidents and accidents were generated by loading material with front loader (1), auxiliary welding work such as nail strengthening (1) and auxiliary mechanical work such as corrective maintenance (1), for a total of 3.

The Figure 6 shows the number of incidents and accidents by item, where the total number of substandard acts and substandard conditions related to occupational safety and health was 5 in 2021 and 2022, and 3 in 2023. Substandard acts were more frequent than substandard conditions in all three years, with the item with the highest number of cases in 2022 (4) and 2023 (2). Likewise, work, and personal factors were not reported in any of the years.

The high occurrence of incidents in welding activities underscores the critical need for a thorough review of safety procedures and the implementation of critical controls [14, 15].

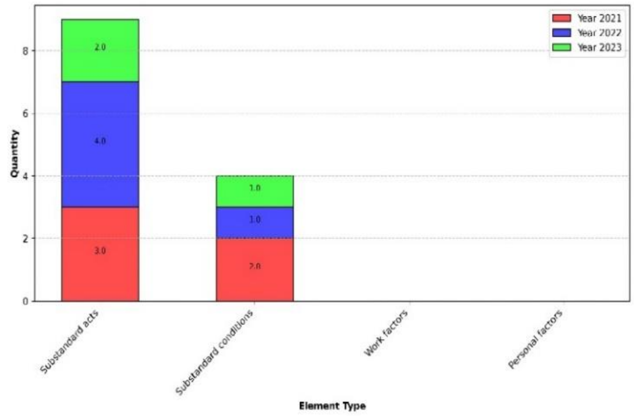

Figure 6. Number of incidents and accidents by elements

3.2 Analysis of the IPERC baseline

The safety area has a truck for transporting welding motorcycles for field work, and a list of the hazards and risks in the welding area is also shown.

The activities with the most reported incidents and accidents are auxiliary welding work and auxiliary mechanical work (see Table 1).

3.3 Determination and implementation of critical controls for the activities with the highest reporting of incidents and accidents

In a period between 2021 and 2022, a total of 10 incidents and accidents related to various activities were recorded. Auxiliary welding work had the highest frequency with 50% of the total, followed by auxiliary mechanical work with 20% (see Table 2).

3.4 Identifying hazards and assessing risks

To determine critical risks, we used a structured process that included several important steps:

1. Initial Hazard Identification: We started by watching how work was done, looking at past incidents, and talking to staff. This helped us spot potential dangers linked to welding and mechanical tasks. This first step was essential to gather a comprehensive list of possible dangers at the workplace.
2. Risk Assessment: We then evaluated how severe and likely each identified hazard could be. We categorized these hazards into low, medium, and high levels based on how much they could impact worker safety and health. This approach allowed us to focus on the most important hazards first.
3. Detailed Analysis of Critical Risks: Hazards that led to frequent incidents or could lead to serious consequences (like operating heavy machinery) were examined more closely. We aimed to understand the root causes and contributing factors that made these hazards particularly risky.

Table 1. Dangers and risks of the welding area

Hazard	Risk	Consequence
Uneven, uneven, or slippery terrain	Falls due to loss of stability at the same level	Injuries to different parts of the body, blows, fractures
Unsecured doors or gates	Entrapment of body parts (hands)	Blows, finger pinching, fractures
Work area with presence of dust	Exposure to dust	Lung diseases
Extreme temperatures	Exposure to low temperatures	Chills, hypothermia, flu, frostbite, vasodilatation ventricular or fibrillatory arrhythmia
	Exposure to high temperatures	Skin diseases, occupational dermatitis, gradual blindness, heat shock, dehydration
Solar radiation	Exposure to solar radiation	Skin burns (face, arms), dehydration
Moving equipment (dump trucks, yellow line, tanker)	Collisions, rollover, run over	Injuries to different parts of the body, property damage, fatality
Light vehicle in motion (bus, minibus, van, pickup, etc.)	Collisions, rollover, run over	Injuries to different parts of the body, property damage, fatality
Noise from operating equipment >85Db	Noise exposure	Partial or total hearing loss
Worker fatigue and drowsiness.	Collisions	Death, Minor/permanent injuries
Handling of hand or power tools	Contact with the tool	Injuries to different parts of the body, blows, fractures
Contact with hot surfaces	Contact with hot surface	Burns
Metal fumes (welding)	Inhalation of welding fumes	Pneumoconiosis, Occupational Asthma, Allergies, Cancer
Gases, vapors or fumes	Exposure to metallic gases, vapors, or fumes	Occupational Asthma, Laryngeal Cancer, Dermatitis, intoxication
Tanks, bottles and pressurized cylinders	Explosion, fire	Fatalities, Explosion, Fire, Burns, Property Damage
Work with repetitive motions	Prolonged repetitive motions	Osteoarticular injuries, mental fatigue
Lack of tidiness and cleanliness	Fall to level	Injuries to different parts of the body, blows, fractures
Projection of incandescent particles	Impacted by incandescent particle	Burns, injuries to different parts of the body
Sharp-edged surfaces	Exposure to sharp-edged surfaces	Cuts
Incorrect posture	Prolonged incorrect posture	Low back pain, back pain (upper and lower back pain)
Grinder, grinding and cutting discs	Contact with grinder, grinding and cutting discs	Cuts, mutilation, serious injuries
Vibration from hand-held machines	Exposure Hand-arm vibration	Lack of sensation in the hands (white finger syndrome), Joint, neurological, and vascular disorders, Muscle disorders
Presence of loose rocks on slopes	Impact by falling rocks	Death, Minor/permanent injuries
Working on temporarily energized equipment	Contact with electrical energy	Electric shock, Serious Injury, Fatality
Adverse weather conditions (thunderstorm, heavy rain, hailstorm)	Electrical shock, Flooding, Material slides, slippery surfaces	Fatalities, Total disability, Serious injuries, Property damage, Stoppage of production process
Handling of sheet metal	Cuts, blows, amputations	Injuries, fractures, mutilation
Pathogenic biological agents (COVID-19)	Direct-indirect contact with contaminated environments or surfaces and/or infected people	Acute Respiratory Disease

Table 2. Frequency of incidents and accidents years 2021-2022

Activities	Number of Incidents/Accidents 2021-2022	Frequency (%)	Accumulated (%)
Loading of material with front loader	1	10	10
Material push with loader	1	10	20
Auxiliary work with loader	1	10	30
Auxiliary welding work	5	50	80
Auxiliary mechanical work	2	20	100
Total	10		

It can be observed that 50% of the incidents had a low risk level, while 40% had a high-risk level. Only 10% of the incidents were classified as medium risk. Incidents with a low risk level were considered in the following activities: loading material with front loader, pushing material with loader, auxiliary work with front loader, auxiliary mechanical work, and auxiliary welding work, with 1 accident/incident each. For the medium risk level, only the activity of auxiliary welding work was considered, with 1 accident/incident. At the high-risk level, the activities of mechanical auxiliary work (1 accident/incident) and auxiliary welding work (3) were considered, giving a total of 4 (see Table 3).

Table 3. Percentage risk level in type of pre-test incidents

Risk Level	Frequency 2021 and 2022	Frequency (%)	Accumulated (%)
Under	5	50	50
Medium	1	10	60
High	4	40	100
Total	10	100	

3.5 Spearman correlation analysis

In this analysis, the Spearman correlation coefficient values were consistently 1.00 for different risk levels. This means there is a perfect positive correlation. Essentially, this tells us that activities identified as higher risk are always linked to more frequent incidents and accidents. This highlights the importance of targeted and specific controls for these high-risk areas to reduce risks effectively (see Table 4).

Table 4. Spearman correlation coefficient for risk levels

Risk Level	Spearman Correlation Coefficient
Under	1.00
Medium	1.00
High	1.00
Total	1.00

This table shows that for every type of risk level-low, medium, and high - the correlation coefficient is 1.00, indicating a perfect match. This strong correlation underscores the need for careful attention to activities with higher risks as they consistently lead to more incidents and accidents.

3.6 Determination of critical control measures

The critical hazards obtained from the risk analysis in the welding area of the mining contractor company are shown in the Table 5. The previous studies indicate that the management of critical risks are essential tools for safeguarding the health and safety of employees [15, 31-33].

The selection and formulation of critical control measures were based on a systematic approach that integrates the results of our risk analysis with industry best practices and applicable safety regulations. The criteria for selecting these measures included:

1. Proven Effectiveness: Priority was given to controls that have demonstrated success in mitigating similar risks.
2. Technical Feasibility: Each control's practicality was considered, considering the operational context of the company.
3. Regulatory Compliance: All proposed controls align with current occupational safety regulations.
4. Maximum Risk Reduction: Controls were chosen to offer the highest possible risk reduction using a combination of engineering, administrative measures, and personal protective equipment (PPE).

To strictly control the above hazards in a work environment, it is important to implement specific safety measures, i.e. critical controls, which are shown in the Table 6. These critical controls are essential to prevent incidents and accidents, thus ensuring a safe environment [19, 33].

Table 5. List of critical hazards

No.	Critical Hazards
1	Moving equipment (dump truck, yellow line, tanker)
2	Light vehicle in motion (Bus, minibus, van, pickup truck)
3	Handling of hand or power tools
4	Hot surfaces
5	Metal fumes (welding)
6	Gases, vapors or fumes
7	Pressurized tanks, cylinders, and bottles
8	Projection of incandescent particles
9	Sharp cutting surfaces
10	Grinders, grinding and cutting wheels
11	Contact with energized elements
12	Exposure to UV radiation
13	Lack of order and cleanliness

Table 6. Critical controls for identified critical risks

No.	Critical Hazards	Critical Controls
1	Moving equipment (dump truck, yellow line, tanker)	**Replacement.** **Engineering controls:** work area signage. **Administrative controls:** Comply with speed limits (RITRA). **Personal protective equipment:** Use of basic PPE.
2	Light moving vehicle (Bus, minibus, van, truck)	**Replacement.** **Engineering controls:** mark the work area. **Administrative controls:** Comply with speed limits (RITRA). **Personal protective equipment (PPE):** use of basic PPE.
3	Handling or power tools	Removal of spell tools. Replacing manual tools with electric ones. **Engineering control:** dead man security system. **Administrative control:** Quarterly tool inspection. **Personal protective equipment:** Use of basic PPE.
4	Hot surfaces	**Administrative control:** mark areas with hot surfaces. **Personal protective equipment:** Use of basic, specific PPE.
5	Metal fumes (welding)	**Replacement**: use alternative joining methods that do not generate metal fumes. **Engineering control:** adequate ventilation systems, smoke extractors. **Administrative control:** Training in safe handling of motorcycle welder and welding process. **Personal protective equipment (PPE):** Basic PPE (helmet, glasses, vest, safety shoes, gloves).
6	Gases or fumes	**Replacement:** use materials that do not generate dangerous gases or fumes. **Engineering controls:** adequate ventilation systems (use of extractor hoods). **Administrative controls:** training in safe handling of motorcycle welding machines and welding processes. **Personal protective equipment (PPE):** Basic PPE (helmet, glasses, vest, safety shoes).
7	Pressurized bottles	**Replacement:** use materials that do not generate dangerous gases or fumes. **Engineering controls:** storage according to gas compatibility, secure with chain and placed in cages. **Administrative controls:** regular inspection of cylinders, training in the safe handling of gas cylinders. **Personal protective equipment (PPE):** Basic PPE (helmet, glasses, vest, safety shoes, gloves, respirator).

8	Projection of incandescent particles	**Engineering controls:** use of screens to avoid projection of sparks and prevent light, fire blankets. **Administrative controls:** inspection of electric welding equipment. **Personal protective equipment (PPE):** Basic PPE (helmet, glasses, vest, safety shoes, gloves, respirator, with mixed filters).
9	Sharp surfaces	**Administrative controls:** Keep the surface clean and free of sharp material. **Personal protective equipment (PPE):** Basic PPE (helmet, glasses, vest, safety shoes, gloves, respirators, leather clothing).
10	Grinder, grinding and cutting discs	**Engineering controls:** safety guards (I use disc guards and safety shields on pillows). **Administrative controls:** perform periodic inspections of equipment, training on risks associated with vibration and how to minimize them. **Personal protective equipment (PPE):** helmet, safety glasses, vest with reflective tape.
11	Contact with energized elements	**Engineering controls:** Guidance and blocking of energy sources. **Administrative controls:** training in LOTO and in the identification of electrical hazards. **Personal protective equipment (PPE):** helmet, safety glasses, vest with reflective tape, safety shoes.
12	Exposure to UV radiation	**Administrative controls:** Training on risks associated with UV radiation and its prevention. **Personal protective equipment:** helmet, safety glasses, vest with reflective tape, welding helmet, with auto-darkening visors, sun blocker.
13	Lack of order and cleanliness	**Administrative controls:** prior inspection of the area, carry out order and cleanliness, prior inspection of the area, carry out order and cleaning. **Personal protective equipment:** Helmet, safety glasses, vest with reflective tape, safety shoes, hearing protection, gloves.

3.7 Evaluation of the effectiveness of control measures

The study variable was the total number of reported incidents and accidents. A Student's t-test was applied with two groups: Group 1 (before intervention - 2021) and Group 2 (after intervention - 2023). Statistical analysis indicated that the average number of incidents was 5 for Group 1 and 3 for Group 2. The Shapiro-Wilk test was used to assess normality, the results of which are shown in Table 7.

Table 7. Normality test of data

Year	Test Statistic	p-Value	Result
2021	0.778	0.005	Not normal
2023	0.884	0.100	Normal

The hypotheses set were:

H_o: There is no difference in the number of incidents between 2021 and 2023.

H_a: There is a difference in the number of incidents between 2021 and 2023.

To determine the effectiveness of the control measures implemented in welding operations, a student's t-test for independent samples was conducted, comparing the number of incidents and accidents in 2021 and 2023. The data revealed a decrease in the number of incidents from 5 in 2021 to 3 in 2023 (see Table 8).

Table 8. Student's t-test statistical analysis

T-Statistic	p-Value
5.34	0.000023

The observed reduction in incidents was evaluated for statistical significance. The results showed a p-value of 0.000023, suggesting that the implemented interventions were effective in reducing the frequency of incidents and accidents. This underscores the importance of continuing with the rigorous application and evaluation of safety control measures.

4. CONCLUSIONS

The activities with the most incidents and accidents reported in the welding area of the mining contracting company were auxiliary welding work (4 incidents), followed by auxiliary mechanical work (3 incidents); the sub-activities with the most incidents were: reinforcement of excavator buckets in the field, nail grinding and corrective maintenance. Likewise, the critical risks identified in the baseline IPERC, such as exposure to hot surfaces, metal fumes, projection of incandescent particles and handling of hand tools, are directly related to welding activities, which represent the highest risk of incidents, where a Spearman correlation coefficient of ρ=1.00 was obtained for the low, medium and high-risk levels.

Specific critical controls were determined and effectively implemented for activities with the highest risk of incidents and accidents, such as: equipment and vehicles in motion, handling of manual or power tools, hot surfaces, metal fumes, gases, vapors, smoke, tanks, pressurized, projection of incandescent particles, sharp surfaces, grinders, grinding and cutting discs, contact with energized elements, exposure to UV radiation and lack of order and cleanliness, generating controls such as replacements, engineering control, administrative controls and personal protective equipment (PPE). Likewise, a 40% reduction in the number of incidents and accidents was recorded in the last year in the welding area, which suggests that the measures implemented are having a positive impact on the mining contracting company. According to the evaluation of the control measures, the t-student statistical test was used, which showed a p value of 0.000023, which suggested that the implemented interventions were effective in reducing the frequency of incidents and accidents.

For future research, it is necessary to evaluate the impact of new technologies and techniques in the reduction of specific risks associated with the activities of the different areas, such as the use of Artificial Intelligence (AI), as well as to maintain its relationship with the regulations and standards on labor safety related to welding and always ensure compliance.

REFERENCES

[1] Tei-Tominaga, M., Nakanishi, M. (2020). Factors related to turnover intentions and work-related injuries and accidents among professional caregivers: A cross-sectional questionnaire study. Environmental Health and

Preventive Medicine, 25: 1-10. https://doi.org/10.1186/s12199-020-00863-8
[2] Arango-Retamozo, S.M., Cotrina-Teatino, M.A., Marquina-Araujo, J.J., Portilla-Rodríguez, H.R., Torres-Rivera, C.M., Vega-Gonzalez, J.A. (2023). Estimating the economic impact of mining accidents: A case study from Peru. International Journal of Safety & Security Engineering, 13(3): 539-545. https://doi.org/10.18280/ijsse.130316
[3] Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., Eburdy, R. (2020). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. International Journal of Production Research, 58(5): 1384-1400. https://doi.org/10.1080/00207543.2019.1636323
[4] Stemn, E. (2019). Analysis of injuries in the Ghanaian mining industry and priority areas for research. Safety and Health at Work, 10(2): 151-165. https://doi.org/10.1016/j.shaw.2018.09.001
[5] Selamat, M.N., Mukapit, M. (2018). The relationship between task factors and occupational safety and health (OSH) performance in the printing industry. Akademika, 88(3): 65-76. http://journalarticle.ukm.my/13225/1/18955-90471-1-PB.pdf.
[6] Li, W., Cao, Q., He, M., Sun, Y. (2018). Industrial non-routine operation process risk assessment using job safety analysis (JSA) and a revised Petri net. Process Safety and Environmental Protection, 117: 533-538. https://doi.org/10.1016/j.psep.2018.05.029
[7] Tuhul, H.S., El-Hamouz, A., Hasan, A.R., Jafar, H.A. (2021). Development of a conceptual framework for occupational safety and health in Palestinian manufacturing industries. International Journal of Environmental Research and Public Health, 18(3): 1338. https://doi.org/10.3390/ijerph18031338
[8] SGS. (2020). Reporte de sostenibilidad de SGS Perú. https://www.sgs.pe/-/media/local/peru/documents/reporte-de-sostenibilidad-de-sgs-per%C3%BA-2020.pdf?la=es-es.
[9] Papageorgiou, G., Kaltsidis, D., Nako, O., Paschalis, E., Alamanis, N., Chrysanidis, T. (2021). Speed limits and accident rates on highways around the world, is there a correlation? IOP Conference Series: Earth and Environmental Science, 899(1): 012063. https://doi.org/10.1088/1755-1315/899/1/012063
[10] Chan, A.P., Guan, J., Choi, T.N., Yang, Y., Wu, G., Lam, E. (2023). Improving safety performance of construction workers through learning from incidents. International Journal of Environmental Research and Public Health, 20(5): 4570. https://doi.org/10.3390%2Fijerph20054570
[11] Muñoz Valdivia, P.L. (2019). Determinación de los factores de riesgo crítico y propuesta de solución en las operaciones de la concesionaria de alimentos Servicios Corporativos Fabisere SAC mediante la aplicación de Iperc de línea base. https://repositorio.unsa.edu.pe/items/c79000d7-6ef3-4fdf-bc93-315a0b408aa6.
[12] Vásquez Orellana, G.J. (2020). Plan de gestión de control de riesgos críticos y productividad. Santiago, Chile. https://repositorio.uchile.cl/handle/2250/178847.
[13] Rosas, M.A.M. (2023). Gestión de riesgos críticos para reducir accidentes mortales e incapacitantes en la unidad minera Julcani. Revista del Instituto de investigación de la Facultad de minas, metalurgia y ciencias geográficas, 26(51): e24574-e24574. https://doi.org/10.15381/iigeo.v26i51.24574
[14] Vidal Castañeda, M.K.S. (2022). Gestión de controles críticos y trabajo seguro en la prevención de eventos no deseados en Volcan Cía Minera SAA. https://repositorio.uncp.edu.pe/handle/20.500.12894/7631.
[15] Del Carpio Barriga, E.A. (2021). Gestion de riesgos criticos en la unidad minera inmaculada; CIA MINERA ARES SAC–HOCHSCHILD MINING. Lima. https://repositorio.unfv.edu.pe/handle/20.500.13084/5418.
[16] Vásquez Rodríguez, J.R. (2020). Propuesta de gestión de riesgos en el servicio de operación de pozos-dewatering y alquiler de grúas para minería yanacocha. Trujillo. https://repositorio.upao.edu.pe/handle/20.500.12759/6949.
[17] Paredes Honores, O.E. (2019). Prevención de fatalidades a través de la gestión de riesgos críticos de seguridad: caso operaciones de empresa contratista minera CONGEMIN JH SAC en mina subterránea Uchucchacua 2008-2017. Lima. https://repositorio.uni.edu.pe/handle/20.500.14076/21295.
[18] Nolasco Terreros, K.R. (2019). Implementación de estrategias de planificación y desarrollo para el mejoramiento de la gestión de riesgos críticos de la Empresa SMED PERÚ SAC–. 2019. Cerro de Pasco. http://repositorio.undac.edu.pe/handle/undac/1773.
[19] Palacios Huaman, C.E. (2019). Implementación de controles de riesgos críticos para la reducción de incidentes y accidentes en la Empresa Contratista Robocon Servicios SAC, UP Andaychagua. Huancayo. https://repositorio.uncp.edu.pe/handle/20.500.12894/5070.
[20] Kainat, S., Shahzadi, A. (2021). Managing occupational health and safety in the mining industry. Agriculture and Environment, 2(2): 17. https://www.researchgate.net/publication/354850287_Managing_Occupational_Health_and_Safety_in_the_Mining_Industry.
[21] Cano, Y., Quispe, G., Chavez, H., Mamani-Macedo, N., Raymundo-Ibañez, C., Dominguez, F. (2020). Occupational health and safety management model for mining contracts. In Human Interaction, Emerging Technologies and Future Applications II: Proceedings of the 2nd International Conference on Human Interaction and Emerging Technologies: Future Applications (IHIET–AI 2020), Lausanne, Switzerland, pp. 486-492. https://doi.org/10.1007/978-3-030-44267-5_74
[22] Thirumalai, R., Seenivasan, M., Sivakumar, A. (2021). Study and analysis of safety management system at granite mining industry using non-conventional machining process. Materials Today: Proceedings, 47: 4409-4412. https://doi.org/10.1016/j.matpr.2021.05.207
[23] Wang, H., Li, Z. (2020). Safety management of coal mining process. IOP Conference Series: Earth and Environmental Science, 598(1): 012005. https://doi.org/10.1088/1755-1315/598/1/012005
[24] Aggarwal, R., Ranganathan, P. (2019). Study designs: Part 2–descriptive studies. Perspectives in Clinical Research, 10(1): 34-36. https://doi.org/10.4103%2Fpicr.PICR_154_18

[25] Joore, P., Stompff, G., Van de Eijnde, J. (2022). Applied Design Research, Nederlands: Taylor & Francis. https://doi.org/10.1201/9781003265924
[26] Shagofah, N., Omid, T., Jawad, G. (2022). Simple random sampling. International Journal of Education & Language Studies, 1(2): 78-82. https://doi.org/10.22034/ijels.2022.162982
[27] Bocianowski, J., Wrońska, D., Krysztofiak, A., Matusiak, K., Wiatrowska, B. (2023). Comparison of pearson's and spearman's correlation coefficients values for selected traits of pinus sylvestris L. Preprints. https://doi.org/10.20944/preprints202312.1604.v1
[28] Zhao, G., Ding, W., Tian, J., Liu, L., Gu, Y., Shi, S., Wang, R., Sun, N. (2022). Spearman rank correlations analysis of the elemental, mineral concentrations, and mechanical parameters of the Lower Cambrian Niutitang shale: A case study in the Fenggang block, Northeast Guizhou Province, South China. Journal of Petroleum Science and Engineering, 208: 109550. https://doi.org/10.1016/j.petrol.2021.109550
[29] Erklig, A., Yeter, E. (2013). The improvements of the backhoe-loader arms. Modeling and Numerical Simulation of Material Science, 3(4): 37536. http://dx.doi.org/10.4236/mnsms.2013.34020
[30] Sun, Y., Wang, Y., Wang, L., Li, C., Tang, L., Wang, D., Ma, R., Xue, X., Wei, X., Cui, M., Chong, H., Xu, W. (2023). Digging performance and stress characteristic of the excavator bucket. Applied Sciences, 13(20): 11507. https://doi.org/10.3390/app132011507
[31] Arata Martínez, F. (2019). Análisis, evaluación y control de riesgos en área de corte y soldadura en planta de producción de revestimientos mineros de METSO, CONCÓN, V REGION, Chile: Repositorio Digital Universidad Federico Santa Rosa. https://hdl.handle.net/11673/48319.
[32] Mamani Cutipa, E., Quispe Huanca, F. (2019). Factores de riesgo según causas básicas que influyen en la ocurrencia de accidentes de trabajo en los supervisores de la división de limpieza pública y áreas verdes de la municipalidad distrital de Miraflores, Arequipa 2018, Arequipa: Repositorio Institucional Universidad Nacional San Agustín de Arequipa. https://repositorio.unsa.edu.pe/items/8c9a2c39-a097-45d0-b13a-82aab7639a67.
[33] Mamani, P. (2019). En la UP ANIMON de la CÍA. Minera CHUNGAR SAC, enfocándonos en lo crítico para la prevención de riesgos, Arequipa: Repositorio Institucional Universidad Nacional de San Agustín. https://repositorio.unsa.edu.pe/items/09aa114d-2cb7-4574-a8ea-3e7a469f736e.

NOMENCLATURE

RITRA	Internal Traffic Regulations
IPERC	Hazard Identification and Risk Assessment and Controls
UV	Ultraviolet
EPP	Personal Protective Equipment
ρ	Spearman coefficient