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RISK AND SAFETY ASSESSMENT IN THE FOUNDRY PROCESS IN THE METALLURGICAL INDUSTRY

AVALIAÇÃO DE RISCO E SEGURANÇA NO PROCESSO DE FUNDIÇÃO NA INDÚSTRIA METALÚRGICA

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Abstract: The metallurgical industry, crucial for the global economy, faces considerable challenges in the casting process, with workers exposed to physical, chemical, and ergonomic risks. This study emphasizes the importance of risk management, utilizing tools such as the Ishikawa Diagram, Pareto Diagram, and GUT Matrix. Regulatory Standards (NRs), like NR 4 and NR 9, play a crucial role in safety by establishing guidelines for specialized services and environmental risk prevention. Risk assessment, essential for the safe operation of the metallurgical industry, involves identifying and controlling potential threats such as high temperatures, hazardous chemicals, and ergonomic risks. Moreover, effective risk management, addressing challenges like dehydration, burns, and intoxication, contributes not only to workplace safety but also to compliance with government regulations and the industry's sustainability. Quality tools like the GUT Matrix, Ishikawa Diagram, and Pareto Analysis are fundamental for optimizing processes and identifying root causes of issues. The Effort X Impact matrix, derived from the GUT Matrix, allows prioritizing actions, focusing efforts where they are most needed. In conclusion, risk analysis and the implementation of preventive measures are essential to ensure safe working environments, comply with regulations, and promote operational efficiency in the metallurgical industry.

Keywords: Casting Process. Safety at work. Regulatory Standards. Ishikawa Diagram. GUT Matrix. Paret.

Resumo: A indústria metalúrgica, crucial para a economia global, enfrenta desafios consideráveis no processo de fundição, com trabalhadores expostos a riscos físicos, químicos e ergonômicos. Este estudo enfatiza a importância do gerenciamento de riscos, utilizando ferramentas como o Diagrama de Ishikawa, o Diagrama de Pareto e a Matriz GUT. As Normas Regulamentadoras (NRs), como a NR 4 e a NR 9, desempenham um papel fundamental na segurança, estabelecendo diretrizes para serviços especializados e prevenção de riscos ambientais. A avaliação de riscos, essencial para a operação segura da indústria metalúrgica, envolve a identificação e o controle de possíveis ameaças, como altas temperaturas, produtos químicos perigosos e riscos ergonômicos. Além disso, o gerenciamento eficaz de riscos, abordando desafios como desidratação, queimaduras e intoxicação, contribui não apenas para a segurança no local de trabalho, mas também para a conformidade com as normas governamentais e a sustentabilidade do setor. Ferramentas de qualidade como a Matriz GUT, o Diagrama de Ishikawa e a Análise de Pareto são fundamentais para otimizar processos e identificar as causas-raiz dos problemas. A matriz Esforço X Impacto, derivada da Matriz GUT, permite priorizar ações, concentrando esforços onde eles são mais necessários. Concluindo, a análise de riscos e a implementação de medidas preventivas são essenciais para garantir ambientes de trabalho

seguros, cumprir os regulamentos e promover a eficiência operacional no setor metalúrgico.

Palavras-chave: Processo de fundição. Segurança no trabalho. Normas regulamentadoras. Diagrama de Ishikawa. Matriz GUT. Paret.

1. INTRODUCTION

The metallurgical industry plays a crucial role in the global economy, providing essential materials that support a wide range of sectors. Focusing on the casting process within this context, it becomes imperative to understand and address challenges related to risk assessment and safety. Considering data from the Ministry of Labor and Employment of Brazil, which highlights an alarming average of 700,000 workplace accidents per year, underscores the urgency of effective measures to mitigate risks in industrial environments (Souza, 2017).

As per the Regulatory Standard - NR 4 Specialized Services in Safety Engineering and Occupational Medicine - SESMT, the casting industry falls under the activity of producing castings of iron and steel, with a risk level of 04 and CNAE code (National Classification of Economic Activities) 24.51-2 (Federal Government, 2023). In the casting industry, workers are exposed to various types of risks, including physical, chemical, ergonomic, and accidents. Fusion furnaces, for example, reach temperatures exceeding 1300ºC, making fusion sectors high-risk areas for workplace accidents (Moraes *et al.*, 2017).

This article aims to analyze the importance of risk management using quality tools such as the Ishikawa Diagram, Pareto Diagram, and GUT Matrix. It addresses effective risk management and prioritizes actions to comply with regulations for a safe working environment. Thus, it aims to demonstrate the main and most impactful risks surrounding the metallurgical worker.

2.THEORETICAL FRAMEWORK

2.1 Regulatory Standards (RSs)

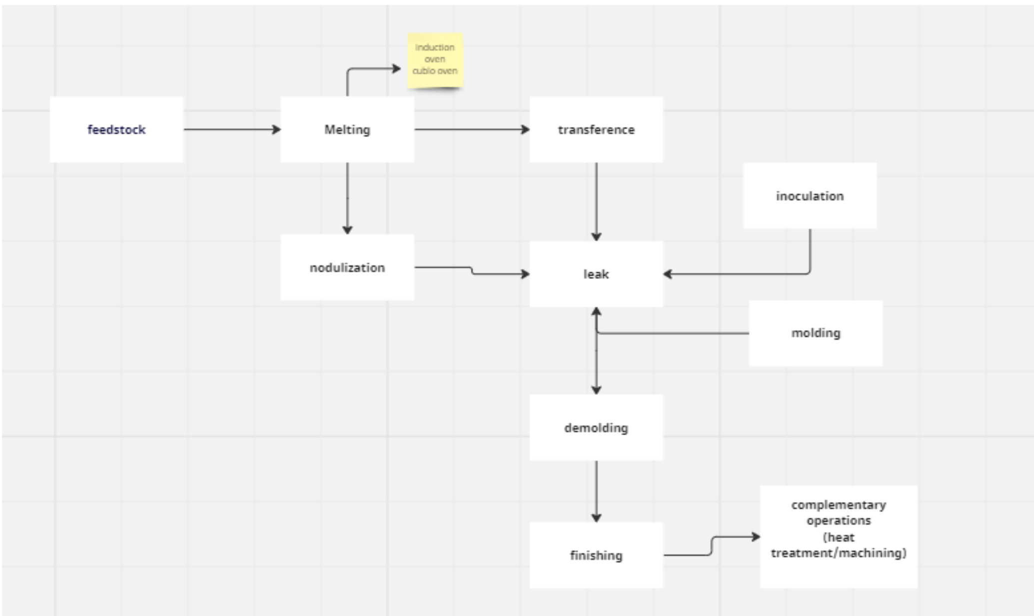
Regulatory Standards (RSs) are a set of guidelines established by the Ministry of Labor and Employment of Brazil (MLE) with the aim of ensuring the safety and health of workers in various industrial sectors. Two RSs of great relevance to the foundry industry are RS 4 and RS 9 (Camisassa, 2015). RS 4, known as the Regulatory

Standard for Specialized Services in Safety Engineering and Occupational Medicine (SSSOM), is crucial for safety management in companies. It establishes the mandatory creation of SSSOM, consisting of professionals specialized in safety and occupational medicine, according to the size of the company and the risk level of the activity. SSSOM plays a fundamental role in promoting safe work environments, accident prevention, and monitoring the health of workers (Federal Government, 2023). On the other hand, RS 9 deals with the Program for the Prevention of Environmental Risks (PPRA). This standard aims to anticipate, recognize, assess, and control environmental risks in the workplace. PPRA is an essential tool for promoting the health and safety of workers, enabling the identification of potential threats and the implementation of preventive measures, contributing to the preservation of the physical integrity of employees (Federal Government, 2023). Both RSs, when applied effectively, play a crucial role in creating safe work environments and protecting the health and integrity of workers in the foundry industry (Camisassa, 2015).

2.2 Casting Process and Threats

The casting industry presents various situations that require special attention to safety and accident prevention. During the different stages of the process (Annex 1), potential opportunities for incidents arise, requiring the implementation of effective preventive measures (CIMM, 2023).

Figure 1 - Metal Casting Process Flow



Source: CIMM, 2023.

Unlocking the process, it was possible to understand how each step of the casting works and thus identify their threats.

Table 1 - Threats per Process Step

Process	Process Description	Threats
Raw Material	Involves the selection and preparation of raw materials, such as metals and alloys, for the melting process.	Possibility of exposure to harmful chemicals during the handling and preparation of raw materials.
Melting	Involves heating the raw material until it reaches a liquid state to form molten metal	Risks of burns and thermal injuries due to the high temperature of the molten metal
Nodulization	Addition of nodulizing elements to promote the formation of spheroidal graphite in molten metal	Exposure to chemicals during the nodulization process.
Inoculation	Introduction of inoculants to modify the structure of molten metal and improve its properties.	Risks of exposure to chemicals and handling hazardous materials
Molding	Creation of molds from sand or other materials to receive molten metal.	Possibility of inhaling fine particles during the preparation and handling of molds
Pouring	Controlled pouring of molten metal into prepared molds	Risks of splashes from hot metal and possible burns
Demolding	Removal of molds after solidification of molten metal	Handling of hot pieces and exposure to residual dust from the molding process.
Finishing	Processes such as deburring, machining, and surface treatments to finalize the pieces.	Risks of injuries related to cutting, machining operations, and handling of tools.
Supplementary Operations	Application of heat treatments or machining processes to adjust the properties of cast pieces	Exposure to high temperatures and operation of machining equipmen

Source: authorship.

Every stage of the casting process presents specific threats that require appropriate safety measures to protect workers and ensure a safe and productive work environment.

2.3 Risk Assessment

Industrial risk management is an essential component of the safe and effective operation of the metallurgical industry. According to Santos (2017), it is based on identifying, assessing, controlling, and monitoring all potential risks associated with operations, aiming to protect workers, the environment, and company assets. In the context of foundry operations in the metallurgical industry, this involves recognizing the inherent risks of handling molten metals, high temperatures, and hazardous chemicals. Therefore, building a preventive environment by implementing rigorous measures to mitigate these risks is of utmost importance (Lapa; Goes, 2011). Industrial risk management not only contributes to workplace safety but is also crucial for compliance with government regulations and the overall sustainability of the metallurgical industry (Chagas; Salim; Servo, 2011, p. 10-15).

2.4 Risk Management

A series of impacts affect employees' health within the company. Therefore, risk management is a fundamental tool for planning, operating, and controlling activities in the workplace. In line with such tools, measures to mitigate these risks must be present and culturally embedded in the company through a qualified, trained workforce prepared for all necessary interventions (Suprema, 2022).

Dehydration and Electrolyte Loss

Due to high temperatures in workspaces, there is a loss of electrolytes, minerals responsible for transporting water into cells and electrical impulses in the human body, as well as dehydration, which can affect employees' muscle groups (Somiti, 2020).

Burns

In these occupational environments, the risk of burns is extremely concerning, not only due to high temperatures but also because of molten metals and emitted radiation, which can cause burns due to prolonged exposure (Suprema, 2022).

Intoxication

Various chemicals (metals and solvents themselves) are used in the foundry environment. With the presence of such elements, vapors and gases may be released, and when inhaled by employees, they can cause injuries and impact the respiratory system (Suprema, 2022).

Ergonomic Risks

Ergonomic risks occur when the work environment is not suitable for human operations. Improving working conditions must take into account physical and psychological conditions related to external (environmental) and internal (emotional level) factors. In summary, dysfunction occurs between the workplace and the individual (Herzer, 1997).

For the State Labour Inspection (2017), providing good ergonomic conditions at the workplaces, the work abilities and productivity can be increased and employees will be more motivated to work better

Splashes of Molten Metal

Liquid metals pose a serious safety risk for all foundry industries. When molten metal comes into contact with moisture or water, it becomes vapor almost instantly, exponentially expanding its volume, causing an extremely violent explosion. This happens, and solid particles are thrown out of the furnace, hardly noticeable, causing damage to employees, the furnace itself, and parts of the factory in the process (Herzer, 1997).

The violent and unpredictable nature of a molten metal explosion makes the use of Protective Equipment indispensable. In sealed containers and closed pipe sections at both ends, combustible liquids or their vapors will explode long before the scrap metal melts (Tabatabei, 2009).

Environmental Risks

According to Pontes (2005), industries have faced a higher level of demand, especially for more qualified professional labor, seeking a workplace more conducive to safe work, adhering to safety norms and standards established by labor agencies. Additionally, ensuring and providing conditions to increase productivity and product quality without increasing risks to employees.

To progress towards improvements in working conditions, it is necessary to invest capital, and the company's management must focus on risk assessment and management, effectively mitigating them, thus taking measures to ensure the comfort and well-being of employees. Developing actions to avoid exposure to such dangers is a step away from losses for both workers and the company (Cardella, 1999).

2.5 Quality Tools

Exploring the quality and efficiency of organizational processes involves the use of various tools. In this context, the FMEA (Failure Mode and Effect Analysis), Scatter Diagram, Control Chart, Histogram, and the 5 Whys technique stand out. However, for this study, attention was focused on three specific tools that play a central role in process optimization: GUT Matrix, Ishikawa Diagram, and Pareto Analysis.

GUT Matrix:

The GUT Matrix is a methodology that prioritizes actions by assessing the Gravity, Urgency, and Tendency of a problem. By quantifying these three elements, it is possible to determine which issues deserve immediate attention. Gravity refers to the magnitude of the problem's impact, Urgency indicates how quickly action is needed, and Tendency assesses the likelihood of worsening if not promptly addressed. This tool is valuable for effective time and resource management, ensuring efforts are directed to areas of greater relevance and urgency (Rabello, 2023).

Ishikawa Diagram:

Also known as Fishbone Diagram, the Ishikawa Diagram is a visual technique that aids in identifying possible causes of a specific problem. It organizes factors into categories such as People, Processes, Materials, among others, to provide a comprehensive view of the influences involved. This tool is valuable for in-depth analysis of complex situations and the search for effective solutions (Soares, 2022).

Pareto Analysis:

Based on the Pareto Principle, this technique suggests that the majority of problems (80%) are caused by a minority of causes (20%). By identifying and focusing on the main causes, significant improvements in operational efficiency can be achieved. Pareto Analysis is valuable for the effective allocation of resources, ensuring efforts are directed to areas of greater impact (Layoan, 2022).

3. METHODOLOGY

The methodology adopted in this study involved a systematic approach to investigate the metal casting process. Initially, the operational flow of this practice was sought to be understood by analyzing each stage meticulously. To achieve this, Quality Engineering tools such as Ishikawa Diagram, Pareto, GUT Matrix, and Effort x Impact Matrix were used. This in-depth analysis provided a comprehensive view of the process in question, establishing a robust starting point for subsequent investigations.

Subsequently, the focus shifted to the identification and evaluation of risks associated with each phase of the casting process. The first tool used was the Ishikawa Diagram, aiming to identify risks and present their causes and subcauses. Next, the GUT Matrix combined with Pareto was applied to observe more clearly the severity, urgency, and trend, as well as the causes that exceeded 80%. Finally, the Effort x

Impact Matrix was applied with the aim of making interventions of lesser effort that generated the greatest impacts.

This analysis encompassed a wide range of variables, covering technical aspects as well as environmental and safety considerations. To deepen the understanding of the identified risks, the Ishikawa Diagram was used. This analytical tool provided a detailed view of the underlying causes of each type of risk, enriching the analysis and contributing to the formulation of more precise solutions.

To prioritize the identified risks, the GUT Matrix was adopted, a technique that assesses the Gravity, Urgency, and Tendency of risks. This approach offered a solid foundation for the efficient allocation of resources and the implementation of mitigation strategies. By considering the severity of impacts, the urgency of response, and the trend of risk evolution, the GUT Matrix provided a comprehensive view, allowing the management team to direct their efforts more precisely and strategically.

For the identification of areas of greater impact, the Pareto Diagram was used. This tool, based on the principle that a significant portion of problems comes from a reduced number of causes, highlighted the causes that contribute most significantly to the identified risks. This detailed analysis allowed for a more efficient allocation of resources for mitigation, concentrating efforts on critical areas that require prioritized attention.

Finally, the analysis of effort versus impact of risks was carried out. This step was essential to assess the effectiveness of proposed mitigation strategies and to ensure the proper allocation of resources, aiming to minimize the identified risks throughout the metal casting process.

The implementation of this study methodology proposed by our team, using all the tools mentioned above, provided a solid and structured foundation for conducting this research, ensuring a comprehensive approach grounded in the analysis of the metal casting process flow, as well as the identification and mitigation of risks inherent in each stage of this process. This study contributes significantly to the understanding and effective management of risks associated with metal casting, representing a substantial advancement in the field of metallurgical engineering.

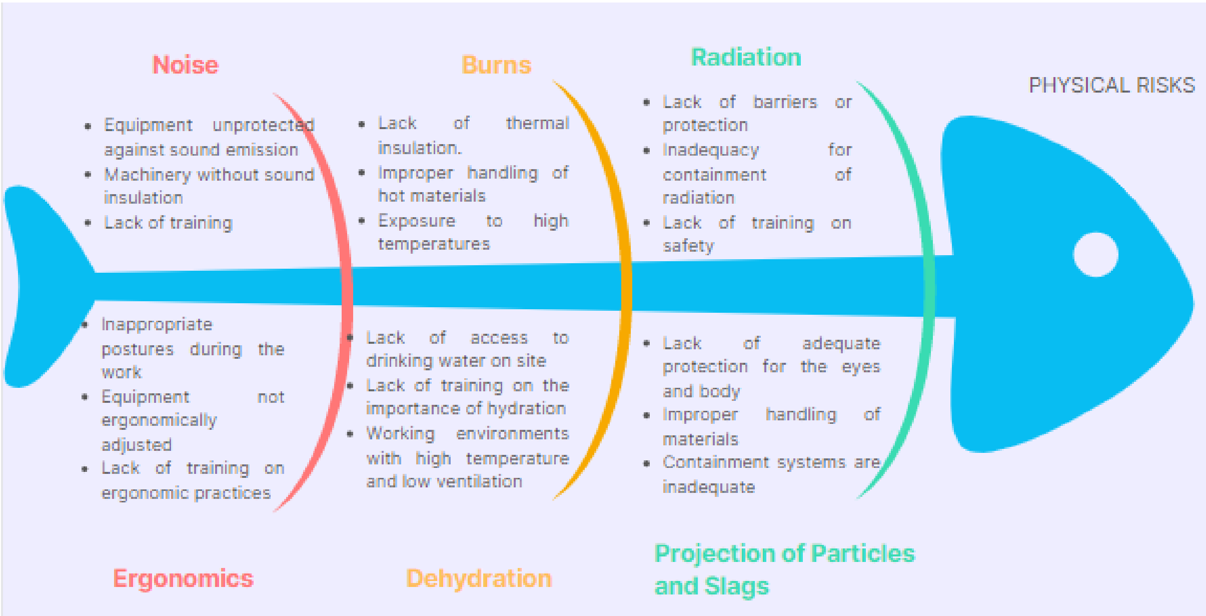
4. RESULTS

4.1 Ishikawa Diagram

Once the types of risks and their impacts on workers and the environment were identified, an Ishikawa Diagram was created for each associated risk type. This analytical tool provided an in-depth insight into the underlying origins of each form of risk.

Therefore, the Ishikawa Diagram will be performed for risks classified as: Physical, Chemical, Biological, and Environmental. Firstly, the Ishikawa Diagram was developed for Physical Risks, where we can present their causes and subcauses for this issue.

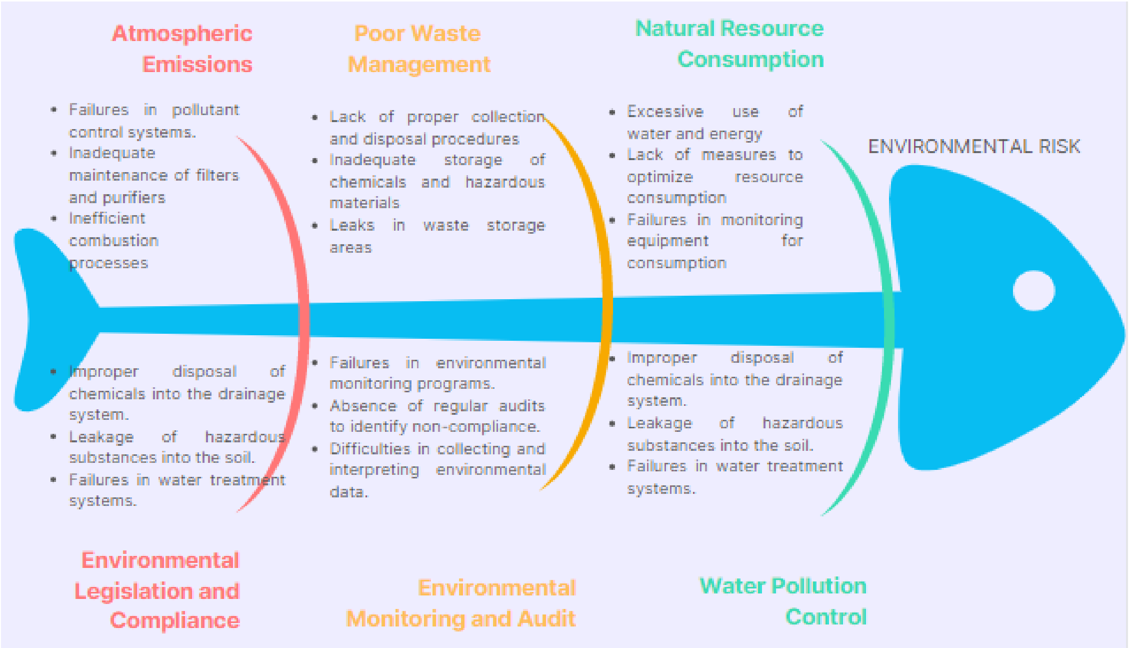
Figure 2 - Ishikawa Physical Risks



The in-depth analysis of physical risks in foundry operations revealed critical factors that require immediate action. The lack of adequate personal protective equipment and operation without acoustic isolation contributes to excessive noise exposure. Additionally, dehydration in hot environments is a concern, emphasizing the need for continuous access to potable water. Measures to minimize burns and ensure safety in high-temperature environments, as well as protection against radiation, are essential. Furthermore, workplace ergonomics and protection against particle projection emerge as critical points, reinforcing the importance of specialized training and ergonomically suitable equipment. These findings highlight the urgency of implementing preventive and corrective measures, promoting a safe and productive working environment in metallurgical foundry operations.

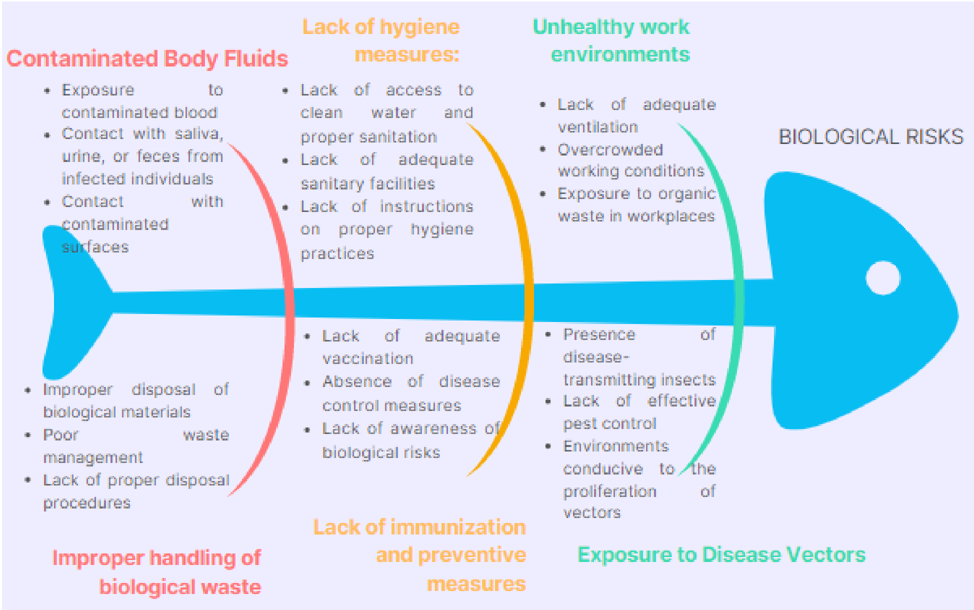
Next, the diagram for environmental risks was developed:

Figure 3 - Ishikawa Environmental Risks



The Ishikawa Diagram dedicated to environmental risks in the metallurgical foundry provides a comprehensive view of potential causes influencing the sustainability of the process. By identifying categories such as "Atmospheric Emissions," "Waste Management," "Natural Resource Consumption," "Water Pollution Control," and "Environmental Monitoring and Auditing," the importance of more ecological and efficient operational practices is highlighted. The inclusion of the category "Legislation and Environmental Compliance" underscores the critical need to stay aligned with current regulations, emphasizing the metallurgical responsibility regarding the environment.

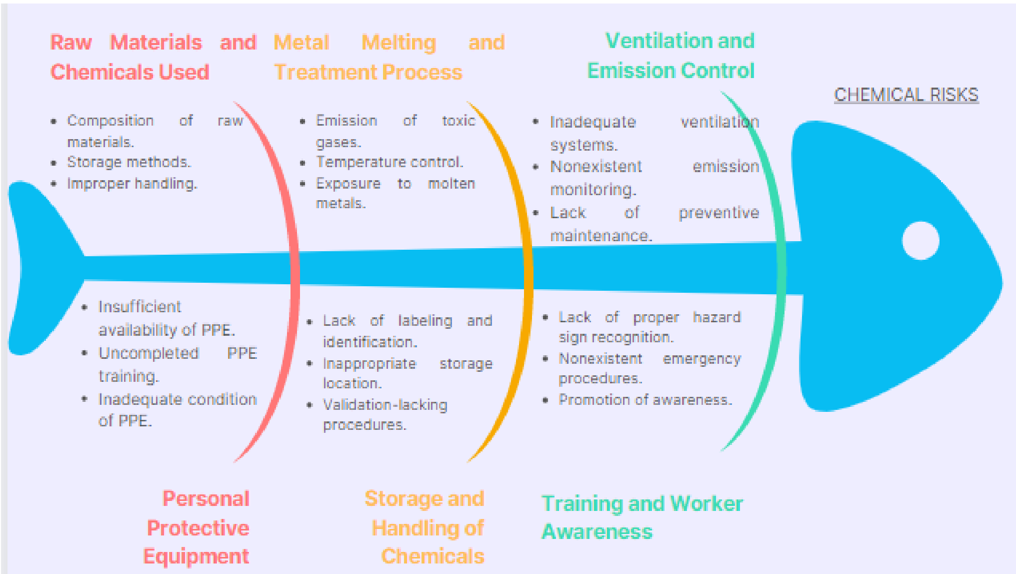
Figure 4 - Ishikawa Biological Risks



The Ishikawa Diagram focused on biological risks provides insight into the main factors contributing to the emergence of risks posed by living agents that cause diseases. By analyzing and characterizing the sources of this risk, the importance of seeking preventive and mitigating measures becomes evident. Proper waste disposal, awareness campaigns about biological risks, appropriate hygiene measures, and employee immunization are crucial actions to address these issues, ensuring compliance with safety standards and human health well-being.

Chemical Risks:

Figure 5 - Ishikawa Chemical Risks



In the foundry industry, chemical risks are a critical concern. Raw materials containing toxic substances, high-temperature melting processes, and the handling of specific products can expose workers to hazards. Effective ventilation, proper use of Personal Protective Equipment (PPE), safe storage of chemicals, and employee training are essential aspects to reduce these risks. Therefore, awareness of the dangers and the importance of safe practices also play a vital role in mitigating chemical risks in the foundry industry, contributing to a safer and healthier work environment.

4.2 GUT Matrix and Pareto Diagram

The GUT matrix will then identify which problems should be prioritized by addressing the Severity, Urgency, and Trend of each. As shown in the table below:

Table 2 - GUT classification

Grade	Severy	Urgency	Tendency
5	Extremely Serious	Needs immediate action	will get worse quickly
4	Verv Serlous	Is lt urGent	wlll 11et worse over time
3	Serlous	ASAP	wlll 11et worse
2	Little Serious	No urgence	will get worse in the long term
1	No Serious	It cann wait	won't change

Source: Periard (2011).

Therefore, the GUT matrix in the article was meticulously crafted with an approach grounded in the metal casting process flow. This strategy combined an in-depth analysis of the stages involved in casting with the use of historical knowledge available in specialized literature. To assign values from 1 to 5 to the severity, urgency, and trend of identified risks, we referred to previously established standards and guidelines. The severity score reflects the potential impact of the risk if it materializes, while urgency indicates the immediate need for intervention. The trend refers to the predicted trajectory of the risk over time. This structured and informed approach provides a robust assessment of risks, enabling effective prioritization of necessary corrective and preventive measures to ensure safety and efficiency in the metal casting process.

In addition to the GUT assessment, the principles of the Pareto diagram were applied to each of the previously developed Ishikawa diagrams (Physical, Chemical, Environmental, and Biological). This approach was employed to identify and prioritize more specifically the subcauses that have the greatest impact in each risk category. Pareto was applied considering the classification A, B, C, and the percentage cuts of 80%, 95%, and 100%. This means that subcauses were analyzed in terms of their contribution to the total of each risk category. The most impactful subcauses were identified and prioritized based on their relevance to the overall set of risks.

Table 3 - GUT and Pareto Physical Risks

Physical Risks							
Subcause	**Severity**	**Urgency**	**Tendency**	**GUT**	**% single**	**% accumulated**	**rating**
Unprotected equipment reduces noise emissions	4	4	4	64	7%	7%	A
Machinery without sound insulation	4	4	4	64	7%	14%	A
Exposure to high temperatures	4	4	4	64	7%	21%	A
Work environments with high temperatures and poor ventilation	4	4	4	64	7%	28%	A
lack of training	3	5	4	60	7%	35%	A
lack of safety training	3	5	4	60	7%	42%	A
lack of training on ergonomic practices	3	5	4	60	7%	48%	A
lack of thermal insulation	4	4	3	48	5%	54%	A
improper handling of hot materials	4	4	3	48	5%	59%	A
lack of barriers or protection	3	4	4	48	5%	64%	A
unsuitability for radiation containment	4	4	3	48	5%	70%	A
inappropriate postures during work	3	4	4	48	5%	75%	A
equipment not ergonomically adjusted	3	4	4	48	5%	80%	B
lack of adequate eye and body protection	3	4	4	48	5%	86%	B
inadequate containment systems	3	4	4	48	5%	91%	B
improper handling of materials	3	4	3	36	4%	95%	B
lack of training on the importance of hydration	2	5	3	39	3%	98%	C
lack of access to drinking water	2	4	2	19	2%	100%	C

Table 4 - GUT and Pareto Environmental Risks

Environmental Risks							
Subcause	**Severity**	**Urgency**	**Tendency**	**GUT**	**% single**	**% accumulated**	**rating**
Failures in pollutant control systems	4	4	4	64	8%	8%	A
inadequate maintenance of filters and purifiers	4	4	4	64	8%	16%	A
Inefficient combustion processes	3	4	4	48	6%	22%	A
Lack of adequate collection and disposal procedures	4	3	4	48	6%	28%	A
Inadequate storage of chemicals and hazardous materials	4	3	4	48	6%	34%	A
leaks in waste storage areas	4	4	3	48	6%	40%	A
Excessive use of water and energy	3	4	4	48	6%	45%	A
Inadequate disposal of chemical products in the drainage systen	4	4	3	48	6%	51%	A
Leaks of dangerous substances in the ground	4	4	3	48	6%	57%	A
Failures in water treatment systems	4	4	3	48	6%	63%	A
Inadequate disposal of chemical products in the drainage systen	4	4	3	48	6%	69%	A
Dangerous substance leaks into the ground	4	4	3	48	6%	75%	A
Failures in water treatment systems	5	4	2	40	5%	80%	A
failures in consumption monitoring equipment	3	4	3	36	4%	84%	B
failures in environmental monitoring programs	3	4	3	36	4%	89%	B
difficulties in collecting and interpreting environmental data	3	4	3	36	4%	93%	B
lack of measures to optimize resource consumption	3	3	3	27	3%	97%	C
Lack of regular audits to identify compliance	3	3	3	27	3%	100%	C

Table 5 - GUT and Pareto Biological Risks

Biological Risks							
Subcause	**Severity**	**Urgency**	**Tendency**	**GUT**	**% single**	**% accumulated**	**rating**
Exposure to contaminated blood	5	4	4	80	11%	11%	A
Contact with saliva, urine, or feces of infected individual	5	4	4	80	11%	22%	A
Contact with contaminated surfaces	5	4	4	80	11%	33%	A
Lack of access to clean water and adequate sanitation	4	4	4	64	9%	41%	A
Lack of proper sanitary facilities	4	3	4	48	7%	48%	A
Lack of instructions on hygiene practices	4	4	3	48	7%	54%	A
Lack of adequate ventilation	4	4	3	48	7%	61%	A
Overcrowded working conditions	4	4	3	48	7%	67%	A
Exposure to organic waste in workplaces	4	3	3	36	5%	72%	A
Improper disposal of biological materials.	4	3	3	36	5%	77%	A
Poor waste management	4	3	3	36	5%	82%	B
Lack of proper disposal procedures	3	4	3	36	5%	87%	B
Lack of adequate vaccination	3	3	2	18	2%	89%	B
Absence of disease control measures	3	3	2	18	2%	92%	B
Lack of awareness of biological risks	3	3	2	18	2%	94%	B
Presence of disease-transmitting insects	3	3	2	18	2%	97%	C
Lack of effective pest control	3	2	2	12	2%	98%	C
Environments conducive to the proliferation of vectors	3	2	2	12	2%	100%	C

Table 6 - GUT and Pareto Chemical Risks

Biological Risks							
Subcause	**Severity**	**Urgency**	**Tendency**	**GUT**	**% single**	**% accumulated**	**rating**
Training on PPE not conducted	5	4	4	80	11%	11%	A
Emission of toxic gases	5	4	4	80	11%	21%	A
Lack of adequate recognition of danger signals	5	4	4	80	11%	32%	A
Absence of preventive maintenance	4	3	4	48	6%	39%	A
Lack of proper sanitary facilities	4	3	4	48	6%	45%	A
Promotion of awareness	4	4	3	48	6%	51%	A
Procedures without validation	4	4	3	48	6%	58%	A
Storage methods	4	3	3	36	5%	63%	A
Exposure to molten metals	4	3	3	36	5%	67%	A
Nonexistent emissions monitoring	3	4	3	36	5%	72%	A
Inadequate condition of PPE	4	3	3	36	5%	77%	A
Temperature control	4	3	3	36	5%	82%	B
Improper handling	3	3	4	36	5%	87%	B
Insufficiency in the availability of PPE	3	3	3	27	4%	90%	B
Nonexistent emergency procedures	4	3	2	24	3%	94%	B
Composition of raw materials	3	3	2	18	2%	96%	C
Inappropriate storage location	3	3	2	18	2%	98%	C
Inadequate ventilation systems	3	2	2	12	2%	100%	C

4.3 Effort x Impact Matrix

The effort x impact matrix is a task prioritization tool that helps categorize activities into 4 groups, classifying them based on the generated impact and expended effort. Widely used in Lean Six Sigma, this matrix can be applied in your company's daily operations to raise awareness about time utilization and plan project execution. The matrix is divided into two axes, vertical and horizontal. The vertical axis, dealing with impact, takes into account factors like profit, sales, and customer satisfaction. Meanwhile, the horizontal axis, effort, considers the time, energy, money, or human resources that will be invested in the task (Coutinho, 2021).

1st Quadrant: Tasks that yield significant results with minimal effort. These actions should be prioritized in execution.

2nd Quadrant: Important actions that are challenging to execute. They require time, planning, and a larger allocation of financial resources.

3rd Quadrant: Tasks that require minimal effort and do not generate a significant impact. They can be delegated or postponed to a more suitable time.

4th Quadrant: Tasks that demand significant effort and do not yield a substantial impact. They should be avoided and addressed at opportune moments.

The parameters and data obtained through the GUT matrix laid the foundation for the development of the Effort x Impact matrix, enabling the identification of actions that should be prioritized to enhance productivity and achieve more significant results in reducing accident risks associated with each risk category (Physical, Biological, Chemical, and Environmental). In the first quadrant of each table, there are actions that require more time and capital investment to address these issues. Initiating these measures as a priority ensures greater safety in the workplace and the well-being of employees.

Figure 5 - Effort x Impact matrix Physical risks

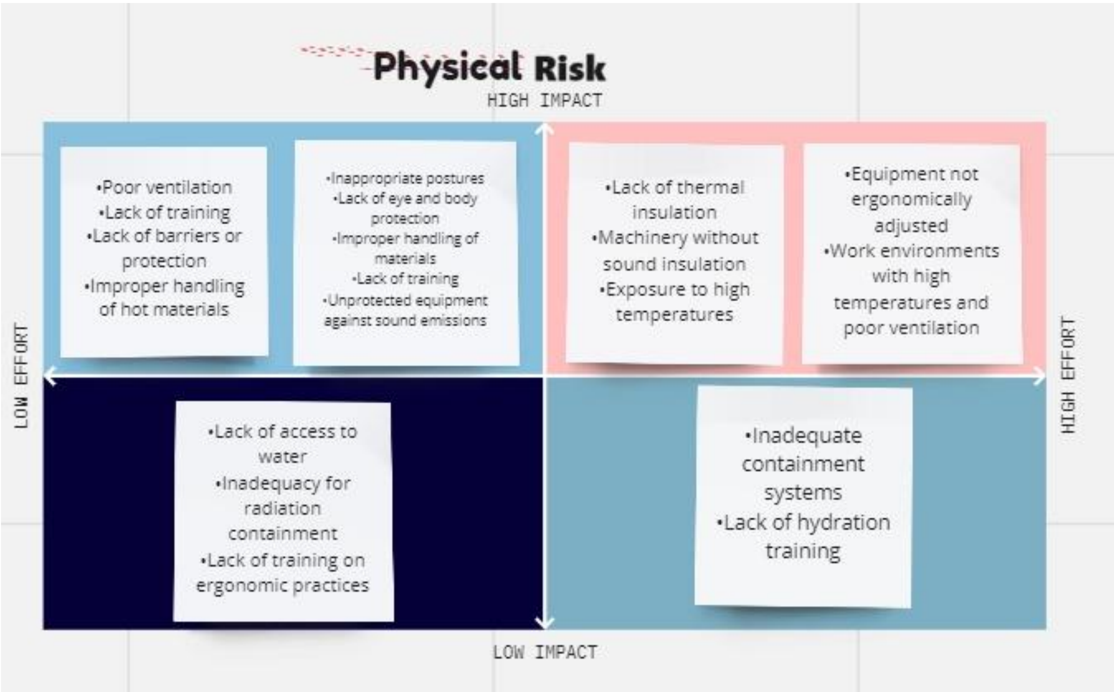


Figure 6 - Effort x Impact matrix Environmental risks

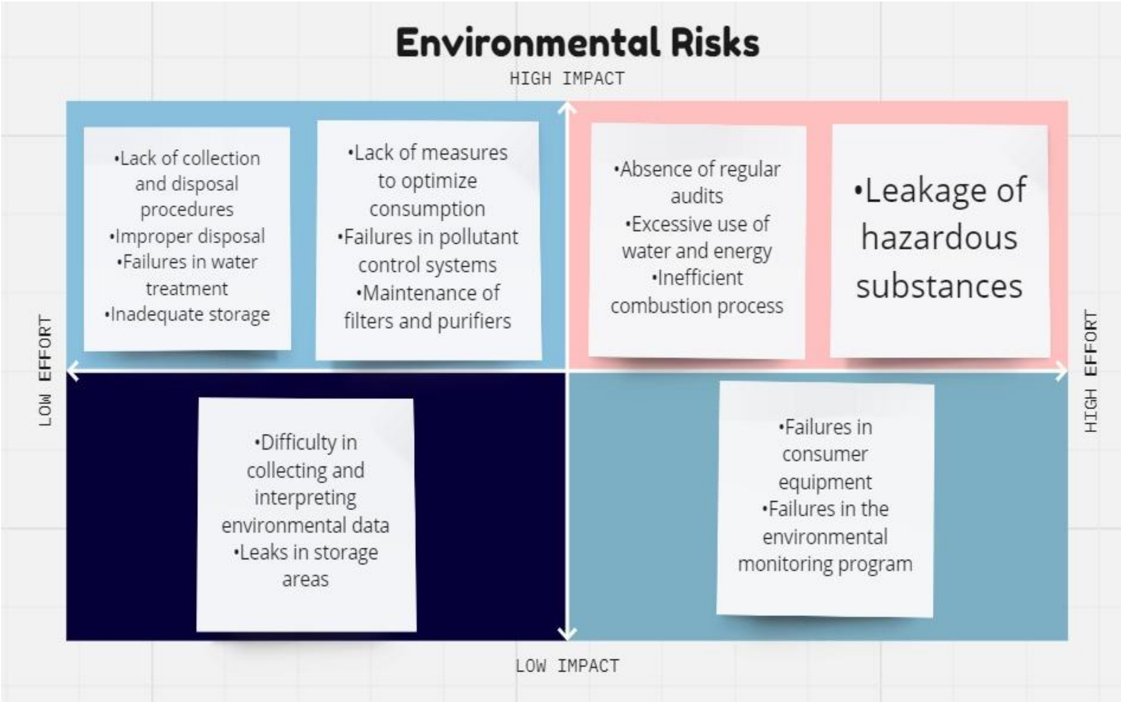


Figure 7 - Effort x Impact Matrix Biological risks

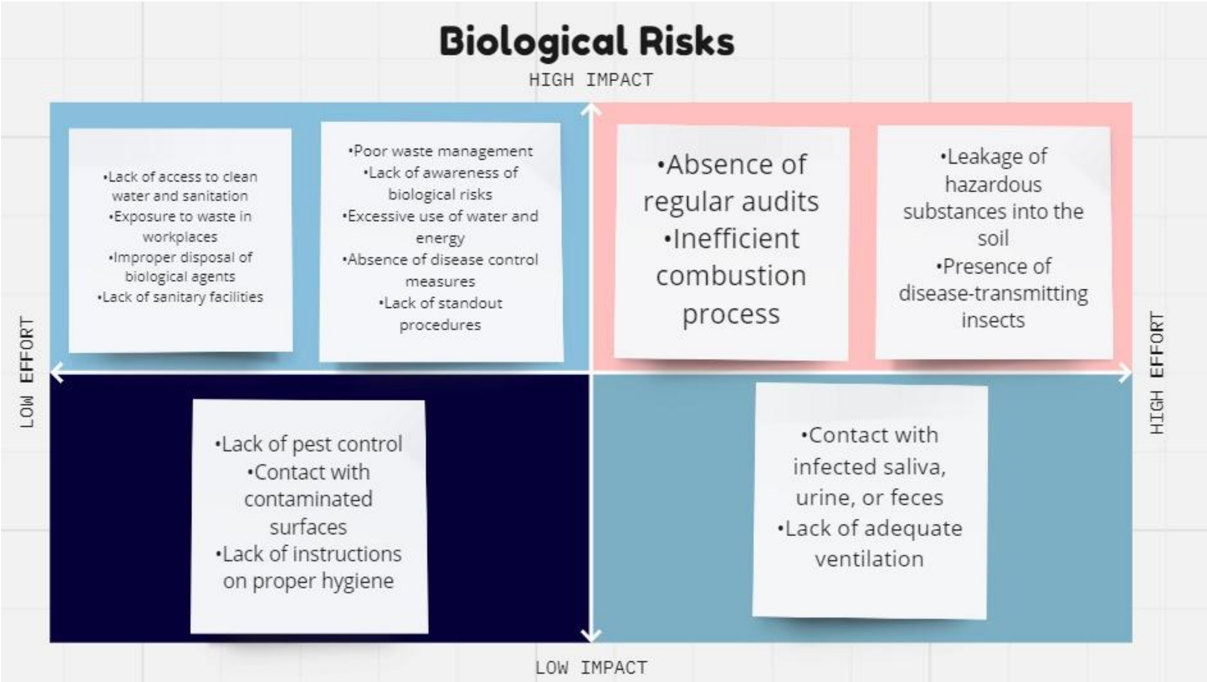
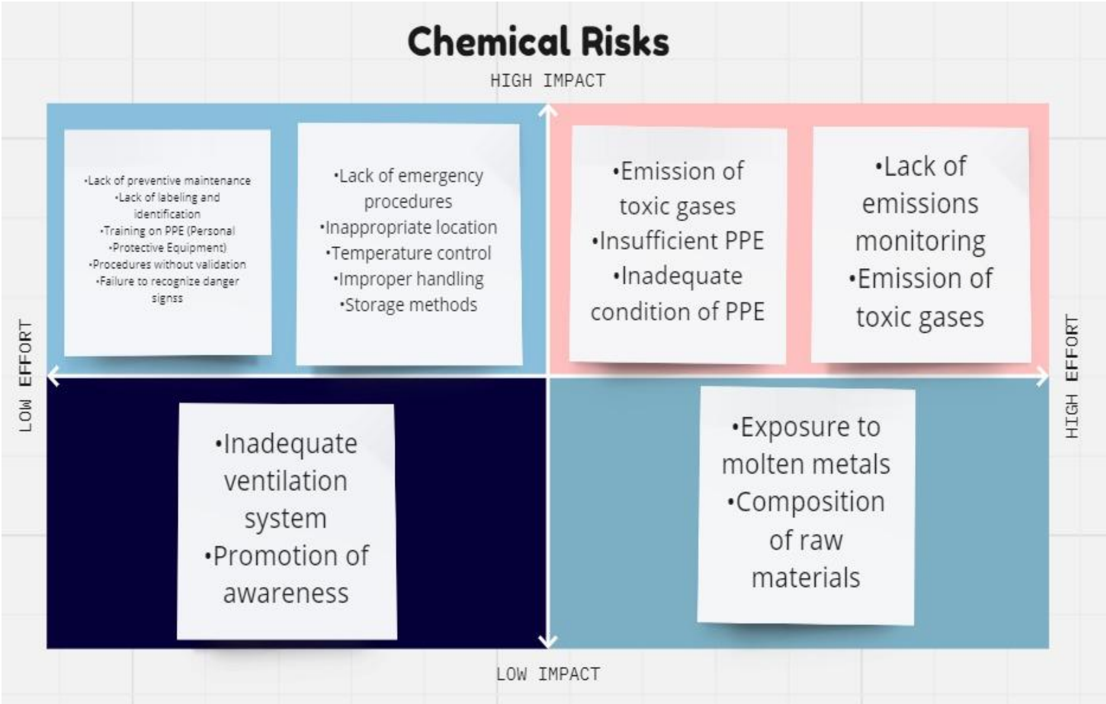


Figure 8 - Stress x Impact matrix Chemical risks



5. Analysis and Discussions

In this section, we will present the results of the risk and safety assessment in the metal casting process in the metallurgical industry, as well as an in-depth discussion on the implications and strategies for dealing with the identified risks. The results will be organized based on the risk categories mentioned in the article: physical, chemical, biological, and environmental risks.

Physical Risks

When analyzing the physical risks involved in the casting process, the GUT assessment indicated that the main risks are related to excessive noise, dehydration, burns, radiation exposure, and ergonomic issues. The lack of adequate personal protective equipment, coupled with prolonged exposure to hot environments, poses serious challenges to worker safety. As described in the "National Strategy for Reducing Work Accidents 2015-2016" report, released in 2015 by the Ministry of Labor and Employment, 2,797 fatal work accidents were identified in Brazil in the same year. These incidents were linked to a mortality rate of 6.53 individuals per 100,000 insured individuals in the country. Additionally, the document points to the International Labor Organization's (ILO) estimate, indicating that over two million people lose their lives annually due to work accidents (MTE, 2015).

The Pareto analysis identified the subcauses that have the greatest impact in each risk category. For example, regarding noise, improper use of Personal Protective Equipment (PPE) and the lack of acoustic insulation emerged as the main contributors to excessive noise exposure. To address this issue, it is imperative to invest in worker training on the importance of PPE and implement acoustic insulation measures in work areas.

Regarding dehydration in hot environments, the lack of continuous access to drinking water was identified as a critical subcause. Simple solutions, such as providing regular access to water and raising awareness among workers about the importance of hydration, can help mitigate this risk.

In the case of burns and radiation exposure, more rigorous safety measures and the use of appropriate PPE are essential. Additionally, workplace ergonomics and protection against particle projection require the implementation of specialized training and the use of ergonomically suitable equipment.

Finally, the effort x impact matrix highlighted the need to prioritize actions related to these physical risks. Immediate actions to ensure the proper use of PPE, the maintenance of safe working environments, and worker awareness are essential to minimize these risks.

Chemical Risks

With the establishment of the Consolidation of Labor Laws (CLT) in 1943, initiated by the Brazilian government, mechanisms were established to identify situations of hazard and insalubrity related to certain work activities associated with the exposure and continuous use of chemicals. This resulted in an expanded focus on worker health.

As stated in Article 193 of the CLT: "Activities or operations are considered hazardous, according to the regulation approved by the Ministry of Labor, those that, due to their nature or methods of execution, involve constant contact with flammable or explosive materials in conditions of imminent risk."

The chemical risks associated with the casting process include exposure to harmful chemicals from raw materials, high temperatures, and handling of certain products. The GUT matrix identified the need to address issues such as effective ventilation, proper use of PPE, safe storage of chemicals, and employee training.

The Pareto analysis revealed that, concerning chemical risks, the lack of effective ventilation and improper handling of chemicals has the greatest impact. To reduce these risks, it is crucial to implement adequate ventilation systems and ensure that workers are aware of safe chemical handling procedures.

The effort x impact matrix emphasized the importance of immediate actions to minimize exposure to chemical risks. Investing in ventilation, providing ongoing training, and supervising the handling of chemicals are crucial steps to ensure worker safety in this context.

Biological Risks

According to Cussiol (2008), the management of waste from health services constitutes a system composed of two distinct phases, encompassing both activities performed internally in the establishment and those that occur outside of it. The intrahospital phase covers the moment of waste generation to its preparation for external collection, while the extrahospital phase includes processes carried out by the collection team or in external environments.

The assessment of biological risks in casting revealed that improper waste handling and lack of awareness about biological risks are the main concerns. The GUT matrix emphasized the importance of implementing measures for proper waste disposal and employee awareness of these risks.

The Pareto analysis identified improper waste handling as the main cause of biological risks. This requires the implementation of safe waste disposal procedures and training workers on the importance of following these procedures. The effort x impact matrix emphasized the need to prioritize actions related to biological risks, focusing on the implementation of waste disposal procedures and employee awareness.

Environmental Risks

According to Unced (1992), to safeguard the environment, it is of utmost importance for states to carefully observe the precautionary principle, adjusting to their capacities. If there are threats that can cause serious harm to the environment, absolute scientific uncertainty should not be used as a justification for delaying the adoption of effective and economically viable measures to prevent environmental degradation.

Environmental risks in casting are related to atmospheric emissions, waste management, consumption of natural resources, control and water pollution, and environmental monitoring and auditing, as well as compliance with environmental legislation. The GUT matrix highlighted the need for more ecological and efficient operational practices, along with compliance with environmental regulations.

The Pareto analysis identified compliance with environmental legislation as one of the main causes of environmental risks. This emphasizes the importance of ensuring that the company complies with current regulations. The effort x impact matrix indicated that actions related to compliance with environmental legislation should be prioritized, as non-compliance can result in serious legal and environmental consequences.

Final Considerations

The risk and safety assessment in the casting process in the metallurgical industry provides valuable insights for risk mitigation and the promotion of safer work practices. The results emphasize the importance of measures such as worker training, proper use of PPE, effective ventilation systems, safe waste disposal procedures, and compliance with environmental regulations.

To ensure a safe and efficient working environment in metal casting, it is essential for the industry to implement corrective and preventive actions promptly and effectively. Additionally, continuous awareness among workers about risks and the importance of safety measures plays a fundamental role in promoting safe practices.

7. CONCLUSION

The facts and data presented on the risks associated with activities in the metal casting process in the metallurgical industry demonstrate the importance and necessity of risk management and control. Equipment, waste, operational systems, people, and processes all have associated risks that require companies to have a management system that encompasses and enforces the provisions of the legislation, relying on preventive measures and workplace safety.

The objective of this work was to present a qualitative methodology that could assist in the management of operational risks in a metallurgical industry. To achieve this, simple tools that did not require a specialized technical team in the sector were used. It was proven that this approach is effective in preventing risks in the sector and raising awareness among employees about safety in the analyzed sector.

There are several methodologies described in the literature for risk analysis. Many of these methodologies are simple and easy to apply, such as the Ishikawa diagram, Pareto diagram, GUT matrix, and Effort x Impact matrix. Thus, it is possible to characterize the main risks, their causes, and subcauses associated with each type of risk.

Therefore, it is concluded that risk analysis and actions to mitigate and control risks are essential for every company. Using quality management and risk management tools strengthens the fight against accidents and improves the production process, ensuring the well-being of employees and a safe environment for work activities. Throughout the development of the work, limitations were encountered, such as the need to conduct interviews with employees in the metallurgical industry and assess the results after the implementation of proposed actions for an initial and final comparison. We also see the possibility of investing more resources in future tasks and delving deeper through other quality tools and field research on the challenges in the casting process and the risks related to the activity, seeking ways to mitigate and identify threats associated with the metallurgical industry.

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