ISBN: 978-628-96613-1-6. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2025.1.1.428

Ergonomic Risk Prevention Model by applying PHA, HIRARC Matrix and OWAS Method in a Construction Sector: A Case Study

Ariana Domysé Acosta-Aguilar, Bsc[1]; Marly Isabel Polo-Villar, Bsc[2]; Jorge Antonio Corzo-Chavez, Msc[3]
[1,2,3] Carrera de Ingeniería Industrial, Universidad de Lima, Perú, 20200015@aloe.ulima.edu.pe, 20203430@aloe.ulima.edu.pe, jacorzo@ulima.edu.pe

Abstract*– The construction sector has a high occupational incidence rate, mainly due to musculoskeletal injuries caused by ergonomic risk factors in the various construction site activities. This research aims to identify these risks in the construction process of concrete elements and develop an occupational health and safety model using the tools PHA, the HIRARC matrix, and the OWAS method, to reduce the rate of musculoskeletal injuries and occupational incidents. The proposed model includes the use of technical data sheets, checklists for machinery maintenance, and the proper use of personal protective equipment (PPE). In addition, ergonomic measures such as the use of lumbar belts and knee pads were implemented, along with safety, occupational health, and ergonomics training specific to the construction site environment. In addition, visual materials were developed, such as informative posters on the correct use of PPE and stretching exercises, promoting both risk prevention and workers' well-being. The results obtained revealed significant improvements in the key indicators of the company under study. The rate of musculoskeletal injuries decreased from 26.67% to 13.33%, while the rate of occupational incidents decreased from 46.67% to 3.33%. These advances reflect a considerable positive impact on workers' health and safety. The project is financially viable and profitable, with a Net Present Value (NPV) of USD 4,451.20, indicating that the financial returns outweigh the investment made.

Keywords: Musculoskeletal injuries, Risks, Construction, Health and Safety.

I. Introduction

A. Background

By February 2024, it is projected that the worldwide construction industry will have experienced a growth of 5.8% in output, primarily due to a substantial 65.4% advancement in public infrastructure projects [1]. Furthermore, there was a 1.8% increase in employment in the construction sector over the last year, with around 367,000 workers engaged in construction activities in the Lima Metropolitan Area during the September-October-November quarter [2]. Furthermore, the building industry made up 9.19% of 3,070 reports concerning workplace injuries, dangerous incidents, and job-related illnesses [3].

The company being researched has been working in the construction industry since 2001, focusing on completing both public and private projects including parks, retaining walls, infrastructure for vehicles and pedestrians, recreational facilities, single and multi-family housing, and buildings with up to five floors. The main difficulty the company faces is in how well it manages the occupational health and safety of its workers on-site, as they often choose not to wear personal protective equipment (PPE) because it is uncomfortable. Engaging in this behavior raises the chances of deadly incidents and harm. Additionally, the absence of staff training, handbooks, and preventative initiatives are crucial obstacles to increasing employee awareness.

The primary goal of this study is to develop a preventive occupational health and safety model by applying the tools PHA (Process Hazard Analysis), the HIRARC (Hazard Identification, Risk Assessment and Risk Control) matrix, and the OWAS (Ovako Working Posture Analysis System) method, aiming to decrease the occurrence of occupational illnesses and accidents at work. The specific goals include determining risk levels in different phases of concrete element construction, suggesting engineering solutions, and assessing the economic consequences of these actions.

The research focuses on the stages of the concrete element construction process within worksites, employing a correlational and explanatory approach with a quasi-experimental design. This approach evaluates how independent variables like inadequate training, absence of prevention programs, lack of technical manuals, and poor maintenance of machinery, are related to the dependent variable: the rate of occupational diseases and incidents.

To evaluate the results of the model's implementation, certain key performance indicators (KPIs) have been pinpointed, such as the training index, incident rate, musculoskeletal injury rate, and the amount of worker complaints about bodily pain at work. These measures will help assess how effective the project is and how it contributes to improving workplace safety and employee welfare.

B. State of the art

In previous research, the management of safety and health towards workers is significantly affected by various risk factors. These include uncomfortable postures, strenuous efforts, and prolonged repetitive manual activities such as pushing and lifting, which are particularly prevalent in concrete assembly tasks [4], [5]. Another study showed that floor formwork tasks pose a 39% ergonomic risk, mainly in the various positions involving the legs; likewise, cutting steel beams represents a 23.1% risk in the limbs above the shoulder, this activity belongs to the assembly of columns [6].

The PHA and the HIRARC matrix are key tools for the systematic identification of occupational risks, enabling the analysis of their causes and potential effects on workers' performance. These methodologies provide a comprehensive understanding of potential workplace hazards and support the development of effective risk control strategies. Such strategies include the implementation of safety initiatives, the integration of ergonomic tools, and the improvement of PPE provision.

In this context, various studies have highlighted the application of both PHA and HIRARC methodologies, particularly in the construction, textile, and fishing industries. Their use has proven especially valuable during the early stages of planning, aiming to anticipate and mitigate risks before operations begin. The implementation of corrective measures (such as the proper use of PPE, optimized placement of machinery, and ergonomics training), which were developed based on assessments using these methodologies, has resulted in significant improvements. For example, in the fishing sector, a 67% reduction in identified risks was observed, underscoring the effectiveness of this preventive risk management approach [7], [8], [9].

The OWAS method is an ergonomic assessment technique aimed at detecting and classifying postures adopted during the working day, with the objective of reducing the occurrence of musculoskeletal disorders (WMSD). In the field of construction, its application has been key to examine activities that demand high physical effort, such as transporting, pushing and pulling materials. In one study, inertial sensors and artificial intelligence models were integrated, achieving accuracy levels between 74.6 % and 98.6 % in the classification of physical load, which facilitated the identification of excessive efforts and the implementation of corrective measures [5]. In addition, a personalized mobile health system was implemented that recorded trunk inclination in real time and alerted the workers to prolonged postures, thus helping to prevent low back disorders (LBDs) [10]. In the case of the manufacturing sector, the method made it possible to analyze postures associated with tasks such as quality control and tool handling, which led to improvement proposals such as reorganization of the workspace, mechanization of processes and personnel rotation. Taken together, these results support the effectiveness of the OWAS method as a key preventive resource for optimizing health and safety in physically demanding work environments [11].

Fig. 1 illustrates the relationship between the set goals and the suggested tools. The HIRARC matrix will be utilized to address the proper use of PPE and preventive maintenance of machinery and tools, which are the first and third objectives. The PHA tool has been chosen for the safety and health training objective. The OWAS method will be used to minimize operators exposure to risks that lead to body pains.

Scientific articles \ causes or objectives	Raise awareness and properly use PPE	Training on safety in the workplace	Preventive maintenance of machinery or tools	Reduce exposure to risks that cause physical pain	Training on occupational health topics
ABC Design, Inventory Control, HIRARC Matrix, DMAIC Method, and CPM Method to Reduce Costs in a Hygiene Products Manufacturing Company	HIRARC		HIRARC		
Ergonomic Design of the workplace for Final Quality Control				OWAS	
Risk Analysis: A generalized Hazop methodology state-of-the-art, applications, and perspective in the		PHA			PHA
Risk management implementing the Peruvian law 29783 in a fishing company	HIRARC		HIRARC		
Customized method for self-control of ergonomic postural risks of the trunk in construction fittings				OWAS	
Integrated system for construction companies in Cusco	HIRARC	PHA	HIRARC		PHA
Prediction of ergonomic risks and impacts on the construction schedule through agent-based simulation				OWAS	
Hazard Identification and Risk Assessment and Control (HIRARC) in the mini spinning and weaving plant at the Faculty of Industrial Engineering - UNMSM	HIRARC		HIRARC		
Proposal	**HIRARC**	**PHA**	**HIRARC**	**OWAS**	**PHA**

Fig. 1 Comparative matrix of causes or objectives vs the state of the art

II. Problem

By conducting on-site inspections and collecting feedback from employees, it was determined that the primary issue within the company is related to its performance in occupational health and safety management. This issue has a significant impact on the frequency of work-related accidents and incidents, affecting the safety and health of workers as well as adherence to applicable laws. It is important to mention that operators often choose not to wear their PPE due to discomfort, impacting their safety and health and increasing the risk of fatal accidents and injuries affecting different body parts; similarly, the absence of proper training, manuals, and prevention programs is crucial to enhance operator awareness.

The general manager was interviewed to gather information about the company's internal regulations. Specifically, data on the number of training programs conducted per year was obtained. There are a total of four scheduled training sessions, but only two were completed in the last year, resulting in a 50% compliance rate. The priority of projects and the intense work schedules are some of the factors leading to non-compliance.

However, the incident indicator is crucial for assessing and pinpointing areas with a high risk of incidents, assisting the company in implementing preventive actions. The indicator calculation is based on operators' reports of incidents such as tool-related injuries, serious cuts, and falls from heights, among others. The indicator currently stands at 46.67%.

However, based on feedback from certain workers, it is typical to experience back injuries like lower back pain, along with tendinitis from repetitive duties and sprained ankles and/or wrists. Furthermore, it is crucial to point out that these injuries occur more often in adults who fail to uphold correct posture while carrying out their designated duties. By using this data, the musculoskeletal injury rate (MSLT) can be determined, considering that the average number of total workers is 15 workers, which results in 26.67%.

In relation to the quantity of worker complaints about physical discomfort while working (NQ), it was documented that just 5 employees reported feeling pain in their back, neck, and hands from using hand tools; along with foot injuries from tripping and shoulder pain. After analyzing the data, it was found that 33.33% of all employees reported experiencing body pain.

To analyze the technical gap, it is necessary to consider the target indicators of the sector, which have been extracted from the articles of the Law on Occupational Safety and Health, as well as from the health and ergonomics standards in force in the country (see Fig. 2).

Indicators	Sector	Company under study	Percentage difference
Training Index	100%	50%	50%
Incident rate	6.67%	46.67%	-40%
Rate of musculoskeletal injuries	6.67%	26.67%	-20%
Number of worker complaints about physical pain at work	13.33%	33.33%	-20%

Fig. 2 Comparative Analysis between Company and Sector

Root causes are identified using a problem tree to determine the causes linked to health and safety management in a construction site. Similarly, the research goals focused on utilizing important tools like PHA, HARIRC matrix, and OWAS method to decrease the rate of musculoskeletal injuries and occupational incidences, as seen in Fig. 3.

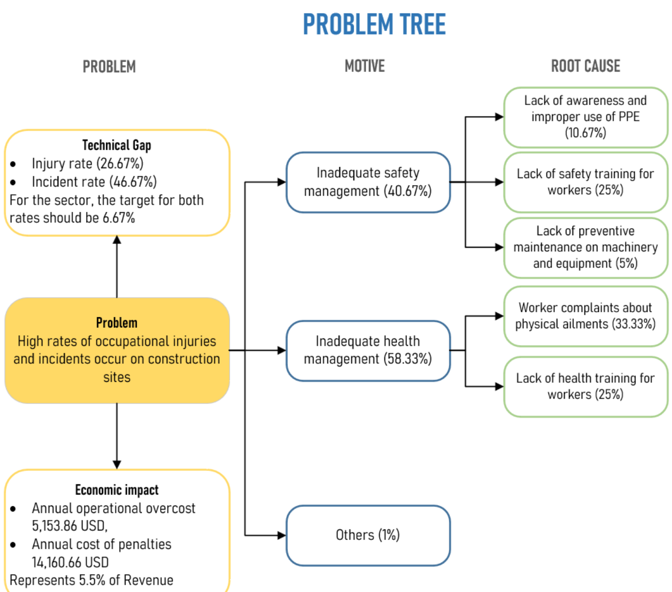


Fig. 3 Problem tree

III. Methodology And Innovative Proposal

The root causes were associated with the three engineering tools identified, based on the findings from the state of the art. The PHA tool was applied to conduct an initial analysis of the current state of safety and health management in activities related to the construction of concrete elements. The proposed improvement for this tool is centered on implementing targeted training sessions. Meanwhile, the HIRARC matrix facilitated the quantification of risks and hazards in each activity and the proposal of corresponding preventive measures.

The OWAS technique was employed to address the ergonomic risks faced by workers during their routine tasks. For the risk analysis using the PHA and HIRARC matrix tools, a group of 15 workers present on-site during the evaluation period was selected. These workers were chosen based on their direct involvement in critical construction activities, which enabled the identification of potential hazards and the assessment of their impact in terms of probability and severity.

Regarding the ergonomic risk assessment, the OWAS method was applied specifically to the formwork phase, which was identified as the most physically demanding stage and the one with the highest incidence of musculoskeletal disorder reports. For this analysis, a sample of 5 workers directly engaged in formwork activities was considered, allowing for a detailed examination of the postures adopted during the execution of specific tasks.

Considering the mentioned tools, the following model was developed as an improvement proposal, as shown in Fig. 4.

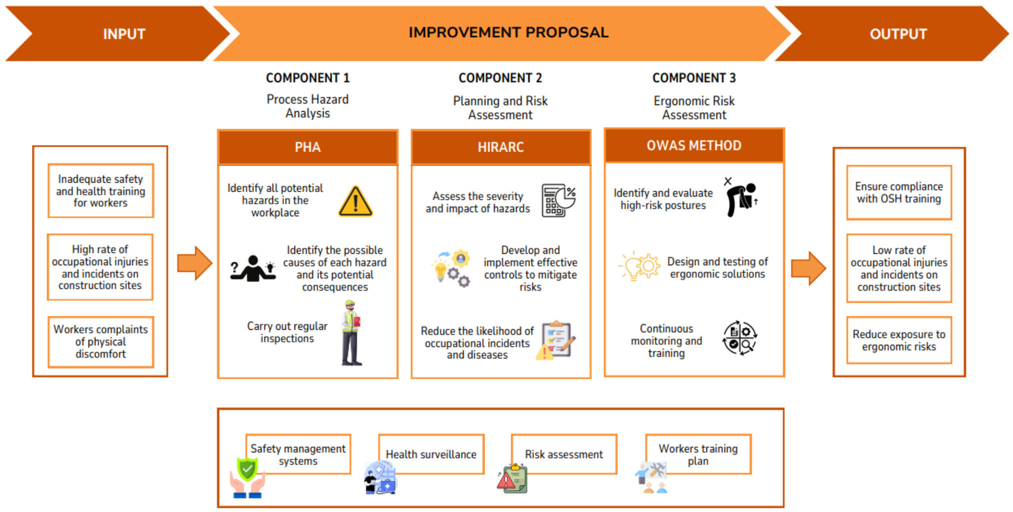


Fig. 4 Proposed Model

A. *Component 1: Process Hazard Analysis*

The first component corresponds to the PHA tool. It began by identifying the hazards and risks to which workers are exposed at each stage of the concrete elements construction process. This analysis allowed for the design of a training program to address the topics identified in the PHA.

In this training program, audio-visual materials such as presentations, brochures, and pamphlets were prepared. Additionally, active participation from the workers was encouraged during the training sessions, using simulations to ensure a more interactive learning experience. At the end of each session, an evaluation was conducted to gather feedback on the effectiveness of the training and measure its impact on the workers. Fig. 5 shows a flowchart of the consolidated activities carried out.

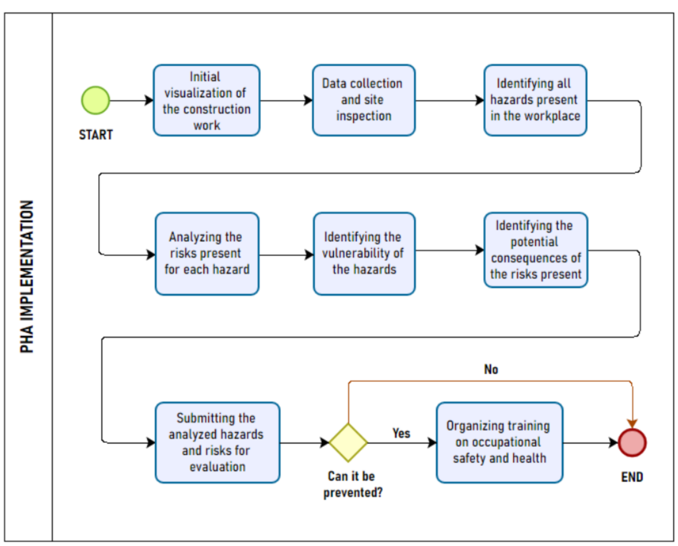


Fig. 5 PHA implementation

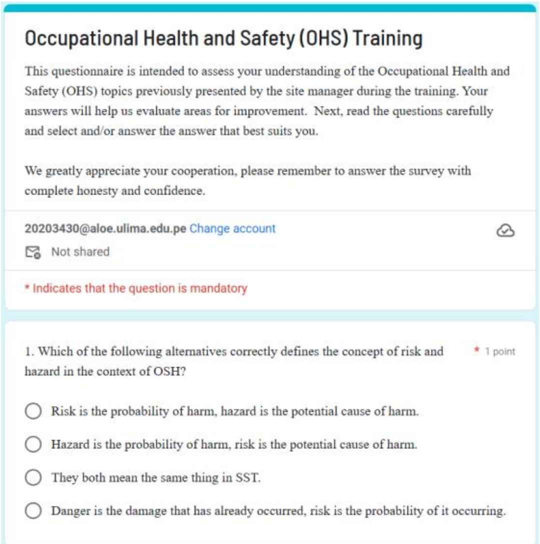
Fig. 6 displays the Training Technical Data Sheet Format, created to arrange and categorize the subjects addressed during training sessions. Meanwhile, Fig. 7 highlights the Occupational Health and Safety Training Questionnaires, designed to collect feedback and opinions from employees regarding the material presented. This procedure focuses on identifying areas that need enhancement and ensuring that the information provided is relevant and meets their requirements.

	OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEM	**CODE:**
		VERSION:
	TRAINING TECHNICAL DATA SHEET	**PAGE 1 OF 1**
OCCUPATIONAL HEALTH AND SAFETY TRAINING TECHNICAL DATA SHEET		

START TIME:	**DATE:**
END TIME:	**TOPIC:**

JUSTIFICATION	
OBJECTIVE	
TOPICS TO BE COVERED	
TRAINER PROFILE	

Fig. 6 Training Technical Data Sheet Format


Occupational Health and Safety (OHS) Training

This questionnaire is intended to assess your understanding of the Occupational Health and Safety (OHS) topics previously presented by the site manager during the training. Your answers will help us evaluate areas for improvement. Next, read the questions carefully and select and/or answer the answer that best suits you.

We greatly appreciate your cooperation, please remember to answer the survey with complete honesty and confidence.

20203430@aloe.ulima.edu.pe Change account

Not shared

* Indicates that the question is mandatory

1. Which of the following alternatives correctly defines the concept of risk and hazard in the context of OSH? * 1 point

- Risk is the probability of harm, hazard is the potential cause of harm.
- Hazard is the probability of harm, risk is the potential cause of harm.
- They both mean the same thing in SST.
- Danger is the damage that has already occurred, risk is the probability of it occurring.

Fig. 7 Questionnaires on occupational health and safety training

The intended result of this suggested solution is to meet completely (100%) the annual training indicator.

B. Component 2: Planning and Risk Assessment

The second component involves the implementation of the HIRARC matrix. It starts with extracting the hazards and risks that were previously analyzed in the PHA tool. Then, the hazards and risks are segmented by each process to establish the corresponding legal requirements. After that, the probability and severity indexes of these risks associated with each hazard were calculated to determine their level and significance. Finally, control measures were proposed to mitigate them, such as the implementation of PPE and preventive maintenance of machinery and/or equipment. Fig. 8 shows a flowchart of the consolidated activities carried out.

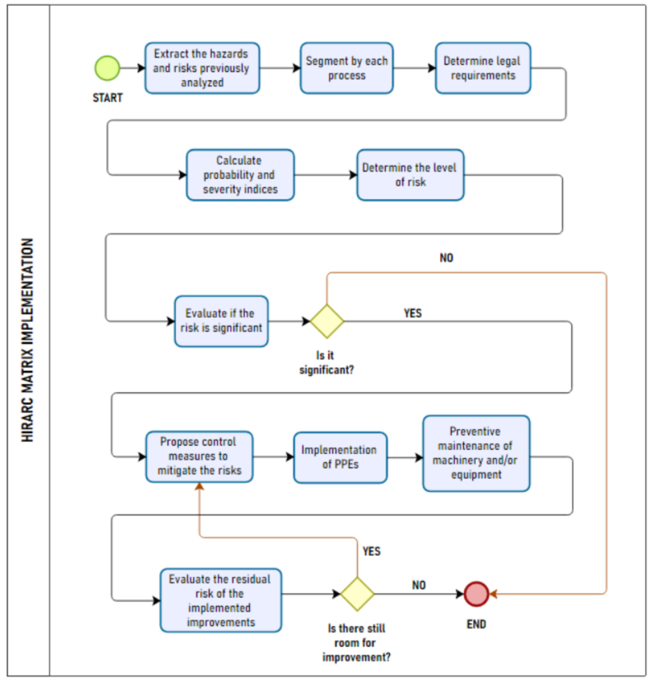


Fig. 8 HIRARC Matrix implementation

Fig. 9 presents the personal protective equipment inspection format, designed to ensure proper oversight of PPE inspections conducted by operators. Meanwhile, Fig. 10 displays the questionnaire on PPE usage and machinery maintenance, created to evaluate employees understanding and habits related to the implemented safety protocols.

PERSONAL PROTECTIVE EQUIPMENT INSPECTION CHECKLIST

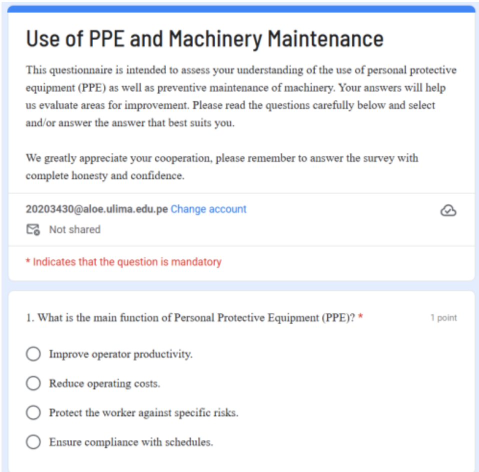
CHECKING FREQUENCY: ____________________ **DATE:** ___________

No.	IDENTIFICATION				
1	BASIC PPE FOR WORKERS	Good	Bad	N/A	Observation
1.1	Long sleeve shirt and pants				
1.2	Windbreaker				
1.3	Safety helmet				
1.4	Safety shoes				
1.5	Goatskin gloves				
1.6	Safety glasses				
1.7	Hearing protectors				
1.8	Reflective vest				
1.9	Rubber boots				

INSPECTION CARRIED OUT
NAME:
POSITION:
SIGNATURE:

INSPECTION REVIEWED
NAME:
POSITION:
SIGNATURE:

Fig. 9 Personal protective equipment inspection checklist



Use of PPE and Machinery Maintenance

This questionnaire is intended to assess your understanding of the use of personal protective equipment (PPE) as well as preventive maintenance of machinery. Your answers will help us evaluate areas for improvement. Please read the questions carefully below and select and/or answer the answer that best suits you.

We greatly appreciate your cooperation, please remember to answer the survey with complete honesty and confidence.

20203430@aloe.ulima.edu.pe Change account

Not shared

* Indicates that the question is mandatory

1. What is the main function of Personal Protective Equipment (PPE)? * — 1 point

- Improve operator productivity.
- Reduce operating costs.
- Protect the worker against specific risks.
- Ensure compliance with schedules.

Fig. 10 Questionnaire on the use of PPE and machinery maintenance

The expected outcome of this proposal is to reach a 6.67% in the incidence rate indicator. It is important to note that two root causes impact the result: the lack of awareness and improper use of PPE, and the lack of preventive maintenance of machinery or equipment. The goal is to reduce these causes to 0%.

C. Component 3: Ergonomic Risk Assessment

The third component involves the development of the OWAS method. This process begins with the observation of the postures of the five workers performing the formwork activity. The "Ergosoft Pro" simulator was used, specifying the method in use to identify those postures and limbs that present the highest risk of affecting the workers' health. The result showed that the back and legs are the body parts most at risk during the activity, with 50% and an average of 27% risk, respectively. Based on this, a proposed solution was developed. Fig. 11 shows a flow chart of the consolidated activities carried out.

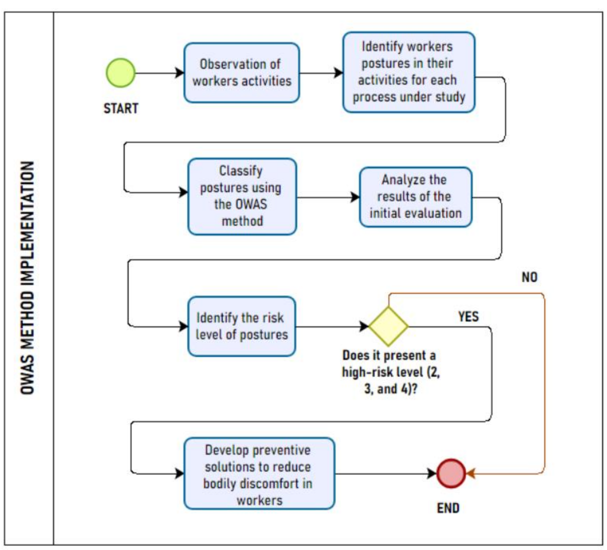


Fig. 11 OWAS Method implementation

The suggestion for improvement revolved around incorporating ergonomic belts and knee pads in order to alleviate physical discomfort. The suggested model also recommends organizing training sessions regarding the subject at hand. Moreover, posters providing information on correct postures when handling loads were taken into account.

Fig. 12 shows the OSH training sessions record, which monitors the attendance of workers at the scheduled training sessions. Meanwhile, Fig. 13 illustrates the questionnaires on ergonomic training, created to assess employee's awareness and practices regarding the safety measures implemented and to measure their overall effect.

RECORD OF 5-MINUTE TALK, INDUCTION TRAINING, TRAINING SESSIONS, AND DRILL	OHSMS
	N° 0_

MARK (X)				
5-MINUTE TALK	INDUCTION	TRAINING	PRACTICE	SIMULATION

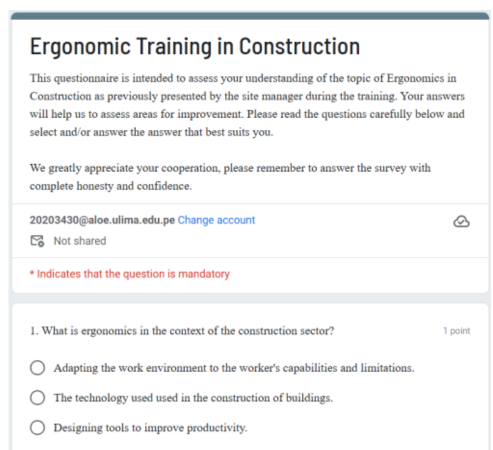
DATE:	START TIME:	A.M
TOPIC: Occupational Health and Safety		

ITEM	NAME AND SURNAME	COMPANY	POSITION	DNI	SIGNATURE
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					

OBSERVATIONS

REGISTER RESPONSIBLE	
PRESENTER:	
POSITION:	
DATE:	SIGNATURE

Fig. 12 Record of OSH training sessions



Ergonomic Training in Construction

This questionnaire is intended to assess your understanding of the topic of Ergonomics in Construction as previously presented by the site manager during the training. Your answers will help us to assess areas for improvement. Please read the questions carefully below and select and/or answer the answer that best suits you.

We greatly appreciate your cooperation, please remember to answer the survey with complete honesty and confidence.

20203430@aloe.ulima.edu.pe Change account

Not shared

* Indicates that the question is mandatory

1. What is ergonomics in the context of the construction sector? — 1 point

- Adapting the work environment to the worker's capabilities and limitations.
- The technology used used in the construction of buildings.
- Designing tools to improve productivity.

Fig. 13 Questionnaires on ergonomic training

The goal of this proposal is to achieve a 6.67% reduction in the musculoskeletal injury rate indicator. Furthermore, the objective is to achieve a 13.33% score in the metric measuring worker grievances related to physical discomfort.

IV. Results

A. Analysis Results

Comprehensive analyses were conducted on the construction sites using tools like PHA, the HIRARC matrix, and the OWAS method to develop improvement proposals. Fig. 14 displays the PHA matrix, outlining the hazards and risks linked to various construction processes.

OPERATION	DESCRIPTION	HAZARDS	VULNERABILITY	RISKS	CONSEQUENCES
Site preparation	The area is cleaned, the land is leveled and the soil is compacted.	The grader and the plate type compacting machine.	Lack of maintenance	- Likelihood of being struck by machinery - Probability of tripping and falling on unstable ground.	- Suffer minor bumps and/or injuries - Sprained ankle - Infection of the eye by projection of particles (dust) - Musculoskeletal injuries (back pain, hernias, tendinitis, etc.)
Granular base	Shaping and compacting of the pavement layer is carried out.	Skid steer loader and compactor plate	Lack of machinery maintenance	- Probability of being struck by iron	-Suffering blows and/or minor injuries. -Suffering musculoskeletal injuries (low back pain, hernias, tendinitis, etc.)
Formwork	The wooden boards are cut according to the specifications of the plans. Then, they are joined together to delimit the area. They must be properly fixed and propped.	Power and hand tools (cutter, saw, hammer); sharp materials (wire, stirrups, steel, nails); and scaffolding and ladders.	Operators without PPE, lack of tool maintenance, and unstable bases	- Probability of suffering minor and severe cuts - Likelihood of minor bumps and/or injuries - Probability of falling	-Loss of a limb due to the cuts -Infection in the eye due to projection of particles (dust). -Musculoskeletal injuries (lumbago, hernias, tendinitis, tenosynovitis, etc.)
Preparation and pouring of concrete	First, the materials (sand, water, cement and stone) are transported. Then, the aggregates are mixed according to concrete strength and dosage specifications. Finally, the concrete is poured.	Contact with chemicals and drum or Mixer	Operators without PPE's and lack of maintenance	- Likelihood of skin irritation and infections - Likelihood of trips and falls - Likelihood of cuts	- Suffering cuts - Infection of the eye by particle projection (dust) - Skin irritation due to contact with raw materials. - Suffering musculoskeletal injuries (lumbago, hernias, tendinitis, tenosynovitis, etc.)
Concrete curing	Curing is carried out according to the project (chemical products or water).	Contact with chemical products (liquid additives)	Operators without PPEs	- Likelihood of skin irritation and infections	- Skin irritation by contact with chemicals - Burns - Musculoskeletal injuries (low back pain, hernias, tendinitis, tenosynovitis, etc.)
Formwork removal	Wooden formwork is removed (unnailing).	Truper, hammer and metal structures (scaffolding) and/or ladder	Tools in poor condition and/or lack of maintenance, unstable base of scaffolding and/or ladder	- Probability of bumps and falls - Probability of cuts	- Suffering cuts - Infection of the eye by projection of particles (dust). - Musculoskeletal injuries (back pain, hernia, tendinitis, tenosynovitis, etc.)

Fig. 14 PHA Matrix

The HIRARC matrix, depicted in Fig. 15, outlines adherence to legal obligations for each process stage and assesses risk impact levels. This matrix shows the important risks that need to be addressed within a set timeframe, with the formwork stage being the riskiest.

In conclusion, as shown in Fig. 16, the analysis using the OWAS method identified that postures such as a bent back, arms raised above the shoulders, and bent or kneeling legs fall into risk category 2. Fig. 17 shows that these postures could pose a potential threat to the long-term musculoskeletal wellbeing of operators, so it is crucial to take immediate action in the near future to prevent possible damage to employees' musculoskeletal health.

Body part	Position	Quantity	Frequency	Risk category	Need corrective action?
Back	Straight	5	50%	1	No
	Bent	5	50%	2	Yes
	With rotation	0	0%	1	No
	Bent and rotated	0	0%	1	No
Arms	Both arms below the shoulder	7	64%	1	No
	An arm above shoulder level	0	0%	1	No
	Both arms above shoulder level	4	36%	2	Yes
Legs	Seated	0	0%	1	No
	Standing, both legs straight	3	23%	1	No
	One-legged support, straight leg	3	23%	1	No
	Both legs bent	4	31%	2	Yes
	One-legged support, leg bent	0	0%	1	No
	Kneeling or squatting	3	23%	2	Yes
	Walking	0	0%	1	No

Fig. 16 Simulator: Risk categories by body part

RISK CATEGORY	EFFECT OF POSTURE	ACTION REQUIRED
1	Normal, natural posture with no harmful effects on the musculoskeletal system.	No action required.
2	Posture with the potential to cause damage to the musculoskeletal system.	Corrective actions are required in the near future.
3	Posture with harmful effects on the musculoskeletal system.	Corrective action is required as soon as possible.
4	The load caused by this posture has extremely damaging effects on the musculoskeletal system.	Corrective action is required immediately.

Fig. 17 Risk categories and corrective actions

Hazard Identification, Risk Assessment and Risk Control (HIRARC)													
				Probability Indexes									
Stage of the Process	Danger	Risk	Legal requirement	Exposed persons index	Index of existing procedures	Training index	Risk exposure index	Probability index	Severity index	Riesgo= Probabilidad x Severidad	Risk level	Significant Risk	Control Measures
Site preparation	The grader and the plate type compacting machine.	- Likelihood of being struck by machinery - Probability of tripping and falling on unstable ground.	Standard G.050	2	2	2	3	9	1	9	Moderate	Yes	- Preventive maintenance checklist - Training on risks and proper use of machinery
			Residual risk	2	1	1	3	7	1	7	Tolerable	No	
Granular base	Skid steer loader and compactor plate	- Probability of being struck by iron	Standard G.050	2	3	2	3	10	1	10	Moderate	Yes	- Preventive maintenance checklist - Training on risks and proper use of machinery
			Residual risk	2	1	1	3	7	1	7	Tolerable	No	
Formwork	Power and hand tools (cutter, saw, hammer); sharp materials (wire, stirrups, steel, nails); and scaffolding and ladders.	- Probability of suffering minor and severe cuts - Likelihood of minor bumps and/or injuries - Probability of falling	Standard E.060	3	2	2	3	10	2	20	Important	Yes	- Check List of preventive maintenance of machinery and tools. - Check List of PPE inspection - Supervise that scaffolding and ladders have a stable base. - Training on risks and proper use of PPEs
			Residual risk	3	1	1	3	8	1	8	Tolerable	No	
Preparation and pouring of concrete	Contact with chemicals and drum or Mixer	- Likelihood of skin irritation and infections - Likelihood of trips and falls - Likelihood of cuts	Standard G.050	2	2	2	3	9	1	9	Moderate	Yes	- Check List of PPE inspection. - Supervision of correct maintenance - Implementation of gloves and glasses - Training on risks and proper use of PPE
			Residual risk	2	1	1	3	7	1	7	Tolerable	No	
Concrete curing	Contact with chemical products (liquid additives)	- Likelihood of skin irritation and infections	Standard E.060	1	2	3	1	7	2	14	Moderate	Yes	- Implementation of gloves and glasses. - Training on risks and proper use of PPE
			Residual risk	1	1	1	1	4	1	4	Trivia	No	
Formwork removal	Truper, hammer and metal structures (scaffolding) and/or ladder	- Probability of bumps and falls - Probability of cuts	Standard E.060	2	2	2	2	8	2	16	Moderate	Yes	- Supervise that scaffolding and ladders have a stable base. - Training regarding risks and proper use of PPE. - PPE inspection checklist
			Residual risk	2	1	1	2	6	1	6	Tolerable	No	

Fig. 15 HIRARC Matrix

B. *Implementation Results*

After the implementation of the proposals on the construction site over a period of six months, the results for the four main indicators initially defined were obtained and these were compared with the target values set for each of them.

Firstly, the incident rate indicator started with an initial value of 46.67%, with the aim of reducing it to 6.67%. During the implementation, a reduction of 26.67% was achieved, and the value was finally set at 20%, as shown in Fig. 18. It should be noted that this indicator is partly influenced by other KPIs, which have been evaluated according to their importance, based on information gathered through surveys, and whose values have been reduced to 2.67% and 1.25%, respectively.

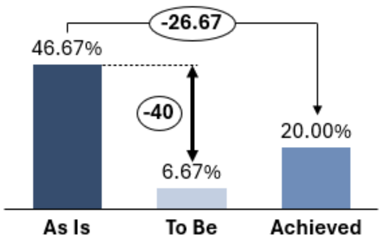


Fig. 18 Incident Rate

In terms of the rate of musculoskeletal injuries, as shown in Fig. 19, the initial value was 26.67%, with a target reduction to 6.67%. Implementation reduced the indicator by almost half to a final value of 13.33%.

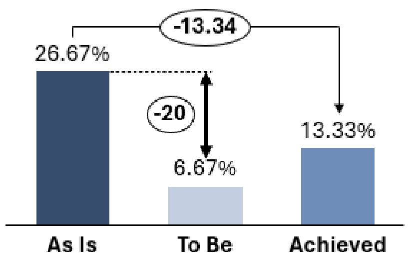


Fig. 19 Musculoskeletal Injury Rate

The training index started with an initial value of 50%, with a target of 100%. This target was successfully achieved, covering all the planned annual training, as depicted in Fig. 20.

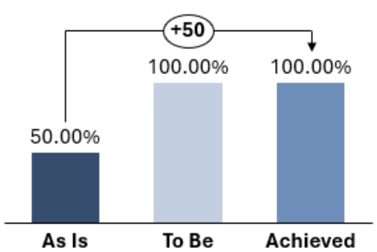


Fig. 20 Training Index

Finally, as shown in Fig. 21, the indicator for the number of complaints from workers about physical pain at work started with a value of 33.33%, with a target to reduce it by 20%. After implementation, a reduction of 13.33% was achieved, which is close to the target set and reflects an improvement in working conditions.

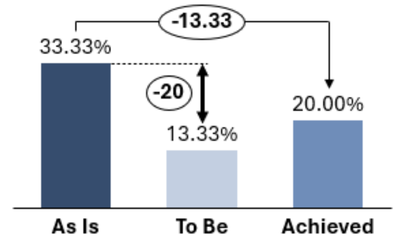


Fig. 21 Indicator of Workers' Complaints on Body Aches

C. *Economic Evaluation*

Analysis of the financial indicators requires calculation of the Opportunity Cost of Capital (COK) using the following formula:

$$COK = Rf + \beta * (Rm - Rf) \quad (1)$$

Formula (1) incorporates key variables such as the project's industry-specific deleveraged beta (β), risk-free rate (Rf), market rate (Rm), and the risk premium (Rm - Rf). These data are obtained from reliable sources, including the Federal Reserve (FED), Damodaran, and the Standard & Poor's 500 Index (S&P 500). Based on these values, a monthly COK in dollars of 0.97% was calculated, considering an inflation rate of 2.50% in the United States and 3.20% in Peru.

Based on this monthly COK, the profitability indicators of the incremental flow of the improvement project were determined over a period of six months, as shown in Fig. 22.

Profitability Indicators	
NPV	4,451.20
IRR	314.69%
B/C	15.11 USD
PR	7.71 days

Fig. 22 Profitability Indicators

The results obtained confirm that the project is economically viable and profitable. This is supported by the fact that the Net Present Value (NPV) is positive, the Internal Rate of Return (IRR) is higher than the COK, the benefit-cost ratio (BCR) is greater than 1, and the payback period (PR) is short. These factors indicate that the project will generate cash flow quickly, which reinforces its financial attractiveness.

D. *Sensitivity Analysis*

The sensitivity analysis was performed using the @Risk tool, which allows us to quantify the impact of three scenarios (pessimistic, normal and optimistic) of the main economic indicators. For this purpose, the following scenarios were considered:

• Penalties and/or fines for non-compliance with safety regulations: economic sanctions applied for non-compliance with standards for the protection of workers and the environment, the amount of which varies according to the seriousness of the violation. In the sensitivity analysis, the optimistic scenario assumes zero penalties, the normal scenario assumes 4 UIT (USD 5,500.67) and the pessimistic scenario assumes 6 UIT (USD 8,251).

• Hospitalization costs due to employee accidents: This scenario considers the cost of accidents that occur in areas far from medical centers covered by insurance. In priority cases, the company must bear the cost of transporting the worker to the nearest hospital (these accidents are usually related to the lack of use of PPE).

• Hiring additional personnel: This occurs when a worker is unable to work due to an injury. Alternatively, the company hires additional personnel for specific activities. In the optimistic scenario, no hiring is required; in the normal scenario, 2 additional workers are hired; and in the pessimistic scenario, 3 additional workers are hired.

Fig. 23 shows the scenarios and their corresponding economic indicator values.

Variable	Type	Value	NPV	IRR	B/C	Payback Period
Penalties and/or fines	Pessimistic	$ 8,251.00	$ 2,776.52	266.45%	2.33	8.93
	Normal	$ 5,500.67	$ 4,412.17	271.92%	3.54	8.73
	Optimistic	0	$ 5,152.01	288.91%	4.09	8.2
Accident rate	Pessimistic	4%	$ 4,405.78	226.79%	3.53	11.03
	Normal	1%	$ 4,965.45	273.08%	3.95	9.21
	Optimistic	0%	$ 5,133.13	275.00%	4.07	8.73
Hiring of additional personnel	Pessimistic	$ 2,576.93	$ 1,436.46	91.08%	1.33	23.26
	Normal	$ 1,717.95	$ 2,928.36	256.55%	2.44	8.73
	Optimistic	0	$ 5,344.04	305.29%	4.23	8.29

Fig. 23 Profitability Indicators

V. Discussion

Regarding the PHA indicator, the company was able to achieve only half of the planned annual training initially. In order to achieve a 100% completion rate, two extra sessions were included in the original four, with both operators and the site manager actively participating as trainers. Herrera et al. [12] highlights the significance of training in risk detection and prevention as a key factor in maintaining safety at construction sites. Furthermore, Cuba [7] emphasizes that employees in this industry face various dangers regularly, highlighting the importance of enacting efficient safety measures to reduce common risks and ensure a secure work setting.

In the case of the HIRARC tool, the initial incident rate was 46.67% (7 out of 15 workers involved). To reduce it to 6.67%, measures such as maintenance checklists, PPE inspections and safety information posters were implemented. Although the final indicator was 20%, this reduction represented a significant improvement in worker safety. According to Medina et al. [8], it is essential to conduct a thorough analysis of the company's activities and processes to identify the most critical issues and risks. This study presents similarities in the hazards identified, such as mechanical, chemical, physical and locational risks, and in the control measures implemented, such as the registered use of PPE and preventive maintenance of equipment, both of which are essential to mitigate risks. On the other hand, Díaz et al. [13] emphasize that continuous monitoring of the HIRARC matrix, which is periodically updated, makes it possible to evaluate the progress made in risk management in the face of new hazards or changes in the work environment. Moreover, they point out that the HIRARC matrix helps in decreasing accident-related costs, producing monthly advantages, and enhancing safety and operational effectiveness from an economic standpoint.

In relation to the OWAS method, the starting incidence of musculoskeletal injuries stood at 26.67% (with 4 out of 15 workers affected). After implementing quarterly training sessions, providing lumbar belts, knee pads, and ergonomic information material, the percentage decreased to 13.33%. Even though the goal of 6.67% was not met, the progress made still benefited occupational health. Zhang and Lin [14] highlight that the OWAS technique helps pinpoint risky postures, enabling the prioritization of preventive actions and the preservation of productivity while safeguarding workers' health. Yan et al. [10] suggests adding more protective gear to improve postures and reduce negative impacts on employees.

Fig. 24 shows the indicators used by each improvement tool, which have been obtained through their respective implementation. It also displays the status of traffic lights for every indicator based on critical, risky, and acceptable levels, along with the present value (As Is), projected value (To Be), and real value (Achieved).

Tool	Indicator	Traffic lights			As Is	To Be	Achieved
		Critic	Risky	Acceptable			
PHA	Enablement Index (EI)	= 0%	> 0% - 100% <	= 100%	50%	100%	100%
HIRARC	Incidence rate (TRIFR)	> 45%	> 45% - 10% <	< 10%	46.67%	6.67%	20.00%
OWAS	Musculoskeletal injury rate (MSIR)	> 45%	> 45% - 10% <	< 10%	26.67%	6.67%	13.33%
OWAS	Number of workers' complaints about physical pain at work (NQ)	> 50%	> 50% - 15% <	< 15%	33.33%	13.33%	20%

Fig. 24 Traffic Light System for Improvement Indicators

VI. Conclusions

In general terms, the application of the tools PHA, HIRARC matrix and the OWAS method in the construction of concrete elements allowed the identification and analysis of the main ergonomic risks, where it became evident that most of the tasks present risks derived from long-term musculoskeletal injuries, due to forced and repetitive postures, load handling, lack of personal protective equipment, especially in the formwork stage. The suggestions from this evaluation emphasize the significance of integrating ergonomic clothing and training initiatives to minimize risk exposure, improve safety, and enhance worker well-being in the construction industry.

Based on these suggestions, a new occupational health and safety model was created and put into practice, with enhancements proven effective within six months, leading to a 13.33% decrease in musculoskeletal injuries and a 26.67% decrease in occupational incidents. Similarly, these measures enabled the attainment of 100% of the necessary yearly training and a decrease in employee grievances regarding physical discomfort by 13.33%. Even though the indicators did not decrease as much as expected, the measures put in place still had a significant positive impact on occupational health and safety, showing that they were effective.

The economic assessment confirmed the financial feasibility of the project, with profitability indicators revealing a return of USD 15.11 for every dollar invested, a favorable NPV, an IRR above the COK, and a relatively short payback period, all of which underscore the economic viability of the proposed initiatives.

References

[1] Cámara Peruana de la Construcción. (2024). *El Informe Económico de la Construcción - IEC, marzo 2024: Construcción sigue al alza en febrero, pero debilidad institucional afectaría inversiones en 2024*. https://iec.capeco.org/ediciones/

[2] Cámara Peruana de la Construcción. (2023). *El Informe Económico de la Construcción - IEC, diciembre 2023: El 2024 será un año retador para la construcción (y para el Perú)*. https://iec.capeco.org/ediciones/

[3] Ministerio de Trabajo y Promoción del Empleo. (2024, 13 de abril). *Notificaciones de accidentes de trabajo, incidentes peligrosos y enfermedades ocupacionales - Febrero 2024.* https://www.gob.pe/institucion/mtpe/informes-publicaciones/5334571-notificaciones-de-accidentes-de-trabajo-incidentes-peligrosos-y-enfermedades-ocupacionales-febrero-2024

[4] Seo, H., Pham, H.T.T.L., Golabchi, A., Seo J., & Han, S. (2023). A case study of motion data-driven biomechanical assessment for identifying and evaluating ergonomic interventions in reinforced-concrete work. *Developments in the Built Environment*, 16, 1-19. https://doi-org.ezproxy.ulima.edu.pe/10.1016/j.dibe.2023.100236

[5] Yang, K., Ahn, C. R., & Kim, H. (2020). Deep learning-based classification of work-related physical load levels in construction. *Advanced Engineering Informatics*, 45, 101104. https://doi.org/10.1016/j.aei.2020.101104

[6] Hajaghazadeh, M., Marvi-Milan, H., Khalkhali, H., & Mohebbi, I. (2019). Assessing the ergonomic exposure for construction workers during construction of residential buildings. *Work (Reading, Mass.)*, 62(3), 411-419. https://doi.org/10.3233/WOR-192876

[7] Cuba, A. (2015). Sistema integrado para empresas de construcción en Cusco. *Observatorio Medioambiental*, 18, 41-56. https://doi.org/10.5209/rev_OBMD.2015.v18.51358

[8] Medina Escudero, A. M., Chon Torres, E. W., & Sánchez Condori, S. (2016). Identificación de Peligros y Evaluación y Control de Riesgos (IPERC) en la miniplanta de hilandería y tejeduría de la Facultad de Ingeniería Industrial - UNMSM. Industrial Data, 19(1), 109-116. https://www.redalyc.org/articulo.oa?id=81650062013

[9] Miñan, G., Monja, J., Gonzales, O., Simpalo, W. & Castillo, W. (2020). Gestión de riesgos implementando la ley peruana 29783 en una empresa pesquera. Ingeniería Industrial, 41(3). https://dialnet.unirioja.es/servlet/articulo?codigo=7674012

[10] Yan, X., Li, H., Zhang, H., & Rose, T. M. (2018). Personalized method for self-management of trunk postural ergonomic hazards in construction rebar ironwork. *Advanced Engineering Informatics*, 37, 31-41. https://doi.org/10.1016/j.aei.2018.04.013

[11] Breznik, M. & Vujıca Herzog, N. (2021). Ergonomic design of the workplace for final quality control. *Ergonomi*, 4 (1), 1-9. https://doi.org/10.33439/ergonomi.887250

[12] Herrera, M. A., Severino Luna, A., Augusto da Costa, A. C., & Monte Blanco Lemes, E. (2018). Risk Analysis: A generalized Hazop methodology state-of-the-art, applications, and perspective in the process industry. Vigilância Sanitária em Debate: Sociedade, Ciência & Tecnologia, 6(2), 106-121. https://doi.org/10.22239/2317-269X.00990

[13] Díaz Díaz, M. A., Rabanal-Chavez, E. H., Rocca Musse, M., & Zapata Rodriguez, M. D. (2023). Diseño ABC, Control de inventario, Matriz IPERC, Método DMAIC y Método CPM para reducir costos en una empresa manufacturera de artículos de higiene. *Proceedings of the 3rd LACCEI International Multiconference on Entrepreneurship, Innovation and Regional Development (LEIRD 2023): "Igniting the Spark of Innovation: Emerging Trends, Disruptive Technologies, and Innovative Models for Business Success"*. https://www-scopus-com.ezproxy.ulima.edu.pe/record/display.uri?eid=2-s2.0-85187303032&origin=resultslist&sort=plf-f&src=s&sid=91b7a0dcafef44abffdf09e36b427f63&sot=b&sdt=b&s=TITLE-ABS-KEY%28matriz+iperc%29&sl=27&sessionSearchId=91b7a0dcafef44abffdf09e36b427f63&relpos=0

[14] Zhang, H., & Lin, Y. (2022). Prediction of ergonomic risks and impacts on construction schedule through agent-based simulation. *Journal of Construction Engineering and Management*, 149(3). https://dx.doi.org/10.1061/(asce)co.1943-7862.0002437