ISBN: 978-628-96613-1-6. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2025.1.1.1838

Ergonomic Risk Management Model using Rula, Niosh and Ocra Techniques in a metalworking SME

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***Abstract*– In the metal-mechanical sector, where activities such as the assembly and construction of metal structures with large machinery are carried out, workers are exposed to various risk factors that can generate serious consequences if not properly controlled and managed. The objective of this research is to determine occupational risk prevention techniques that can significantly improve the performance and efficiency of processes in the metalworking industry. Four phases were developed, the first presents the diagnosis that considers the initial proposal, followed by the action plan together with the redesign of the process, the third shows the implementation where the improvement is presented, and the last one corresponds to the validation. After the implementation of the pilot plans and the simulation performed with Arena, we obtained an increase of 32.64% on productive efficiency.**

***Keywords*-- Ergonomic techniques, Risk prevention techniques, Metalworking sector**

I. INTRODUCTION

The metalworking industry is central to various economic activities, such as heavy machinery and manufacturing. Being highly dependent on transformation processes, it constantly faces challenges in operational efficiency and ergonomic risk management [1]. From the manufacture of precision metal parts to complex assemblies, through processes such as turning, milling and welding, its role in the supply chain is crucial, as it provides key inputs for infrastructure, transport and industrial equipment, driving the technological development of economies. Occupational safety and health must establish an environment that ensures proper management of occupational risks, promoting an effective preventive culture.

This implies that the different responsible sectors must be able to design a plan as well as supervise occupational safety and health measures. According to INEI (), the manufacture of metal products accounts for almost 50% of manufacturing GDP. In 2015, the metal-mechanic industry accounted for 15.56% of this manufacturing GDP. Law N° 29783, Law on Occupational Safety and Health, aims to promote the prevention of occupational risks. In this sector, SMEs represent only 9.6% of the total number of enterprises, amounting to about 14,070.

The motivation for this study stems from the high incidence of musculoskeletal disorders (MSDs) and productivity losses in metalworking SMEs. Although individual techniques such as RULA, NIOSH and OCRA have been shown to be effective in isolated cases, few studies have combined these methodologies into an integrated model. In addition, emerging technologies such as virtual reality have shown potential to strengthen safety and training in industrial settings, including forklift operation and accident prevention [2]. This article addresses that gap by posing the following question: How can a combined ergonomic risk assessment approach improve both health and operational efficiency in metalworking processes? Each method targets a different type of ergonomic exposure-posture, lifting and repetition-allowing for a more complete risk diagnosis when employed together (INSST, 2019)[3].

II. STATE OF THE ART

A. Production Models to Increase Efficiency in the Metalworking Sector

Efficiency is a key factor for the success of an industry. According to studies, the improvement in efficiency depends on the optimization of production processes, which allows the identification of bottlenecks in production lines, the reduction of cycle times and the use of resources through tools such as 5S. In addition, the use of simulations facilitates the improvement of processes through TPM, 5S and the standardization of activities. Other important elements include the reduction of defective parts through the application of these standardized tools.

B. Lean Manufacturing in the Metalworking Sector

Lean tools help to establish stable production standardized and efficient methods. Reductions in production times and defects of between 20 and 30% have been observed. Waste reduction and process optimization are also beneficial when using Lean tools such as 5S and TPM. Research highlights the positive impact of tools such as SMED and process standardization, managing time and reducing errors by 15-25%; in addition, an improvement in efficiency of between 10 and 15% has been achieved, with increases of up to 10-20% in some cases.

C. Ergonomics and Occupational Health in the Metalworking Sector

One of the most relevant effects of ergonomic risks on work performance is the increase in musculoskeletal injuries and disorders. These conditions are caused by inadequate postures, repetitive movements, excessive physical effort and lack of adequate rest. This research is based on a qualitative and descriptive bibliographic review that collects information from various scientific sources. The objective of the study is to analyze the impact of ergonomic risks on work performance, addressing the problem through training workshops, active breaks and the use of personal protective equipment [4]. Additionally, occupational health education initiatives have been shown to contribute to greater awareness and adoption of preventive behaviors in industrial environments [5].

D. 5S Methodology in the Metalworking Sector

The 5S methodology consists of classifying items, organizing daily-use tools for easy access, keeping the workspace clean, and standardizing procedures to ensure compliance and maintenance. This tool benefits SMEs by reducing manufacturing costs and improving efficiency. Case studies show that the application of 5S and 5W2H saved 3 hours per week per operator, which meant a gain of 15% of available time per week. In a case developed in Peru, the implementation of 5S and TPM resulted in a reduction in machine downtime and a significant increase in production efficiency [6].

E. TPM in the Metalworking Sector

The implementation of the TPM (Total Productive Maintenance) system in the metalworking sector helps reduce downtime, lower operating costs and improve the quality of the final product. By ensuring the efficient operation of the equipment, productivity is improved, since the machines remain available and in optimal conditions to meet the production demand without interruptions. Studies have shown that companies that adopt TPM achieve significant improvements in their performance, with increases in equipment availability that can range from 10% to 30% [7].

D. Single-Minute Exchange of Die (SMED) in the Metallurgical Industry

It is a methodology focused on reducing tool change times and machine configurations, allowing metalworking companies to improve their flexibility and operational efficiency. The implementation of SMED in the metalworking industry reduces changing times, which decreases production costs and improves the ability to respond to customer demand. By reducing change times by 50% or more, companies achieve an increase in effective production and improve the efficiency of production lines [8].

III. CONTRIBUTIONS

A. Model Justification

The analysis of workstations in the industrial sector revealed a significant lack of ergonomics in various manufacturing companies, resulting in decreased efficiency and increased occupational risks. This situation adversely affects work quality, worker health, and competitiveness. To address these issues, we aimed to implement tools and methodologies that improve working conditions. Ergonomic assessment tools like RULA, NIOSH, and OCRA were identified as crucial for evaluating and enhancing physical workload at workstations. By optimizing workstation design, training workers in ergonomic techniques, and establishing active breaks, we achieved significant improvements, reducing risk levels from critical to normal. Additionally, further exploration of the benefits and synergies from combining ergonomic tools with other organizational improvement methodologies remains a priority.

The selection of RULA, NIOSH, and OCRA was grounded on the nature of the tasks observed. RULA was selected to assess awkward postures during prolonged machining in the milling station. NIOSH was applied to quantify risks from manual handling and lifting of metal tubes in the turning station, where the load exceeded 27.5 kg. The NIOSH lifting equation was used to assess physical load during manual handling tasks. This method allows for the calculation of a lifting index based on factors such as weight, posture, and frequency. According to the Ministry of Labor, Employment and Social Security of Argentina, the use of this method is crucial in evaluating and mitigating risks associated with manual load handling [9]. OCRA was used in the pressing station, which involves repetitive actions such as 25 steel cuts per minute. To evaluate the risk of repetitive movements, the OCRA checklist was applied, which considers frequency, force, posture, recovery time, and additional risk factors. The Ministry of Labor, Employment and Social Security also highlights the relevance of this method in industrial settings to prevent upper limb disorders [10]. By addressing posture, force, and repetition, the combination of these techniques allowed for a multidimensional ergonomic diagnosis tailored to each workstation's specific risks.

As shown in Fig 1, the proposed ergonomic risk management model integrating RULA, NIOSH, and OCRA techniques through a 5W+2H-based continuous improvement cycle, aimed at enhancing productivity and occupational health in metalworking SMEs.

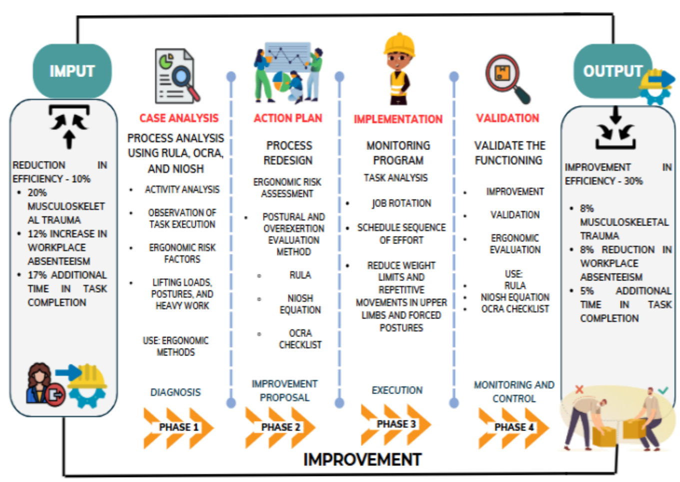

Fig. 1 Proposel Model

The use of tools like RULA, NIOSH, and OCRA, combined with workstation design, reduces ergonomic risks and improves occupational health. An innovative model for small and medium-sized Peruvian metalworking companies integrates ergonomic evaluation through a structured implementation plan based on the 5W+2H methodology [11].

This covers ergonomic evaluations, intervention design, and workstation improvements, establishing a continuous improvement system to assess productivity and worker health via KPIs. The approach optimizes production management and fosters the sustainable growth of SMEs in the metalworking sector.

C. Model Components

Component 1: Problem Analysis. A visit was made to the plant to understand the processes, and the lack of ergonomics was identified as a significant issue. This facilitated the formulation of relevant indicators for the analysis. A root cause analysis was conducted to determine the underlying problems, serving as the basis for creating a case study that suggests instruments for the ergonomic improvement model.

Component 2: Intervention. An initial diagnosis was conducted to assess the levels of ergonomic risk, revealing that all three workstations indicated high risk levels, necessitating urgent intervention. In response, ergonomic improvements were proposed for each station, including training in proper lifting techniques and the use of safety equipment. These interventions were simulated using the software "Ergoniza" due to the high budget required for physical implementation. The first step involves redesigning the workstations to enhance operator mobility and improve the flow of materials throughout the plant, aiming to minimize travel distances and promote seamless transitions between work areas. Additionally, standardizing processes will be emphasized to establish consistent methods for regulating production times and ensuring the efficient use of available materials, thereby reducing waste and shrinkage.

Component 3: Control. In this phase, a pilot test was conducted to obtain values that closely reflect real conditions, addressing the limitation of implementation. The Arena software was utilized to simulate the machining processes, focusing on reducing cycle times and minimizing waste levels. The indicators calculated during this simulation were then compared to the initial values to assess the effectiveness of our ergonomic improvement proposal. Additionally, an economic savings analysis was performed to estimate the financial benefits the company would generate from implementing these enhancements.

Component 4: Following the recommendations of ergonomics specialists, it is essential to reassess the task results using the newly obtained data and applying them to the same methods previously employed. This process will ensure the effectiveness of the proposed improvements and allow for necessary adjustments to optimize performance. The expected outcomes include increased productivity, reduced worker absenteeism, and a decrease in the development of Musculoskeletal Disorders.

As summarized in Table I, the study defines key performance indicators (KPIs), including their definitions and formulas for measuring efficiency, downtime, waste, absenteeism, musculoskeletal disorders, and cycle time.

TABLE I. INDICATORS

Indicators	Formula	Use
Efficiency	Actual Production / Planned Production	Measures the capability of a process or machine to achieve its planned output or utilize its available time effectively.
Downtime rate	Downtime/ Total Machining Time) ×100%	Enhance productivity by minimizing idle times in production.
Waste rate	(Kg of Waste/Total Amount of Material Used) ×100%	Calculates the percentageof materials that are lost during the production of a batch of products.
Absenteeism Rate	(Number of absence days/ Total number of working days) ×100%	Measures employee absence to assess workforce availability and its impact on productivity.
MSD	(Number of MSD cases / Total number of employees) ×100%	Track musculoskeletal disorder cases to evaluate workplace ergonomics and employee health.
Cycle Time	Total Production Time / Number of Units Produced	Monitors production efficiency by measuring the time required to complete one unit.

IV. VALIDATION

A. Initial Diagnosis

In the metalworking plant, it was found that in the milling station, the RULA method yielded a score of 8, indicating a high risk that requires immediate intervention to prevent musculoskeletal disorders due to loads exceeding 10 kg. In the pressing station, the OCRA Check List resulted in an index of 33.76, which is considered unacceptably high, suggesting the need to improve the workstation design and provide training for the operators. In the lathe station, the NIOSH method calculated a lifting index (LI) of 3.79, indicating that the current lifting conditions are hazardous and must be modified to avoid health issues among workers. These results highlight the urgency of implementing ergonomic improvements across all workstations.

Maintaining a constant focus on ergonomics and continuous improvement is essential to ensure safe and healthy work environments in the long term. Below are tables with the detailed results obtained during the experimentation process, including the initial data, the results after applying improvements, and the percentage of improvement achieved. First, an initial diagnosis was carried out using the RULA, NIOSH and OCRA methods to assess ergonomic risks. Subsequently, improvements were proposed and evaluated and compared using the Ergoniza software. Where it has been proven that the implementation of ergonomic solutions in machining stations has proven to be effective in reducing ergonomic risks and increasing efficiency by 30%.

These results were achieved by optimizing tools, adjusting postures, and redesigning the workspace, which has significantly contributed to improving occupational health and safety, as well as increasing operational efficiency. With the simulation of our improvement in Ergoniza, a 28% reduction in effort during lifting is expected compared to the effort before the improvement in the lathe station. Likewise, a 17% reduction in downtime due to fatigue is projected in the pressing station and a 68% reduction in waste.

As shown in Table II, ergonomic improvements at the milling station, evaluated using the RULA method, resulted in significant postural improvements and reduced physical strain.

TABLE II. PRESENTATION OF IMPROVEMENT WITH THE RULA METHOD AT THE MILLING STATION

Indicator	Before	After	Improvement
GROUP A: Upper extremities	Arm: 21-45° flexion, >20° extension Forearm: <60° or >100° flexion Wrist: 0-15° flexion/extension	Arm: 20° flexion/extension Forearm: 60-100° flexion Wrist: flexed/extended >15°	Adjust press height, ergonomic tools to reduce strain.
GROUP B: Lower extremities	Neck: 11-20° flexion Trunk: 0-20° flexion Legs: standing, weight distributed evenly	Neck: 0-10° flexion Trunk: seated, hip angle >90° Legs: supported while seated	Adjust height, ensure neutral neck position, proper trunk support.
FORCES	Static activity, repetitive, 2-10 kg load	Dynamic activity, brief, <2 kg load	Tools to reduce force, task rotation, rest.

As summarized in Table III, the OCRA Checklist evaluation highlights ergonomic risk factor improvements at the pressing station.

TABLE III. PRESENTATION OF IMPROVEMENT WITH THE OCRA CHECKLIST METHOD AT THE PRESSING STATION

Factor	Before	After	Improvement
FR: Recovery Factor	FR: 4	FR: 2	Increased recovery time.
FF: Frequency Factor	FF: 2.5	FF: 1	Adjustable equipment to minimize reaching/stretching.
FFz: Strength of the arms or hands during the cycle.	FFz: 8	FFz: 2	Added levers/actuators to reduce force.
FP: Postures and Movements Factor	FP: 15	FP: 2	Redesigned flow, reduced shoulder/elbow stress.
FC: Additional Risk Factor	FC: 7	FC: 3	Protective gloves, reduced machine vibration.
ICKL: Working Conditions and Light Workload Index	$ICKL$: 33.76	ICKL: 6.25	Risk reduced by 27.51 points, now acceptable.

As evidenced in Table IV, improvements at the lathe station significantly reduced the lifting risk according to the NIOSH method.

TABLE IV. PRESENTATION OF IMPROVEMENT WITH THE NIOSH METHOD AT THE LATHE STATION

Multiplier	Before	After	Improvement
LC: Recommended weight for lifting	23 kg	23 kg	LC is a constant in both scenarios.
HM: Horizontal Distance	HM = 25/28 = 0.89	HM = 25/25 = 1	Use sliding carts to bring steel tubes closer to the operator, reducing reach distance
VM: Vertical Distance Factor	VM = 0.865	VM = 1	Position pipes at a height of 75 cm using adjustable platforms.
DM: Vertical Distance Factor	DM = 0.756	DM = 1	Minimize vertical lifting by raising pipes to an intermediate height before the final lift.
AM: Symmetry Factor	AM = 0.9264	AM = 0.97	Use sliding carts to transport steel pipes, reducing asymmetry
FM: Frequency Factor	FM = 0.65	FM = 0.97	Incorporate breaks and distribute lifting tasks.
RWL: Recommended Weight Limit	RWL = 7.25	RWL = 21.64	Improved factors allow for greater weightlifting capacity
LI: Lifting Risk	LI = 3.79	LI = 1.27	Reduced lifting risk by 2.98

B. Design of the Validation and Comparison with the Initial Diagnosis

The model validation design was structured around three main stages. In the first stage, the root causes of the Peruvian company's low productivity in machining operations were identified by developing a problem tree. It was found that 43% of the issue was attributed to high average times for manual loading tasks at the lathe station, 36% to excessive idle times in the machining processes, and 21% to a high level of scrap in the milling operations.

As illustrated in Fig 2, the problem tree outlines the main factors contributing to low productivity (60%) in the machining operations of a metalworking SME. It identifies three root causes, each linked to a specific ergonomic risk, along with the corresponding improvement action and solution technique applied.

Root Cause 1:
High manual loading times at the lathe station were identified as a critical factor affecting efficiency. Workers had to manually handle steel tubes weighing approximately 27.5 kg, leading to excessive physical strain.

- Improvement Action: Redesign the workstation layout and introduce ergonomic aids to minimize manual lifting distances.
- Solution Technique: Application of the NIOSH Lifting Equation method to assess and reduce lifting risks, which resulted in a Lifting Index (LI) of 3.79, classified as high risk.

Root Cause 2:
An elevated scrap rate was observed at the pressing station, mainly due to repetitive movements and improper postures during operations. These conditions increased the likelihood of musculoskeletal disorders and reduced product quality.

- Improvement Action: Redesign work methods, provide ergonomic supports, and incorporate rest breaks to mitigate repetitive strain.
- Solution Technique: Application of the OCRA Checklist to evaluate and control repetitive movement risks, obtaining an initial OCRA score of 33.76, considered unacceptably high.

Root Cause 3:
Significant downtime at the milling station was linked to operator fatigue caused by prolonged static postures and poor workstation ergonomics. This not only reduced productive time but also increased health risks.

- Improvement Action: Ergonomically redesign the milling station to encourage dynamic postures and provide support elements like adjustable seating and footrests.
- Solution Technique: Use of the RULA (Rapid Upper Limb Assessment) method to evaluate and improve postural risks, resulting in an initial RULA score of 5, indicating a high risk that necessitated immediate intervention.

Based on these analyses, improvement actions were proposed to reduce ergonomic risks. Impacts identified include a 10% reduction in efficiency, an 8% increase in musculoskeletal disorders, and a 12% increase in absenteeism.

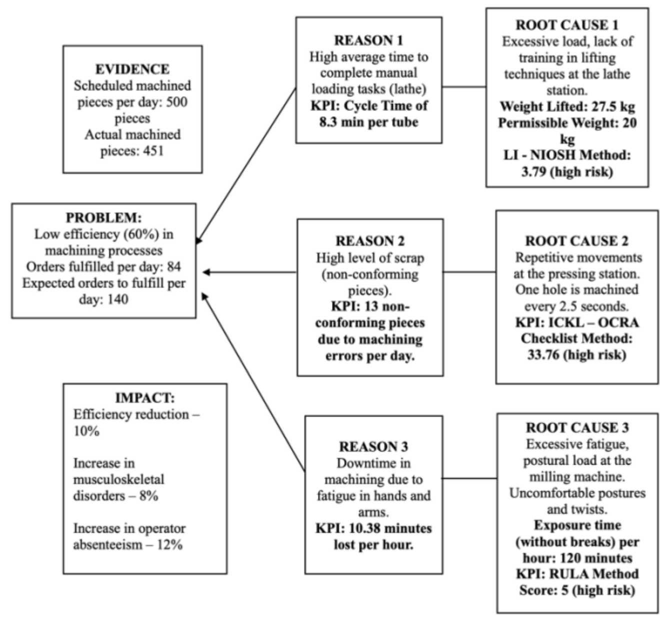

Fig. 2 Problem Tree

In the second stage, ergonomic tools were selected, and their applications defined. The pilot plan began with the design of ergonomic solutions for each identified problem area. First, we implemented improvements in manual load handling at the lathe station by evaluating lifting tasks with the NIOSH method and designing ergonomic aids accordingly. Second, to address idle times, we developed a workflow adjustment strategy, including job rotation and rest breaks, guided by the RULA assessment to optimize worker postures and reduce fatigue. Lastly, to reduce scrap levels in milling, we applied the OCRA checklist to assess repetitive motion risks and implemented process adjustments.

As depicted in Fig 3, the ergonomic design of the turning station details dimensions and equipment positioning to reduce operator fatigue and promote neutral postures.

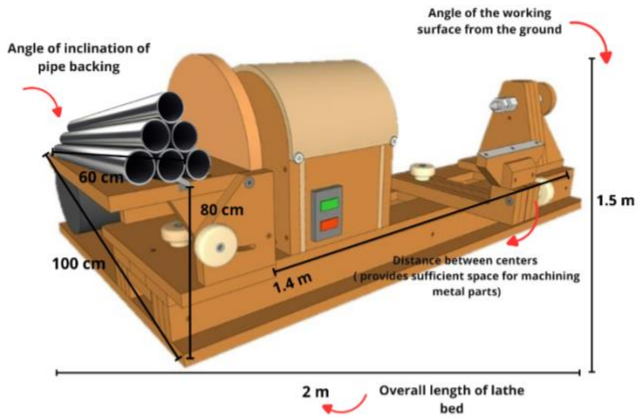

Fig. 3 Dimensions of the Turning Station

The Industrial Standing Parallel Lathe is designed with ergonomics in mind to reduce fatigue and ensure comfort. Key features include a lathe bed and work surface set at 90-150 cm (35-54 inches), aligned at elbow height for a neutral arm position. Controls are positioned at or just below elbow height for easy access, while measuring tools and inspection stations are positioned at this working height for seamless task transitions. Three feet of clearance around the lathe allows for free movement, and an optional 10-20 cm footrest provides posture variation. Adequate lighting at 150-180 cm ensures visibility during operation.

As detailed in Fig 4, the ergonomic design recommendations for the milling station include adjustable workbench heights, optimized control placement, and supportive seating to minimize strain.

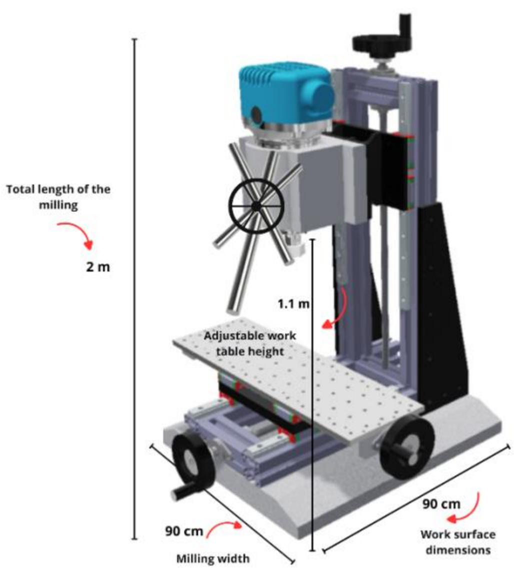

Fig. 4 Dimensions of the Milling Station

The work bench should be adjustable to heights between 700 mm and 1100 mm to accommodate different heights and tasks, and to promote a comfortable posture. Controls should be at an accessible height (600-1200 mm) to reduce forced movements. Rotating tables and adjustable workpiece holders allow easy access to all parts, minimizing arm and back movement. Ergonomic chairs with lumbar support and an adjustable footrest are recommended to change posture and reduce fatigue. Lighting should be appropriate, preferably cold LED (4000-6000K), to improve visibility and concentration. In addition, vibration dampening systems and soundproofing will help reduce fatigue. For CNC systems, milling machines with large screens and intuitive interfaces, placed between 1.4 and 1.6 meters high, make the work easier. Finally, tools should be at waist level, with shelves, hooks and sliding trays to reduce unnecessary effort.

As presented in Fig 5, the ergonomic layout of the mechanical pressing station ensures safe control accessibility, proper operator reach distances, and posture support features to reduce musculoskeletal risk.

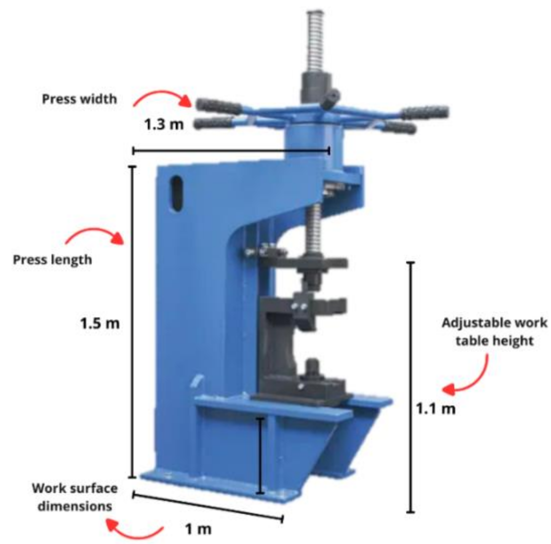

Fig. 5 Dimensions of the Pressing Station

An ergonomic mechanical press should have several features to ensure operator comfort and safety. The bench height should be adjustable, typically between 75 cm and 110 cm, to allow for both standing and sitting work. The work area should be large, approximately 50 cm x 50 cm, or up to 1 m x 1 m for larger presses. Accessibility is key, with a maximum reach of 50 cm from the operator's position to avoid uncomfortable movements. Press force varies, with smaller presses ranging from 10 to 200 tons and larger presses exceeding 500 tons. Ergonomic controls, such as buttons and pedals, should minimize repetitive strain and be easily accessible without excessive force. Transparent guards are essential for safety without obstructing visibility. When seated, ergonomic chairs with lumbar support are necessary to promote healthy posture and reduce back fatigue. Proper, adjustable lighting is critical to reducing eye strain and improving task accuracy. Finally, tools and materials should be within easy reach to streamline workflow and reduce unnecessary movement.

Then, in the final stage, a pilot test was conducted where a simulation of the proposed improvements was carried out. During this test, operators were trained on proper ergonomic postures, appropriate handling techniques, and the use of safety and protective equipment. This pilot simulation allowed us to observe the potential impact of the improvements, focusing on reducing manual load times, minimizing idle times, and lowering scrap levels in the machining operations. With the data obtained from our pilot test and supported by the research of Sendra et al. (2010) [12], we simulated the proposed improvements in Arena to assess the economic impact. This comprehensive approach facilitated the validation of the enhancements, demonstrating measurable improvements in productivity and quality across each of the identified problem areas.

C. *Simulation Improvement Proposal*

For the simulation, they chose to model the three processes under analysis: turning, milling, and pressing, from the arrival of the tubes to be machined until their final output. Among the activities that consumed a significant portion of productive time were the lifting of loads and downtime caused by fatigue or exhaustion. Additionally, it was observed that in the pressing station, there was a high number of defective pieces due to a lack of ergonomic adaptation. For our simulation, we utilized the data on time reductions and defective pieces obtained from the pilot test. To achieve this, we require Arena simulation software, version 16.2. The Input Analyzer program was used to evaluate the data from 30 observations and determine the appropriate distribution fit for each activity's model. We considered 30 replicates for the data sample calculation, with a confidence level of 90% and a margin of error of 10%. An ideal size of 87 replicates was found, with a confidence range, using the current mean width value of 1.72 displays the findings from the simulation and the pilot plan that was carried out [13].

As shown in Fig 6, the Arena simulation model of the milling process reflects workflow optimization and cycle time reduction after ergonomic improvements.

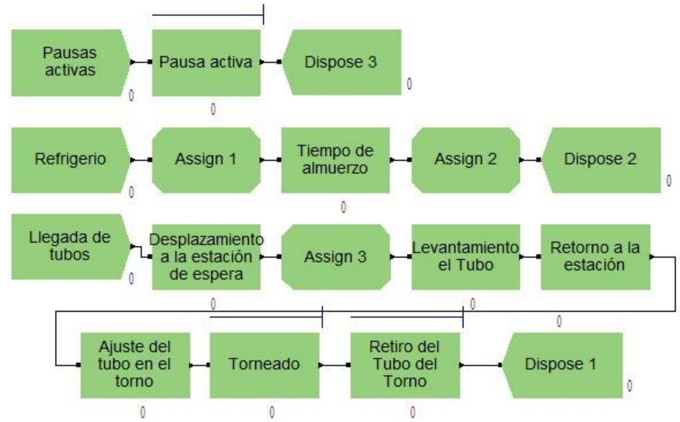

Fig. 6 Simulation Model of the milling process in Arena

As observed in Fig 7, the Arena simulation model of the turning process highlights the workflow changes and ergonomic improvements made after implementing interventions.

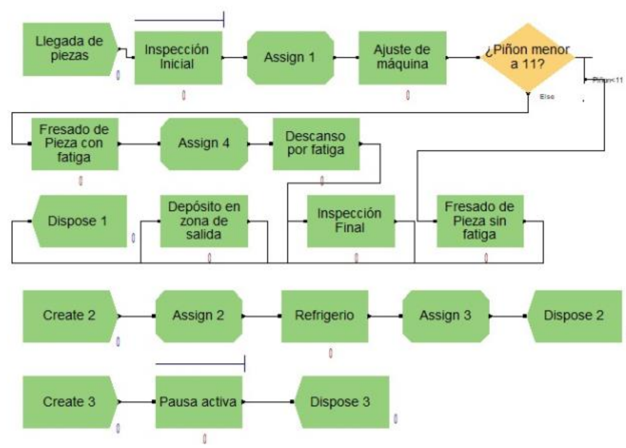

Fig. 7 Simulation Model of the turning process in Arena

As displayed in Fig 8, the Arena simulation model of the pressing process shows improved material flow and a reduction in defective outputs.

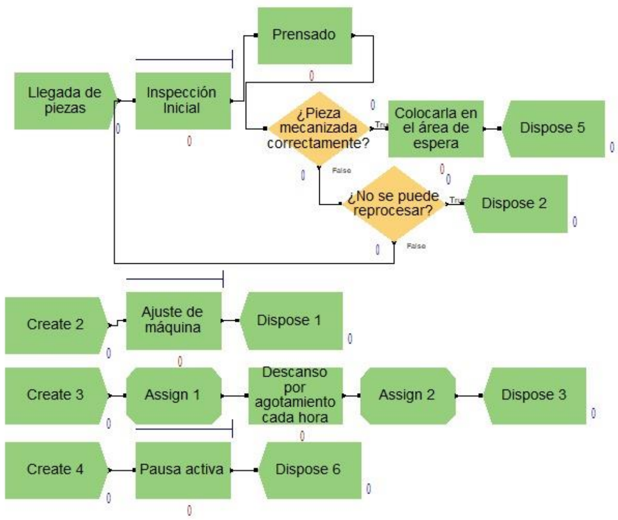

Fig. 8 Simulation Model of the pressing process in Arena

The values obtained from our pilot test were compared with the article by Sendra et al. (2010) [12] as a reference. This allowed us to validate that our simulation closely approximates reality, ensuring that the percentages of time reduction and waste reduction are accurate. To conduct the analysis of the results, it was essential to document the values of the current model and compare them with the outcomes obtained after implementing the proposed improvement, which was based on the tools utilized in its development.

As detailed in Table V, the comparative analysis shows notable improvements in productivity indicators such as manual loading time, defective pieces, and downtime across the three stations.

TABLE V. COMPARATIVE TABLE OF INDICATORS PER STATION

Stations	Initial Value	Final Value	Improvement
Turning Station (Manual loading)	1.78 minutes	1.21 minutes	32.09%
Turning Station (batches milled per day)	10 batches	12 batches	20%
Pressing Station (defective pieces per day)	33 pieces	28 pieces	15.12%
Pressing Station (pressed pieces per hour)	128 pieces	151 pieces	18%
Milling Station (downtime)	4.836 minutes	1.750 minutes	63.81%
Milling Station (machines pieces per hour)	25 pieces	32 pieces	28%

The selected workstations for our improvement proposal represent 51% of the company's entire manufacturing process, highlighting their importance and the potential impact of the modifications. The improvement at the Lathe station will contribute 7.8% to the company's efficiency, the Pressing station will add 4.64%, and the Milling station will account for 20.20%. Overall, our improvement proposal has a total impact of 32.64% on the company's productive efficiency.

These findings align with previous studies that highlight the importance of ergonomic design in improving manufacturing performance. For instance, Lara et al. (2022) [14] reported a 11% increase in productivity after ergonomic intervention. Our model yielded a 32.64% improvement, validating the benefits of integrating RULA, NIOSH, and OCRA simultaneously. Likewise, Saldaña et al. [13] reported similar benefits by integrating ergonomic techniques with lean tools, further supporting the effectiveness of this methodological synergy in manufacturing environments.

Moreover, by simulating work processes using Arena software, we observed reductions in lifting strain (NIOSH), improved postural scores (RULA), and decreased repetition index (OCRA), confirming the holistic effectiveness of our model. Future work could explore real-world implementation over extended periods and include ergonomic specialists for deeper validation.

Figures reveal that the major contributing components to the global burden of occupational disease are ergonomic risk and injury. In studies conducted by Vaquero et al. (2018) [15], NIOSH conducted a systematic review in which they concluded that there are several occupational factors associated with considerable physical strain. These factors include heavy tasks, heavy lifting, improper spinal postures, vibrations, repetitive movements and trunk twisting, all of which are supported by a variety of evidence [15].

Performing the respective study with these techniques within the production plant showed an intolerable final score of 7 in RULA, indicating the urgency to implement changes and carry out immediate interventions. The workload of the operators has been identified as high, which can result in musculoskeletal disorders and other health problems. In addition, the OCRA Check List index yielded an unacceptably high value of 33.76, underscoring the need to improve working conditions, provide staff training, and conduct medical evaluations and monitoring. Similarly, the NIOSH method revealed a lifting index above 3, confirming that load handling under current conditions could cause problems for most workers, and modifications are required.

As shown in Table VI, ergonomic improvements contributed substantially to the overall production efficiency across the turning, pressing, and milling stations.

TABLE VI. MANUFACTURING PERCENTAGES BY STATION

Stations	Percentages	Improvement	Percentage improvement
Turning Station	15%	52.02%	7.8%
Pressing Station	14%	33.12%	4.64%
Milling Station	22%	91.81%	20.20%
Total	51%	176.95%	32.64%

The selected workstations for our improvement proposal represent 51% of the company's total manufacturing process, highlighting their importance and the potential impact of the proposed modifications. The improvement implemented at the Lathe station will contribute 7.8% to the company's efficiency, while the Pressing station will add 4.64%, and the Milling station will account for 20.20%. Overall, our improvement proposal has a total impact of 32.64% on the company's production efficiency.

Regarding our research objectives, we achieved a 32.64% improvement in efficiency, surpassing our initial goal of 30%. For cycle time, we set a target improvement of 5% and achieved a 4.81% improvement in our proposal. This was made possible by the enhancements in lathe operation times, bringing us significantly closer to our proposed target.

For the idle time indicator, a 12% improvement was expected, but we exceeded this goal with a 14.04% improvement, attributed to the advancements at Milling station. Regarding the scrap rate, we aimed for a 2.7% improvement and achieved a remarkable 14.17% at the Pressing station.

Additionally, the simulation in Ergoniza reduced the risk level of all three workstations from high to acceptable. During our pilot test, we trained operators and applied our improvements in a simulated manner, achieving a 50% reduction in musculoskeletal discomfort reported in the field study. Finally, absenteeism decreased by 12% compared to 2023, exceeding the initial target.

V. DISCUSSION

The purpose of this improvement model is to increase productivity and efficiency in the metalworking industry by focusing on the ergonomic hazards associated with milling, pressing, and turning workstations. Using techniques such as RULA, NIOSH, and OCRA, the goal is to identify and mitigate factors that contribute to musculoskeletal injuries and reduced work performance. Complementary tools such as 5S and TPM facilitate workspace organization and preventive maintenance of equipment, resulting in a 50% reduction in injuries.

Results show that improving workplace ergonomics not only protects operator health but also increases operational efficiency by 53.76%. Employee surveys reflected increased job satisfaction, suggesting that a healthy work environment promotes team engagement and morale. Despite implementation challenges such as resistance to change, the model has proven effective in creating a safer and more productive environment.

Comparing our results to previous studies, we find that our findings are consistent with research indicating that ergonomic improvements positively impact both worker health and productivity. These findings align with recent NIOSH guidelines that emphasize proactive ergonomics programs as essential to preventing work-related musculoskeletal disorders and improving productivity [16]. For example, previous studies have shown that ergonomic interventions can lead to productivity increases of 10% to 30%, which is consistent with the 53.76% improvement reported in our study.

However, this study has limitations. It was conducted in a single metalworking SME, which may affect the generalizability of the results to other contexts or industries. In addition, model validation was based on pilot testing and Arena software simulations rather than full-scale implementation, which limits the applicability of the results to other industrial settings. Although the ergonomic assessments were methodologically valid, they were not conducted by certified professionals, which may have affected the accuracy of the conclusions. In addition, due to time and resource constraints, the improvements implemented were primarily low-cost adaptations that may not have addressed all potential ergonomic risks.

Therefore, future studies should expand the scope of the research to include multiple companies and industries and involve a wider range of operators and ergonomics specialists to validate the model more broadly. Conducting large-scale evaluations and involving certified ergonomics professionals could strengthen the findings and provide more robust results. In addition, conducting long-term follow-up studies on the impact of the interventions would provide more comprehensive data on their sustainability and effectiveness over time.

Practical recommendations derived from this study include the continuous integration of ergonomic assessments into work processes, training operators in safe practices, and the gradual implementation of ergonomic improvements to overcome resistance to change. It is also recommended to establish a continuous feedback process with workers to adjust interventions and ensure their long-term acceptance and effectiveness.

VI. CONCLUSION

In conclusion, the improvement of machining processes in the turning, milling, and pressing stations using the RULA, NIOSH, and OCRA methods to assess ergonomic risks and optimize working conditions. The analysis with RULA identified dangerous postures that increase the risk of injuries, while the NIOSH method helped establish safe limits for handling heavy materials, and OCRA evaluated the risk of musculoskeletal disorders due to task repetitiveness and duration.

The findings indicate that the proposed ergonomic improvements have led to a reduction in risk levels to acceptable standards across all stations. Specifically, the results showed that in the Turning Station, manual loading time was reduced from 1.78 minutes to 1.21 minutes, achieving an improvement in efficiency of 16.67%, with milled batches increasing from 10 to 12 per day. In the Pressing Station, the number of defective pieces decreased from 33 to 28 per day, resulting in an improvement of 15.23%, while the number of pressed pieces increased from 128 to 151 per hour. Lastly, Milling Station saw downtime reduced from 4.836 minutes per hour to 1.750 minutes per hour, reflecting an improvement in efficiency of 21.86%. These improvements not only reduced the risk of injuries but also enhanced overall productivity.

This study contributes to the field of occupational ergonomics by demonstrating the benefits of a multi-technique approach tailored to SMEs in high-risk industrial environments. By integrating RULA, NIOSH, and OCRA, the proposed model not only improves worker well-being but also increases efficiency and competitiveness. The results show that addressing ergonomic risks strategically can lead to measurable gains in both health and performance.

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