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Ergonomic Risk Reduction in Poultry SME Workstations: A Peruvian Case Study with a Lean-SLP Integrated Redesign Model

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Abstract

This study analyzes the redesign of workstations and the reconfiguration of the layout in a small poultry egg processing enterprise, aiming to increase productivity. It offers an innovative solution to the poultry industry's low technification and productivity issues created by poorly built workstations, which produce delays and inefficient work techniques that bottleneck core processes. The investigation involves four phases. This study's major analysis focused on the problem and its core causes, which helped complete the first step. Second stage involves workstation and method redesign. Thirdly, it aims to improve workstations and layout through the application of tools such as 5S, SLP, and Design Work. The final stage evaluates the solution's effects. The proposed model was simulated using Delmia V5 simulation software, and ergonomic evaluation methods like RULA, REBA and NIOSH, and schematic representation of working processes reduced ergonomic loads. The validation enhanced effort reduction by 22,088.1 Kg-m and expected savings of 10,557.37 PEN in the first year. This study focuses on productivity, extra operational motions, operator physical effort, and ergonomic considerations on work environments. This work provides a model that other poultry enterprises can simply adopt and serves as a foundation for future research.

Keywords
Ergonomics; Delmia V5; Poultry Industry, 5S Methodology, Systematic Layout Planning.

1. Introduction

The poultry industry in Peru is one of the largest economic sectors of the country because it greatly contributes to agricultural output and provides a critical source of protein. As the major product of the industry, eggs play an important role in the economy and dietary requirements of the country (MIDAGRI, 2023). However, the industry has low levels of industrialization, poor workstation configurations, and repetitive manual work, which in turn lowers productivity and increases ergonomic risks. All these results in operator fatigue, musculoskeletal disorders, and absenteeism. The combination of these issues greatly impairs operational and worker productivity.

To feasibly address the highlighted concerns, operators should be placed in well-designed workstations that reduce physical exertion while adopting ergonomic redesigns. Existing literature has shown that ergonomic assessment tools such as the Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), National Institute for Occupational Safety and Health (NIOSH) lifting equation effectively increase productivity when they are used in conjunction with other approaches such as Systematic Layout Planning (SLP) and 5S. These approaches detect and control ergonomic hazards and improve productivity of the workflow (Rawan et al. 2022; Iwakiri et al. 2024).

Previous research highlights successful applications of these tools in diverse industries. For instance, ergonomic interventions in the manufacturing sector have demonstrated significant reductions in postural strain and improvements in productivity (Diego-Mas J et al. 2015). Similarly, the integration of RULA and REBA in manual material handling processes has effectively minimized musculoskeletal risks, contributing to safer and more efficient work environments (Sarkar et al. 2016). In another study, combining SLP with ergonomic assessment tools yielded optimized layouts and reduced unnecessary movements, showcasing the potential for systemic improvements (Kawakami-Arevalo, S et al. 2023).

The reviewed literature reveals limited investigations focused on ergonomic risks in Peruvian poultry SMEs, particularly concerning repetitive and manual tasks. This gap highlights the necessity of adopting robust ergonomic interventions to improve worker safety and operational efficiency. Previous studies demonstrate the potential of ergonomic assessments to enhance productivity, yet there remains a lack of comprehensive models that integrate advanced simulation tools and systematic ergonomic evaluations tailored to the poultry sector (Rawan et al. 2022; Iwakiri et al. 2024).

This research contributes to the field by offering a validated ergonomic redesign model that emphasizes health and productivity. The incorporation of ergonomic interventions within Delmia V5 software simulation applications allow for the removal of excessive physical strain while improving overall efficiency of the task. The proposed model also facilitates practical managerial implications for SME managers within the poultry sector, considering the peculiarities of these operations and setting the basis for further research.

1.1 Objectives

The present investigation aims to design and validate an integrated ergonomic and layout redesign model for small and medium-sized enterprises (SMEs) in the poultry sector, oriented toward reducing ergonomic risks, improving operational productivity, and enhancing worker safety. The study focuses on the systematic redesign of workstations and material flows through the combined application of ergonomic assessment tools (RULA, REBA, and the NIOSH lifting equation), Lean methodologies (5S and Standard Work), and Systematic Layout Planning (SLP), supported by digital simulation using Delmia V5 software. Furthermore, the research evaluates the impact of the proposed redesign on key ergonomic and operational indicators, establishing direct comparisons between pre- and post-intervention conditions. Variables such as postural load, physical effort (expressed in kg-m), unnecessary movements, absenteeism rates, and productivity levels are analysed to quantify the effectiveness of the intervention. The study also includes an economic validation to assess the financial feasibility of the proposed improvements through indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and payback period. The objective of this analysis is to demonstrate the technical, ergonomic, and economic viability of an integrated redesign model tailored to poultry SMEs, providing a replicable and sustainable framework that can be adopted by similar enterprises seeking to reduce musculoskeletal risks while improving operational efficiency and competitiveness.

2. Literature Review

To lay the groundwork for this inquiry, a comprehensive search of modern literature was carried out with the primary goal of determining ergonomic risks and their causes, consequences, and mitigation efforts for poorly constructed workstations and inefficient working procedures in the poultry sector. The literature cites the growing incidence of work-related musculoskeletal disorders (WMSDs) as consequences of excessive physical activities, negligence of proper body postures, and monotonous work. These factors, especially in small and medium-sized enterprises (SMEs), are often responsible for high rates of absenteeism and low productivity (Sarkar et al. 2016; Iwakiri et al. 2024).

Some risk assessment and management tools, like the Rapid Upper Limb Assessment (RULA) , Rapid Entire Body Assessment (REBA), and National Institute for Occupational Safety and Health (NIOSH) lifting equation, are known to identify and quantify ergonomic risks. For example, postures or movements of a person during a repetitive task can be evaluated using RULA and REBA, and the NIOSH equation helps in determining the risks of manual material handling. These measures aid in systematic risk assessment and finding solutions to decrease work task-related ergonomic stresses and improve workplace ergonomic conditions (Rawan et al. 2022; Yazdanirad et al. 2022).

The workflow optimization and reduction of unnecessary movements can be achieved using methodologies like Systematic Layout Planning (SLP) or the 5S methodology. Studies show that integration of SLP with ergonomic design helps in achieving greater operational productivity while reducing postural risk. For instance, one case of using SLP in a food processing plant demonstrated a reduction of ergonomic load while improving the overall workflow efficiency, which exemplifies the benefits of using ergonomic and layout design tools in tandem (Kawakami-Arevalo, S. et al. 2023; Widodo, L et al. 2020).

Furthermore, some ergonomic redesign activities include incorporating adjustable workstations, assistive devices like hydraulic tables and even changing the workstation layout. The overall goal is to improve the operator's comfort and safety while increasing productivity. Emphasis on using ergonomic principles in redesigning furniture in related industries such as food processing are vivid in case studies, especially those that utilized simulation models using Delmia V5 (Biradar 2024; Diego-Mas J et al. 2015).

This review calls for an ergonomic model to be adopted and developed to fit the unique problems faced by poultry SMEs. It plans to integrate ergonomic tools with systematic methodologies to fill in the literature gaps and enhance worker wellbeing along with operational output.

3. Problem identification

We carried out an analysis of the main reasons for our problem. For this purpose, we used a diagnostic tool such as the Pareto diagram, which states that 80% of the consequences caused by a phenomenon or problem are attributed to 20% of the causes [10]. According to the above, we supported our problem using the respective diagram. The main reasons were the absence of operators, breakage of heat sealing, overtime incurrence, and cleaning delay. As above, the problem has been sustained using the pareto diagram as described in Table 1. The main reasons were the absence of operators, rupture of the heat seal, incurrence of overtime and delay in cleaning.

Table 1. Frequency of the identified problems

Problems	**Frecuency**
Absence of operators	110
Packing breakage	63
Incurrence of overtime	42
Delay in cleaning	38
Reprocessing	31
Crate breakage	24
Downtime between operations	19
Downtime in deliveries	14
Lack of eggs in the warehouse	10
Lack of cleaning material	5

Figure 1 shows that the four main reasons for 71.10% of the reasons, the high number of absent operators was identified as the most influential factor for the poultry company; therefore, we will focus our analysis on causes as the main reason.

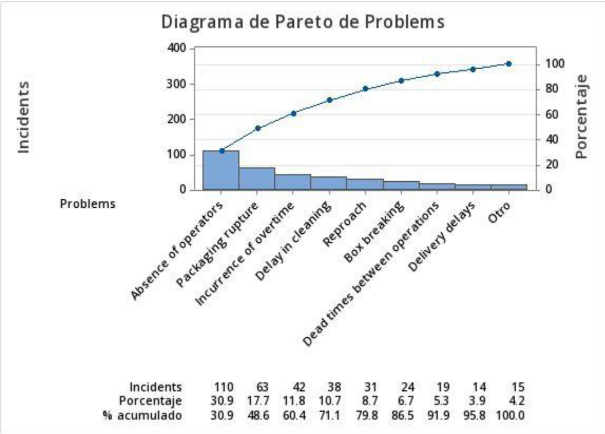


Figure 1. Pareto Diagram of Problems

Table 2 shows the number of monthly absences in the warehouse, the number of times personnel from the area are assigned to another warehouse, and the number of times personnel in the plant are changed.

Table 2. Frequency of the identified absences

Operators	Average monthly absences	Average Monthly Stock Change
Supervisor	0	0
Operator M	1	5
Operator N	3	0
Operator E	2	0
Operator L	1	0
Operator D	2	0

4. Methods

Ergonomic assessments in small and medium-sized poultry enterprises (SMEs) are essential to promoting the health and well-being of workers and improving productivity. In this context, REBA (Rapid Entire Body Assessment) and RULA (Rapid Upper Limb Assessment) are indispensable for detecting ergonomic risks in the poultry work environment. By using REBA and RULA, it is possible to assess the working postures and physical loads that workers in poultry farms are subjected to. Such tools are extremely helpful in detecting improper postures that may result in musculoskeletal injuries. In this field, where work can be monotonous and physically strenuous, ergonomics is essential because it tailors work to the abilities and limitations of people (J. Gomes, 2014; M. Cedeño-Párraga, 2018). By adopting ergonomic measures, occupational injuries can be minimized, which enhances productivity and satisfaction among workers (M. Cedeño-Párraga, 2018). In poultry SMEs, ergonomics training is another important component. An effective ergonomic training program can help to reduce injuries and increase efficiency at work. Ergonomic awareness training aimed at setting work conditions that maintain health should form an essential part of the training (R. Delgado, 2023). Taking into consideration organizational and cognitive factors alongside physical health is a vital aspect of employees' productivity and affects their well-being (J. Gomes, 2014). To sum up, assessments of the office environment with the aid of REBA and RULA tools in poultry operations are of great importance for efficient risk management of the poultry work setting. Incorporating practices of ergonomics, enhancing environmental conditions and training of the employees are the key measures of health and productivity promotion in poultry SMEs.

In the poultry sector, postural evaluation concerning weight bearing is crucial to avoid the occurrence of musculoskeletal disorders (MSDs) in employees. One of the tools which have gained acceptance for measuring the risks while lifting loads is the NIOSH (National Institute for Occupational Safety and Health) equation. This methodology incorporates the load weight, the distance lifted, the frequency of the task, and the posture assumed when lifting. If this methodology is applied accurately, risk situations can be identified, and adequate corrective action (Sarkar et al. 2016; Yazdanirad et al. 2022).

Like many other studies, this also report abnormal postures like lateral twisting and trunk flexion as strong risk factors for low back pain and other MSDs (Sarkar et al. 2016; Iwakiri et al. 2024). Considering the boom in the poultry sector where workers frequently have to lift and transport heavy weights, proper posture is highly important to avoid work related injuries. Method for posture evaluation like Rapid Upper Limb Assessment (RULA) or Rapid Entire Body Assessment (REBA) add to the NIOSH equation by enabling assessment of the exposure to postures and loads of the workers in detail (Yazdanirad et al. 2022; Biradar 2024; Budiyanto et al. 2019).

It has been found that ergonomic programs that include safe lifting exercises and workstation alterations can prevent muscular skeletal disorders from occurring at a workplace on a larger scale (Urrejola-Contreras et al. 2023). For instance, using movable assistive lifting devices or remodeling workstations to minimize the frequency of unnecessary bending and twisting may be effective strategies stemming from ergonomic postural analysis (Kee, 2022).

In conclusion, it can be noted that the combination of the NIOSH equation with postural assessment strategies such as RULA and REBA along with the implementation of ergonomic measures have the potential to mitigate the incidence of MSDs in the poultry sector. Proper attention given to weight bearing and posture aids in enhancing the overall health of the worker as well as improving productivity and operational efficiency.

The increasing concern of ergonomic dangers in the poultry sector is primarily due to the work itself, the working environment, and low levels of automation. Physical activities in the poultry sector can result in musculoskeletal disorders (MSD's) amongst workers. These disorders originate from exposure to repetitive and strenuous work conditions involving awkward postures and lifting of heavy objects (J. Harmse et al. 2016). Analysis of the poultry sector reveals that workers are at risk of permanent damage in the form of tendonitis and lower back pain. These disorders are mainly due to the manipulation of poultry products, particularly eggs, and other tasks performed in non-ergonomic positions (J. Harmse et al. 2016). Moreover, employees' poor performance because of lack of proper ergonomic treatment and control worsens the situation by increasing the rate of absenteeism and decreases the productivity (L. Cantley et al. 2013).

The incorporation of ergonomic measures aids in ameliorating these risks. For instance, the use of appropriate lifting tools and instruction in safe lifting practices offers protective measures (A. Conan et al. 2012). Furthermore, the physical arrangement of work environments, such as the layout of cubicles and the height of standards, is also very important in enhancing the health and productivity of employees (L. Cantley et al. 2013 ; J. Harmse et al. 2016).

According to the study by Kawakami et al. (2023), SLP tools are used to enhance the layout and design of the furniture manufacturing workshop. This research sought to improve productivity in a Peruvian SME that focused on the production of small-scale melamine furniture. A model incorporating Systematic Design Planning (SLP), 5'S, and Standard Work (SW) was developed and put into action using a pilot plan and modeling. The results were an increase in productivity of 11.82%, an increase in production by 50%, and the reduction of time needed to produce from 398 minutes to 330.67 minutes. This study can assist and guide SMEs in that industry to succeed in achieving their business goals using the model developed in this study.

In a different fashion, the authors Cuadros et al. (2021) report comes up with a new methodology for assuring quality in small and medium enterprises (SMEs) operating in the footwear industry. The main aim is to increase the level sophistication and quality of products manufactured by these companies which, in turn, improves their competitive advantage on the market. The suggested model focuses on 5S, standardization, and ERC motivated labor as the main integrated elements. The approach starts with a thorough diagnosis of the company's current state, which enables the system to be aligned based on the results attained.

Subsequently, the quality assurance model is implemented. The results are significant, as the rate of defective production decreases drastically from 23.57% to 10%, leading to cost savings and a notable increase in product quality. This approach offers valuable potential for improving the competitiveness and efficiency of SMEs in the footwear sector.

5. Validation

5.1. Description of the 5S Methodology implementation

A pilot plan was carried out to demonstrate the validation and application of the 5S tool within the nine de October processing plant. The problem to be solved is the lack of order and time loss generated by not finding the materials. This pilot was carried out as of Wednesday, August 30.

5.2 Startup

First, an audit was carried out to identify the processing plant's level of 5S; this allowed for the evaluation and determination of the critical points to be improved. To achieve a good implementation, a training session was conducted for the plant workers, where the importance of this tool was discussed, and what was being sought with the implementation of 5S. After this training, together with the quality manager, the team responsible for the implementation was appointed (Table 3).

Table 3. Team responsible for the 5S implementation

Program	Personnel	Position	Objective
First S Validation - SEIRI (Sort)	Lizbeth Saavedra	Administrative Staff	Classify PPE, cleaning materials, and objects necessary for production.
Second S Validation - SEITON (Set in Order)	Armeidys Mendoza	Selection Operator	Organize PPE, cleaning materials, and necessary objects with labels on respective shelves.
Third S Validation - SEISO (Shine)	Maggye Ipushima	Selection Operator	Complete daily cleaning forms.
Fourth S Validation - SEIKETSU (Standardize)	Eng. Jurassi Muller	Plant Manager/Quality Engineer	Develop continuous improvement plan and keep training the staff.
Fifth S Validation - SHITSUKE (Sustain)	Julissa Huaringa	Selection Supervisor	Act and follow the continuous improvement plan.

Phase 1: First and second S - Seiri and Seiton: Sorting and Ordering

First, all the EPPS, cleaning materials, and necessary objects entered the production process were classified, and control cards were designed to classify them within the shelves and warehouses. These were classified as follows:

- EPPS: White plasticized apron for food handling.

Cleaning materials: brooms, dustpans, mops, scale removers, bio sanitizers, and pesticides that do not harm foodstuffs.

- Production process tools: Cleaning clothes, alcohol, knives.

All these items were classified by frequency of use, need, and form of use if necessary.

This classification also allowed us to identify unnecessary items (water bottles, used gloves, paper, unused containers, scissors, keys). As seen in Figure 2, red cards were used to highlight these objects, and the improvements made will be shown below.

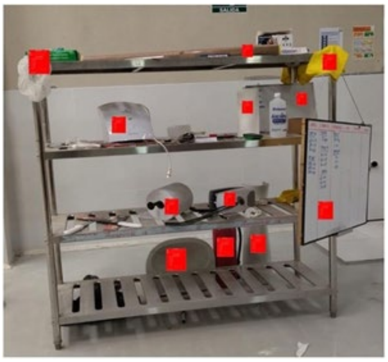


Figure 2. Application of red cards on the rack

Figure 3 provides a detailed view of the shelving reorganized under the new order implemented as part of the 5S methodology. This figure highlights how the materials required for operations are classified and labeled with laminated tags, enabling quick and efficient identification by personnel. Additionally, the optimized arrangement of materials reduces search time and enhances accessibility.

Figure 3. Shelving under the new order

Figure 4 complements this information by showing an improved storage system, including specific hooks for hanging aprons. This design not only contributes to better organization but also ensures that personal protective equipment is always readily available in its assigned location, aligning with hygiene and safety standards in the plant.

Figure 4. Shelving, storage, and hook for aprons under new order

The laminated labels were placed so that personnel could identify the location of the items more quickly. Also, in the cleaning products area, brooms were placed according to their class, away from dustpans. In the cleaning products area, on the left side of the shelf are cleaning materials certified for use in environments where food is present, and on the right side are those materials that are used as long as the warehouse does not contain food. Application of red cards on the rack.

5.2.4 Phase 2: Third S - Seiso: Cleaning

As the third S, we have cleanliness; this is a must for a food processing plant. The tools being tidy, it is much easier for workers to find the materials; talks were held for the staff to understand the importance of cleanliness within the plant; at the end of the day, the plant manager and the person responsible for validation gathered workers to perform the daily cleaning protocol and it was determined that every Saturday there would be general cleaning of the entire plant, the employee fills out the daily format, and the plant manager is in charge of signing as long as what was stipulated is complied with. Otherwise, an observation will be made.

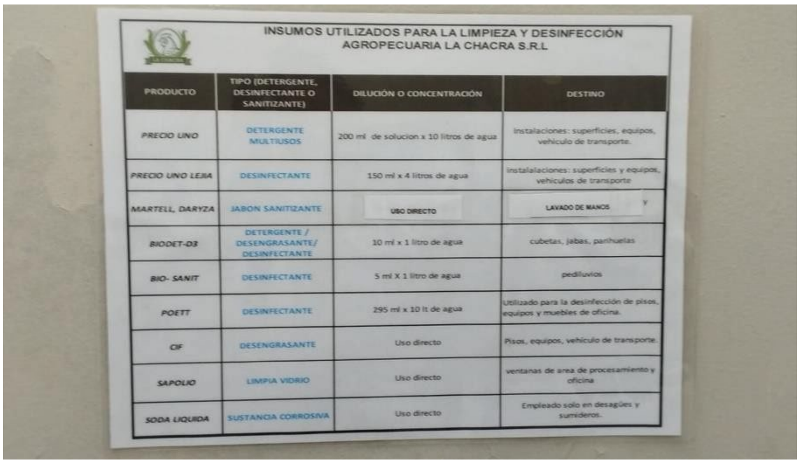
5.2.5 Phase 3: Fourth S - Seiketsu: Standardize

The fourth S consists of constantly following up on the inspections of the proposed new order within the warehouses and shelves. Then, a procedure for using different tools and cleaning products was developed so that the personnel could follow a standard process when using these elements in such a way that an order is followed. This ensures and evaluates what was proposed in the previous three S. This new procedure is shown in Figure 5.

Figure 5. Procedures

5.2.6 Phase 4: Fifth S - Shitzuke: Discipline

Finally, we must remind the employees of the 5S and the method to achieve the proposed objectives. For this purpose, posters were placed in the busiest areas of the processing plant, where the aim, the meanings, and the steps to follow the 5S are indicated. The design of these posters is shown in Figure 6.



INSUMOS UTILIZADOS PARA LA LIMPIEZA Y DESINFECCIÓN
AGROPECUARIA LA CHACRA S.R.L

PRODUCTO	TIPO (DETERGENTE, DESINFECTANTE O SANITIZANTE)	DILUCIÓN O CONCENTRACIÓN	DESTINO
PRECIO UNO	DETERGENTE MULTIUSOS	200 ml de solucion x 10 litros de agua	Instalaciones: superficies, equipos, vehiculo de transporte.
PRECIO UNO LEJIA	DESINFECTANTE	150 ml x 4 litros de agua	instalalaciones: superficies y equipos, vehiculos de transporte
MARTELL, DARYZA	JABON SANITIZANTE	USO DIRECTO	LAVADO DE MANOS
BIODET-D3	DETERGENTE / DESENGRASANTE/ DESINFECTANTE	10 ml x 1 litro de agua	cubetas, jabas, parihuelas
BIO- SANIT	DESINFECTANTE	5 ml X 1 litro de agua	pediluvios
POETT	DESINFECTANTE	295 ml x 10 lt de agua	Utilizado para la desinfección de pisos, equipos y muebles de oficina.
CIF	DESENGRASANTE	Uso directo	Pisos, equipos, vehiculo de transporte.
SAPOLIO	LIMPIA VIDRIO	Uso directo	ventanas de area de procesamiento y oficina
SODA LIQUIDA	SUSTANCIA CORROSIVA	Uso directo	Empleado solo en desagües y sumideros.

Figure 6. Poster with the 5S objectives

5.3 Description of the SLP implementation

5.3.1 Startup

The initial spaghetti diagram was developed to assess the need for optimizing the current layout, aiming to minimize unnecessary movements and reduce both the physical effort and postural strain of the operators during the egg conditioning process. Figure 7- Table 8 shows the current spaghetti diagram of the egg conditioning process, which was used as a reference to identify areas for improvement.

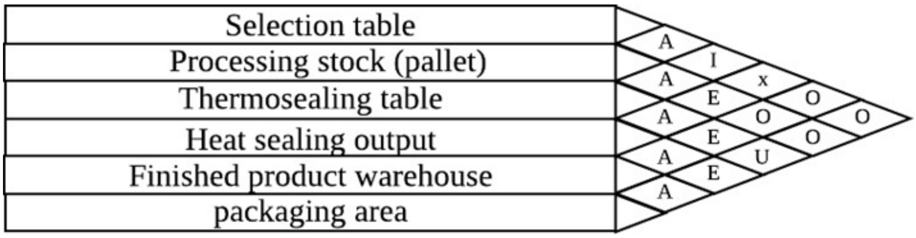


Figure 7. Current Spaghetti Diagram of the Egg Conditioning Process

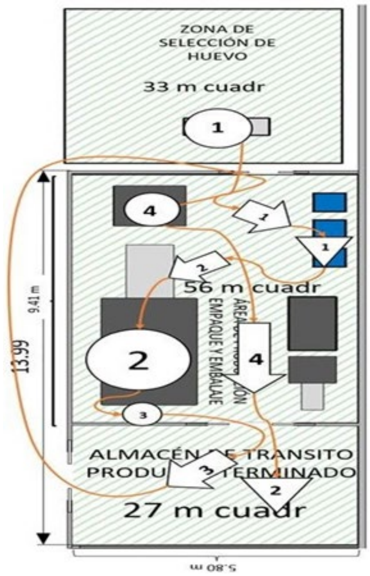


Figure 8. Layout of the egg conditioning process before redesign of Layout

5.3.2 Deployment of SLP methodology

As part of the deployment of the Systematic Layout Planning (SLP) methodology, the activity relationship diagram was developed. This chart identifies the importance of the relationships between process areas, from the selection table to the packaging area, using letters to assess their proximity or functional connection.

Figure 9. Activity relational Chart

Figure 9 illustrates the development of the mentioned tool.

Figure 9 presents an activity relationship chart, a key tool of the Systematic Layout Planning (SLP) methodology. It visually organizes process areas, such as the selection table and packaging area, and uses letters (A, E, I, O, U, X) to denote the importance of their proximity and functional interrelations.

5.3.3 Deployment of matrices

The construction of matrices is an integral part of layout planning because it facilitates analysis and optimization of production processes. It includes the improved distance matrix, quantity matrix, and stress matrix which define the major parameters needed for the redesigning of the operational layout. They help in assessing the productivity and the movement and material handling inefficiencies as well as performing a physical effort calculation for each task. Incorporating these matrices into the analysis allows the methodology to adopt a more precise approach to designing a new layout boundary that focuses on eliminating unwanted movements, lowering operator workload, and improving system efficiency.

Table 4 includes one of the components of the SLP methodology, which is the improved distance matrix. As a quantity metric, this matrix records the physical distances in meters that separate the most active workstations. These include the selection table, processing stock area, thermosealing table, heat-sealing output, finished product warehouse and packaging area. The values given are the optimized ones resulting from the new layout that subsequently, reduces more than 80% the total unnecessary movements while also providing better usability of the workstation features.

These advancements aid in lowering the strain put onto workers while boosting the productivity of operational processes, which is crucial when it comes to optimizing a plant.

Table 4. Improved distance matrix in meters

	Selection table	Processing stock (pallets)	Thermosealing table	Heat sealing output	Finished product warehouse	Packaging area
Selection table		4.12				
Processing stock (pallets)			2.2			
Thermosealing table						
Heat sealing output						1.2
Finished product warehouse						
Packaging area					3.2	

In this Table 5, the said quantity matrix is depicted which considers the distance matrix's same stations and correlates with the weight in kilograms of the material moved between the stations. This analysis is vital as it reveals the weight ramifications within various process areas and the improvements achieved in material handling. These operational results show that a proper design of the layout allows better differentiation of the workloads as well as lessens the operational work burden placed on the operators physically. This matrix serves as a vital indicator of how layout changes influence workload distribution and contribute to ergonomic improvements.

Then the improved quantity matrix was made, which will be shown below:

Table 5. Matrix quantity in Kg improved

	Selection table	Processing stock (pallets)	Thermosealing table	Heat sealing output	Finished product warehouse	Packaging area
Selection table		1108.8				
Processing stock (pallets)			1108.8			
Thermosealing table				1108.8		
Heat sealing output						1108.8
Finished product warehouse						
Packaging area					1276	

Finally, the improved effort matrix was obtained, making use of the results obtained from the previous matrices.

Table 6 details the improved effort matrix, derived from the data in the distance and load matrices. This matrix quantifies the accumulated effort, expressed in kg-m, required to perform transport tasks between workstations. The results show a substantial reduction in effort following the implementation of the optimized layout. This improvement not only enhances the ergonomic conditions for operators, minimizing the risk of musculoskeletal injuries, but also increases operational efficiency by reducing transfer times and physical fatigue. This matrix yielded the following result:

Table 6. Improved effort matrix

	Selection table	Processing stock (pallets)	Thermosealing table	Heat sealing output	Finished product warehouse	Packaging area
Selection table		4568.256				
Processing stock (pallets)			2439.36			
Thermosealing table				0		
Heat sealing output						1330.56
Finished product warehouse						
Packaging area					4083.2	

5.3.4 Improved layout with SLP

In addition, the spaghetti diagram was analyzed. With these last two matrices, the effort matrix was calculated to determine the current state of productivity within the plant. This way, a new plant layout with its spaghetti diagram was designed to represent the new movements. Figure 10 and Figure 11 shows the proposed layout of the processing area.

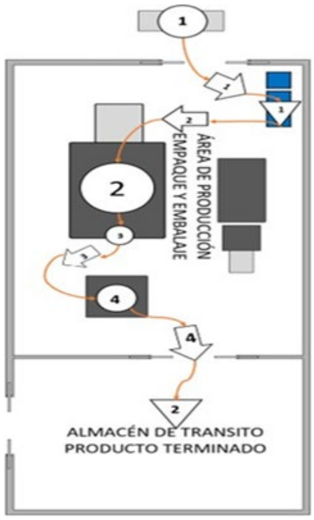


Figure 10. Proposed improvement of the layout of the processing area

Figure 11. Improved layout with the application of SLP in the egg conditioning process

5.4 Development of ergonomic design

Similarly, based on the posture analysis of repetitive movements and load lifting, two simulations were performed in the picking and dispatch areas, using DELMIA V5 software to determine the new operator stations, relocated furniture, and improved work equipment.

In the case of software simulation, each component of the egg packing plant has been added to the system, which is the products (jabs, partitions, worktable, etc.), operator's dummy, dispatch van and hydraulic table. Figure 12 illustrates the redesign of workstations and equipment in the egg conditioning process, using Delmia V5 simulation software to visualize the optimized layout. The simulation presents an ergonomic arrangement where the operators' workstations are strategically positioned to minimize unnecessary movements and postural strain. The integration of hydraulic tables and adjustable work surfaces ensures optimal working heights, facilitating task execution while reducing musculoskeletal risks. The redesign also accounts for the efficient egg handling process with minimal operational downtime. This shows how the application of digital instruments can have remarkable changes to ergonomics and productivity.

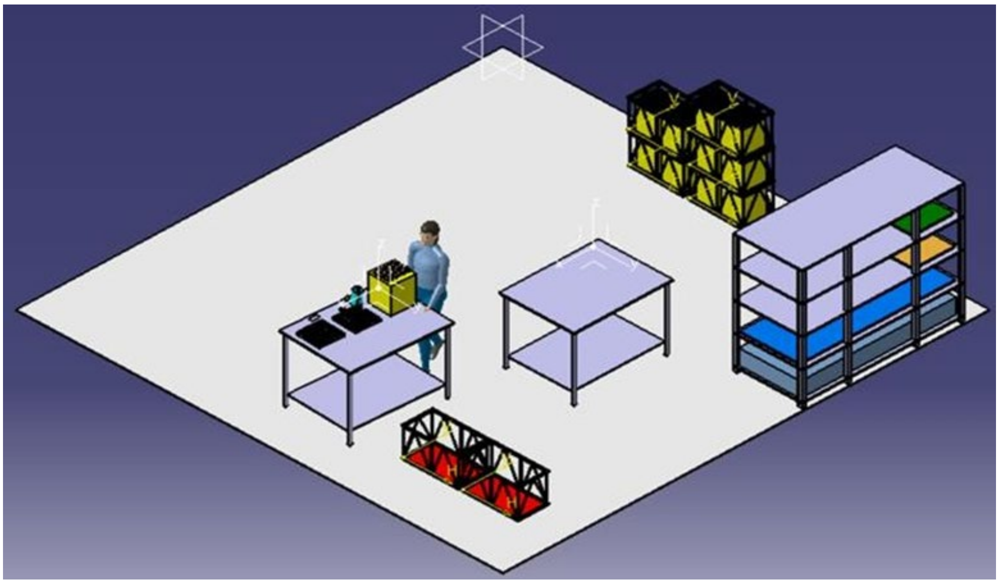


Figure 12. Redesign of workstations and equipment in the egg conditioning process with Delmia V5 simulation software

The new workstations and tools for the dispatching section of the workshop are set out in Figure 13. It also includes a simulation implemented through the Delmia V5 software. In this figure, the design of hydraulic tables and the layout of conveyors was changed so that the transfer of materials to the operators' stations is accomplished with little physical effort. The new workstation design means that operators do not have to perform repetitive overhead lifting, of do so very rarely, which decreases the risk of suffering from physical and ergonomic injuries. Mid-simulation postural evaluation proved enhanced alignment of the body throughout the various stages of the task. This dispatch area redesign demonstrates the integration of ergonomic design and modern simulation techniques to achieve improved safety, efficiency, and workflow.

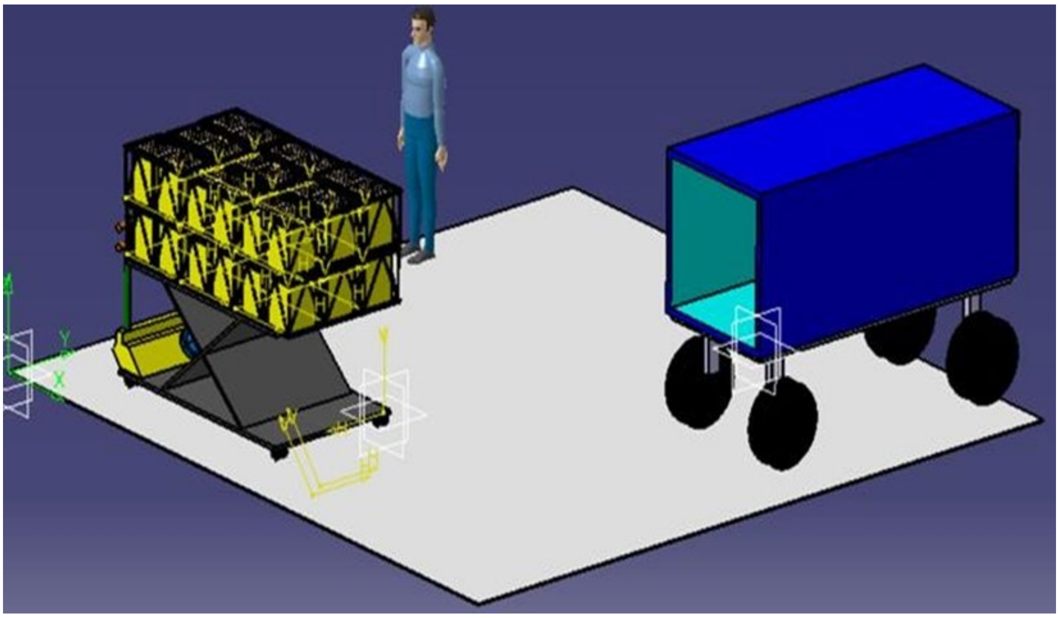


Figure 13. Workstation redesign and workstation and equipment in the egg dispatch process with Delmia V5 simulation software

The following link shows the full video with the simulation of the ergonomic intervention in the Delmia V5 software:

https://youtu.be/1iGyndU_L_c (Video in Spanish)
https://youtu.be/bJuncma_Exc (Video in English)
5.4.1 Verification of ergonomics conditions after the operation Verification of ergonomic conditions after the operation is crucial to analyzing the effectiveness of the designed measures. This phase employs tools such as the REBA, RULA, and the NIOSH lifting index, which assess the changes in the operator's posture, physical exertion, and overall workload. This step is meant to verify that the changes made to the workstations and workflows were effective by evaluating post-intervention ergonomic condition versus pre-intervention conditions. The verification outcomes, go beyond confirming the success of ergonomic conditions after interventions. It also ensures that emerging issues concerning workplace health and safety are addressed and any appropriate action taken to improve it.

Figure 14 shows ergonomic conditions in the selection area before the intervention measures. From the initial evaluation, the ergonomic risk levels were very high, registering a REBA score of 7, RULA score of 6 and NIOSH lifting index of 1.32. These values clearly demonstrate high levels of physical stress which stems from poor workstation layout. The worktable was not at an appropriate height, the materials were not placed conveniently, and all these factors compelled the operators to take up uncomfortable and mobile postures which increases the chances of musculoskeletal disorders.

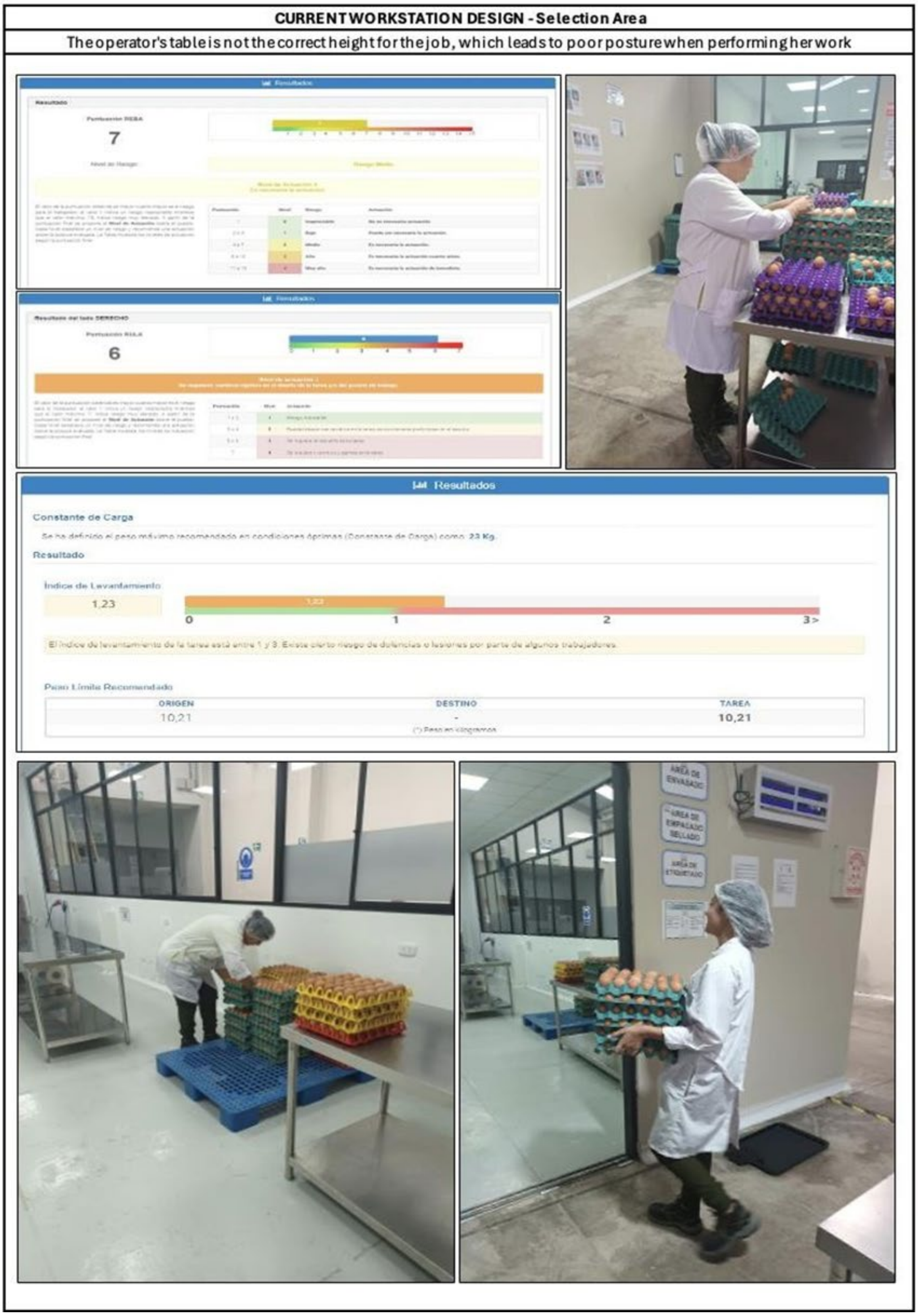


Figure 14. Ergonomic conditions of the process in the selection area prior to ergonomic intervention.

Figure 15 demonstrates the improved ergonomic conditions in the selection area following the intervention. The redesigned workstation included adjustments to table height and the placement of materials closer to the operator, reducing unnecessary movements. Post-intervention ergonomic evaluations showed notable improvements: the REBA score dropped to 3, the RULA score decreased to 2, and the NIOSH lifting index improved to 0.92. These results indicate a significant reduction in physical strain and ergonomic risks, enhancing both operator comfort and productivity.

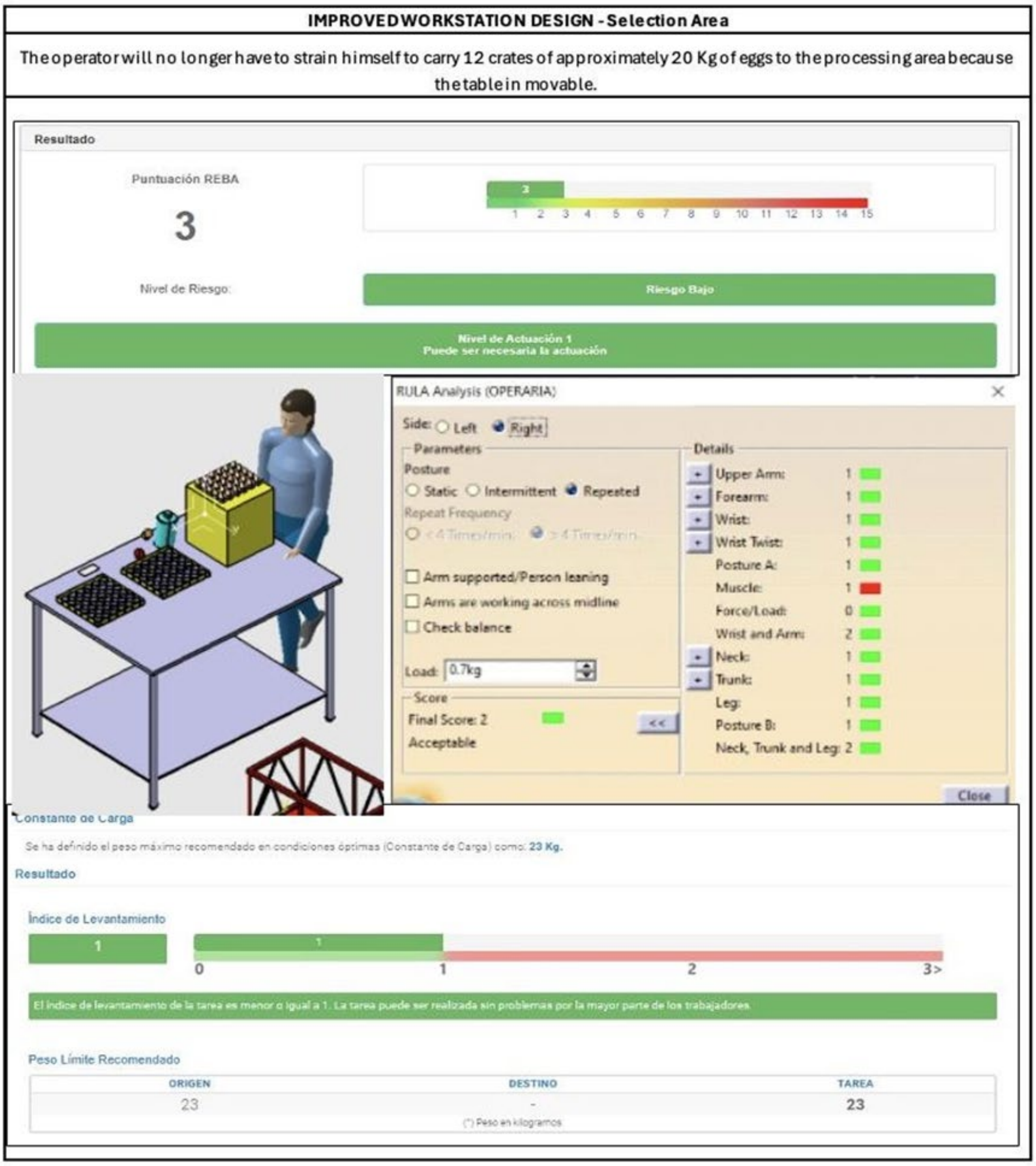


Figure 15. Ergonomic conditions of the selection area process after ergonomic intervention.

Figure 16 depicts the ergonomic conditions in the dispatch area before the intervention. The ergonomic assessments showed elevated risk levels, with a REBA score of 6, a RULA score of 7, and a NIOSH lifting index of 2.61. These scores highlight the physical strain and risk of injury resulting from manual lifting tasks and an inefficient workspace layout that required operators to perform repetitive, physically demanding tasks.

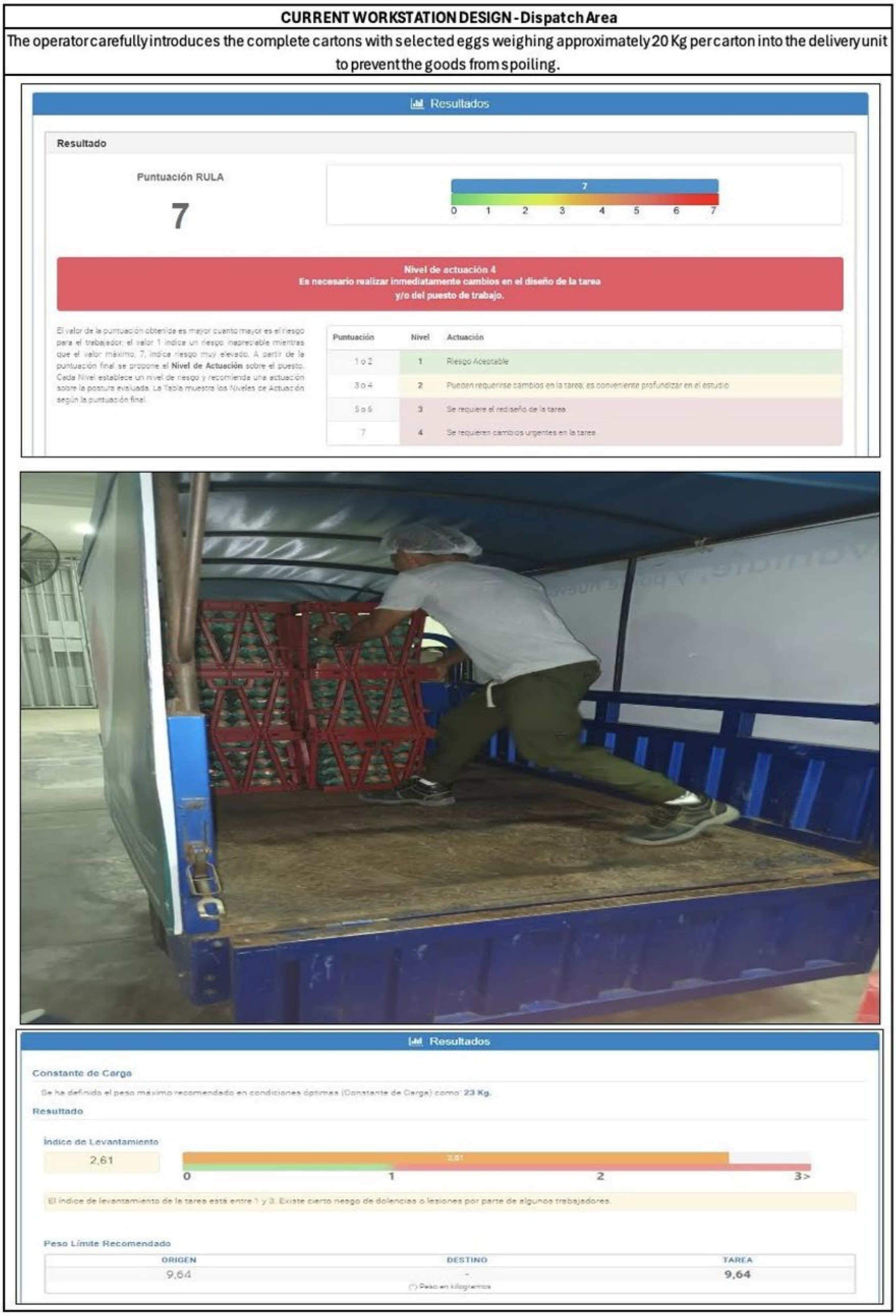


Figure 16. Ergonomic conditions of the process in the dispatch area prior to ergonomic intervention

Figure 17 illustrates the ergonomic improvements achieved in the dispatch area after the intervention. The implementation of hydraulic tables and a reorganized layout effectively eliminated manual lifting and optimized task flows. Post-intervention assessments revealed substantial reductions in ergonomic risks, with the REBA score decreasing to 1, the RULA score improving to 2, and the NIOSH lifting index reduced to 0. These results confirm the effectiveness of the interventions in minimizing physical strain and improving operator safety and efficiency.

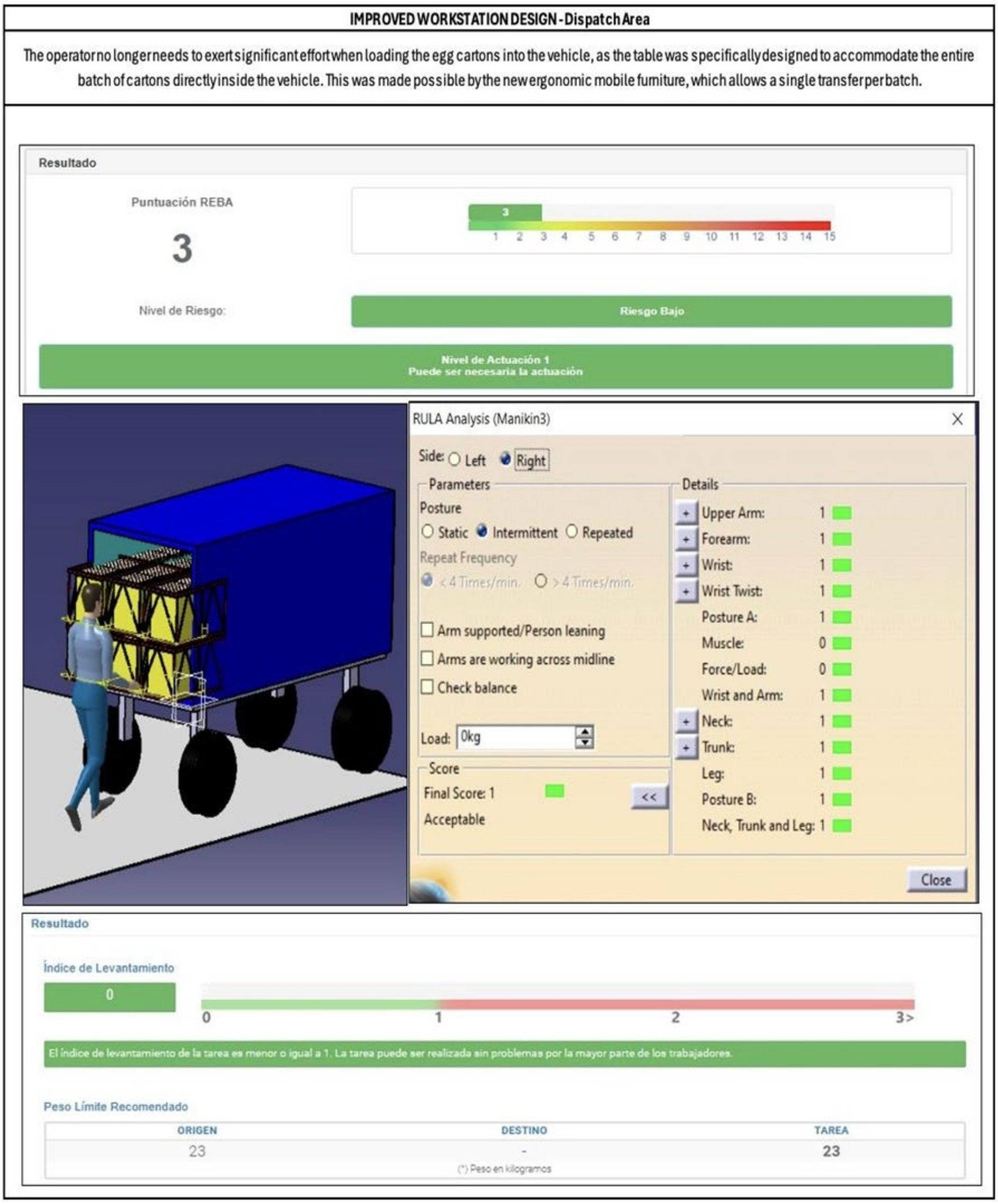


Figure 17. Ergonomic conditions of the dispatch area process after ergonomic intervention.

6. Economic Validation

The following chapter will evaluate the results obtained from the economic studies carried out to determine the impact that the proposed improvement would have on the company's cash flow, as well as to see if the proposal is viable and to calculate the total capital required for the investment.

6.1 Calculation of investment

The investment is composed in the first instance by the implementation of 5S, where a specialist has to be hired, and different materials have to be purchased to start labeling the production plant. The second part of the investment consists of redesigning the workstations, i.e., purchasing materials for the lathe operator, designing a hydraulic work table, and training in its use. Finally, we have the cost of implementation of the SLP, which consists of hiring a specialist, purchasing signaling tape, and training personnel. This results in a value of PEN 14,504.

6.5.2 Savings Calculation

Savings were evaluated based on the increase in annual profits generated by the production plant so we can see how investments are recovered, and we begin to create more income thanks to the rise in productivity after meeting the objectives of our improvements. The improvement results were as follows: in 5S, there was an improvement of 50% in tool search times and 62% in general indicators; in Design Work, the impact on the absenteeism rate was a significant decrease of 77.7%, and the SLP had an improvement of 59.82%. The following Table 7 shows three optimistic, realistic, and pessimistic scenarios showing our economic evaluation results.

Table 7. Economic analysis by scenario

	Pessimistic	**Realistic**	**Optimistic**
VAN	PEN 244,514.00	PEN 301,899.00	PEN 306,165.00
TIR	517%	607%	608%
B/C	PEN 17.92	PEN 21.89	PEN 22.18
Payback	0.38 years	0.23 years	0.21 years

After the economic evaluation, the COK (opportunity cost) was obtained, which would be the minimum profitability for the new investment; the value obtained was 14.12%. In addition, a positive NPV value of 301899 was obtained, which indicates that we should accept the project because the profitability is greater than the rejection rate.
The IRR value obtained is 607%, which means we will have a good profitability percentage during the project.

We obtained an ROI value of 24.13 and a payback of 0.23 years. This tells us that the project is viable and beneficial for the company.

Finally, thanks to the financial analysis, it is expected that net profits will increase by PEN 10577.37 in the first year after the improvements are made, which is completely beneficial for the company, and by PEN 42479.69 in the fifth year.

7. Results and Discussion

The ergonomic simulation demonstrated significant advancements in operator safety and productivity. The elimination of manual load lifting using hydraulic tables resulted in notable ergonomic improvements. Pre-intervention REBA, RULA, and NIOSH evaluations showed scores of 7, 6, and 1.32, respectively, indicating high ergonomic risk levels. After intervention, these scores were reduced to 3, 2, and 0.92.
In the selection area, redesigned workstations ensured materials were within the operator's reach, significantly reducing postural strain. Ergonomic assessments revealed improvements in REBA from 6 to 1, RULA from 7 to 2, and NIOSH from 2.61 to 0. These changes effectively minimized operator fatigue and musculoskeletal risks, enhancing workflow efficiency.

The dispatch area, previously characterized by inefficient layouts and repetitive manual lifting, also experienced substantial improvements. Hydraulic tables and optimized workflows reduced REBA from 6 to 1, RULA from 7 to 2, and NIOSH from 2.61 to 0. The intervention addressed ergonomic challenges while boosting operational efficiency.

Economic validation further supported the intervention's success. Projected savings reached PEN 10,557.37 in the first year, with a net present value (NPV) of PEN 301,899 and an internal rate of return (IRR) of 607%, indicating the project's financial viability and sustainability.

8. Conclusions

The first chapter presents a solid framework for the project, providing an industry context and an illuminating related case study. This chapter clearly and concisely sets out the general and specific objectives of the project, ranging from the construction of the theoretical framework to the quantification of productivity, production, and cost improvements. It also identifies the constraints and limitations that the project will face, such as resource availability, budget, formal authorization, and the geographic location of the study site. The importance of applying effective methodologies and validating the results to ensure the proposed improvements are practical is emphasized. It also highlights the need to measure and compare indicators before and after implementation to evaluate and validate improvements in the field of study. This chapter serves as a solid and complete basis for the project's successful development.

For the design of the solution, the connection between the root causes identified and the proposed solution is rigorously established, presenting a solid overall design and applying the selected engineering tools. It is relevant to highlight that all these methodologies have been exhaustively evaluated in previously analyzed success cases; for the SLP, an initial effort of 36,921 kg-m was obtained, and also with the ergonomic improvement, an evaluation Lack of order in the workstations Relationship diagram before improvement of implementing the 5S validation methodology and its contribution to improving productivity in the plant. In addition, the SLP significantly reduced the effort to 11,090 kg-m. Also, the posture analysis of repetitive movements and lifting based on Ergoniza software yielded REBA and RULA results of 4, 3, 2, and 1 when simulations were performed in the picking, processing, and dispatch areas, which allowed identifying areas for improvement and designing a new plant layout to optimize movements.

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