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Design and Implementation of Integral Ergo-Value Stream Mapping in a Metal-Mechanical Company to Improve Ergonomic and Productive Conditions: A Case Study

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Abstract: The Integral Ergonomic-Value Stream Mapping (Ergo-VSM) methodology is introduced in this study, which is tailored for the metal-mechanic sector and aims to assess the operational and ergonomic conditions of production processes. The methodology is designed to identify ergonomic risks and propose an improvement plan to increase productivity by integrating ergonomic measurement instruments aligned with official standards and lean manufacturing tools such as VSM and Kaizen. The study, which was conducted in a metal-mechanical MSME (micro, small and medium enterprises), resulted in an 11.8% overall improvement in psychosocial risk factors, a 4.4% increase in productivity with a 1.96-h reduction in cycle time, and a 20% decrease in reported quality rejections. Notably, the study shows that the Integral Ergo-VSM can be implemented in a variety of organizational contexts, ensuring adaptability without jeopardizing the methodology's core objectives.

Keywords: VSM; ergonomics; Ergo-VSM; lean manufacturing

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1. Introduction

Occupational diseases (ODs) result directly from workplace factors, including industrial accidents, exposure to hazardous substances or environmental conditions, epidemiological risk factors, mental health stressors, and respiratory ailments. These diseases can affect workers across various industries, emphasizing the critical need for comprehensive workplace health and safety measures [1,2]. A better understanding of occupational diseases has necessitated the development of more comprehensive approaches to workplace health and safety [3]. ODs cause suffering and losses for employees, companies, public health funds, and society at large [4]. According to the International Labor Organization (ILO), approximately two million deaths occur annually due to work-related illnesses [4]. Worldwide, 40% of these ailments are related to musculoskeletal disorders (MSDs), a trend attributed to factors such as sedentary work [5], poor ergonomic conditions [6], and physical strain during the workday [7]. However, studies also suggest that psychosocial risk factors, including occupational stress, contribute to the development of MSDs in employees [8,9].

In addition to MSDs, relatively new diseases such as stress or mental disorders are on the rise [4]. High stress levels can lead to physical and mental exhaustion, anxiety, depression [8], and an increased risk of cardiovascular diseases or MSDs [10]. As a result, the importance of ergonomics in manufacturing companies has significantly grown, prompting the implementation of various laws mandating the identification and reduction of ergonomic risks [11]. Efforts have primarily focused on MSDs due to the substantial costs associated with these ailments globally [12].

Ergonomics plays a critical role in maintaining employee productivity, ensuring work efficiency, and improving workers' physical and mental well-being. Companies can proactively prevent injuries and occupational diseases by integrating ergonomic principles into the workplace, fostering a safer and healthier work environment [13]. In the manufacturing sector, ergonomics involves redesign engineering, training, health management, and administration to mitigate musculoskeletal issues such as low back pain [14]. Organizations can optimize the work environment by implementing ergonomic strategies to reduce physical strain, alleviate workplace-related stress, and create a conducive setting for improved employee well-being and overall performance [13].

Considering the long-term social and economic sustainability, occupational health and safety play a crucial role in identifying and preventing factors that cause work-related injuries and diseases [15]. Implementing effective preventive measures not only reduces the burden of disease in the workplace, but also significantly contributes to the long-term well-being of employees and the overall sustainability of companies [16]. An ergonomically designed workplace not only enhances worker well-being, but also boosts productivity, particularly in manufacturing companies, where it can have a substantial impact on long-term social and economic sustainability [17].

Despite the benefits, it is important to note that making ergonomic improvements after the process has been designed from a productivity-focused perspective may not address root problems as it only targets specific activities [18]. Lean manufacturing, a system known for improving process efficiency levels [19], has shown positive results when correctly implemented in various organizations [20]. However, it primarily emphasizes eco-nomic indicators [21], often neglecting the implications for employees [22]. Rigorous ap-plication of lean manufacturing has been associated with an increase in MSDs and work stress for workers [22–25], as certain activities that are deemed non-value-adding can serve as periods of physical and mental recovery for employees [22,23,26]. Therefore, human factor analysis should be incorporated when implementing lean manufacturing [27].

To bridge the gap between ergonomics and lean manufacturing, Ergo-VSM, a tool that uses the Value Stream Mapping (VSM) with ergonomic analysis [28], was developed to raise awareness among process designers, who often underestimate their impact on employees [29]. While lean manufacturing originated in the industrial sector, particularly in the automotive industry [30], Ergo-VSM applications have been primarily studied in hospitals in Nordic Council countries [31–34], focusing on analyzing physical and psychosocial risk factors among healthcare workers [35]. In the industrial sector, studies focus on identifying physical risk factors associated with employee postures and workloads [36–38]

Among the benefits of implementing Ergo-VSM, the following are noteworthy: achieving ergonomic improvements without compromising productivity [39], mitigating the negative effects that lean manufacturing might have on employees' quality of life [40], and encouraging employee contribution to improvement ideas [35]. Based on the Ergo-VSM, the Integral Ergo-VSM methodology was designed to achieve a global vision of the ergonomic risks to which employees are exposed, integrating analysis of the physical environment, musculoskeletal discomfort, and psychosocial risk factors without neglecting production process indicators, such as productivity. According to the characteristics of the metalworking sector and its unique challenges, this study presents a detailed case analysis with the objective of providing comprehensive information on the ergonomic and operational complexities within this industry, to generate valuable information that can be applied to similar contexts.

Literature Review

Ergo-VSM, a blend of Value Stream Mapping (VSM) and Ergonomic Analysis, stands as an innovative approach that enhances processes without compromising productivity [41]. This lean manufacturing tool not only helps in identifying current process steps and assessing value-added and non-value-added activities, but also strives to improve overall production processes [42]. With a specific focus on waste reduction in healthcare processes, Ergo-VSM also aims to elevate quality, safety, and overall work efficiency within an adaptable and reliable organizational framework [43]. Notably, it serves as a maturity model for environmental manufacturing processes, emphasizing the reduction of energy consumption, cost-effectiveness, and increased profits [44].

A key facet of Ergo-VSM lies in its inclusive approach [45], promoting active involvement from personnel across various work groups. By integrating principles from both lean manufacturing and ergonomics, it fosters the development of sustainable process flows [35], and a collaborative environment that encourages continuous improvement [46].

Initially conceptualized by Mathiassen et al. in 2004, Ergo-VSM was proposed as a complementary framework to VSM, designed to underscore the importance of ergonomic considerations within production systems [29]. This concept emerged from the realization that both VSM and lean manufacturing methodologies often neglect ergonomic factors, potentially leading to increased ergonomic risks and subsequent work-related disabilities among employees [47].

Physical risk factors primarily entail the repetitive nature of tasks, the weight of loads, and the adopted postures [11], whereas psychosocial factors encompass various aspects related to work organization and the overall work environment [48]. On the other hand, cognitive risk factors primarily focus on mental workload and work-induced stress [49].

The instruments utilized for ergonomic risk analysis can be categorized into two groups: those developed by researchers specifically for the study, and those that rely on recognized and validated tools previously employed in the industry (see Table 1).

Table 1. Type of instruments used, and ergonomic factors analyzed in the Ergo-VSM.

Instrument Used	Physical	Psychosocial	Cognitive	Physical and Psychosocial
Previously validated	López-Acosta et al. [38] Aqlan et al. [37] Suryoputro et al. [36]	None	Arce et al. [50]	Pereiro and Goncalves [51]
Developed by the authors	Aqlan et al. [37]	Hasle et al. [52]	None	Edwards and Winkel [32] Gunnarsdóttir and Birgisdóttir [33] Winkel et al. [31] Edwards [18] Jarebrant et al. [28] Winkel et al. [34] Edwards and Winkel [53] Jarebrant et al. [39] Edwards and Winkel [46] Edwards [54] Sakthi et al. [40]

In a comprehensive analysis of physical and psychosocial risks, it becomes apparent that these factors are the most commonly observed, whereas studies focused solely on physical, psychosocial, or cognitive risks are comparatively limited. Notably, both physical and psychosocial risk factors have been the central focus of Ergo-VSM application within the Nordic Council. This emphasis stems from the detection of prevalent physical and mental exhaustion issues among healthcare employees [47]. The pioneering studies in this area were led by esteemed ergonomists such as Jarebrant [28,39], Edwards [18,32,46], and Winkel [31,34]. Over a period of more than ten years and across various hospital settings, these experts meticulously refined the analysis instruments based on their insightful observations.

The analysis of physical and ergonomic factors in the industrial sector primarily re-lies on well-established instruments, which are designed to identify risk loads or postures for employees [36–38]. Further investigations, based on published studies, have emphasized the need to incorporate factors related to the work environment surrounding employees during their tasks. This includes considering elements such as noise levels, temperature variations, and lighting conditions, which can significantly impact workers and their overall performance.

Previous research has predominantly concentrated on the application of Ergo-VSM in the healthcare sector, with limited exploration of its broader industry implications. This discrepancy underscores the critical necessity for a more comprehensive understanding of the distinct challenges and unique ergonomic considerations, particularly within the metal-mechanical industry.

While current literature has initiated explorations into the integration of lean manufacturing principles and ergonomic analysis, as evident in studies examining the correlation between Lean Manufacturing, ergonomics, and improved work conditions, further research is imperative to elucidate the nuanced interactions and potential synergies be-tween these concepts within the specific context of the metal-mechanical industry [55]. Moreover, the introduction of Sustainable VSM (Sus-VSM) as an extension of conventional VSM, incorporating sustainability metrics, has successfully showcased the expanded capabilities of the VSM tool [56].

Our research aims to comprehensively examine the ergonomic risks and operational complexities specific to the metal-mechanical industry, focusing on the potential benefits of incorporating Ergo-VSM principles. We seek to provide practical insights into the implications of Ergo-VSM, shedding light on the interplay between lean manufacturing, ergonomics, and improved working conditions, ultimately enhancing productivity and employee well-being in the metal-mechanical sector.

2. Method

The Integral Ergo-VSM takes the VSM tool and complements it by including indicators that comprehensively analyze ergonomic risks: physical, environmental, and psychosocial occupational risks to which workers are exposed in the production process under analysis, as well as process indicators such as quality defects and product manufacturing time. Figure 1 shows the Integral Ergo-VSM cycle, divided into four stages, which are explained below:

(a) Preparation: It starts with the commitment to accept both—the ergonomics and lean manufacturing approaches—mainly by the company's management. Once the acceptance is obtained, a multidisciplinary work team must be formed to start with the training on the Ergo-VSM methodology and basic concepts of lean manufacturing and ergonomics.

(b) Drawing the current status: The product family to be analyzed must be selected. Then, all the information and material flows that take place to produce the selected family must be identified. The ergonomic and productive measurements will complement the previously identified flows to show the current status of the processes by integrating the information obtained.

(c) Define future status: In this stage, areas of opportunity are identified to build the desired future status. Through Kaizen Teian, the contribution of improvement ideas is promoted with all employees.

(d) Process improvement: The improvement plan to be executed to achieve the desired changes in the production process is made, and after carrying them out, the results obtained from the implementation of the improvements must be evaluated to start with the system control.

The Integral Ergo-VSM is based on the continuous improvement cycle, indicating in its diagram that the methodology preparation stage will continue after completing the last stage of process improvement. However, a brief analysis should be carried out in practice to determine which step to start. The Integral Ergo-VSM should be generated annually for the company's work plan.

Figure 1. Cycle of the Integral Ergo-VSM methodology.

2.1. Steps of the Integral Ergo-VSM

2.1.1. Commit to Lean Manufacturing and Ergonomics (Ergo-Lean)

Adopting a lean manufacturing and ergonomics culture requires a commitment at all levels of the organization. This allows changes in the processes to improve the conditions of physical ergonomics, environment, psychosocial, and productive risk factors. Therefore, from the beginning of the implementation of the Integral Ergo-VSM, all levels must be informed of the benefits that can be obtained, and the requirements to achieve them.

2.1.2. Form a Multidisciplinary Work Team

The integration of the work team should be carried out with personnel from different departments of the company. This will allow each one to contribute with different knowledge and ideas to developing the Ergo-VSM. The main characteristics of the work team should be participation, responsibility, preparation, flexibility, and communication [57].

2.1.3. Basic Training in Lean Manufacturing, Ergonomics, and Integral Ergo-VSM

To ensure that the entire team has the necessary knowledge to perform the remaining steps of the Integral Ergo-VSM, it is considered necessary to include basic knowledge training on the following points:

- Lean manufacturing: the 7 wastes, PDCA (Plan-Do-Check-Act) cycle, and Kaizen methodology.
- Ergonomics: science objective, MSD, Psychosocial Risk Factors at Work (PRF-W), and conditions of the physical environment.
- Integral Ergo-VSM: steps of the methodology, measurement instruments to be used, and calculation of indicators.

2.1.4. Select Product Family

A product family should be selected to perform the Integral VSM-Ergo. This family will have similar processes, and the variations will be minimal. If the product family to be evaluated needs to be clarified, the product-quantity analysis selection method will be used [58]. This technique allows us to select the product with the highest customer demand in the last six months.

2.1.5. Identify Process Flows

In this step, information and material flow between processes should be identified directly on the shop floor and the departments involved. Nothing should be assumed; all information captured should be corroborated by following the material through the production area and directly asking those who perform the activities.

As you go through the flow of material and information, you should start with a paper sketch of the current status, showing the actual flow of information and material, the order of the processes, and the number of people performing the activity. The steps to identify the process flows are as follows:

- Draw the flow of information that is generated between the customer and the company until the production order is generated.
- Point out the information flow of the production orders in the different departments required to manufacture of the product, for example, production control, purchasing, and warehouse.
- Follow the process in the production area, identifying the information and material flows that occur in all the processes required for manufacturing.

2.1.6. Perform Ergonomic and Productive Measurements

The indicators selected for the construction of the Integral Ergo-VSM are shown in Table 2. It is recommended that the creation of process indicators, such as cycle time, quality rejections, etc., be agreed upon with top management and that the workplace and occupational environment indicators be designed under current regulations. Since the Integral Ergo-VSM methodology for this study was developed in Mexico, the Mexican Official Standards (NOM for its Spanish acronym) were applied.

Table 2. Integral Ergo-VSM indicators.

Indicator	Acronym	Method	Formula
Cycle Time	CT	Perform at least 3 process measurements.	$CT_{area} = \frac{\text{area cycle time}}{\text{total cycle time}} \times 100$
Quality Rejections	QR	Take the last six months of quality rejection history.	$QR_{area} = \frac{\text{number of area rejections}}{\text{total rejections}} \times 100$
Noise Level	NL	NOM-011-STPS-2001 [59]	$NL_{area} = \frac{\text{zones of the area exceeding the permitted noise level}}{\text{total zones exceeding the permitted noise level}} \times 100$
Temperature Level	TL	NOM-015-STPS-2001 [60]	$TL_{area} = \frac{\text{zones of the area exceeding the permitted temperature}}{\text{total zones exceeding the permitted temperature}} \times 100$
Lighting Level	LL	NOM-025-STPS-2008 [61]	$LL_{area} = \frac{\text{zones of the area that do not comply with the light level}}{\text{total zones that do not comply with the required light}} \times 100$
Psychosocial Risk Factors at Work	PRF-W	NOM-035-STPS-2018 [62]	$PRF - W_{area} = \frac{\text{sum of the total scores of the employees in the area}}{\text{number of employees in the selected area}}$
Musculoskeletal Disorders	MSDs	NOM-036-STPS-2018 [63]	$MSDs_{area} = \frac{\text{number of people reporting MSDs in the area}}{\text{total number of employees who reported MSDs}} \times 100$

These standards were critical in data collection and the comprehensive evaluation of ergonomic risks and working conditions in the workplace during the implementation of the Integral Ergo-VSM methodology. The use of NOM-011-STPS-2001, for example, to regulate maximum noise exposure levels was critical in preventing potential hearing problems and ensuring a safe work environment [59]. Similarly, the use of NOM-015-STPS-2001 aided in the control and maintenance of appropriate ambient temperature, promoting employee well-being and avoiding risks associated with extreme temperature conditions [60].

Furthermore, NOM-025-STPS-2008 [61] compliance established specific parameters for regulating lighting levels in workspaces, ensuring a properly illuminated work environment and preventing vision problems and visual fatigue. The use of NOM-035-STPS-2018 [62] allowed for the comprehensive addressing of psychosocial risk factors in the workplace, providing essential guidelines for managing aspects such as work-related stress, workload, and the organizational environment, and ensuring a work environment conducive to employees' mental and emotional health.

Finally, the application of NOM-036-STPS-2018 [63] focused on musculoskeletal disorders, providing guidelines to prevent workplace injuries and health issues caused by repetitive movements and improper postures. Compliance with these standards not only ensured a safe and healthy work environment, but also contributed to the company's overall productivity and efficiency, demonstrating a strong commitment to employee well-being and safety.

2.1.7. Integrate Current Status Information

The values of each indicator by area are noted in the data boxes of the corresponding process in the map of the flow of information and materials previously made. In order to facilitate decision-making, the data are classified into three priority levels: the low level is identified with green, the medium level with yellow, and the high level of relevance with red.

The classification of the three levels is performed, taking as a reference the method for constructing a frequency distribution [64]: define the range of values of the observations, identifying the maximum and minimum value to obtain the difference (range = maximum–minimum). The amplitude of the interval is obtained by dividing the range obtained by three (amplitude = range/3) since it is the number of levels defined for the classification. The limits of each category are established through the lower limit of the first category, which can be equal to or less than the minimum value of the data. The interval amplitude is added to this value to obtain the lower limit of the following category until the number of categories is completed.

2.1.8. Identify Areas of Opportunity

Once the information on the current status of the process has been integrated, meetings should be held to identify areas of improvement. Priority is given to the indicators in each category's highest level (red).

The following questions, with both ergonomic and productive focus, were developed based on the key questions indicated by Rother and Shook [65], which will guide in identifying the areas of opportunity that will be sought to improve the process:

- What are the main PRF-Ws identified?
- What actions can be taken to reduce the main PRF-Ws and improve productivity?
- What is the environmental condition (noise, lighting, temperature) with the highest risk for employees?
- How can the physical environmental conditions of employees be improved?
- Is there a relationship between MSDs and the activities performed by employees?
- What changes can be made in the process to reduce MSDs?
- What are the main non-value-adding activities with the longest cycle times in the process and how can they be eliminated?

2.1.9. Define Desired Future Status

At this stage, the objectives to be achieved for each high-priority indicator, corresponding to the red color, should be set. It is recommended to set achievable objectives; therefore, it is suggested to set the measurements that present the upper limit of the medium priority level as a goal.

2.1.10. Kaizen Teian

The contribution of ideas focused on improving the identified areas of opportunity will be encouraged through a Kaizen Teian. The Japanese word Teian means suggestion or proposal, which can be defined as the system for implementing improvements based on employee proposals [66]. It is one of the most effective and popular methods for improving in Japan, organized so that each employee shares their ideas [67].

The Kaizen Teian implementation method is carried out by explaining to employees the main problems identified and inviting them to make suggestions for improvement in a suggestion box placed in the production area. The work team members oversee the review of ideas, selecting those that they consider feasible to implement and that adhere to the identified areas of opportunity, always trying not to affect the ergonomic or productive conditions negatively.

2.1.11. Carry out an Improvement Plan

The implementation plan guides the execution of the identified process changes. Table 3 shows the classification of restriction levels for human resources, material resources, and time, all of which are important for project selection.

Table 3. Classification of restriction levels.

Level	Human Resource	Material Resource	Time
Low	Company personnel	Use of own equipment	<6 months
Medium	National Consulting	Repair of own equipment	6–12 months
High	Foreign consulting/Recruitment of personnel	Acquisition of new equipment	>12 months

A matrix, as shown in Table 4, is used for project selection to assess the area to be impacted, a brief description of the idea, the risk levels of human resources, material resources, and time constraints, as well as the project's scope, indicating the intended positive impact on indicators.

Table 4. Ideas analysis matrix for project selection.

Area	Idea	Restrictions			Scope						
		Human Resource	Material Resource	Time	CT	QR	LL	TL	NL	PRF-W	MSDs
Process 1	New distribution in the work area.	Medium	Medium	High	X			X	X	X	
Process 1	Perform occupational gymnastics.	Medium	Low	Low	X					X	X
Process 2	Perform quality checklist.	Low	Low	Low		X					
Process 3	Weekly production plan.	Low	Low	Low							

2.1.12. Execute Kaizen Projects

Each kaizen project is established in the project tracking matrix, where the area or process to be improved is recorded, as well as a brief description of the project, the name of the team leader, start date, tentative end date, and comments to identify if any setbacks were encountered or whether resource allocation is required.

The Ergo-VSM project leader will be responsible for updating the matrix, reporting to management on progress, and following up with the teams and managers to verify the progress of the project. Personnel involved with the area or process will integrate the work teams.

2.1.13. Evaluate Results Obtained

Once the Kaizen projects have concluded, it is necessary to measure each indicator again to determine whether the changes made in the process achieved the desired effect. Evaluating the results obtained will give certainty to the company on the benefits of continuing to work with the Integral Ergo-VSM methodology, as well as replicating in other areas those actions that gave positive results and discarding those ideas that did not achieve their objective.

2.1.14. System Control

The system control is the stage of standardization of procedures. After identifying the changes that must be followed in the processes, as well as those that will not continue to be carried out, it is necessary to start with the process definition stage and then document them and implement the necessary controls for follow-up through work instructions, process flow maps, checklists, procedures, and standard worksheets, among others.

3. Case Study

The experimental analysis of the Integral Ergo-VSM was carried out in a small metal-mechanical MSME company specialized in selling, designing, and manufacturing trailers. The production area has a roof that covers the work areas, and due to the nature of the activity, the work is done in an open space. Hence, the climatic conditions directly affect the employee's physical environment. The strategic selection of this sector was based on its economic importance, as well as its impact on the health and well-being of its employees. The inclusive approach not only provided a comprehensive view of the working conditions, but it also allowed for an accurate assessment of the effectiveness of the Integral Ergo-VSM methodology in the metal-mechanical MSME sector.

3.1. Preparation

The work team comprised five employees: the production manager, three production supervisors, and an area leader. The production manager was the project leader responsible for following up on activities and coordinating efforts. Basic training on lean manufacturing, ergonomics, and Integral Ergo-VSM was conducted in four two-hour sessions.

3.2. Define Current Status

Figure 2 shows the current status of the Integral Ergo-VSM of the production process; however, it does not contain the information flows between departments, the material flows between processes, or the company's manufacturing sequence. The data box for each analyzed process allows us to identify each process indicator's priority level visually.

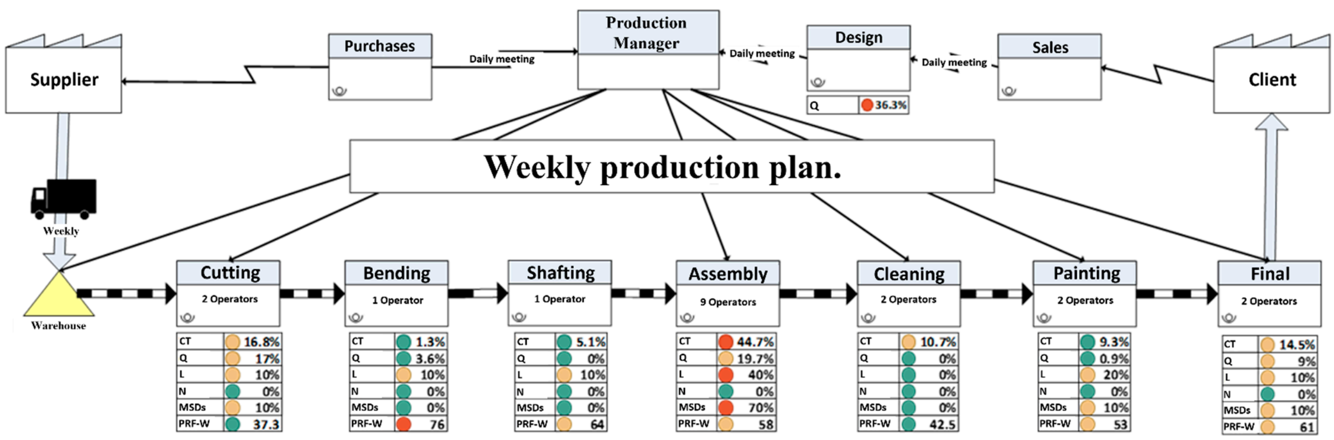

Figure 2. Integral Ergo-VSM current status of the production process.

The cleaning process has a low priority level with green indicators. The assembly area, on the other hand, has CT, LL, and MSDs at a high priority level, which is why it was selected as a priority for improvement. The PRF-W in the bending process represents a risk for the employee, so an in-depth analysis of the answers given by the employee in the reference guide II was carried out.

The design department has the highest percentage of quality rejections due to a lack of information or incorrect data in the trailer drawings. Even though the personnel in this department are not directly involved in production, their errors or successes directly affect the manufacturing process, which is why the decision was made to include them in this indicator.

3.3. Define Future Status

The desired future status was achieved by selecting the process with the highest score for each indicator: quality issues in the design process, PRF-W in the bending process, cycle time, lighting, and MSDs in assembly. In addition, a weekly production plan was defined for the bending and shafting processes, which lack this planning, causing labor stress.

Meetings were held with production and design personnel to explain the areas of opportunity identified, and the desired future status, and after brainstorming on how the current conditions could be improved, a friendly and non-judgmental environment was created for the personnel to express their ideas.

Even when the indicators to be improved were defined, the personnel contributed ideas from other areas or indicators. The work team noted down all the ideas generated by the employees since they are valuable and can be implemented at another time by the company. Table 5 shows the main ideas contributed by employees. The record was made by noting the idea, the area where it can be implemented, as well as a column of comments from the staff to include briefly why they think it can help or how the idea will be implemented.

Table 5. Main ideas contributed by production and design personnel.

Area	Idea	Personnel Comments
Production	Meetings at the beginning of the shift.	This will allow us to have clear priorities for the day.
	Boards with indicators.	Know the important information.
	Work instructions.	It will facilitate training for new personnel.
	Annual training plan.	Training is required to do the job better.
Assembly	Template manufacture.	The manufacture of templates for trailer assembly can reduce assembly time.
	Define work cells and leaders.	Forming work teams with cell leaders will help the organization and personnel follow-up.
	Stretching at the beginning of the shift, calisthenics.	Stretching helps to prepare for the workday.
	New lighting distribution.	More lighting fixtures are required to facilitate the work.
	Improve lighting.	At the beginning of the shift, there is not enough light.
Bending and Shafting	Work plan for each day.	Having a daily priority plan will help.
Design	Meetings for validation of production drawings.	Presenting drawings to experienced production personnel will allow errors to be identified prior to product manufacture.
	Standardization of drawings.	The drawings do not have a standardized design; each designer presents the information differently.
	Solid Works training.	Program tools to facilitate the design of plans have yet to be discovered.

3.4. Process Improvement

The improvement plan was determined by top management to work as a team at all levels. The ideas selected for implementation in the production area are shown in Table 6. Some are indicated to be from the production area because it was decided they would be applied to all production personnel.

Table 6. Ideas analysis matrix for the selection of projects.

Area	Idea	Restrictions			Scope				
		Human Resource	Material Resource	Time	CT	QR	LL	PRF-W	MSDs
Production	Meetings at the beginning of the shift.	Low	Low	Low	X			X	
	Production boards.	Low	Medium	Low	X			X	
	Generate work instructions and visual aids.	Low	Low	Medium	X	X			X
	Annual training plan.	Medium	Low	High	X	X		X	
	Update of the quality checklist.	Low	Low	Low		X		X	

Table 6. *Cont.*

Area	Idea	Restrictions			Scope				
		Human Resource	Material Resource	Time	CT	QR	LL	PRF-W	MSDs
Assembly	Manufacture and use of templates for ST model (handrail, ramp, and lance).	Low	Low	Low	X	X		X	
	Work cells and cell leader assignment.	Low	Low	Low	X	X		X	
	New lighting fixture distribution.	Medium	High	High			X		
	Stretching routine at the beginningof the shift.	Medium	Low	Low	X			X	X
Bending and Shafting	Weekly work plan for the area.	Low	Low	Low	X			X	
Design	Meetings for validation of drawings with production personnel.	Low	Low	Low	X	X		X	
	Solid Works training.	Medium	Low	Medium		X			
	New design in work drawings.	Low	Low	Low		X			

The implementation of the Kaizen improvement projects was carried out over nine months. Table 7 shows the progress percentage up to that time, which was calculated based on the activities defined to achieve each project. The actions not completed during this period will continue to be worked on.

Table 7. Kaizen improvement projects progress overview.

Area	Project	Progress	Comment
Production	Meetings at the beginning of the shift.	100%	Each supervisor holds meetings in their area.
	Production boards.	100%	Follow-up of work orders.
	Generate work instructions and visual aids.	60%	There are processes to be documented.
	Annual training plan.	100%	It is being executed.
	Update of the quality checklist.	100%	Used by supervisors and leaders.
Assembly	Manufacture and use of templates for ST model.	100%	Extend to other trailer models or processes.
	Work cells and cell leader assignment.	100%	Three employees were promoted to cell leaders.
Bending and Shafting	Weekly work plan for the area.	100%	Performed by the production manager every week.
Design	Meetings for validation of drawings with production personnel.	100%	It was defined in the designer's standard worksheet.
	Solid Works training.	90%	The design will reduce the time allocated to generating BOM (Bill of Materials).
	New design in work drawings.	100%	Production personnel defined it.

3.4.1. Cycle Time

The reduction in cycle time was focused on the assembly area because it contributes to 41.1%, the highest percentage in the manufacture of a trailer. The project applied was manufacturing and using three templates, as shown in Figure 3, to assemble the handrail, ramp, and drawbar. Using templates, a 4.4% reduction was achieved, corresponding to 117.7 min (1.96 h).

3.4.2. Quality Rejections

Quality rejections indicate an increase of one point in the average monthly findings of the Design department. Even though this department did not have the expected improvement after the actions taken, the Integral Ergo-VSM team will continue to take improvement actions.

The production area had an overall reduction of 20% in quality incidents in 2021. This result is related to the update and use of the quality checklists, which consisted of identifying the main quality findings of each process, holding work sessions with the personnel of each area, and defining the critical inspection points. It is considered that the use of templates for the ST models, as well as the generation of work instructions and visual aids, could have influenced the reduction of quality incidents.

Figure 3. Use of templates in the production process.

3.4.3. Noise Level

As shown in Figure 4, the measurements taken about the noise level in the production area did not obtain values equal to or greater than 90 dB (A). As a preventive measure and according to NOM-011-STPS-2001 [59], the use of earplugs in the production area is in the company's regulations, which provides soft polyurethane foam earplugs with a noise reduction level factor of 32 dB [68]; therefore, it is considered that the noise exposure level (NEL) is not a risk factor for employees.

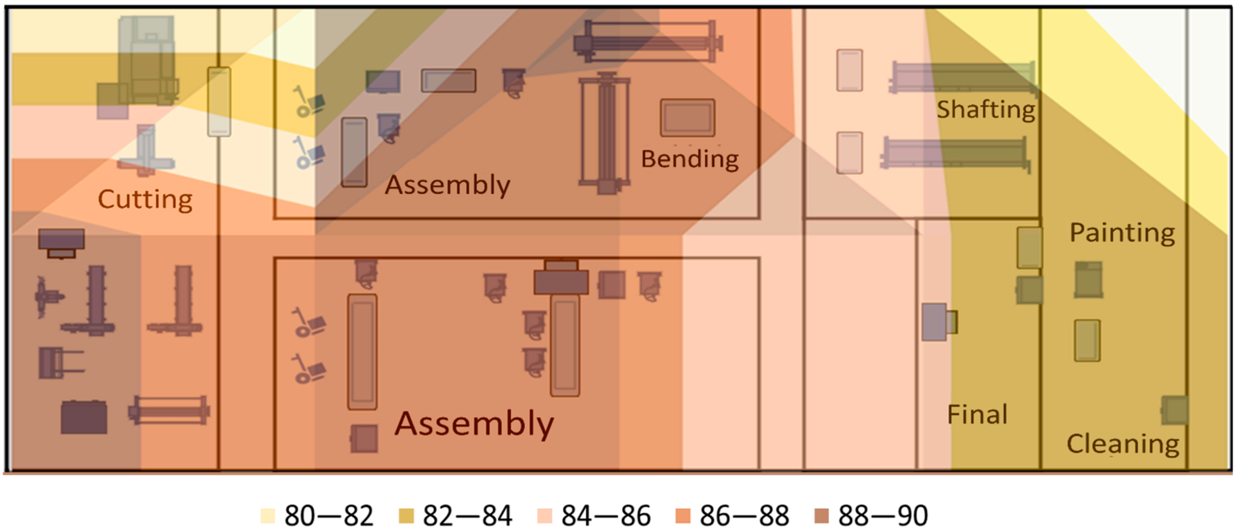

Figure 4. Behavior of noise levels on the production floor (decibel scale).

3.4.4. Lighting Level

The recorded lighting levels in the production area are shown in Figure 5. According to NOM-025-STPS-2008 [61], the minimum value required for the activities carried out in the manufacturing process is 300 lux; therefore, 62% of the production areas do not comply with the lighting conditions. The company has yet to be able to make these changes due to the economic cost of installing lighting fixtures in areas that do not meet the minimum levels defined by the standard. Senior management was made aware that they could dedicate economic resources to improving this condition in the future.

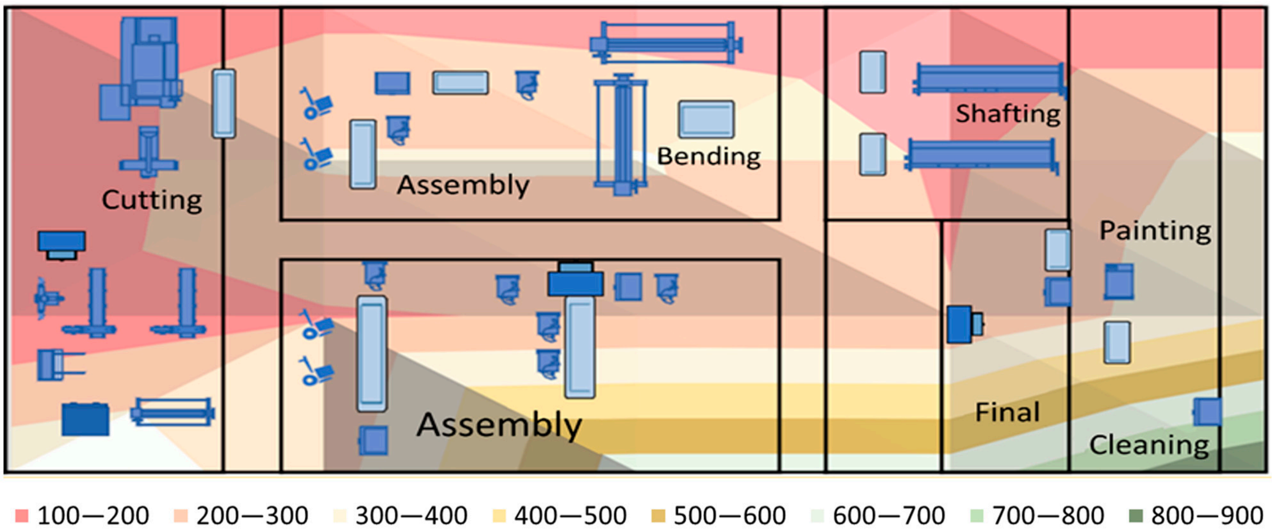

Figure 5. Behavior of lighting levels on the production floor (scale in lux).

3.4.5. PRF-W

The psychosocial risk factors were identified and analyzed by applying reference guide II of NOM-035-STPS [62], which is recommended for workplaces with up to 50 employees. The domains evaluated were the following: work environment conditions, workload, lack of control over work, workday, interference in the work-family relationship, leadership, work relationships, and violence.

Table 8 shows the results obtained from the application of the reference guide II, indicating the evaluated domain and the production process. According to the guide [62], the colors represent a risk level: null identified in white, low in green, medium indicated in yellow, high in orange, and very high in red.

Table 8. Average score obtained by manufacturing domain and process.

Domain	Cutting		Bending		Shafting		Assembly		Cleaning		Painting		Final	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Conditions in the work environment	5	8.2	8	3	12	12	7	7.2	4.5	6.3	7	3.5	8	6
Workload	17.3	22	28	24	31	29	23.1	22.5	14.5	21	24	22	26.5	20.3
Lack of control over work	7.7	5.3	14	14	0	0	10.1	8.2	12	8.3	11	11.5	11.5	8.3
Workday	0	1.7	6	0	0	2	1.8	2.6	1.5	1.7	2	4.5	3	2.8
Interference in the work-family relationship	1.7	1.8	3	2	0	2	1.5	2	1	0.7	0.5	0.5	1	1.8
Leadership	2.3	2.3	12	9	8	0	7.9	3	3.5	1.7	4	2	4	3.5
Work relationships	1	1.2	2	3	7	4	3	3.5	3.5	1.3	3	4	1.5	2
Violence	2.7	2	5	2	8	8	4.1	5	3	2	4.5	3.5	5.5	1.5

The PRF-W showed an improvement in 75% of the domains evaluated, with a 48.4% decrease in the leadership domain and a 26.8% decrease in the violence domain. In the domains of working hours and interference in the work-family relationship, there was an increase in the score obtained, maintaining the medium and low-risk levels, respectively. The overall average PRF-W of the production area improved by 11.8% overall, going from 57.2 points to 50.5, with a medium-risk level for both results.

When the results in Table 8 are examined, it becomes apparent that it is critical to consider the specific environment of each workstation, as well as its interaction with other areas of the operational process. Despite the fact that some stations have only one operator, communication and interrelationships with other sections can influence the levels of violence and labor relationships observed. Furthermore, despite having a single operator, the role of leadership in certain processes can have a significant impact on overall coordination and task management, justifying the higher scores recorded in Table 8. This in-depth knowledge of individual contexts allows for a more precise assessment of psychosocial risks and lays the groundwork for implementing specific and effective improvement strategies in each operational area.

3.4.6. MSDs

The application of the Kuorinka Nordic questionnaire, indicated by NOM-036-STPS-2018, can be performed on employees who perform manual load handling to detect symptoms of body discomfort [63]. It is also one of the most widely used evaluation methods in the world for the identification of MSDs symptoms [69].

MSDs showed an increase of 33% overall, starting with a figure of 10 employees, who presented some discomfort in 2021, increasing to 20 employees. The dramatic increase in MSDs among employees was related to the high demand for overtime that the company had after the first application of the questionnaire; it is estimated that, on average, employees went from working 3.2 h of overtime per month to working up to 21.6 h on average in the most critical month.

3.4.7. Updated Integral Ergo-VSM

The new current status of the production process is shown in Figure 6. The CT in the assembly process was reduced by 15.7%; however, a slight growth in the CT of the rest areas is identified. Therefore, it is recommended to continue working in this area and analyze the second area with more time.

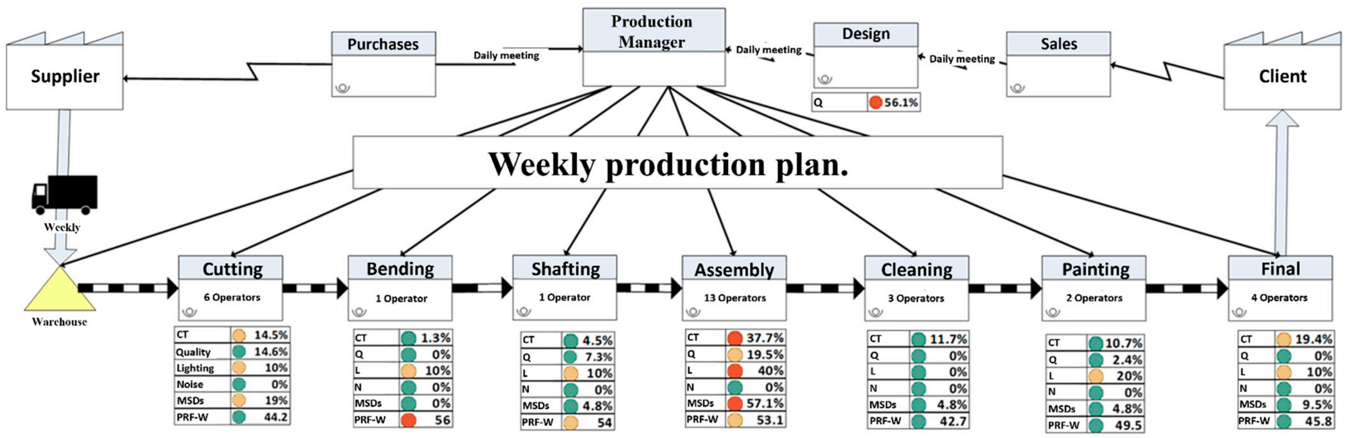

Figure 6. Updated status of the Integral Ergo-VSM.

Quality rejections related to the design department increased by 20%, indicating a strong area of opportunity in this department. Although the MSDs presented a decrease in the percentage of the assembly process, they had an overall increase in all areas, thus being an opportunity for improvement for the company in general. PRF-W showed an overall reduction of 11.2%. However, the bending process has the highest score, so work should continue in these areas.

3.4.8. System Control

The company's definition and standardization of work procedures are under development since, because of the application of the Integral Ergo-VSM methodology, document control began with the generation of work instructions and visual aids for the processes, as well as the update and application of the quality checklists.

The company will continue to work at this stage with the following actions: standardize shift start meetings through the application of a standard sheet for supervisors, indicating the points to be discussed; work instructions in the assembly area will be updated to include the use of templates in the corresponding products; templates will be made for other types of trailers to continue reducing cycle time; and a policy will be developed to regulate employee overtime.

3.4.9. Limitations and Challenges

During the implementation of the Integral Ergo-VSM methodology, we encountered a series of challenges and limitations that required careful attention. Among these challenges was the need to deal with the complexity of real-world work environments and adapt methodology to the metal-mechanical sector's specific conditions. Obtaining employee participation and initial commitment proved to be a difficult process that necessitated a careful motivation and training strategy.

Furthermore, the data collection process was hampered by limitations in the accessibility and availability of relevant information, which had an impact on the breadth and depth of the data obtained. Some ergonomic indicators were evaluated subjectively, necessitating the development of clearer and more defined criteria for the evaluation and analysis of the collected data.

Despite these challenges and limitations, additional safeguards were put in place to ensure the data and results' integrity. The research team collaborated closely with employees, leaders, and managers to address these issues and ensure the methodology's successful implementation. Throughout the process, continuous analyses and reviews were performed to identify potential biases and limitations and to take the necessary steps to mitigate their impact on the study's results.

4. Discussion

The openness of management and personnel was crucial for carrying out this implementation, showing interest and commitment to perform each of the stages of the methodology. Rother and Shook [65] emphasize the importance of management commitment and responsibility, as well as the constant effort to adapt the VSM methodology to the process of interest. Jarebrant et al. [28] agree on the relevance of having management leadership and commitment to implement the VSM with an ergonomic approach in any organization.

Hasle et al. [52] indicate that even when work teams can identify problems in their organization and other departments, if they feel limited or unable to suggest changes affecting them, the staff only focuses on their areas, limiting process improvement. There-fore, the meetings with the staff and the Kaizen Teian fostered an atmosphere of openness and commitment to the organization, allowing employees to contribute ideas for improvement not only in their work areas, but also in their own areas.

The lack of a lean manufacturing culture in the company required training to understand basic concepts and tools used in the project, as well as delays in the implementation of improvements. Lopez-Acosta et al. [38] highlight the relevance of training personnel in lean manufacturing and ergonomics. When implementing the VSM with an ergonomic approach, preparing personnel in these topics allows them to understand and apply them in their work activities.

Sakthi et al. [40] indicate that the Ergo-Lean approach, directly related to the VSM with an ergonomic approach, could be easily adaptable and improve results if the ergo-nomic approach is included in the initial phase of lean manufacturing implementation in a company. Hasle et al. [52] emphasize that if the personnel lack the required competencies, external personnel will be needed to make progress in the implementation. Jarebrant et al. [35] highlight responsibility, participation, and focused leadership as competencies, and if any of them are absent, the possibility of successfully implementing the tool decreases.

The measurement of ergonomic indicators required more resources in terms of time and personnel to perform the measurements. Studies of VSM with an ergonomic approach, such as that of Jarebrant et al. [39], conclude that the extra hours invested in this methodology are reasonable since they obtain positive results in the ergonomic conditions of the employees without affecting productivity. Sakthi et al. [40] indicate that the additional time required is justified by management.

The development of the Integral Ergo-VSM methodology provides a new tool for both ergonomic and productive process analysis, including the physical environment in which employees perform their activities. Sakthi et al. [40] specify the inclusion of environmental factors in this type of analysis as an area of opportunity.

The application of a VSM with an ergonomic approach has been carried out mainly in the health sector [31,35,51], so performing the experimental analysis in the metal-mechanical industry proves that this type of methodology can be adapted to other types of processes with positive results that can be replicated in other industries.

The inclusion of production personnel was relevant in identifying the changes to be made and also being able to implement them later. Winkel et al. [45] emphasize the inclusion of operational personnel to facilitate the acceptance of improvements, especially if they are identified as helping to improve working conditions. Hasle et al. [52] indicate that in the absence of communication or coordination between departments, the approach to solving problems is lost, considering that the current situation cannot be changed.

Cuatrecasas [70] shows that effective decisions are based on the analysis of data and information. Therefore, calculating indicators and the signaling system for each result facilitates this decision-making. It allows us to visually identify the areas that will be prioritized to improve the ergonomic conditions or productive character.

5. Conclusions

The comprehensive Integral Ergo-VSM methodology was successfully designed and implemented in our study, incorporating official Mexican standards for measuring the physical environment, psychosocial risk factors, and musculoskeletal disorders, as well as integrating it with production indicators, cycle time, and quality rejections. The metal mechanical MSME experimental analysis provided a thorough understanding of the current process status in terms of ergonomic risks and productivity, as well as information and material flow. As a result, a solid improvement plan was developed, which included targeted actions aimed at improving both productivity and ergonomic conditions.

Our implementation resulted in a remarkable 11.8% overall improvement in psychosocial risk factors, as well as a notable 4.4% increase in productivity, owing to a significant reduction in cycle time by 1.96 h and a significant 20% reduction in reported quality rejections. Furthermore, our analysis highlighted the critical importance of incorporating official regulations on ergonomic working conditions, an area that remains relatively unexplored within this methodology. By emphasizing the Integral Ergo-VSM's adaptability in large companies and diverse industrial sectors, we envision its potential for widespread implementation, albeit with necessary adjustments tailored to individual company contexts while preserving the methodology's essence and objectives.

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