Reducing the Ergonomic Risk Level in the Production Area of a Manufacturing Company

Arturo Realyvásquez-Vargas, Karina Cecilia Arredondo-Soto, Guadalupe Hernández-Escobedo
Departamento de Ingeniería Industrial
Tecnológico Nacional de México/Instituto Tecnológico de Tijuana
Tijuana, Baja California, Mexico
arturo.realyvazquez@tectijuana.edu.mx, karina.arredondo@tectijuana.edu.mx, guadalupe.hernandez@tectijuana.edu.mx

Jorge Luis García Alcaraz
Department of Industrial Engineering and Manufacturing
Autonomous University of Ciudad Juárez
Ciudad Juárez, Chihuahua, Mexico
jorge.garcia@uacj.mx

Cuauhtémoc Sánchez Ramírez
Division of Research and Postgraduate Studies
Tecnologico Nacional de México/Instituto Tecnologico de Orizaba
Orizaba, Veracruz, Mexico
csanchezr@ito-depi.edu.mx

Abstract

Musculoskeletal disorders (MSDs) are considered the leading cause of occupational disability and loss of productivity. The manufacturing industry is one of the work sectors where workers are most exposed to risk factors that can cause MSDs. This article reports the case of workers in a manufacturing company located in Tijuana, Mexico. This research aims to minimize the ergonomic risk workers are exposed to in the mechanical kick press and packaging stations. Rapid Entire Body Assessment (REBA) and Job Strain Index (JSI) methods are applied to evaluate the risk levels caused by postural load and repetitive movements before and after redesigning the stations. To redesign the stations, an anthropometric study was performed on the workers. The results show that, with the design of the new press station, the level of risk caused by the postural load is reduced from 10 (high) to 1 (negligible), while the level of risk caused by repetitive movements is reduced from 13.5 (high) to 1 (low). In the case of the packaging station, the level of risk caused by postural load was reduced from 9 to 2, while the level of risk caused by repetitive movements remained at 3. It can be concluded that the correct application of different Ergonomics tools allows for eliminating several risk factors.

Keywords
Musculoskeletal disorders, REBA, JSI, Anthropometry and Workstation design.

1. Introduction

Musculoskeletal disorders (MSDs) are considered the leading cause of work disability, sick leave, and lost productivity (Bevan 2015). Several studies show that the manufacturing industry is one of the work sectors where workers are most exposed to risk factors that can cause MSDs. For example, Hembecker et al. (2017) indicate that workers in the manufacturing industry in Brazil suffer from MSDs in shoulders, elbows, forearms, hands and wrists, which negatively impacts workers' health. In other similar research, Ayub and Shah (2018) conducted a cross-sectional study with 48 manufacturing workers aged 18 to 45 years and reported that 79% of the participants had experienced pain in some part of the body, mainly in the upper body. For their part, Lu et al. (2016) evaluated the risk of MSDs in 393 workers in a liquid crystal display manufacturing company in Taiwan, and the results indicate that 93.18% of the workers had MSDs, either in the neck, shoulders or upper extremities. Other authors who detected the presence of MSDs in the manufacturing industry are Choobineh et al. (2021), Zare et al. (2015), and Kahya (2021), to mention just a few. Among the main risk factors that favor the development of MSDs are repetitive movements, awkward postures, static muscle loading, application of force, and vibration (Kolgiri et al. 2016).

One of the scientific disciplines that helps prevent the occurrence of MSDs is Ergonomics. According to Tosi (2020), Ergonomics focuses on the interaction that people establish with the other elements of a system in which and with which they perform their work and activities of daily living. Ergonomics aims to optimize people's well-being and the system's overall performance by assessing and designing interventions to make them compatible with people's needs, capabilities, and limitations. Among the successful applications of Ergonomics to prevent the occurrence of MSDs is the one carried out by Shin and Park (2017), who report improvements in the specification of ten workstations using a three-dimensional human modeling tool and a well-balanced work schedule to prevent MSDs in China. Similarly, Choobineh et al. (2021) implement an ergonomic intervention program in the manufacturing industry to eliminate the risk of MSDs and include three basic layers: training workshops, participatory ergonomics, and workstation redesign in Iran. More recently, Grobelny and Michalski (2020) applied the workplace design methodology involving digital human models to prevent the occurrence of MSDs and propose an approach to model two real workstations of the manufacturing industry in a 3D Studio Max environment using an Anthropos ErgoMax system.

The above leads to the conclusion that even today, workers in the manufacturing industry are exposed to MSDs, and it is due to poor workstation design (Ayub and Shah 2018). This is the case of the workers of a manufacturing company located in Tijuana, Mexico, that manufactures innovative holster designs. The production area manufactures Product A, which adheres to the user's belt and has two containers to hold bullet magazines for firearms. This product represents 26.6% of all the company's annual sales, with 106,612 finished pieces, and it is the most processed product throughout the year. In the manufacturing process, operations have been detected that represent a health risk for workers and are caused by machinery in poor condition and workstations that were not designed from an ergonomic approach. Product A comprises three models, each of which has an assembly called a "beltloop plate" that attaches the product to the user's belt. This plate is square, measures 3.5 x 3.5" and is assembled with 4 rivets, one for each corner of the plate, as shown in Figure 1a. These 4 rivets are assembled with a mechanical kick press (see Figure 1b and Figure 1c), which is 25 years old and causes the worker to adopt uncomfortable postures and repetitive movements. In a normal 8.6-hour workday, a worker operates the press 1313 times, which means that he/she performs this movement every 23 seconds, causing worker fatigue, muscle discomfort and poor performance. In addition, the quality of Product A is also directly affected, and proof of this is that as of 2020, defects caused by the use of the press began to appear.

a) b) c)

Figure 1. a. Product A, b. Mechanical kick press, c. Posture adopted by the worker when using the press.

Between December 2020 and January 2021, there were three customer complaints of nonconformity in the manufacture of product A, since they mentioned that they had problems with the fastening of the product to the users' belts. In addition, the final packaging station is one of the workstations where workers have reported feeling more uncomfortable because the table's design forces workers to adopt postures that cause pain in their back and neck (see Figure 2). This could lead to back injuries such as muscle pain, impaired sciatica, low back pain, and disc injuries due to the non-ergonomic design of the workbench.

Figure 2. Posture adopted by the workers at the packaging station

Worker dissatisfaction is directly reflected in daily absenteeism in the production area. The minimum percentage of absenteeism accepted by the human resources department is 10% per month per work area. However, the percentage of absenteeism for December 2020 was 16%, while in January 2021, it was 15%, in both cases being higher than the acceptable 10%. Based on the above, this research aims to eliminate the ergonomic risk to which workers are exposed in the mechanical kick press station and the final packaging station, applying the ergonomic design of workstations.

The rest of the document is structured as follows: Section 2 presents a literature review on ergonomic risk assessment and design methods. Section 3 presents the methodology applied to decrease the ergonomic risk level to which workers are exposed. Section 4 shows the results obtained by applying the methodology. Finally, Section 5 shows the conclusions and a discussion of the results obtained in this research.

2. Literature Review

2.1 REBA method for posture evaluation

In ergonomics, one of the most widely used methods to assess the level of risk caused by postural loading is the Rapid Entire Body Assessment (REBA) method (Schwartz et al. 2019), as it allows the postures of the upper limbs (arm, forearm, wrist), trunk, neck and lower limbs to be analyzed together (Hita-Gutiérrez et al. 2020). In addition, it discriminates the type of grip and the muscular activity performed, and it identifies five risk levels: negligible, low, medium, high and very high (Hignett and McAtamney 2000). The most problematic ergonomic aspects are identified based on the individual score obtained after evaluating each body part (Hita-Gutiérrez et al. 2020).

REBA offers the following advantages (Realyvásquez et al. 2018): 1) it divides the body into segments that are individually coded, 2) it provides a scoring system for muscle activity caused by static, dynamic, rapid changes and unstable postures, 3) it provides a level of action with an indication of urgency to find the type of ergonomic interventions that should be implemented, and 4) it does not consume too much time and resources. However, the REBA method also has the following limitations (Hita-Gutiérrez et al. 2020): 1) it only allows the analysis of individual postures, so it is not possible to analyze a set or sequence of postures, 2) task evaluations will depend on the evaluator, 3) some of the positions adopted may not be evaluated, 4) it only measures the intensity of the effort, so it does not consider the duration of exposure or the frequency of postures throughout the workday.

During the evaluation, the evaluators observe the tasks to be analyzed, and there are three techniques to carry it out: direct observation, video recording or taking photographs (Hita-Gutiérrez et al. 2020), where the objective is to collect data that will allow the method to be used to obtain results.

2.1 Método JSI para evaluación de movimientos repetitivos

The Job Strain Index (JSI) method measures the level of ergonomic risk caused by repetitive movements of the upper extremities (Patradhiani et al. 2021). The tasks must be analyzed to apply this method, and the stress index is calculated separately for each hand (Mohammadpour et al. 2018). To carry out the evaluation, the JSI analyzes six variables: intensity of effort (IE), duration of effort (DE), work speed (SW), duration of activity per day (DD), number of efforts per minute (EM), and hand-wrist posture (HWP) (Diego-Mas 2015a). Each variable is assigned a multiplication factor. Once the multiplying factors for each variable are obtained, the final score is calculated according to Equation (1):

$$JSI = IE \times DE \times SW \times DD \times EM \times HWP \quad (1)$$

A fixed number for each variable makes this method easy to use. Initially, this method recommended a JSI score of 5 to differentiate between a safe or hazardous condition (Moore and Garg 2010). Subsequently, Drinkaus et al. (2015) proposed a 4-level JSI risk level scale: risk level 1 (safe condition) when JSI $\leq$ 3; risk level 2 (uncertain condition) when 3 < JSI $\leq$ 5; risk level 3 (low-risk conditions) when 5 < JSI $\leq$ 7; risk level 4 (hazardous conditions) when JSI > 7.

2.3 Antropometría para el diseño ergonómico

Pheasant and Haslegrave (2018) mention that anthropometry is a branch of ergonomics that deals with body measurements (body size, shape, strength, mobility, flexibility and work capacity) and that the dimensions, proportions and shapes of human beings are variable, so user-centered design requires an understanding of this variability. They also mention that the objective of anthropometry is to adapt the work to the worker and the product to the user, and in Ergonomics, the application of anthropometry includes the design and layout of the spaces in which people work (Dianat et al. 2018). The above indicates that anthropometry studies the relationship between body dimensions and workstations dimensions (Kushwaha and Kane 2016; Dianat et al. 2018) and the force applied by the worker (Dianat et al. 2017) to reduce the negative consequences on health. Then, the ergonomic design approach seeks that all elements of a work system, including workstations and tools, are adapted to the anthropometry of the worker (Dianat et al. 2018).

In summary, anthropometry provides data that allows the design of equipment, tools, and/or workstations with an ergonomic approach (Kushwaha and Kane 2016; Dianat et al. 2018) and the minimum expectation is that they will suit most workers (typically from a woman in the 5th percentile to a man in the 95th percentile) (Onawumi et al. 2016). For this reason, anthropometry can positively impact work efficiency, productivity, ease of use, worker comfort, and safety (Kushwaha and Kane 2016; Dianat et al. 2018).

3. Methods

3.1 Materials

For the evaluation and analysis of the manufacturing process of Product A and the ergonomic design of the workstations, the following tools were used: measuring tape, scale, REBA online software (Diego-Mas 2015b), and JSI online software (Diego-Mas 2015a), and design software SolidWorks® and AutoCAD®.

3.2 Method

The method applied in this research to analyze operations and design workstations from an ergonomic approach is divided into the six stages shown in Figure 3.

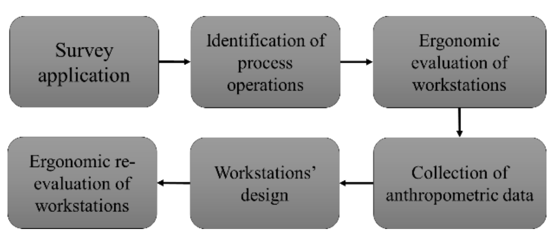


Figure 3. Applied method for evaluating operations and designing workstations

3.2.2 Stage 1: Survey application

This stage consists of 8 questions: 1) Do you perform any activity after your workday that causes discomfort in your body? 2) Have you had previous jobs? 3) Have you had any musculoskeletal injuries in your previous jobs? 4) In what part of your body? 5) How many years have you been working in the production area? 6) Have you felt any discomfort in your body while performing your work activities in the production area? 7) What work activity has caused discomfort or pain in your body? And 8) In what part of your body you have felt the most discomfort? In addition, they were also asked about their age and the position they currently hold within the company.

3.2.1 Stage 2: Identification of process operations

In this stage, the manufacturing process operations to be evaluated and the number of models that make up the product A family are defined. With this, the number of products that will undergo improvements in its manufacturing process is known and allows visualizing each of the operations of its manufacturing process. A classification is made in a table containing three columns with the headings of the part number, product description, and the model to make a flow chart of the manufacturing process of the models that correspond to product A's family. The flow chart allows distinguishing the sections of the preparation area and the main manufacturing line.

3.2.3 Stage 3: Ergonomic evaluation of workstations

The REBA and JSI methods are implemented to ergonomically evaluate the postures adopted by workers in the production area at their workstations and repetitive movements. This allows identifying the critical operations detrimental to the workers' health. For this purpose, REBA and JSI online software, available on ergonautas.com, are used (Diego-Mas 2015a, b).

3.2.4 Stage 4: Collection of anthropometric data

The objective of this stage is to define the characteristics of the population. For this purpose, anthropometric data of the population working in the production area are used, taking into account weight, height, height at the elbow, arm length from the vertical and forearm measurement. An anthropometric tape and a scale were used to take the measurements. The total population is 30 workers, divided into 20 seamstresses and 10 assemblers. To define the size of the sample of workers who undergo the anthropometric study, Equation (2) is applied:

$$n = \frac{Z^2 \times P \times Q \times N}{(N-1)E^2 + Z^2 \times P \times Q} \tag{2}$$

Where:
n = Sample size
N = Population size = 30 workers
P = Probability of success = 50%
Q = Probability of failure = 50%
Z = Confidence coefficient = 1.96
E = Sampling error = 88%

By substituting these values in Equation (2), the sample size is 25 workers.

3.2.5 Stage 5: Workstations' design

Once the ergonomic evaluation of each of the workstations of the manufacturing process is performed and the areas affected by bad postures and repetitive movements are detected, the new workstations are designed using computer-aided design software SolidWorks® and AutoCAD®. The anthropometric measurements from step 4 are used in the design.

3.2.6 Step 6: Ergonomic re-evaluation of workstations

Once the workstations have been redesigned, they are re-evaluated from an ergonomic approach using the REBA and JSI methods, using the online software available on ergonautas.com.

5. Results and Discussion

5.1 Results of stage 1

The age range of the workers surveyed is 21 to 45 years, with an average age of 36 years. Of the 25 workers surveyed, 68% are seamstresses, and 32% are assemblers, and Table 1 shows the results obtained from applying the survey to the 25 workers. Of the most noteworthy results, 33.33% of the workers already had some injury to their lower back, neck or fingers before joining the company. In addition, 68% of the workers indicated that they currently feel discomfort in their bodies when performing some activity in the production area. Likewise, the 25 workers indicated that they had felt discomfort or pain in their body, 16 (62.5%) when performing activities in the mechanical kick press, and the other 9 (37.5%) when performing activities in the packaging station. Finally, of the 25 workers, 37.5% indicated that they had felt more discomfort in the lower back, 25% in the legs, and 12.5% in the neck.

Table 1. Descriptive results of the survey

Question	Results				
Do you perform any activity after your workday that causes discomfort in your body?	Yes	No			
	22 (88%)	3 (12%)			
Have you had previous jobs?	25 (100%)	0 (0%)			
Have you had any musculoskeletal injuries in your previous jobs?	22 (88%)	3 (12%)			
In what part of your body?	Lumbar region (33.33%), neck (33.33%), and fingers (33.33%)				
How many years have you been working in the production area?	< 1	1-3	3-5	5-10	> 10
	28%	28%	20%	20%	4%
Have you felt any discomfort in your body while performing your work activities in the production area?	Yes	No			
	68%	32%			
What work activity has caused discomfort or pain in your body?	Mechanical kick press	Packaging station			
	16 (62.5%)	9 (37.5%)			
In what part of your body have you felt the most discomfort?	Lumbar region (37.5%), legs (25%), neck (12.5%)				

5.2 Results of stage 2

Figure 4 shows the flowchart obtained for the manufacturing process of the three models of product A. As can be seen, two sections were identified, the preparation section (marked in blue) and the main manufacturing line (marked in red). The diagram also indicated that the main manufacturing line consists of 7 operations, which were evaluated.

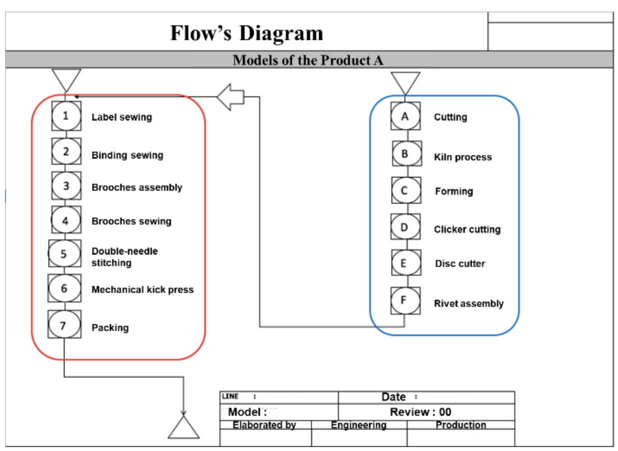


Figure 4. Product A process flow diagram

5.3 Results of stage 3

Table 2 shows the ergonomic evaluations applied to the 7 workstations in the production area using the REBA and JSI methods. In the case of the REBA method, a score of 2 or 3 was obtained in most of the workstations, so the risk caused by postural load was low, and it is not necessary to redesign these stations. However, in the mechanical kick press and packaging stations, scores of 10 and 9 were obtained, so redesigning them from an ergonomic approach is required since the risk level is high in both of them. In the case of the JSI method, in 6 of the 7 stations, a score of 3 or less was obtained, so it was determined that repetitive movements cause no risk, and it is not necessary to redesign the work method in those stations. However, in the mechanical kick press station, the score obtained was 13.5, so it was determined that there is a high risk for the worker to develop MSDs caused by repetitive movements, and it is required to redesign the work method.

Table 2. Results of the ergonomic evaluation of the workstations

Workstation	REBA evaluation		JSI evaluation	
	Score	Requires redesign?	Score	Requires redesign?
Label sewing	2	No	1.5	No
Binding sewing	2	No	1	No
Brooches assembly	2	No	2.25	No
Brooches sewing	3	No	3	No
Double-needle stitching	3	No	1.5	No
Mechanical kick press	10	Yes	13.5	Yes
Packaging	9	Yes	3	No

5.4 Results of stage 4

Table 3 shows the results of the anthropometric study for the variables to be considered in the redesign of the mechanical kick press station and the packaging station. Note that the heaviest person was a 79 kg worker, while the lightest was a 58.5 kg worker. In the case of height, the highest value was 174 cm, while the lowest value was 166 cm. Note that in almost all variables, the data obtained for the 25 workers fall within the interval defined by the 5th and 95th percentile. The lowest weight worker falls outside this interval only in the weight variable.

Table 3. Measurement of anthropometric variables of workers in the production area

Worker	Weight (Kg)	Height (cm)	Height at elbow (cm)	Arm length from vertical (cm)	Forearm length (cm)
1	63.7	168	92	74	41
2	58.5	171	97	70	39
3	73	167	92	72	40
4	70	167	95	70	38
5	78	172	90	74	39
6	71	174	96	70	43
7	61	170	97	71	43
8	74	167	89	75	43
9	78	168	95	70	42
10	60	170	90	69	41
11	78	171	97	73	43
12	69	166	97	72	39
13	59	168	95	71	42
14	78	174	89	71	40

15	66	169	96	70	39
16	73	172	92	76	45
17	76	170	93	71	45
18	69	174	97	72	44
19	63	168	89	74	44
20	79	168	97	70	43
21	78	170	97	76	41
22	74	172	88	71	45
23	61	168	92	74	42
24	74	174	95	71	42
25	72	172	88	76	38
Average	70.25	170	93.4	72.12	41.64
Percentile 5	68.8	168.36	91.76	70.48	40
Percentile 95	81.49	174.10	98.82	75.67	45.24

5.5 Results of stage 5

The mechanical kick press and packaging press workstations were redesigned using the anthropometric data shown in Table 3. In the case of the mechanical kick press, the mechanical redesign of the station included the fabrication of a semi-automatic press for the assembly of the beltloop plate to Product A. For the structure's design, the 50th percentile (average) of the anthropometric variables of height and height at the elbow was considered, while the 5th percentile was considered for the forearm length variable. This semi-automatic press is operated employing a bimanual command control that sends the signal to assemble the 4 rivets of the product in a single movement. The operation of the semi-automatic press requires a fixture to hold Product A while a press is applied to the beltloop plate to properly assemble it to the part in a single motion.

In addition, the mechanical design of the packaging station included the fabrication of a wooden table with the adaptation of a shelf for material placement. The packaging card area was relocated to the upper part of the table to avoid the workers' sudden change of uncomfortable postures. The table's design considered the 50th percentile of the anthropometric variables of height, height at the elbow, and the 5th percentile of the variables arm length from the vertical and forearm length. Figure 5 shows the 3D design of the semi-automatic press station and the packaging station, with their corresponding dimensions in centimeters.

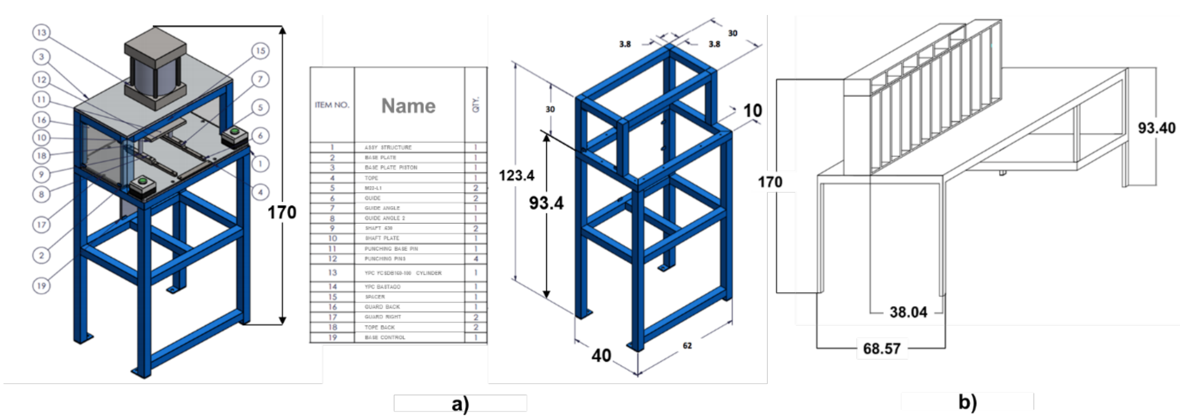


Figure 5. Workstation design: a) Semi-automatic press, and b) Packaging

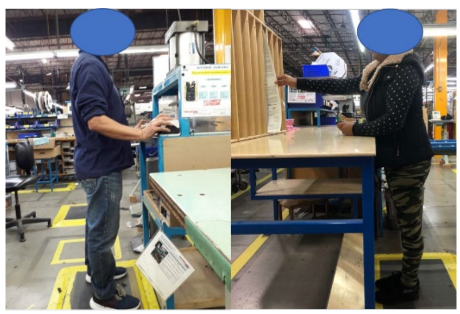
5.6 Results of stage 6

Figure 6 shows two people working at the redesigned semi-automatic press and packing stations. After re-evaluating the level of risk caused by postural loading and repetitive movements at these stations, scores of 1 and 2 were obtained with the REBA method, while scores of 1 and 3 were obtained with the JSI method for the semi-automatic press station and the packing station, respectively. In all cases, the risk level was low, so the tasks were safe for the workers.

6. Conclusions

In this research, two workstations were evaluated from an ergonomic approach to detect and eliminate risk factors that could favor the appearance of MSDS in workers. Based on the results obtained, it is concluded that the objective initially set out in this research has been achieved since the risk levels were reduced from high to low, reducing workers' exposure to factors that favor the development of MSDS.

In general, this research concludes that even today, workers in the manufacturing industry in Mexico are exposed to risk factors that favor the development of MSDs. For this reason, it is recommended that further research be carried out in companies in this sector. In addition, this research validates that the REBA and JSI methods are easy to apply and allow the detection of risk factors and opportunities for improvement in the design of workstations to eliminate exposure to these factors. Due to this, and based on the results obtained in this research, it is recommended that the company apply these methods to evaluate the levels of risk caused by postures and repetitive movements in other work areas. Finally, it is concluded that the anthropometric design of workstations is a practical and efficient tool to eliminate or reduce the level of risk caused by the postural load. Therefore, it is recommended to companies, specifically managers, supervisors, and health and safety department personnel, to go deeper into the anthropometric design, know the other variables, the application process, and its advantages and disadvantages.



a) b)

Figure 7. Workers at the redesigned stations: a) Semi-automatic press, and b) Packaging.

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Biographies

Arturo Realyvásquez-Vargas is a full-time professor from the Department of Industrial Engineering at Tecnológico Nacional de Mexico/Instituto Tecnológico de Tijuana in Mexico. He received a master's degree in Industrial Engineering and a Ph.D. in Engineering Sciences from the Autonomous University of Ciudad Juarez in Mexico. Currently, he is studying a Ph.D. in Innovation in Product Engineering and Industrial Process at the University of La Rioja (Spain). In addition, his main research areas are related to the optimization of industrial processes, lean manufacturing, and ergonomics. He is an active member of the Society of Ergonomists of Mexico Civil Association (Sociedad de Ergonomistas de México, SEMAC) and the Network of Optimization of Industrial Processes (Red de Optimización de Procesos Industriales, ROPRIN). Currently, Dr. Realyvásquez is a National Researcher recognized by the National Council of Science & Technology of Mexico (CONACYT) as level I. Furthermore, Dr. Realyvásquez is an author/co-author in around 12 papers published in journals indexed in the Journal Citation Reports. He has attended international conferences and congress in Mexico and the United States of America. Nowadays, Dr. Realyvásquez has supervised more than twenty bachelor theses and five master theses. In addition, Dr. Realyvásquez is the author of two books published by the international publisher Springer, related to ergonomics. Also, Dr.

Realyvásquez has edited books in IGI Global and Springer related to industrial engineering or ergonomics. ORCID: https://orcid.org/0000-0003-2825- 2595, Scopus Author ID: 56167726800.

Karina Cecilia Arredondo-Soto received the B.S. and master's degrees in industrial engineering from the Technological Institute of Tijuana, Mexico, in 2005 and 2010, respectively, and the Ph.D. degree in sciences of industrial engineering from the Technological Institute of Ciudad Juarez in 2017. She is currently a Professor of industrial engineering with the Chemical Sciences and Engineering Faculty, Autonomous University of Baja California. She is the Leader of the Process and Product Innovation Academic Group endorsed by the Teacher Professional Development Program (PRODEP) in Mexico. She has participated in several research projects related to process improvement. She is the author/co-author of more than 30 journal articles, books, book chapters, and conference papers. Her research interests include linkage with the productive sector to improve the indicators of the productive processes from the perspective of sustainability and human factors. She is a member of the National System of Researchers of the National Council of Science and Technology in Mexico.

Guadalupe Hernández-Escobedo has a Ph.D. in Information Behaviour and Cognitive Engineering at The University of Leeds, UK; National Researcher Candidate by CONACYT and Perfil Deseable by PRODEP; and more than 23 years of experience in teaching, research and application of Industrial Engineering at Tecnológico Nacional de México/Instituto Tecnológico de Tijuana.

Jorge Luis García-Alcaraz received the M.Sc. and Ph.D. degrees in industrial engineering, the Ph.D. degree in innovation in product engineering and industrial process, and the Ph.D. degree in sciences and industrial technologies. He was a Postdoctoral Researcher in production systems. He is currently a full-time Researcher with the Autonomous University of Ciudad Juarez. He is the National Researcher in Mexico. He has been the author/co-author in more than 150 papers, conferences and congress, author/co-author/editor of ten books, and academic editor in some JCR journals. His main research interests include manufacturing, production process modeling, and supply chain.

Cuauhtémoc Sánchez-Ramírez is a full-time researcher from the Division of Research and Postgraduate Studies of the Orizaba Technology Institute. He received a Ph.D. in Industrial Engineering from COMIMSA, a center of research of the National Council of Science Technology of Mexico (CONACYT). CONACYT and PRODEP have recognized his research projects. Dr. Sánchez is a founding member of the Industrial Process Optimization Network (ROPRIN) and a member of the National Researcher System by CONACYT level 2. He won the National Logistics Prize in 2017 given by the Secretariat of Economic, The Secretariat of Communications and Transportation of Mexico, and Soy Logístico Association in the Academic Category. Similarly, he has supervised 6 bachelor theses, 9 master theses, and 3 Ph.D. theses. Currently, he is working on 5 master theses and 1 Ph.D. thesis that are in progress. He has been editor of the following books: New Perspectives on Applied Industrial Tools and Techniques, published by Springer Verlag, Handbook of Research on Managerial Strategies for Achieving Optimal Performance in Industrial Processes, published by IGI Global Publishing. He has given 6 magistral conferences and workshops on Industrial Engineering, mainly focused on supply chain performance; he has 2 international patents. Moreover, his research interests are modeling, and simulation of logistics processes and supply chain from a system dynamics approach. He is the author/co-author in around 50 journal and conference papers in logistics and supply chain management. ORCID Number: orcid.org/0000-0002- 0344-1966.