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A Methodology for Detecting Musculoskeletal Disorders in Industrial Workplaces Using a Mapping Representation of Risk

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Abstract

A correct identification of ergonomic risks and their physical location in production areas becomes vital for the prevention of work-related illnesses. The method proposed for detecting musculoskeletal disorders (MSDs) in industrial workplaces has the objective of identifying the relationship between the workplace design and the nonergonomic task content. A mapping of work conditions was implemented to develop a diagnosis about hazards and ergonomic risk factors present in the work system. The information collected was organized in an ergonomic risk map with the following structure: inputs, information about risks and hazards, process, information about how the risk exposure leads to MSDs and outputs, and information about the consequences of risk factor exposure. The mapping results allowed determining the causes of work-related illnesses in activities of polishing and screening metals, establishing as a main cause of risk the barrel height (1.70 m) that forces the material handling above the shoulders. Force demands required to perform the task (around 277 N in each lifting) were determined. The work-related illnesses identified were low back injuries and rotator cuff injuries. The information contained in the map improves the understanding of employers and workers about the origin of ergonomic problems and supports the decision-making about improvement projects focused on risk elimination.

Keywords: ergonomics, musculoskeletal disorders, process mapping, risk assessment, hazard identification

1. Introduction

The specialist designing workplaces, equipment, and tools and selecting workers for a specific task must understand the purpose of designing activities and devices that need muscular strengths. The human muscle strength measurement is important for understanding human capabilities. Nevertheless, the knowledge about strengths developed by an individual during work does not give the specialist enough information to solve ergonomic problems that lead to musculoskeletal disorders (MSDs). Thus, a work-system elements assessment should be necessary

to find hazards that cause microtraumas [1]. The microtraumas outrun the body's recovery system causing work-related injuries that result in musculoskeletal disorders (MSDs).

From a mechanical point of view, when a machine repeats intensely specific movements during its operation, the applied forces cause fatigue in its mechanisms [2]. From a biomechanical point of view, the musculoskeletal system suffers from fatigue and wears down in joints and muscle injuries [3], when there are ergonomic risk factors at work such as employees' prolonged exposure time to awkward postures, excessive force exertion, repetitive movements, and manual material handling, causing fatigue and impacting on the health and well-being of workers [4, 5].

Consequently, a correct identification of ergonomic risks and their physical location in production areas becomes vital for the prevention of work-related illnesses.

1.1 Development of MSDs: Current situation in Mexico

In Mexico, MSDs were included in the work-related illness classification by the Mexican Health Secretary (SSA) until 2008. The Mexican Institute of Social Safety (known as IMSS) categorized the information about MSDs into seven diseases and one injury. This catalog is named "MSDs classification according to a kind of injury" and contains the following diseases [8]:

1. Other synovitis, tenosynovitis, and bursitis
2. Radial styloid tenosynovitis (Quervain)
3. Shoulder injury
4. Carpal tunnel syndrome
5. Epicondylitis
6. Other enthesopathies
7. Osteoarthritis/arthrosis
8. Dorsopathies

In 2009, the number of MSDs was recounted for the first time. **Table 1** presents data of a nine-year period (2009–2017) [6, 7]. During that period, the IMSS reported only 20,523 cases, showing an underreporting problem. Aspects like authorities not properly reporting risk conditions or workers' fear of being fired if they notify symptoms, as well as employers' evasion of mandatory law compliance [8, 9], contribute to the problem of lack of information. Despite work related-illnesses not being appropriately studied as MSDs yet, there was a data ascendant tendency in the results; see **Figure 1**.

In Mexico City, during the first forum on safety and health at work carried out in August 2015, it was determined that MSDs will be subjects of care because of their impact on workers' health [10]. To abate this health problem, the Mexican Ministry of Labour and Social Safety Secretaria del Trabajo y Previsión Social (STPS) issued a mandatory rule called Federal Rule for Safety and Health at Work (Reglamento Federal de Seguridad y Salud en el Trabajo) in November 2014 [11].

Year	Work-related illnesses	Work-related injuries	Percentage of MSDs with respect to work-related injuries
2009	266	4101	6.49
2010	513	3466	15.80
2011	788	4105	19.20
2012	1309	4853	26.97
2013	1893	6364	29.75
2014	2604	8301	31.37
2015	3722	12,009	30.99
2016	4273	12,622	33.85
2017	5155	14,159	36.41
Total	20,523	69,980	29.33

Table 1.
Total cases of MSDs developed by workers in Mexico reported by the IMSS [8, 9].

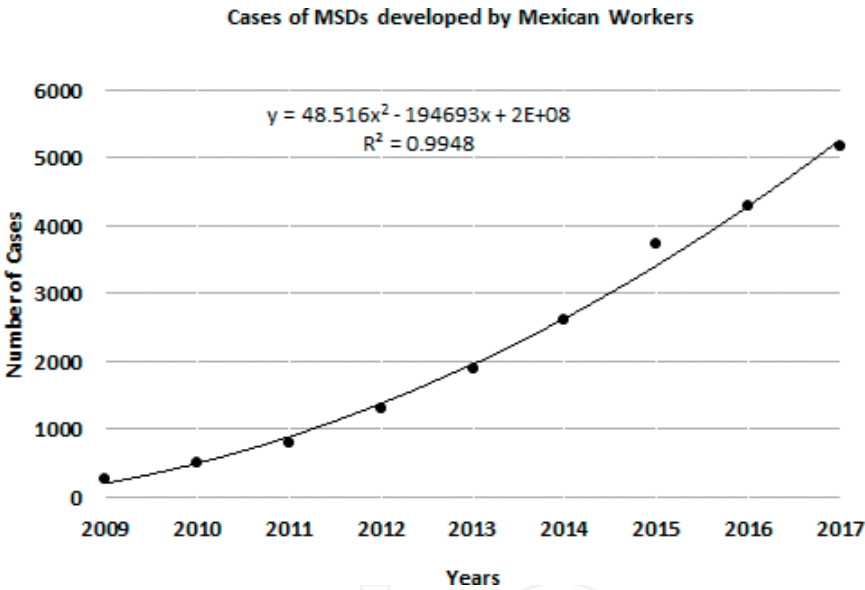


Figure 1.
Data ascendant tendency of MSD cases developed by workers in Mexico [8, 9].

It includes a new employer obligation for identifying, reporting, and reducing ergonomic risks inside facilities. Now, ergonomic risk factors are highlighted. Hence, the correct identification of MSDs becomes a big problem for the employers. Thus, the identification of ergonomic risk and musculoskeletal disorders (MSDs) for their prevention is too important. The aim of identifying the risks is to find process conditions that lead to musculoskeletal disorders and work-system elements that need changes from an ergonomic point of view.

In this chapter, a methodology for detecting musculoskeletal disorders was employed in a case study, and the diagnosis and analysis developed were used to propose a mapping representation of risks inside the workplace. The mapping resulted in a standardized representation of risks to ensure risk identification. The method includes (a) reports of the employees' complaints about workstation design and symptomatology suffered by workers as input information, (b) a description about the nonergonomic elements of the task and biomechanical studies on ergonomic risk factors that cause MSDs, (c) risk assessment results and work-related

injuries and illnesses as output information, and (d) the cost of nonergonomics spent per year giving extra information that supports the decision-making about future ergonomic interventions and workstation redesign.

2. Mapping process tool

There are representations of conditions from an ergonomic point of view, for example, the empirical design of a human-machine system about the person-process relationship designed by Lemon [12], which involves an analysis about job organization, environment, and workplace; however, his model did not consider the work-system inputs/outputs, that is, inputs, information about risks and hazards that lead to MSDs and outputs, and information about the consequences of risk factor exposure. Axelsson's design [13] included work-systems and quality in a model of ergonomics. The model combined the concept of "fitness for use" developed by Juran [14] and the concepts in the book "Fitting the Task to the Man" developed by Grandjean [15]. His model based on Lemon's proposal considered only the work-system inputs, like interaction between the worker and the process, inside work space but did not include the outputs. Delgado-Bahena et al. proposed the Ergonomic Hazards Mapping System (EHMS). The model was developed using a rough layout in which the body parts exposed to hazards or risk factors were identified [16]. Nevertheless, their model only considers the work-system outputs and did not provide information on what leads to MSDs. It is important to consider that the models presented above contribute to understanding the ergonomic process problem, but they do not add information for detecting and preventing MSDs.

In the industrial context, a system comprises an interacting component collection that brings together common purposes; the system is limited by variables at any moment in time and is subject to a cause-effect mechanism [17]. The process mapping schematizes the system model using a pictorial relationship between variables. It is composed of legends, symbols, and scales explaining the interactions between system elements with the aim to identify the activities that add value [18]. It is divided into three parts: input-process-output, where the input connections or linkages among a selected part of a process (work system) transform the resources into another valued form (output). The process map represents the whole (end-to-end) work process [19]. Therefore, designs of ergonomic risk map based on the process map concept can contribute to identifying the risk of developing MSDs.

3. Case study

The workplace comprises three polish-screeners designed and built by company personnel, and they were used for polishing pieces of metal. The three machines polished around 50,000 pieces daily. The production time comprised three shifts of 8 h, with three operators per shift. The task was developed on a standing posture. Workers took a lunch time of 0.5 h, at the middle of the work period. Ergonomic risk factors like manual material handling, repetitive movements, awkward postures, and force exerted were to be identified as a part of task performance as is observed in **Table 2**.




	Task description	Repetition by shifts
	Barrel filling with: <ul style="list-style-type: none">• Metal parts.• Corn cob powder.	44 times
	Sieve the corn cob powder from the metal parts. <ul style="list-style-type: none">• Metal parts.• Fill a metallic bucket with metal polish using a manual metallic collector.• Fill the cardboard container with the polished metal.	2295 times
	Move the filled cardboard container to the inspection area.	310 times

Table 2.
Work method.

4. Ergonomic risk map design

To design the mapping, an analogy between the process map elements and ergonomic risks was developed. The relationship map regards the input/output connections or linkages among selected work tasks, and workstations were defined. The result is presented in **Table 3**.

The notations used for classifying the body segment affectation and the risk level of developing MSDs were based on the concept used by the ergonomic standards ISO 11228-3 [20] where the color identification for each risk level was as follows:

- Green—there is no risk of developing musculoskeletal disorders; a change in working conditions is unnecessary.
- Yellow—there is a risk of developing musculoskeletal disorders; a change in working conditions is needed.
- Red—there is a high risk of developing musculoskeletal disorders; a change in working conditions is needed immediately.

Information developed during the work-system assessment that can contribute to identifying risks that cause MSDs was organized according to the connections or linkages between ergonomic risk map elements as follows:

Inputs: work place conditions and human factors

- Work place design
- Nonergonomic task content
- Individual characteristics

Process components	Ergonomic risk map
Input	Information about risks and hazards that lead to MSDs <ul style="list-style-type: none">• Work place conditions• Human factors
Process	Information about how the risk exposure leads to MSDs <ul style="list-style-type: none">• Ergonomic risk factors present in the work place• Force demands
Output	Information about the consequences of risk factor exposure <ul style="list-style-type: none">• Simple risk assessment results• Work-related injuries and illnesses• Cost of nonergonomics

Table 3.
Analogy between the process map elements and the ergonomic risk map elements.

Processes: ergonomic risk factors that cause MSDs and force demands by shift required to perform the task

- Weight manipulated
- Body segments affected
- Color identification of the risk level
- Force demands by shift required to perform the task measured in Newtons by movement
- Number of repetitions of the exertion strength

Outputs: risk assessment results, work-related illnesses, and the cost of nonergonomics

- Pain points in body segments
- Resume of task assessments
- Work-related injuries and illnesses
- Cost of nonergonomics

4.1 Method of construction

4.1.1 Inputs

Step 1. A list was made with risks or hazards that had been identified in a work-place, using data from assessment checklists. It should include only the workstation elements that limit the overall movement of the body or increase force requirements, causing pain or discomfort.

Step 2. A list was made with nonergonomic task elements, like awkward postures, repetitive movements, force exertion, and insufficient time recovery, among others.

Step 3. A list was made with individual characteristics that workers should change to prevent MSD development.

4.1.2 Process

Step 4. Photographs were added to identify the manipulated weight in each task element.

Step 5. Workstation layout was added. It represented machinery used for developing tasks.

Step 6. Images of body segments affected with color identification of the risk level were added.

Step 7. A list was made with force demands that caused pain/discomfort and exceeded the permissible standard value. It included isometric strength, leg lifting strength, grip strength, push and pull (initial force/kept force), and dynamic back extension strength, among others, in Newtons. The analysts were free to choose the measurement method that they consider most appropriate to complete this section.

Step 8. The number of repetitive exertions developed by workers was included.

4.1.3 Outputs

Step 9. A drawing of a body segment that identifies a point of pain was added. It represented the pain symptoms suffered by workers.

Step 10. All the simple risk assessments developed to determine the acceptability of risk were provided in one table. Identification of results with a color according to each risk level was obtained. REBA, NIOSH equation, and OCRA among others were included.

Step 11. All the work-related injuries or illnesses suffered by workers were categorized according to frequency in a Pareto chart.

Step 12. The cost of nonergonomics was estimated. It comprised workers with work-related injuries or illnesses, the daily salary (it included allowance for temporary inability and replacement worker salary), an average of lost workdays by a worker, and the total lost workdays per year.

5. Results and discussion

5.1 Analysis of inputs: work place conditions and human factors

5.1.1 Work place conditions

The ergonomic risk map was implemented in three polish-screener machines used for polishing pieces of metal; only nine workers were assigned to develop this task. The machines were poorly designed and built by engineers from the company. The workstation design did not consider basic anthropometric requirements, and this situation caused insufficient space for legs, incorrect working height and inconvenient arm reach, producing awkward postures that cause pain and discomfort.

5.1.2 Nonergonomic task content

With respect to nonergonomic task content, the risks found were as follows: exerting excessive force, similar task repetitively, doing work in awkward postures, being in the same posture for a long period, coming into contact with vibration surfaces, and manual handling—pushing and pulling loads and lifting and carrying loads; these conditions caused microtraumas that affect the body's recovery system of the workers.

5.1.3 Human factors

Moreover, individual characteristics like poor work practices, poor fitness, poor health habits, and poor work readiness add a probability of developing MSDs. Thus, programs about healthy life and better practices of manufacturing should be implemented.

5.2 Analysis of process: ergonomic risk factors that cause MSDs and force demands per shift required to perform the task

5.2.1 Weight manipulated

The work method included three task elements with manual handling—lifting and carrying loads:

1. Barrel filling with metal parts: a filled cardboard with 30 kg of weight is lifted over the shoulder 44 times, exerting an excessive force of around 277 N in each lifting,
2. sieving the corn cob powder from the metal parts: a filled metallic bucket containing metal polish with 20 kg of weight is handled 2295 times, exerting an excessive force of 77.62 N in each grip strength, and
3. moving filled cardboard containers with 80 kg of weight to an inspection area 310 times. Leg lifting strength of 143.20 N, dynamic back extension strength of 245.15 N, and push and pull (initial force/kept force) of 291/236 N, respectively, were considered in this force demands.

The task exceeds the biomechanical work load capacity of workers; this means that the musculoskeletal system suffers from fatigue and wears down in joints and muscle injuries. The workers have developed dorsopathies.

5.2.2 Body segments affected and color identification of the risk level

- Upper limbs—Red—there is a high risk of developing musculoskeletal disorders; the repetitive movements need to be eliminated immediately.
- Shoulders—Red—there is a high risk of developing musculoskeletal disorders; the height of the barrel need to be reduced immediately.
- Trunk (back)—Red—there is a high risk of developing musculoskeletal disorders; the conditions of manual material handling need to be changed immediately.

5.2.3 Force demands by shift required to perform the task measured in Newtons by movement and a number of repetitions of the exertion strength

The method used for the classification and definition of human muscular strength was proposed by Mital and Kumar [21], which divides the strength criteria into two sections: characteristics of the effort that include static isometric muscle strengths and isokinetic muscle strengths and characteristics of the application that include static functional strengths and dynamic functional strengths. The results obtained are summarized in **Table 4**.

5.3 Analysis of outputs

5.3.1 Pain points in body segments

In order to determine the pain points in body segments a questionnaire about MSD symptoms was to apply to the 9 operators of the three polish-screener machines. In the questionnaire the workers had to mark the body segment where they felt pain or had any injury. The resume of their answers is shown in **Figure 2**. The results do not correspond with the official information provided by the safety and health department used for building the Pareto chart developed for determined work-related injuries and illnesses (see Section 5.3.3).

5.3.2 Identification of task assessments

The results from the simple risk assessments were summarized in a table. In all the cases, the resulting risk levels were unacceptable. It allowed identifying the main unsafe and unhealthy task components. See **Figure 3**.

5.3.3 Work-related injuries and illnesses

The method employed to represent the work-related illnesses was the Pareto chart. It is a frequency distribution (or histogram). It was used for arranging injuries and illnesses by category. The Pareto method and rules of 70/30 (Pareto principle) allow identifying the main MSDs developed by workers in the work area. It can be used from the ergonomic intervention standpoint [22]. The information to build the Pareto chart was proportioned by the safety and health department. This official information indicates that all workers in the area (nine in total) have been suffering from almost two work-related injuries or illnesses (see **Figure 4**). It confirms the analysis developed in Section 5.2.1. However, it is contradictory with respect to workers' complaints. They identified the shoulder pain as the main

Classification	Measurement by movement (N)	No repetitions
Isometric shoulder strength	277.00	44
Leg lifting strength	143.20	310
Grip strength	77.62	2295
Push and pull (initial force/kept force)	291/236	310
Dynamic back extension strength	245.15	310

Table 4.
Force demands by shift required to perform the task.

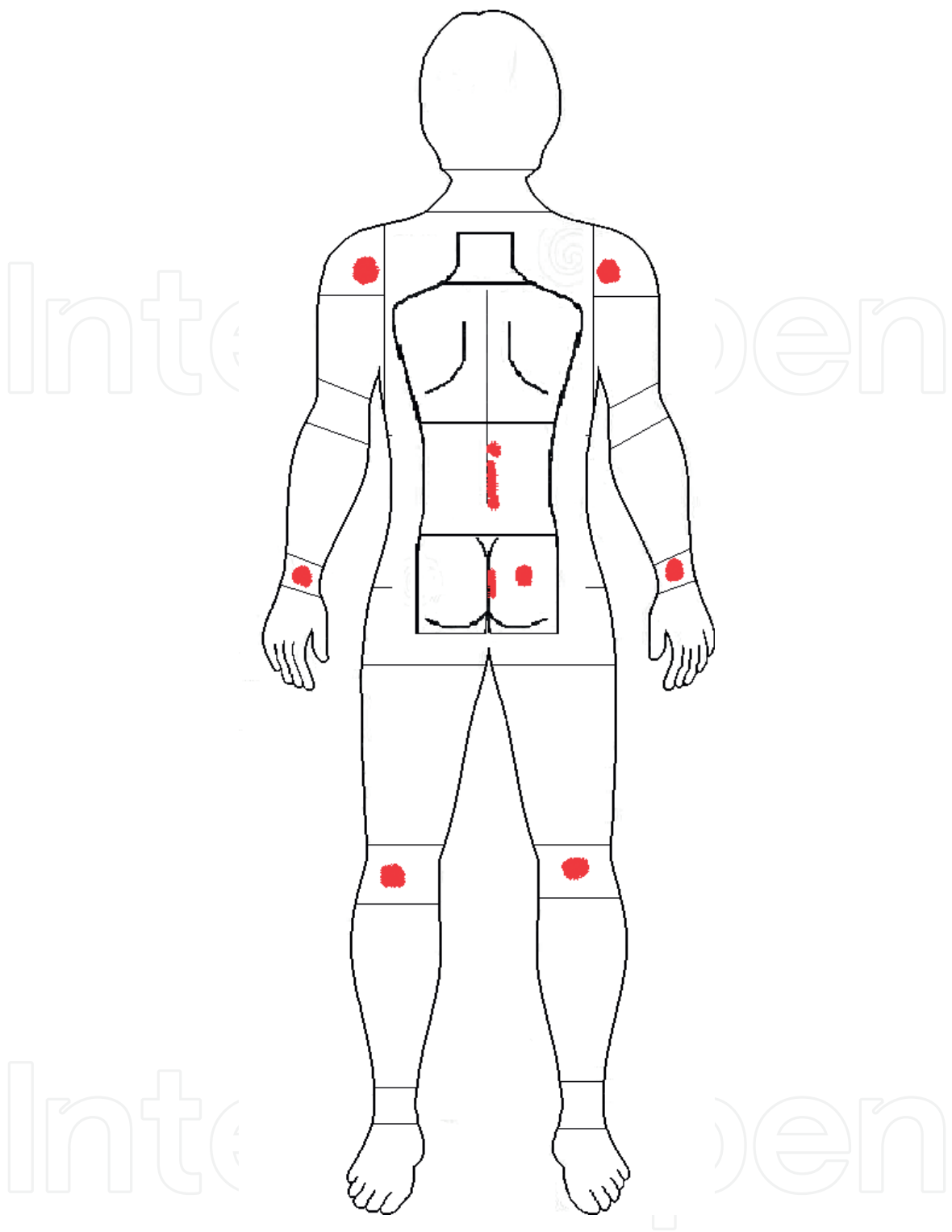


Figure 2.
Pain points in body segments selected by the workers through a questionnaire.

OCRA		X	
NIOSH			X
SNOOK and CIRIELLO			X
REBA			X
ADDITIONAL FACTORS			X
TIME RECOVERY			X

Figure 3.
Identification of task assessments.

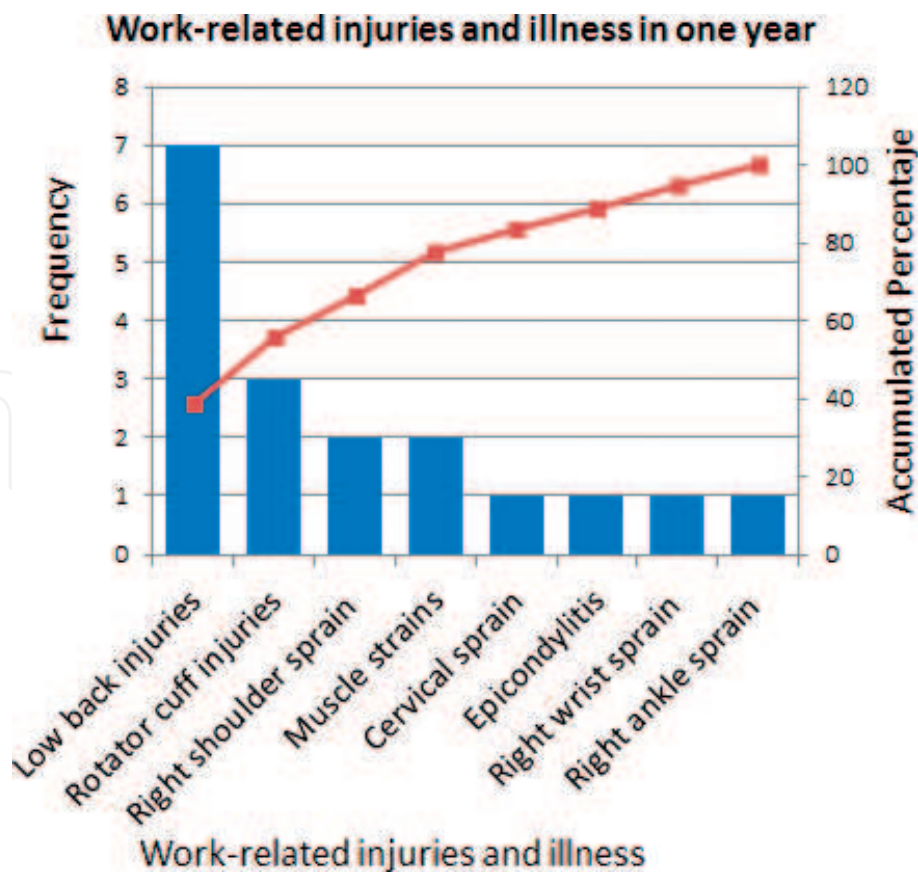


Figure 4.
Pareto chart about work-related injuries and illnesses.

symptom of MSDs. Thus, new studies to implement strategies to balance the differences of opinion are necessary.

5.3.4 Cost of nonergonomics

Workers with work-related injuries or illnesses: 18.
Daily salary: \$34.63 USD (includes allowance for temporary inability).
Average of lost workdays by a worker: 35.
Total lost workdays per year: 630.
Total cost of nonergonomics: \$392,704 USD (\$7,461,380 MXP).
The resulting cost supports the suggestion to change the working method to eliminate repetitive movements, reduce the barrel height, and improve conditions about manual material handling.

5.4 Ergonomic risk map

All the information presented in previous sections was organized in a single spreadsheet. The ergonomic risk map shown in **Figure 5** summarizes result series derived from an exhaustive work place evaluation. The map added evidence necessary to determine that musculoskeletal disorders were caused by the work-place and incorrectly designed tasks. The resulting ergonomic risk map allowed to determine the causes of MSDs developed in activities in a three polish-screener, establishing the barrel height as a main cause of risk. The excessive height forces the material handling above the shoulders. This increases force demands required to perform the task. On the other hand, the work method must be changed in order to reduce repetitive movements. The map improves the employers’

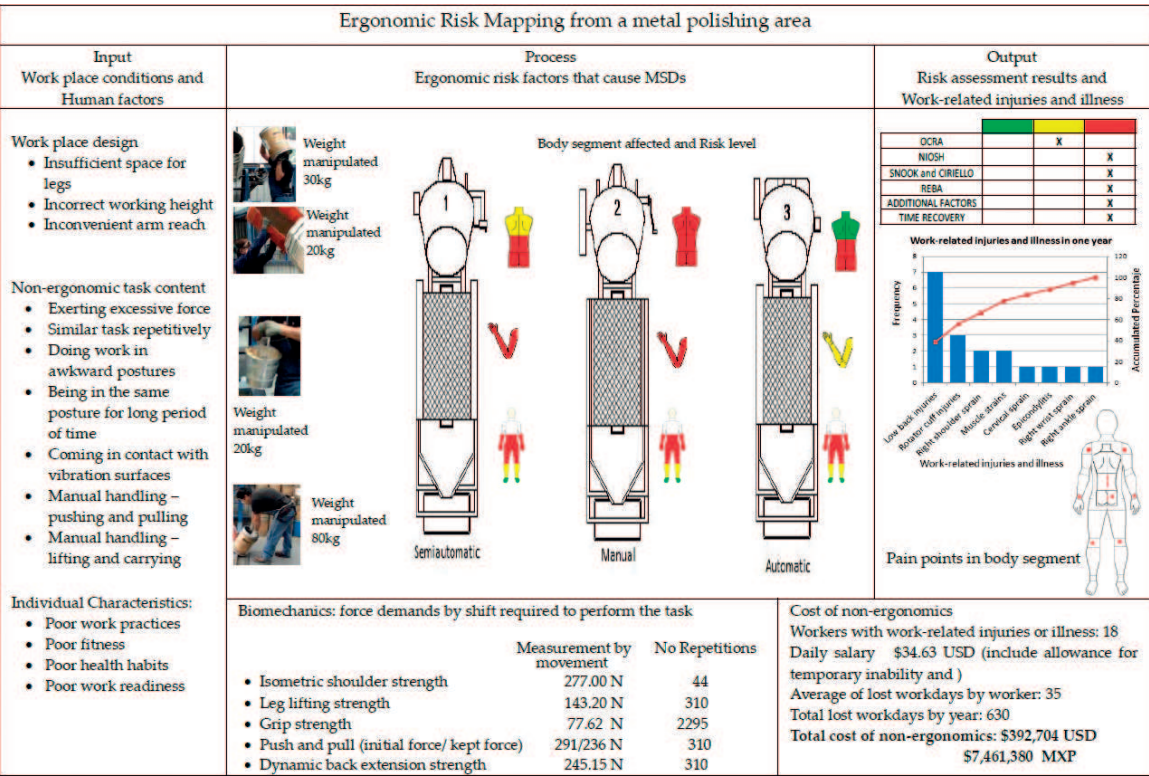


Figure 5.
Ergonomic risk map from three polish-screener machines.

understanding about the origin of ergonomic problems present in the polishing area and supports the decision-making about improvement projects focused on risk elimination.

6. Conclusions

The assessment and diagnosis method used for building an ergonomic risk map was developed and implemented with the objective of identifying the relationship, between the workplace design and the nonergonomic content task. The standardized method allows obtaining relevant diagnosis about hazards and ergonomic risks factors present in the work system that leads to musculoskeletal disorders. The study shows that the ergonomic risk map (a) improves the understanding of the workers and employers about the origin of ergonomic problems present in working areas, (b) identifies the main unsafe and unhealthy areas and work-system components, (c) supports the decision-making about improvement projects focused on risk elimination. However, the complaints and employers’ opinion in many cases were contradictory with respect to official information. Thus, new studies to implement strategies to balance the differences of opinion are necessary.

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