Prioritization of the Industrial Maintenance Activities According its Ergonomics Risks using Multi-criteria Analysis AHP

Marjorie Belinelli[1], Izabel C. Zattar[2], Marcel Matsuzaki da Silva[3], Robson Seleme[4], Gilberto F.M. de Souza[5], Marcelo Rodrigues[6],Claudilaine Caldas de Oliveira[7], Apledinei Savoldi[8]

[1,6]Professor, Department of Mechanical Engineering and Maintenance Industrial,UTFPR – Federal University of Technology of the Paraná Professora Laura Pacheco Bastos Avenue.800, 85053-525 Guarapuava, Brazil
[2,4]Professor, Department of Production Engineering,UFPR – Federal University of the Paraná Coronel FranciscoH. Dos Santos str. S/n,, 81531-980 Curitiba, Brazil
[3]Master Degree Academic Student,
[8]Tecnician,Sciences of Healthcare,
[5]Professor, Department of Mechanical Engineering,USP – University of São Paulo Professor Mello Moraes Avenue. 2231, 05508-030 São Paulo, Brazil
[7]Doctoral Student, Department of Production Engineering, UFSC – Federal University of Santa Catarina

Abstract.-*Theactivities of industrial maintenance, which provide operational availability and reliability to the industrial production system, have at their core occupational risks to workers, particularly of ergonomic that influence the physical and organizational working conditions. The ergonomic factors related to industrial maintenance activities are poorly studied. Therefore, there is a need to identify the risks of ergonomic intrinsic to industrial maintenance activities and thus classify them regarding: the degree of treatment priority, their dangerousness concerning the physical conditions of the maintenance technician and their influence on the quality of maintenance services. This article demonstrates the identification of ergonomics risks presents during the performance of industrial maintenance activities, with the application of the AHP (Analytic Hierarchy Process) multi criteria analysis. This risk analysis directs to the criticality level determination, and to the impact that these risks may result regarding the quality of the industrial maintenance service provided.*

Keywords:*Industrial Maintenance,Multicriteria Analysis,Risk Analysis,Ergonomics,Analytic Hierarchy Process (AHP).*

I. INTRODUCTION

Within industrial organizations, it is clear that the major priorities are the high productivityindex and high quality levels. Therefore, the labor productivity as well as the quality of the performed service have be seen as key elements for achieving these priorities. Accordingly, the study of ergonomics is highly important to identify the risks involved in the physical and organizational working conditions and to determine the appropriate ergonomic recommendations for the performance of industrial tasks, providing safety, self-satisfaction and quality of life during labor activity to the worker.

Industrial maintenance increasingly becomes a strategic function to obtain operational availability and reliability in the industrial system, for it is one of the functional and operational activities that ensure operational consistency, efficiency and productivity of an industrial system, and its main objective is to avoid or to mitigate the consequences of failure and, therefore,to provide aneconomic and reliable operation of an industrial system ([1]-[5]).

However, labor activities for the industrial maintenance can result in risk factors of ergonomic nature arising from the inadequacy of the workplace, leading the workers to adopt inappropriate postures during their working time([4],[6]-[8]).

In this context, the adoption of inappropriate postures in any industrial activity to perform certain tasks associated with other existing occupational hazards in the workplace constitute the major causes of absence from work and human suffering ([1],[10]-[16]).

Therefore, the prevalence of occupational hazards forworkers in industrial maintenance,mostly originating in the work environment, are: confined space, radiation, presence of chemicals, inappropriate layout for performing the maintenance work, etc.

Work environments with risk to the workers' health, even if indirectly, reflect in the cost for companies, for example, costs related to productivity loss due to the absenteeism of workers, lower efficiency of the worker's abilityinfluencing in the quality of the performed work, which contributes to the increase of defects, rework and downtime([17]-[19]).

The present studydeals with the issue of risks of ergonomic nature related to musculoskeletal functions, which are intrinsic to industrial maintenance activities, by characterizing their criticality with the application of the AHP multicriteria method (Analytical Hierarchy Process). This criticality is determined by the impact level of the risk of ergonomic nature in the worker's health and safety, as well as by the quality of the performedservice, factors that influence the operational availability and reliability of the industrial system.

The AHP multicriteria decision-making process is widely used in the maintenance engineering decisions in the selection of appropriate maintenance strategies for each type of production system, this type of application is present in articles by authors such as ([20]-[23]). This article differs from the others byapplying the AHP decision-making method in the prioritization of critical activities of industrial maintenance regarding the risk factors of intrinsic ergonomic nature in the performance, in order to assess their impact on the worker's health concurrently with the level of quality of the performed maintenance service.

Throughout this article, the means of identification and description of the activities performed by industrial maintenance and the characterization of the critical level of each of them by applying the AHP multicriteria method are shown in detail. Thisrisk analysis aims atprioritizing these maintenance activities regarding the risk posed to workers' health andthe impact of ergonomic factors in the indicators of operational availability and reliability.This analysis determines the critical level and the impact that these ergonomics risks may influence regarding the quality of the industrial maintenance activities and the workers health, assisting the industrial management in the making - decision in which maintenance activity must initiate the improvements related to ergonomic aspects in the work environment.

II. METHODS AND MATERIALS

This research aims at evaluating the impact of risks of ergonomic nature inherent in industrial maintenance activities, classifying them as to their degree of impact on the workers' quality of life and on the quality of the maintenance service provided.

Initially, the activities performed by the workers in the industrial maintenance sector were listed (Table 1) with their respective risk factors of ergonomic nature by the means of a review of the literature.

TABLE 1.ACTIVITIES CARRIED OUT IN THE INDUSTRIAL MAINTENANCE SECTOR

Industrial maintenance activities	
Maintenance in confined space	Work at height
Machinery assembly	Painting
Great effort to maintenance activities execution	Welding
Vibration movement during maintenance activities execution	Lubrication
Electrical equipment maintenance	Maintenance of equipment and parts on workbenches (maintenance workshop)
Cutting machinery maintenance	Predictive maintenance

In parallel, the risk factors of ergonomic nature assigned to the activities were checked. These factors were obtained by the means of records contained in the literature and in the Ergonomics Regulatory Standard in Brazil - NR17. Moreover, to obtain the risk factors of ergonomic nature,techniques of Anthropometry and Biomechanics were considered.

Table 2 presents the risk of ergonomic nature, which were divided into five categories: upper limbs (arms and elbows), lower limbs (hips and legs), torso structure (neck and head), whole body structure and limbs hands and fists.

TABLE 2. RISK CATEGORIES OF ERGONOMIC NATURE

Category (Musculoskeletal Group)	Criteria (Risks ofErgonomic Nature)
Category 1 Upper Limbs - Arms and Elbows (Criteria)	1.1 Difficulty in moving the arms
	1.2 Elbow flexion
	1.3 Arm abduction - lateral

	1.4 Pushing
	1.5 Pulling
	1.6 Arm flexion - horizontal
	1.7 Arm flexion - vertical
Category 2 Lower Limbs - Hips and Legs (Criteria)	2.1 Difficulty in moving the legs
	2.2 Squat–flexion of the legs
Category 3 Torso Structure - Neck and Head (Criteria)	3.1 Neck flexion
	3.2 Difficulty in moving the torso
	3.3 Pressure on the chest
	3.4 Back flexion
Category 4 Body Structure (Criteria)	4.1 Static posture (standing position) for a long period of time
	4.2 Lifting
	4.3 Carrying
	4.4 Muscle fatigue
	4.5 Limbs perforation
	4.6 Limbs injuries by crushing
	4.7 Fall risk with multiple severe musculoskeletal injuries
Category 5 Limbs Hands and Fists (Criteria)	5.1 Wrist flexion
	5.2 Wrist twist
	5.3 Tightening
	5.4 Riveting
	5.5Screwing
	5.6Unscrewing

Regarding the abovementioned data (ergonomic risks and critical activities), the AHP multicriteria method was appliedto evaluate the activities related to the ergonomic impacts on workers of the maintenance sector in order to sort them according to their level of criticality. To this end, an adaptation of the procedure proposed by Saaty in 1980 [24]was used,which consists of three stages: (i) building a hierarchy; (ii) establishing priorities, and (iii) analysis of the inconsistency of the judgments. These stages will be developed throughout this study.

III. BUILDING A HIERARCHY

This stagedemonstrates the problem addressed hierarchically.This hierarchy is based on the link between the objective (to analyze the impacts of ergonomic risk) and the categories of musculoskeletal groups and their criteria (their ergonomic risks) which relate to the alternative (activities performed by workers in the maintenance sector that have the risks analyzed).

In sequence, a cross was made between the related maintenance activities and their risks of ergonomic nature,which have been assigned within each of the categories, thus forming a hierarchical relation of this work (Figure 1).

The hierarchy's objective was to analyze the risk impacts of ergonomic nature on industrial maintenance activities, this objective being directly related to the general objective of this research.

Regarding the criteria, they are used by the theoretical model as parameters for the individual assessment of the alternatives, being expressed quantitatively. Hence, in this study the criteria are the risks of ergonomic nature and the alternatives are the maintenance activities. Thus, the hierarchy allows specialists to evaluate each maintenance activity (alternatives) from the perspective of ergonomic risks (criteria), allowing their ranking according to their respective criticality.

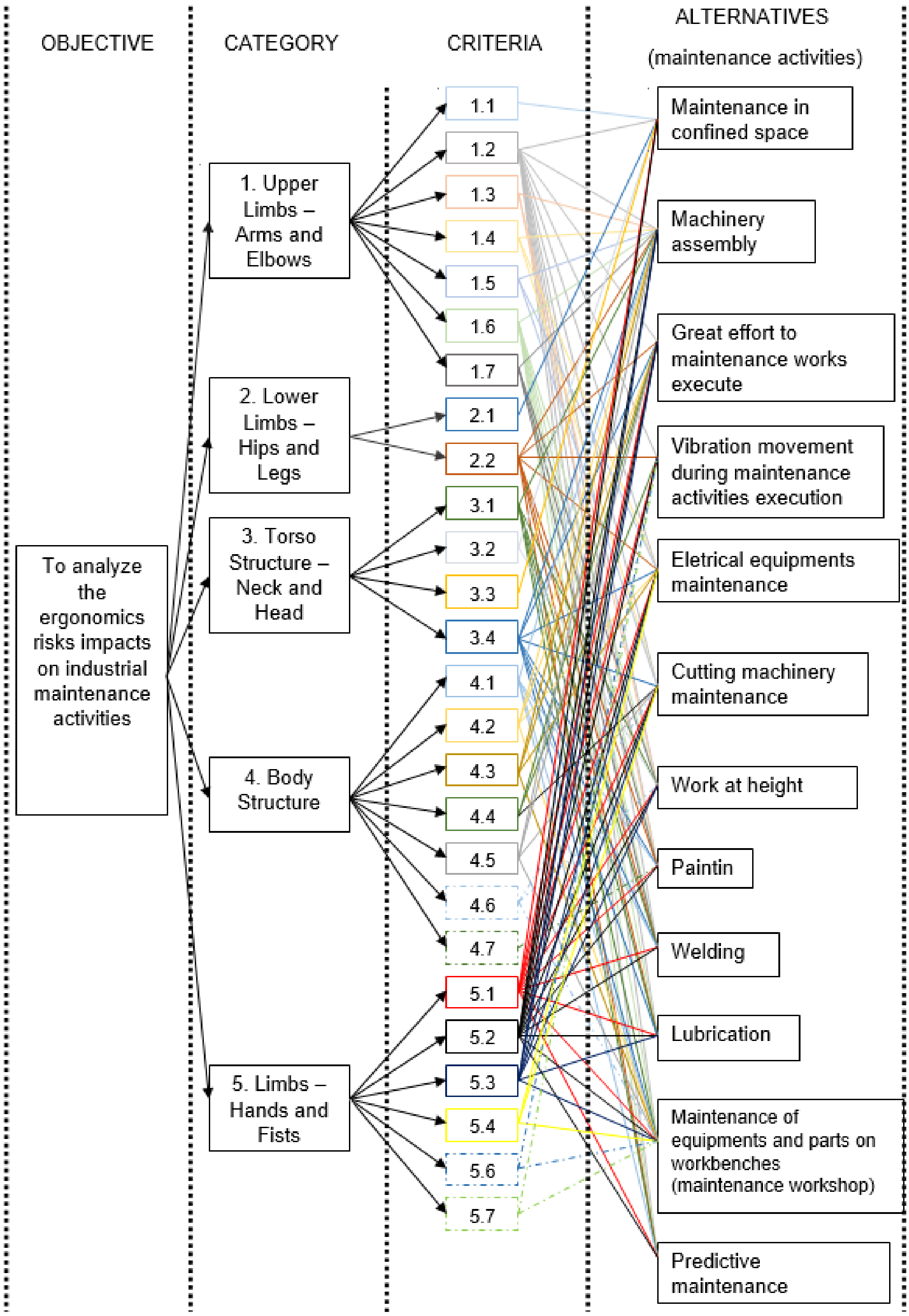

Fig. 1:Hierarchy among categories based on the criteria of ergonomic risks

A. Establishing Priorities

In this stage, firstlyit is performed the calculation of the constants of scale (K), also (commonly) called weights, to each criteria and hierarchy category (shown in Figure 1), in the view of the decision makers (specialists). To obtain the KCR for categories and criteria, every decision maker should conduct a pairwise comparison: of the criteria (ergonomic risks), of the categories and of the performance of the maintenance activities related tothe criteria (risks) inherent to their performance, assigning a value according to theSaaty scale [24] on the points: **1 – equal importance;3 – moderateimportanceof one over another;5 – strong or essential importance;7 – very strong ordemonstrated importance;9 – absolute importance;2, 4, 6 and8 – intermediate values.**

The assignment of weights to categories/criteria (V1, V2 and V3) was performed by three decision makers: anspecialist in the maintenance and human reliability engineeringarea (S1); anspecialist in the industrial maintenance engineering area (S2); and anspecialist in the ergonomics area (S3).

In which:**V1 = Value assigned by the specialist to an equal comparison of the criteria;V2 = Value assigned by the specialist to a pairwise comparison of the categories;V3 = Value assigned by the specialist to a pairwise comparison of the performance of maintenance activities in relation to the criteria (risks of ergonomic nature).**

As an example, Table 3 shows the pairwise comparison made by the specialistS3 for the categories in the hierarchy.

TABLE 3. EVALUATION OF THE PAIRWISE COMPARISON FOR EACH CATEGORY OF THE MUSCULOSKELETAL GROUPS

V_2 - Value assigned by the specialistS_3					
Category X Category	Upper Limbs - Arms and Elbows	Lower Limbs - Hips and Legs	Torso Structure - Neck and Head	Body Structure	Limbs Hands and Fists
Upper Limbs - Arms and Elbows	1	3	$\frac{1}{3}$	$\frac{1}{3}$	1
Lower Limbs - Hips and Legs	$\frac{1}{3}$	1	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
Torso Structure - Neck and Head	3	3	1	3	5
Body Structure	3	3	$\frac{1}{3}$	1	3
Limbs Hands and Fists	1	3	$\frac{1}{5}$	$\frac{1}{3}$	1

It was observed (Table 3) that the five categories were compared among each other forming a 5x5 matrix in which the main diagonal represents the comparison among the categories, being assigned the value 1, for when the category is confronted with itself it presents "equal importance". Nevertheless, the other pairs can assume different values, for example, the specialist assigned the value 5 when comparing the category 3 to the category 5, indicating that the former has strong or essential importance in relation to the latter.

After the performance of the pairwise comparison of categories, the same procedure for the criteria listed in the same categories began. To the pairwise comparison performed to criteria of the categories (**criteria details on Table 2. Risk categories of ergonomic nature**) was applying the same method and steps. It is emphasized that for assigning values to the criteria and categories, specialists (S1, S2 and S3) followed relevant matters regarding pairwise comparison, which are expressed below:

Matter A: To determine the value (V_1) for each criterion (risk of ergonomic nature) within its category (musculoskeletal group) in relation to the other criteria of the same category, its impact is assessed: (1) In the health, safety and quality of life of the workerin the maintenance area;(2) In the quality of the maintenance service provided.

Matter B: To determine the value (V_2) of each category (musculoskeletal group), its influence on the other categories is assessed: (1) In the performance of the workers' activities in the maintenance area during their working time; (2) In the quality of the maintenance service provided in relation to the other categories of musculoskeletal groups; (3) In the health, safety and quality of life of the worker in the maintenance area.

To obtain theconstants of scale for each criterion and category (KCR and KCT), the matrix generated by pairwise comparison, denoted A, is subjected to a normalization process. This process is performed through the division of each element (wi) by the sum ofits respective column. Subsequently, the objective is to obtain the priority vector ($\overline{W}$) which represents the constants of scale of the evaluated elements in the matrix A (which in this study refer to the KCR and KCT values).

In which: KCR = Constant of scale calculated by the AHP method for criteria;KCT = Constant of scale calculated by the AHP method for categories.wi = Element of the matrix and $\overline{W}$ = Priority vector

The priority vector is calculated by the means of $a_{i1} w_{i1}, a_{i2} w_{i2}, \ldots, a_{in} w_{in}$, i.e., by the Equation (1):

$$\bar{W}_1 = \frac{1}{n} \sum_{j=1}^{n} a_{ij} w_j \ , \qquad i = 1, 2, \ldots, n \quad (1)$$

After identifying the constants of scale, the determination of the performance for the alternatives (maintenance activities details on **Table 1. Activities carried out in the industrial maintenance sector**) in function of the criteria (ergonomic risks details on **Table 2. Risk categories of ergonomic nature**) begins. The procedure is similar to the previous one, starting with the pairwise comparison and finding the priority vector, now confronting the alternatives instead of the criteria and the categories. In this process, the priority vector ($\bar{W}$) represents the performance of the activities in function of the criteria from the perspective of the specialist.

For the analysis of assigning values regarding the performance of the criteria (risks of ergonomic nature) for each industrial maintenance activity that was identified, specialists (S1, S2 and S3) followed this pertinent matter:

Matter C: To determine the value (V3) of the performance of each criterion for each maintenance activity that presents this risk of ergonomic nature during its performance, in relation to the other criteria present in the analyzed activity, its impact is assessed: (1) Inthe quality of the maintenance service provided in conjunction with its consequences on the quality of life, health and safety of the worker in the industrial maintenance sector.

B. Analysis of the Inconsistency of the Judgments

After establishing priorities, the analysis of the inconsistency of the judgmentpaired with the criteria and categories begins. To this end, the procedure inherent to the AHP method was used, which consists in finding the consistency ratio (CR) given by the Equation (2).

$$CR = \frac{CI}{RI} (2)$$

The CI representstheconsistency indexfound in the pairwise comparisons of the specialistsand it is represented by the Equation(3):

$$CI = \frac{\lambda_{max} - n}{n-1} (3)$$

On the other hand, the RI refers to the random index and its values are found in [27], as shown in Table 4.

TABLE 4.RANDOM INDEXES RI

Matrix order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The judgment is inferred as consistent if the CR is less than 0.10, thus being possible to proceed with the method. None of the judgments was inferred as inconsistent, on the contrary, all of them obtained CR less than 0.10.

IV. RESULTS

With the application of the AHP multicriteria decision-making method, the classification of the maintenance activities regarding the criticality of the impacts of the risks of ergonomic nature intrinsic to the performance of these activities was obtained.

The calculation of the criticality value of each industrial maintenance activity was obtained by joining the constants of scale related to: (1) The criteria that are related to the risks of ergonomic nature (K_{CR});(2) The categories of the musculoskeletal groups (K_{CT}) and (3) The performance of the industrial maintenance activities (K_{DS}).

Initially the criticalities of each industrial maintenance activity (C_{SP}) were calculated throughthe evaluation of each specialist (S_1, S_2 and S_3) with the application of the Equation (4).

$$\overline{Csp} = \begin{bmatrix} kds_{1,1} & \cdots & kds_{n,1} \\ \vdots & \ddots & \vdots \\ kds_{m,1} & \cdots & kds_{n,m} \end{bmatrix} . \begin{bmatrix} kcr_1 \\ \vdots \\ kcr_m \end{bmatrix} . \begin{bmatrix} kct_1 \\ \vdots \\ kct_m \end{bmatrix} (4)$$

In which:C_{SP} = Criticality of the industrial maintenance activities calculated by the AHP method by thespecialists;K_{DS}= Constant of scale calculated by the AHP method for the performance of the industrial maintenance activities in function of the criteria (risks of ergonomic nature);K_{CR} = Constant of scale calculated by the AHP method for the criteria and K_{CT} = Constant ofscalecalculatedby theAHP method for the categories.

To obtain the evaluation of the three specialists,the Aggregation of Individual Priorities (AIP) method was used. This method is suggested when a group is formed by individuals who do not have common objectives, tending to evaluate according to their preferences and values, without considering the opinion of the other members of the group. Therefore, the AIP determines that the decision to be taken by the group is given by the geometric mean of the$\overline{CSP}$of all thespecialists ([25]-[26]), called C_{ME}, and is given by the Equation (5), described below:

$$C_{ME} = \sqrt[3]{C_{SP(S1)} . C_{SP(S2)} . C_{SP(S3)}} \quad (5)$$

In which:C_{ME}= Final Resultof the Criticality of the Industrial Maintenance Activities Calculated by the AIP Method.

The final value of the classification of the industrial maintenance activities (regarding the criticality of the ergonomic factors intrinsic to its performance) was obtained by balancing the evaluation of the categories, criteria and performance of thespecialists (S_1, S_2 and S_3), conjointly with the application of the equations related to the AHP multicriteria decision-making method. Figure 2shows the final result of the classification of the industrial maintenance activities related to the risks of ergonomic nature.

Maintenance activities	C_{SP} S_1	S_2	S_3		C_{ME} Result
Maintenance in confined Space	0.2551	0.1464	0.1323		0.17034
Machinery assembly	0.2142	0.1513	0.0366		0.10777
Great effort to maintenance activities execution	0.0426	0.0538	0.0950		0.10585
Vibration movement during maintenance activities execution	0.0698	0.1035	0.0543		0.06017
Electrical equipments maintenance	0.0427	0.0547	0.0377		0.01276
Cutting machinery maintenance	0.0601	0.1600	0.1302	=	0.13570
Work at height	0.0587	0.1147	0.3711		0.07319
Painting	0.0461	0.0345	0.0173		0.10467
Welding	0.0431	0.0207	0.0369		0.03207
Lubrication	0.0090	0.0123	0.0187		0.04446
Maintenance of equipments and parts on workbenches (maintenance workshop)	0.1545	0.1365	0.0544		0.03018
Predictive maintenance	0.0041	0.0117	0.0155		0.00905

Fig.2:Result of the criticality of the industrial maintenance activities related to their intrinsic ergonomic factors

Table 5 shows the classification ranking of the maintenance activities from the most critical activity to the lowest criticality in relation to the risks of ergonomic nature.

TABLE 5. CLASSIFICATION OF THE INDUSTRIAL MAINTENANCE ACTIVITIES

Classification	Maintenance Activity	Criticality Level in Relation to the Risks of Ergonomic Nature
1^{st}	Maintenance in confined space	0,170
2^{nd}	Cutting machinery maintenance	0,136
3^{rd}	Machinery assembly	0,108
4^{th}	Great effort to maintenance activities execution	0,106
5^{th}	Painting	0,105
6^{th}	Work at height	0,073
7^{th}	Vibration movement during maintenance activities execution	0,060
8^{th}	Lubrication	0,044
9^{th}	Welding	0,032
10^{th}	Maintenance of equipments and parts on workbenches (maintenance workshop)	0,030
11^{th}	Electrical equipments maintenance	0,013
12^{th}	Predictive maintenance	0,009

This classification,regarding the criticality of the maintenance activities in relation to their risks of ergonomic nature, allows to prioritize the activities for analysis and recommendations, whose objective is to improve the conditions of the workplace, aiming at the reduction of risk impacts on theworker's quality of life and at the improvement of machinery maintainability, a factor that reflects in the maintenance and production performance indicators.

Through the values shown in the table, it is possible to verify that the most critical maintenance activities are the maintenance in confined space(tanks, reactors, wells, etc.) and the maintenance of cutting machinery (machine tools, tooling, etc.), which involve ergonomic risk factors such as elbow flexion, pushing and pulling, arms and legs flexion (squat), back flexion,lifting and carrying equipment and/or parts, flexion and twist of the wrist during theirperformance. By characterizing industrial maintenance activities involving more serious risks, thus indicated as a starting point in the industrial maintenance sector,it is possible to start an ergonomic risk analysis program in order to make recommendations such as: betterpractices of the performed activity, application of technologies and/or tools, layout modification, etc., which promote improvementsin the ergonomics of the workplace.

Maintenance activities involving machinery assembly, effort and painting (of machines and/or industrial facilities) present too similar values oftheir criticality index, regarding the risks of ergonomic nature involved in theirperformance, practically equaling them to the same priority to the development of the ergonomic analysis and recommendations.

Within the criticality classification of the industrial maintenance activities, the predictive maintenance presented the lowest criticality of risks of ergonomic naturecompared to the other activities, thusits analysis of the risks of ergonomic factors of the musculoskeletal system for recommendations hasthe lowest priority to be performed.

V. CONCLUSION

Industrial maintenance is a strategic function for organizations searchingforoperational availability and reliability of the production system. However, these activities can generate risks of ergonomic nature that may affect the workers' physical integrity during the performance of these tasks, requiring a risk analysis through the identification, removal, control and prevention of these ergonomic risks associated withmaintenance activities.

This paper presents a study on the risks of ergonomic nature intrinsic tomaintenance activities, in order to prioritize these activities for analysis and preventive recommendations. In the technical literature, various maintenance activities were identified and their ergonomic risks (criteria) were assigned to them, which are related to biomechanical factors of the musculoskeletal system.

To identify the criticality level of the assessed maintenance activities, the AHP multicriteria decision-making method was applied, which was developed by assigning values to the risks of ergonomic nature related to the activities, being these risks assessed by their impact on the physical integrity of the maintenance area worker and its influence on the quality of the maintenance service provided, a factor that consequently impacts on the operational availability and reliabilityperformance indicators.

With the application of the AHP multicriteria method, the criticality level of each maintenance activity in function of its associated ergonomic risks wascalculated,thus a classification among these activities was obtained, making it possible to prioritize the most critical one (in relation to the ergonomic risks) to start the ergonomic analysis of the workplace.

The prioritization of activities makes it possible to know the ergonomic factors of greatest impact during their performance, thus identifying their influence on the workers' quality of life and the quality of theperformed maintenance service.

This classification facilitates the prioritization of the most critical maintenance activities for ergonomic risk analysis and for structuring appropriate guidelines for the performance of those activities, providing minimization of risks that affect both the worker's quality of life and the quality of the performed service.

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