Ergonomic Design Measures on Work Process and Workplace Layout in the Selected Structural and Fabrication Shops

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Abstract - *The study aimed to analyze the process and workplace layout in the selected structural and fabrication shops located in Batangas, Philippines thus provide improvements using the results of Ergonomic Design Measures. These shops generally focused on preparation, cutting, welding, grinding and assembly using multi-functioning machines and many aspects of human work. Using different Ergonomic Assessment Checklist, Rapid Entire Body Assessment (REBA), Rapid Upper Limb Assessment (RULA) and Ovako Working Posture Assessment System (OWAS), and with direct observations, it was found out that existing design of the work processes and workplace layout does not match the ergonomic requirements. The study exposed the presence of Musculoskeletal Disorder (MSD) risks due to awkward posture, forceful exertion and fatigue; position of workers is dangerous to themselves due to inappropriate measurement of facilities which is in need of change. The researcher recommended ergonomically based actions to address the health, comfort, and well-being of employees such as changing the workstation surface height, integration of safeguarding; application of Group Technology to reduce the production lead time and material handling and offered smooth workflow in production line. Furthermore, the researcher developed a proposed workstation and workplace design as part of the ergonomic-based actions. The effectiveness of the proposed design alternatives were measured with the use of Trade-off Analysis technique, such as, Standard Weighted Sum Method, MAXIMIN decision and Analytic Hierarchy Process.*

Keywords: *ergonomic, ergonomic design measures, ergonomic assessment, musculoskeletal disorder, trade-off analysis*

INTRODUCTION

The field of ergonomics is drawing attention to many industry sectors because its application results to safe and work-conducive workplace for employees while simultaneously increasing overall productivity and promoting continuous improvement in the organization. Moreover, this interest in applying ergonomic principles to industrial workplaces and products is most likely a result of correlations established between the design of a workplace on ergonomics principles and the resulting productivity and health of the worker [1]. The components of a work system, such as the worker, equipment, environment, task, and organization interact when work is performed. Ergonomics intend to make sure that the work system suits the workers.

Nevertheless, how should a workplace be ergonomically designed? First, it is important to identify those factors that give difficulty to a situation. When determining the factors it is important to define all those attributable to the working environment. Second, appropriate ergonomic design measures can be taken. A great advantage of the ergonomic design measures is the combination of the current situation and the functional analysis for making improvements. It is essential to document and assess as objectively and accurately as possible the workplace in its full complexity in connection with work processes. A workplace layout with process and task demands can be reconsidered when the analysis includes processes.

In an ergonomic environment, equipment and tasks are compatible with the humans using them. Ergonomic design measures can have good results related to the workers and consequently to the whole business. More so, ergonomic design measures ensure that human restrictions and capabilities are met and supported by design options. It is a great method to develop the work content and the system to reduce the risk on heavy demand tasks. Furthermore, ergonomically designed measures also relief workers from work-related physical strain as well as prevent musculoskeletal disorders (WMSDs) such as back pain which consequently largely contribute to workers safety assurance and increase in productivity in the workplace.

The design and planning of layout improvements in structural and fabrication workstation of the construction industry sector and the determination of proper work methods to be employed, taking into consideration the great effect of wide range activities of manual handling, such as transporting materials in the workplace, loading finished products for delivery, packing, etc. are challenging tasks. Furthermore, jobs in metal fabrication are viewed hazardous to workers due to a lot of reasons such as negligence or confusion of safety regulations; exposure to noise or other forms of distractions, risk inhalation of harmful substances and emissions, lack of adequate exhaust and ventilation systems, absence of proper lifting methods, improper tool selections and inappropriate workstation design. According to the Philippine Construction Association Country Report [2], occupations at construction industry are considered to be one of the most hazardous and risky as on-site employees are exposed to various safety and health risks. Based on the Labor Statistics Survey conducted by Bureau of Labor and Employment Statistics in 2007, workers in the construction industry are mostly exposed to the risks of having bronchial asthma, infections, and work-related musculoskeletal diseases. Moreover, stepping on and striking against objects (e.g. stepping on nails) were the most occurring accidents with 241 cases recorded while 149 cases of exposure to harmful substance such as radiation were reported in the same year.

In order to achieve optimal ergonomic results in the construction industry sector, specifically in Structural and Fabrication Company, a comprehensive study through ergonomic design measures must be conducted and several parameters, constraints or risks have to be considered. These ergonomic risk factors include task physical characteristics such as worker-job compatibility setting, awkward posture, task repetition, allowance time, forceful exertion, and segmental vibration. Likewise, a workplace environment characteristic which includes ventilation, lighting, noise and vibration must also be taken into consideration. After the parameters are identified, evaluating and controlling the work risk factors must be performed. Evaluation of the workplace for ergonomic risk conditions generally involves two steps, the identification of the existing ergonomic risks and the quantification of the degree of these ergonomic risks. Controlling on the other hand involves engineering, administrative and work practice control. An improvement of working conditions can be a difficult objective in the field of structural and fabrication but with the application of ergonomic design measures, it can improve human performance and business flow. More so, ergonomic studies prove the essentiality as they are all good and efficient as they are preventive.

Numerous ergonomic studies of same importance have been carried out so far. Rafanan et al. [3] administered three assessment tools namely: symptom survey form, Rapid Upper Limb Assessment, and ergonomic workstation evaluation checklist in five different administrative divisions of the UP–PGH to determine the prevalence of cumulative trauma disorders (CTDs) of the upper extremity among non-medical personnel and to identify risk factors that may have contributed to their development. Jones and Kumar [4] made a comparison of ergonomic risk assessment output in a repetitive saw-mill occupation: trim-saw operator. Kee and Karwowski [5] made a comparison of three observational techniques: OWAS, REBA and RULA for assessing postural loads in industry. Grepo [6] used evaluation tools: Worksite/Job Analysis, CTD Risk Index and Workstation Evaluation Checklist to aid in identifying the injuries and illnesses related to the work done in a manufacturing company that producing a wide range of health and hygiene products. Kostiuk [7] analyzed the adhesive application process workstation and cart design with the aid of ergonomic assessments and surveys while the specific body parts that are at-risk of developing injuries were identified through workplace/ cart design analysis

From these works, the researcher came up with the decision to make an exclusive work layout and work process improvement study executed through ergonomic design measures in structural and fabrication shop in Batangas province. These structural and fabrication shops engaged in manufacturing, sub-contracting export and distribution of fabricated world-class quality metal products for residential, commercial, and industrial applications. These companies is delivering the highest quality products and developing unique services while building an outstanding corporate image. However, in the present condition of these companies, different problems in every process and aspects are evident thus, needs an improvement and enhancement. The study is essentially concerned in finding better ways of solving such problems.

OBJECTIVES OF THE STUDY

The purpose of this study was to analyze the process organization and the workplace layout in the selected structural and fabrication shop located in the province of Batangas and to provide improvements to these areas using the results of an Ergonomic Design Measures. This study aimed to acquire information and response from employees about the current condition of the work processes and layout among the selected structural and fabrication shop; to determine if the design of the work processes and layout able to provide a comfortable or match with a needed of ergonomic factors; to propose specific ergonomically based action in the design of the work process and layout that would address employee health, comfort and wellbeing and thereby enhance optimum performance; and to determine the effectiveness of the proposed ergonomically based action

HYPOTHESIS

This research tests the hypothesis that there is no significant difference in the effectiveness between the current workstation and workplace design and the proposed workstation and workplace design.

METHODS

Research Design

This research study used the descriptive method of research. The analysis of the problem started with obtaining pertinent information regarding the current condition of the work processes and layout among the selected and fabrication shops in Batangas Province. The survey is used in which data are gathered by asking questions to respondents in the company who are working in the shop floor hence, with direct interaction to manual handling, cutting, bending, and assembling process. The researcher had direct observation and evaluation in the equipment, machine and the workplace itself. It used an observational type of case study method that shows in-depth analysis of the participants' activities. Likewise, an experimental study was used.The researcher obtained measurements, tried some sort of intervention, and then obtained measurements again to see what happened in the study. To collect data the researcher used subjective assessment through survey questionnaire, ergonomic assessment checklists, direct observation and workplace design analysis.

Subjects of the Study

The subjects were chosen based on their work tasks in the structural and fabrication shops. The observations, surveys and assessments focused on the employees who are working in the shop floor, hence, with direct interaction to manual handling, cutting, bending, and assembling process. The researcher had direct observation and evaluation in the equipment, machine and the workplace itself. Furthermore, the researcher randomly selected five (5) fabrication shops and a total of 20 respondents who directly interact with the process and equipment from these fabrication shops to evaluate the effectiveness of the current and proposed design output.

Instrument

The researcher used a standard form of Ergonomic Assessment tool to gather data. The three analysis tools were as follows: Rapid Upper Limb Assessment (RULA) Survey, Rapid Entire Body Assessment (REBA) Survey and Ovako Working Posture Assessment System (OWAS) Survey. To accurately complete the assessments, digital camera, digital video recorder, tape measure and stopwatch were used. Moreover, the researcher used ErgoFellow software which has 17 ergonomic tools to evaluate and improve workplaces conditions, in order to reduce occupational risks and increase productivity. The software was developed by FBF Sistemas in 2009. It is very useful for ergonomists and for all professionals in the area of occupational safety and health.

The RULA survey was developed by McAtamney and Corlett in 1993 for use in ergonomic study where work related upper limb disorders are evident. This survey is a screening tool to evaluate biomechanical and postural loading throughout the entire body through repetition, forceful exertion and awkward postures. The survey specifically focused on the neck, trunk, shoulders and upper limbs of the body. While, REBA survey was developed by Hignett and McAtamney [8] to assess working postures of the entire body when a manual material handling task is taking place and to identify posture for risk of work-related musculoskeletal disorders. The third tool used for assessment is the OWAS Worksheet under the

Ergo Fellow software. The method is based on ratings of the working postures for the trunk, arms, lower body, and head and neck considering the load/force of the tasks.

Furthermore, workstation design analysis was conducted. Anthropometric data of workers were collected to establish dimensions and sizes of workplace layout. The charting techniques like Process Flow Chart and Flow Diagram were used to show the flow of tasks that is performed by workers and to assist in the workstation design analysis.

Procedure

Prior to data collection, the researcher discussed the purpose and objectives of the study and the procedures that were used to collect the data needed to the management and workers of selected structural and fabrication shop of Batangas province. The researcher asked workers to perform their normal job tasks while conducting the direct observation method. For problem identification, time study and motion study technique is used. The motion study was carried out for analyzing the material component flow and workers movement. It was used to eliminate the task specifically the walking and combined the task with some other tasks related. More so, it rearranged the elements of work to reduce the work content and to simplify the operation of fabrication process. Likewise, motion study was used in the course of flow process charts and flow diagram. A flow diagram is used to show movement of workers around an entire plant because it gave an accurate physical picture of the entire process.

On the other hand, the stop watch time study technique was used to determine the time required for each of the operation involved in the fabrication task. The researcher measured the time it took a worker to complete a task. After calculating of time for each operation, flow process chart has been prepared to determine the total time to finish a work task. All the jobs were observed before start of the study and collected detailed job information to ensure the completion of ergonomic risk assessment.

A total of six (6) working postures were sampled from layout, grinding and welding process. The work postures were sampled based on the majority postures, the position continued for the longest period of time, and the work posture where the force loads occur. The selected work postures and other field study details were captured from the working images recorded with video camera. The video captured the fixed motion from a screen and manually analyzed. All sample postures were assessed by using three observation techniques: RULA, REBA and OWAS, which resulted to various postural load scores for each posture by every of the applied techniques and found out workers' exposure to the ergonomic risk factors leading to MSD's.

The anthropometric measurements [9] of workers were part of the gathering of data. Measurements, also known as 'anthropometric data' such as standing height, eye height, elbow height, waist height and forward functional reach, were collected and applied to workstation designs and workplace layout designs, to make them more comfortable to use. Similarly, any supplementary observations regarding workplace layout design, safe work practices, and environmental factors were recognized and taken into consideration while analyzing the data.

To determine the effectiveness of the proposed workstation and workplace design for fabrication activities the researcher performed engineering trade-off study through survey in five (5) selected structural and fabrication shops. It was a formal trade-off study which follows a structured and systematic approach for comparison of options/alternatives via formal analysis. Decision criteria were formulated which reflected the graded judgments or importance of each criteria, and a decision process have been established for differentiation among alternatives, and eventually resulted in the clear identification of a preferred alternative design. Also, the current workstation and workplace design of different shops were evaluated using trade-off techniques.

Statistical Treatment of Data

The research study used percentile and descriptive statistics. For the Workstation Design, Percentiles and Z-scores are used to assess anthropometric measurement. The data from the REBA, RULA and OWAS analysis were treated by a descriptive statistics. The analyzed postured were classified on the basis of the load score presented in the Ergonomic Assessment Worksheet, thus, generating a single score that represents the level of MSD risk.

To test the research hypothesis, a paired t-test is used. It was used in the experimental design to test the effectiveness of the proposed workstation and workplace layout design that have been developed.

RESULTS AND DISCUSSION

1. The Current Condition of the Work Processes and Layout.

The researcher visited several shops located in Batangas province, specifically nearby Batangas City. Through observation and survey, the researcher found out the complexity of activities involve in the steel or metal fabrication, which includes product uniqueness, a high product mix, and multiple activities involving a variety of equipment and human disciplines. These shops had different machines, work benches, fabrication tools and small and large metal pieces. The structural and fabrication shops generally focused on the preparation, cutting, welding, grinding and assembly using multi-functioning machines and many aspects of human work. Using motion and time study, the work processes and layouts were observed. There were processes or steps to be undergone every time each sector is produced. There is a problem in the improper cutting/drilling and other tasks because the area is too small for the process or operation. More so, the data showed that there is a lot of time consumed to travel from one process to another because of poor sequence or arrangement of facilities, thus, influences the time to finish the product. Data showed that the transportation time ranges from 30 – 60 minutes or approximately 2% – 9 % of the production time. The Workplace layout dimension ranges from 165 sq. m. to 500 sq. m.

2. Compliance of the Current Design of Work Processes and Layout in Requirements of Ergonomic Factors

The researcher observed numerous dangerous hazards that the workers deal with their everyday activity. Those hazards are having too much exposure to combustible materials, inhalation exposures and burns to the retina of the eye, leg fatigue because of long transportation, awkward posture due to poor workstation, neck and back pain which leads them to take a rest and the operations being idle. Layout cutting, welding, fitting and grinding are done mostly in kneeling, sitting either standing which the workers didn't give too much attention on what position they have. Those activities last within five to eight hours for an entire day. Those activities being performed in awkward position are continuously operating over period of time that may lead into serious worker injuries.

Table 1. Summary of Ergonomic Assessment in Different Tasks

TASK DESCRIPTION	Ergonomic Standards	MSD RISK LEVEL / LEVEL OF ACTION TO BE TAKEN		
		RULA	REBA	OWAS
Layout Cutting	1. Working height is slightly below the elbow height or waist height 2. Make sure that the workplace accommodates the needs of taller workers. 3. Provide a stable multi-purpose work surface at each workstation. 4. Make sure that workers can stand naturally with weight on both feet, and perform work close to and in front of the body. 5. Allow workers to alternate standing and sitting at work as much as possible. RISKS / SYMPTOMS • repetitive strain • monotony • upper limb disorder • low back pain • excessive fatigue	medium risk, further investigation and change is needed soon	medium risk, further investigation and change is needed soon.	dangerous position, investigation and changes are required soon
Angle Bar Framing		medium risk, further investigation and change is needed soon	medium risk, further investigation and change is needed soon	position may be dangerous, corrective action is required in the near future
Cleaning up of fittings		very high risk, investigation and change should be implemented	very high risk, change should be implemented	very dangerous position, improvement is required immediately
Grinding of the circular base		very high risk, investigation and change should be implemented	high risk, investigation and change should be implemented	very dangerous position, improvement is required immediately
Welding of Pipes		very high risk, investigation and change should be implemented	medium risk, further investigation and change is needed soon	dangerous position, investigation and changes are required soon
Welding Process		very high, investigation and change should be implemented.	medium risk, further investigation and change is needed soon	position may be dangerous, corrective action is required in the near future

Table 1 summarizes the ergonomic standards for workstation and workplace layout design [10]; the musculoskeletal disorder risk level of all work tasks for each ergonomic assessment tools and the level of action to be taken by the owner of the company. Data showed that the existing design of the work processes and layout does not match the requirements of ergonomic standards. Using different Ergonomic Assessment Checklist, REBA, RULA and OWAS, the study revealed that there were presence of MSD risks due to awkward posture, forceful exertion and fatigue; position of workers were dangerous to themselves due to inappropriate measurement of facilities which is in need of immediate improvement.

3. Ergonomic-Based Actions in the Design of Work process and Layout

The researcher improved the design of current workstation to make it ergonomic, thus, eliminate or decrease the risk of ergonomic injury using appropriate anthropometric measurements. Likewise, the researcher used the design for the average or the 50th percentile measurement of male worker in the Filipino anthropometric table for standing. The following are several approaches to accomplish the ergonomically based actions of the work process and layout:

A. Changes in work surface height. The researcher considered to change the work surface height of the workstation and workbench/ work table to approximately 97.32 cm. Since the work in fabrication requires the application of force from the shoulder and back muscles, the work surface should be lower than the level of the elbows. Changing heights would lessen or eliminate awkward postures and excessive forces, so significantly reduced the risk of ergonomic injury. Figure 1 shows the different anthropometric measurement considerations in the design phase of the workplace.

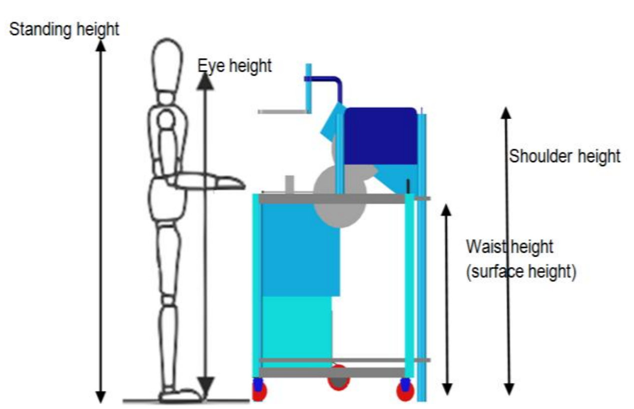

Figure1. Anthropometric Measurement of the Workstation Design

Two workstation designs were developed by the researcher. Workstation Design 1 as shown in Figure 2 combined two major process, the grinding and welding process. Adjustable platform is used for welding process that needs precision work. It has a workstation enclosure, tool drawer, a work space for cutting metal pieces and clamp for bending and grinding using a hand tool. The workstation design 1 has a dimension of 1.68 m x 1.04m.

In Workstation Design 2 as shown in Figure 3, integrates most of the process in metal fabrication such as cutting, grinding, welding and lay-outing. Adjustable platform is used for welding process that needs precision work. It also includes workstation enclosure, tool drawer, clamp for bending and grinding using a hand tool. A clearance on the bottom part of workstation enclosure was also changed in Design 2 to make it safer to worker doing the job. Design 2 maximizes the uses of the workstation since it has a clearance between the work surface and workstation enclosure. The Workstation Design 2 has a dimension of 2.44m x 1.04 m. The researcher also developed a rolling cart for easy transport of metal pieces.

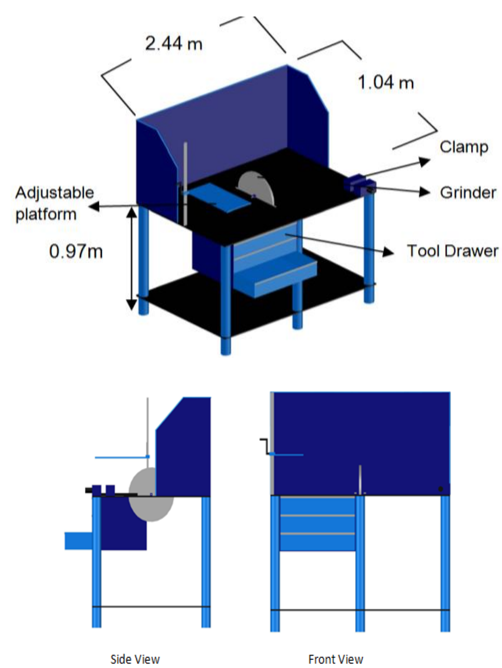

Figure 2. Schematic Diagram of Workstation Design1

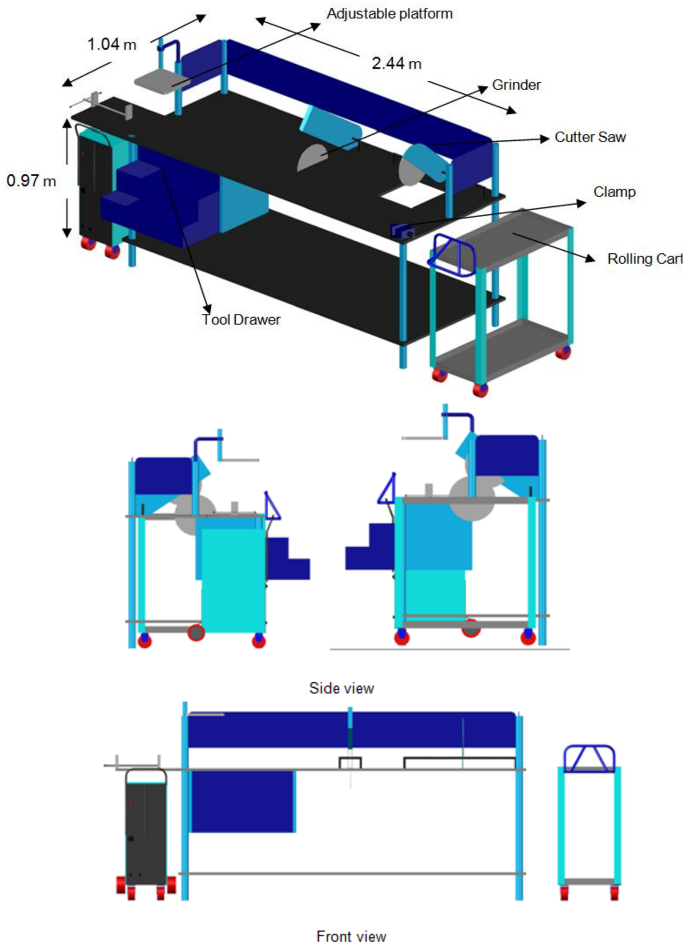

Figure 3. Schematic Diagram of the Workstation Design 2

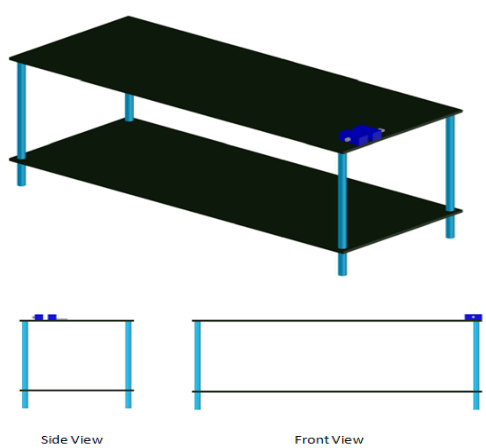

Figure 4. Schematic Diagram of the Worktable/Workbench

A worktable was also developed by the researcher as part of the two workstation design. The worktable serves as area for large metal pieces. The work surface height of the workbench/ work table is approximately 0.97m. The dimension of the worktable is 2.44m x 1.04 m. It is shown in Figure 4

B. Proper guarding of the workstation. The researcher provided proper guarding to common tools used in the fabrication. Furthermore the enclosure of the backside of the workstation is considered in order to prevent accident to those workers passing by. The shoulder height of the 50th percentile of the male worker is used in the design of enclosure. This allows the workplace to be OSHA compliant. It is shown in Figure 3.

C. Application of Group Technology. To reduce the production lead time, material handling, labor and rework the researcher considered the application of group technology to the workplace layout. It combines several production stages, so fewer parts travel through the shop. In addition, it lessens the material handling, improved the workers expertise and created faster operation.

D. Improved workplace layout. Since most of the fabrication shop observed have no fixed location or designated areas to raw materials, finished product and to different processes, the researcher formed a smooth workflow and workplace layout that can improve the productivity and efficiency of worker while health and safety are considered. Workplace Regulations states that work rooms should have enough free space to allow people to get to and from workstations and to move within the room easily.

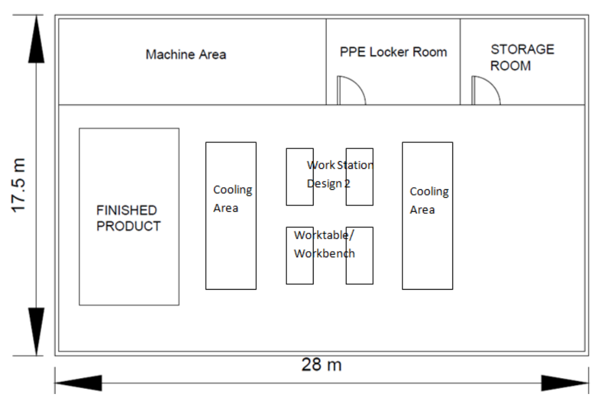

Figure 5. Proposed Workplace Layout 1

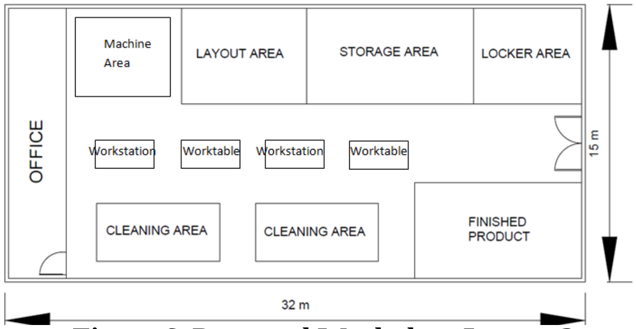

Figure 6. Proposed Workplace Layout 2

The researcher used the L-shaped layout for proposed Workplace Layout 1 as shown in Figure 5 and U-shaped layout for proposed Workplace Layout 2, shown in Figure 6. Each proposed layout provided approximately 1.2 m width for pathway to ensure for two people to pass side by side. The space of at least 2m for each side of the worker is given for them to move around freely and to do their work smoothly. Systematic layout planning is considered in the two proposed layout presented. The location of all machines, employee workstations, material storage areas, aisles, finished goods areas, office and others for the flow patterns of materials and people around, into, and within buildings are planned.

4. Measure of Effectiveness of the Proposed Ergonomic Based Actions.

The researcher used trade-off analysis to determine the effectiveness of the proposed ergonomic work system, specifically the workstation and layout design. By means of the trade-off techniques such as Standard Weighted Sum Method, Maximin Decision and Analytic Hierarchy Process the best design among alternatives were determined.

Workstation Design. The two proposed design alternatives of a workstation, Design 1 and Design 2 were evaluated by different design criteria.

a. Using Standard Weighted Sum (SWS) Method.

The researcher first used the SWS to evaluate the design criteria for Workstation Design 1 and Workstation Design 2. The criterion importance scale used in this method is 0 – 5 which 5 is the highest. Each design ability to satisfy criterion scale used is 1 – 10.

By computing the Standard Weighted Sum the researcher came up with the following results:

$\mathbf{SWS_{Current}} = 3(6.9) + 3(6.75) + 4(7) + 3(6.9) + 5(7.4)$

$\mathbf{SWS_{Current} = 126.65}$

$\mathbf{SWS_{Design\ 1}} = 3(6.95) + 3(7.45) + 4(7.5) + 3(6.75) + 5(7.35)$

$\mathbf{SWS_{Design\ 1} = 130.2}$

$\mathbf{SWS_{Design\ 2}} = 3(7.9) + 3(8.35) + 4(8.2) + 3(7.4) + 5(7.85)$

$\mathbf{SWS_{Design\ 2} = 143}$

Data in Table 2 show the evaluation of design criteria by way of Standard Weighted Sum (SWS). As the result of SWS per design, it indicates that Design 2 with a value of 143 is higher than Design 1 and with the Current Design. It means that under this method Design Workstation 2 is best among the two alternative designs and with the current design respectively.

b. Using Maximin Decision.

Table 3 shows the evaluation of design criteria via Decision Analysis (Maximin). The least of minimum rating for current design is 6.75; Design Workstation 1 is 6.75, while 7.4 on Design Workstation 2. Comparing these values, the maximin or best of worst is 7.4. Therefore, Design Workstation 2 must be chosen.

Table 2. Design Criteria Evaluation of Workstations Using Standard Weighted Sum Method

Criterion	Importance	Current Workstation	Design Workstation 1	Design Workstation 2
Maximize Design Life	3	6.9	6.95	7.9
Maximize Reliability	3	6.75	7.45	8.35
Ease to Use	4	7	7.5	8.2
Cost Effectiveness	3	6.9	6.75	7.4
Low Risk Occurrence	5	7.4	7.35	7.85
Total	**18**			
SWS		126.65	130.2	143

Table 3. Design Criteria Evaluation of Workstations using MAXIMIN Decision

Criterion	Importance	Current Workstation	Design Alternatives Design Workstation 1	Design Workstation 2
Maximize Design Life	3	6.9	6.95	7.9
Maximize Reliability	3	6.75	7.45	8.35
Ease to Use	4	7	7.5	8.2
Cost Effectiveness	3	6.9	6.75	7.4
Low Risk Occurrence	5	7.4	7.35	7.85
Minimum		6.75	6.75	7.4
Maximin Decision			**Design 2**	

c. Using Analytic Hierarchy Process.

Table 4. Ratings Used in Comparing Criteria for AHP

1	Equal Importance
3	Moderate Important of 1 variable to another
5	Strong or essential importance
7	Very Strong or demonstrated Importance
9	Extreme importance
2,4,6,8	Intermediate values

The researcher systematically evaluated its various elements by comparing the design criteria to one another two at a time, with respect to their impact on an element above them in the hierarchy. Table 4 is the rating to be used in comparing design criteria using Analytic Hierarchy Process.

After comparing the design criteria the weight to be used in judging the design alternatives is formulated. It is shown in Table 5.

From the result in Table 6, the magnitude of the final rating does not signify high or low performance of the alternatives but rather it signifies which is the BEST among the alternatives. Therefore, using Analytic Hierarchy Process, the best alternative design is Design Workstation 2 with a percentage rate of 80% compare to current workstation and design workstation.

Table 5. Weight Used in Judging the Alternatives for Workstation Design (AHP)

Criterion	Maximize Design Life	Maximize Reliability	Ease to Use	Cost Effectiveness	Low Risk Occurrence	Weight
Maximize Design Life	1	3	1/5	3	1/7	15%
Maximize Reliability	1/3	1	1/4	3	5	19%
Ease to Use	5	4	1	2	1/4	25%
Cost Effectiveness	1/3	1/3	1/2	1	1/6	5%
Low Risk Occurrence	7	1/5	4	6	1	37%
Total						100%

Table 6. Design Criteria Evaluation of Workstations using Analytic Hierarchy Process

Criterion	Maximize Design Life	Maximize Reliability	Ease to Use	Cost Effectiveness	Low Risk Occurrence	Final Grade
% Weight	15%	19%	25%	5%	37%	100%
Current Workstation	6.90	6.75	7.00	6.90	7.40	71%
Design Workstation 1	6.95	7.45	7.50	6.75	7.35	73%
Design Workstation 2	7.90	8.35	8.20	7.40	7.85	80%

Workplace Layout. The existing and proposed workplace layouts were evaluated by different design criteria. Using Standard Weighted Sum (SWS) Method.

a. Using Standard Weighted Sum (SWS) Method.

Table 7. Design Criteria Evaluation of Workplace Layout Using Standard Weighted Sum Method

Criterion	Importance	Current Layout	Proposed Layout 1	Proposed Layout 2
Smoothness of Process Flow	4	7.15	7.8	8.3
Efficient Usage of Available Space	3	6.75	7.95	8.4
Worker's Productivity in terms of Layout Facility	5	7.15	7.7	8.35
Total	**12**			
SWS		**84.6**	**93.55**	**100.15**

Data in Table 7 shows the evaluation of design criteria by way of Standard Weighted Sum (SWS). As the result of SWS per workplace layout, it indicates that Proposed Layout 2 is higher than the Current Layout with a value of 100.15. It means that under this method Proposed Layout 2 is best among the two proposed layouts and current layout.

b. Using Maximin Decision.

Data in Table 8 shows the evaluation of design criteria using Maximin Decision. The least of minimum rating for the current layout is 6.75; proposed layout 1 is 7.7 while 8.3 on the proposed layout 2. Comparing these values, the maximin or best of worst is 8.3. Therefore proposed layout 2 is more efficient than the other.

Table 8. Design Criteria Evaluation of Workplace Layout Using MAXIMIN Decision

Criterion		**Design Alternatives**		
	Importance	**Current Layout**	**Proposed Layout 1**	**Proposed Layout 2**
Smoothness of Process Flow	4	7.15	7.8	8.3
Efficient Usage of Available Space	3	6.75	7.95	8.4
Worker's Productivity in terms of Layout Facility	5	7.15	7.7	8.35
Minimum		6.75	7.7	8.3
Maximin Decision		**Proposed Layout 2**		

c. Using Analytic Hierarchy Process

Using Analytic Hierarchy Process, the best alternative layout is the proposed layout 2 with a percentage rate of 83.41% compared to proposed layout 1 and current layout respectively.

Table 9. Design Criteria Evaluation of Workplace Layout using Analytic Hierarchy Process

Criterion	**Smoothness of Process Flow**	**Efficient Usage of Available Space**	**Worker's Productivity in terms of Layout Facility**	**Final Grade**
Weight	29%	10%	61%	100%
Current Layout	7.15	6.75	7.15	71.10%
Proposed Layout 1	7.8	7.95	7.7	77.54%
Proposed Layout 2	8.3	8.4	8.35	83.41%

In the trade off studies done by the researcher, the BEST proposed workstation design was the Design Workstation 2 while the BEST proposed workplace layout was the Proposed Layout 2.

Test of Hypothesis

T-test is used to determine if there is significant difference in the effectiveness of the between current workstation design and the proposed best design. The researcher set the null hypothesis, which assumes that the mean of two paired samples are equal. The second hypothesis will be an alternative hypothesis, which assumes that the means of two paired samples are not equal. The study used 5% significance level.

Table 10. Computed T Values of Evaluation Criteria for Workstation Design

Design Criteria for Workstation	mean of Current design (x-bar)	mean of proposed best design (y-bar)	mean difference (d-bar)	Computed Value (T)
Maximize Design Life	6.9	7.9	1	9.746794
Maximize Reliability	6.75	8.35	1.6	8.717798
Ease to Use	7	8.2	1.2	8.717798
Cost Effectiveness	6.9	7.4	0.5	3.248931
Low Risk Occurrences	7.4	7.85	0.45	3.327453

Table 11. Computed T Values of Evaluation Criteria for Workplace Layout Designs

Design Criteria for Workplace Layout	mean of Current design (x-bar)	mean of proposed best design (y-bar)	mean difference (d-bar)	Computed Value (T)
Smoothness of process Flow	7.15	8.3	1.15	5.877033
Efficient Usage of Available Space	6.75	8.4	1.65	7.906363
Workers Productivity in terms of facility layout	7.15	8.35	1.2	6.989788

After calculating the parameter, the researcher compared the computed T values with the tabular value t.025 = 2.093 at (n-1) or 19 degrees of freedom. This was based from the two sided alternative hypothesis used. It can be seen in the table that computed T value in each design criterion is greater than the tabular value of T at (n-1) or 19 degrees of freedom; therefore the null hypothesis is rejected. This suggests that there is significant difference in the effectiveness between the current workstation and proposed best workstation design. Likewise, there is significant difference in the effectiveness between the current workplace layout and proposed best workplace layout design.

Therefore, there was strong evidence that, on average, the proposed best design of workstation 2 and workplace layout 2 is effective and does lead to improvements.

CONCLUSION

The work processes and workplace layout of selected structural and fabrication shops are poorly designed, resulting to low productivity of workforce. The work processes and workplace layout designs of fabrication shops do not comply with the requirements of ergonomic standards. The application of Ergonomic Standards/Checkpoints for Workstation/ Workplace ensures good health, comfort, and well-being of employees. The proposed ergonomically based action in the work system enhances productivity, quality, time, profitability and reduces operation risk.

RECOMMENDATIONS

Make ergonomic efforts as one of the business organization's goal of maintaining and preserving a safe and healthy work environment for all employees and as a main concern with other cost reduction, productivity and quality assurance activities. Implementation of the proposed workstation design 2 in the fabrication shops will make the employees work easier, they can work in a comfortable and standard posture and exposure to MSD risks will be eliminated. Rearranging workstation in a similar way of the proposed Workplace Layout Design will ensure a smooth workflow in the production, stimulate workers in doing their jobs and help them reduce stress levels and workloads. Employers shall provide training on workplace ergonomics issues such as correct work posture to avoid neck, back and eye strain; reduction of stress and strains in repetitive work and safety at the workplace. The training will enlighten employees on the importance of the good workplace and that will contribute significantly to the advancement of ergonomic interventions.

Further researches in the structural and fabrication shops must be undertaken but must focus on other areas of ergonomics like environmental factors such as noise, temperature and housekeeping in order to achieve optimum results in the workplace.

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