Design of Work Facilities for Reducing Musculoskeletal Disorders Risk in Paper Pallet Assembly Station

Dian Mardi Safitri, Zahra Arfi Nabila and Nora Azmi
Laboratory of Work System Design and Ergonomics,
Department of Industrial Engineering, Universitas Trisakti
Jakarta, Indonesia
dianm@trisakti.ac.id

Abstract. Musculoskeletal Disorders (MSD) is one of the ergonomic risks due to manual activity, non-neutral posture and repetitive motion. The purpose of this study is to measure risk and implement ergonomic interventions to reduce the risk of MSD on the paper pallet assembly work station. Measurements to work posture are done by Ovako Working Posture Analysis (OWAS) methods and Rapid Entire Body Assessment (REBA) method, while the measurement of work repetitiveness was using Strain Index (SI) method. Assembly processes operators are identified has the highest risk level. OWAS score, Strain Index, and REBA values are 4, 20.25, and 11. Ergonomic improvements are needed to reduce that level of risk. Proposed improvements will be developed using the Quality Function Deployment (QFD) method applied with Axiomatic House of Quality (AHOQ) and Morphological Chart. As the result, risk level based on OWAS score & REBA score turn out from 4 & 11 to be 1 & 2. Biomechanics analysis of the operator also shows the decreasing values for L4-L5 moment, compression, joint shear, and joint moment strength.

1. Introduction
Work is one cause of injury even though it is not the only major factor. Interaction between occupational factors, relationships with co-workers and supervisors, and organizations is a contributing factor to the occurrence of injury [1]. The phenomenon of work-related injury is still happening. This recommends that the risk of work-related injury is still being a significant study. Several studies on the risk of MSD were applied to several sectors such as health [2], banking in correlation with mental workload [3], fishery [4], butchery [5], etc. Study in South Korea is ensued a conclusion that there is a differences risk distribution between men and women in different work sectors [6]. This research focused on paper pallet assembling operator for consumer goods in one of manufacturing industry in Indonesia. In making pallets for consumer goods, the use of stitching machine is not allowed to assist the gluing process. It must be done manually by the operator using glue auxiliaries to avoid damage to the product packaging due to scratches of the adhesive material used and maintain the safekeeping of the product to customer.

The paper pallet assembling process for consumer goods is divided into six stages of the process i.e. the gluing process for each corrugated paper sheet using a paint roller, multiple corrugated paper gluing process, gluing process on each curve (end of corrugated paper sheet) using carton as sizing tool, the gluing process on each groove using a clamp as a tool to hold the glued portion, the gluing process on each paper pallet element using a paint roller, and the paper pallet element bonding process. Each assembly process involves work movements related with musculoskeletal risk factors...
such as bending, squatting, repetitive motion, and contact stress. This problem was evidenced by the results of body map surveys on 10 operators in the assembly department which shows the percentage value of 50% upwards are complaints on the location of the upper neck, lower neck, back, upper right arm, waist, left wrist, right wrist, left ankle, and right ankle.

2. Musculoskeletal Disorder Risk Analysis
The purpose of the postural observation method is to identify tasks or parts of tasks that potentially cause physical stress. The two methods available for postural observation are REBA [7], and OWAS [8]. REBA was developed to assess the type of work posture with data collected in terms of posture, strength, movement or action, repetition, and coupling [7]. The final score is used to give an indication of the level of risk and urgency of action to be taken. The measurement results using different methods will result in different levels of risk, in which each method has different measurements and measures of risk levels. OWAS was first developed as an observational technique to evaluate work posture [8], [9]. Measurements use a posture work analysis chart consisting of values for backs, hands, feet, and weights. The Strain Index is a method used to evaluate a job on the operator to see if the operator is exposed to musculoskeletal risk on the distal upper extremity (DUE). DUE itself can be interpreted on the elbows, wrists and hands. Measurements with strain index use predefined criteria rating, and then the final score can be determined by multiplying the six multipliers according to the criteria rating in which each job is analyzed subjectively by the analyst [10].

The OWAS method has limitations in which the OWAS method is intended to analyze the work posture, but the measurement of the upper limb assessment has a very small scoring method of precision. From the results of the whole analysis to the measurement results of the entire assembly process, there is one assembly operator that shows the highest level of risk in measuring OWAS, SI, and REBA. Unlike other assembly operators, the measurement results on the assembly operator one using OWAS, SI, and REBA show that work postures and work looping have a high level of risk. The results of high measurements on the assembly process is caused by inappropriate work posture, there are many changes in posture or movement. In addition, the sheer number of repetitions, fast movements, and the length of time required by the assembly operator to handle the job can also increase the risk level on the work loop problem. These results indicate that the assembly operator one needs a refit immediately. Operator’s work posture should be fixed immediately and need another solution to handle the problem on repetitiveness.

3. Ergonomics Improvement for Reducing Musculoskeletal Disorders Risk
Some design improvements on work tool and facility were proposed using the method of Quality Function Deployment (QFD) as the main reference. QFD is used to build a product planning and development framework based on customer needs. QFD consists of a series of “quality tables” that form the design of the voice of customer down to a comprehensive and detail operational level where HOQ is the most important phase of the QFD process [11]. Axiomatic Design is a design method that aims to define the basis of product development by providing a mapping technique between the functions of product requirements and design parameters. In other words, Axiomatic Design can be considered as a more structured, logical, and developed HOQ (House of Quality) version with a focus on design according to product function [12].

Axiomatic House of Quality (AHOQ) can interpret the voice of customers more structured and assist in the development of design with functional requirements, design parameters, and constraints, so decisions can be made with less risk. This method also allows design changes without affecting other design requirements. The Morphological Chart is a table based on functional analysis to support the development of process steps that will allow the morphological chart to be used to generate an integrated conceptual list (interrelated into one) design solution. The purpose of conceptual design is to describe the sketches of the system as a whole, sketches of important sub-systems, and the rough dimensions of the proposed product. CATIA (Computer Aided Three-Dimensional Interactive Application) was developed by French aircraft manufacturer Avions Marcel Dassault which was originally used for home development but has now been used in various industries to develop products [13].
Proposed improvements for the assembly operator are determined through several stages:

1. **List Customer Attributes (CAs)**
   From the results of measurements, observations, and direct interviews with company owners, production managers, and some operators in the assembly department can be known the current working conditions and needs of the work station. This data is converted into criteria for required and desired products (CAs).

2. **Convert CAs into FRs**
   The result of identification to CAs is changed to Functional Requirements (FRs) to create function domain. The output of this stage shows the CA data converted to FRs for the tabletop and paint roller products there is no ambiguous function so decomposition is not necessary to clarify the results to be achieved.

3. **Identifying Constraints**
   Constraints (constraints) are found on table tops and paint products. The size of the work-piece handled has a size large enough, i.e. 1200 mm x 425 mm. The working conditions do not currently have a fixed work place, so this should be considered in product design where these conditions require that the proposed tool be moved easily without disrupting the surrounding activities but can be used according to the conditions and work-piece. For the paint roller, it takes a convenient handle but is able to reach all parts of the work-piece surface. The function constraints for both products look like this:
   1. FR1 = The minimum working ground size is 1200 mm x 425 mm.
   2. FRb = Able to reach all parts of the surface area of 1200 mm x 425 mm.

4. **Formulation of Design Parameters**
   Design Parameters (DPs) is located in the third domain, the physical domain. This domain contains a list of physical elements that aim to meet the needs of each functional. DP1 and DP2 will meet FR1 and FR2, while DPa and DPb will meet FRA and FRb.

5. **Formulating the Design Matrix and Initial Design**
   The relationship between the functional requirements and the design parameters is described using the design matrix. This relationship aims to identify that there is no violation of the function.

6. **Correlation Matrix**
   Correlation in AHOQ (Axiomatic House of Quality) aims to determine the dependencies between design parameters. This correlation is indicated by a sign (+) or (-) on the roof of AHOQ. In both matrices it appears that there is no correlation between design parameters, meaning that one design does not affect changes in other designs.

7. **Listing of Constraints**
   In the identifying constraints stage, it has been found that the function constraint for the table is in the first function while the functional constraint for paint roller is in the second function.

8. **Evaluation of AHOQ Model**
   Evaluation of the AHOQ model is used to ensure that the CAs have been met before entering the conceptual design. The AHOQ model for table and paint rollers has something in common. First, the design matrix shows the ideal matrix (uncoupled design), meaning that each function has a relationship with DPs. Second, there is no dependence (positive or negative dependencies) between DPs. Finally, there are constraints to consider in making the best product design.

9. **Development of Conceptual Design**
   At this stage of development, we were using the morphological chart to select some concepts among several alternative concepts that exist. The result of the combination will be used as comparison of competing product. Based on FR and alternative concepts, six alternative combinations of concepts for each product are produced.

10. **Matrix Screening Concept & Matrix Scoring Concept**
    The alternative choice of concept for table and paint roller is done by direct interview to five main responders i.e. company owner, production manager, and three operators in the assembly department who used or have handled the assembly process one. The combined results of these assessments are used for conceptual selection and select some concepts to continue in concept
development. The concept of the selected table to continue is the concept of 1, 2, 3, and 4, while for the paint roller is the concept of C, E, and F. The scoring concept matrix show that the concept of 1 is selected for the table and the F concept is selected for paint roller to be developed.

11. Concept Testing

The results of interviews with the respondents were used for the examination of selected concepts. In the AHOQ method it is allowed a change as each DP responds to each FR. Based on the results of concept testing on the table, it is necessary to add plastic material to coat the wood used as the basis of work. This aims to avoid table damage due to glue material that accidentally fell on the table. For the wheel, you need to add the tool as a brake tool so that the table remains stable when used for work. In the concept test for paint roller no change is required, but for handles will take precedence over rubber materials based on recommendations provided by the Canadian Centre for Occupational Health and Safety (2017) on hand tool design. The design of the selected product for the table used as the proposal is the adjustable table as needed and equipped with a medium rubber wheel with a diameter of 75 mm, while the paint roller has a thin nap and handle type foam with three types of grip for close, medium and, far.

Illustrations for working conditions as before and after proposed improvements are represented using CATIA software. From the picture, there is a change of work posture performed by the operator while doing the assembly process. The results of the identification of working conditions after the proposed improvement can be concluded that the proposed improvement provides a decrease in the risk level of musculoskeletal disorders. This is evidenced by the decreasing OWAS and REBA score. The new OWAS and REBA score was become 1 and 2. It could be interpreted as low risk and no action changes on posture are required. Improvements to work posture are also related with a decreased level of risk caused by repetition of work, because one way that can be done to reduce the risk of repetitive motion over a long period of time is to change posture with different movements and allow time for stretching. Biomechanical analyses of operators are also conducted for working conditions before and after repair using CATIA software. This analysis is conducted to determine whether there are changes in L4-L5 Moment, Compression, Joint Shear, and Joint Moment Strength values. The analysis results for L4-L5 Moment and Compression can be seen in Table 1.

![Figure 1. Assembly table](image1)

![Figure 2. Paint Roller](image2)

![Figure 3. Paint Roller Front View (left) and Side (right)](image3)
From the results of the analysis for moment and compression, it can be seen that there is a decrease in value for both. For compression there is an increase in value for body load compression. This is due to the pressure of pressure between gravity on the body weight and the reaction force of the floor that encourages each other to maintain balance, resulting in a decreased risk for L4-L5.

Figure 5 provides information on whether the values for compression and shear stress are within the limits recommended by NIOSH and the University of Waterloo. There are two defined limits: Action Limit and Maximum Permissible Limit. Based on the graph, it can be seen that there is a decrease in value for compression and shear stress after repair. Both values are within the safe limits, meaning no further action is required for Action Limits and still within the limit of the compressive force set for Maximum Permissible Limit. These data indicate that the after-repair condition has a decrease in population percentage for lumbar strength (L4-L5). This decrease is caused by posture changes, so the work handled does not require lumbar strength (L4-L5). Figure 6 shows the analysis results of joint moment strength for lumbar (L4-L5). It can be compared with population percentage.

| Analysis                        | Value |
|--------------------------------|-------|
| L4-L5 Moment (Nm)              | 383   |
| L4-L5 Compression (N)          | 94E8  |
| Body Load Compression (N)      | 222   |
| Axial Twist Compression (N)    | 77    |
| Flex/Ext Compression (N)       | 3055  |

| Analysis                        | Value |
|--------------------------------|-------|
| L4-L5 Moment (Nm)              | 5     |
| L4-L5 Compression (N)          | 545   |
| Body Load Compression (N)      | 432   |
| Axial Twist Compression (N)    | 1     |
| Flex/Ext Compression (N)       | 80    |

Figure 4. Illustration of working posture improvement using CATIA

Table 1. L4-L5 Moment, Compression, Joint Shear, and Joint Moment Strength values

Figure 5. Compression Limits & Joint Shear Limits Chart

Figure 6. Joint Moment Strength Data
4. Conclusion
Posture problems that result in the risk of muscle and skeletal injury can be solved by redesigning work facilities. The proposed of ergonomics improvement for assembling department provide a better condition for workers with a lower risk of musculoskeletal disorder. It can be proven by the decrease of risk level based on OWAS score & REBA score turn out from 4 & 11 to be 1 & 2. Biomechanics analysis of the operator also shows the decreasing values for L4-L5 moment, compression, joint shear, and joint moment strength.

References
[1] I. D. Cameron, “How to manage musculoskeletal conditions: When is ‘Rehabilitation’ appropriate?,” Best Pract. Res. Clin. Rheumatol., vol. 18, no. 4, pp. 573–586, 2004.
[2] H. R. Zaker Jafari and M. H. Yekta-Kooshali, “Work-Related Musculoskeletal Disorders in Iranian Dentists: A Systematic Review and Meta-analysis,” Saf. Health Work, no. July, pp. 1–9, 2017.
[3] E. Darvishi, A. Maleki, O. Giahi, and A. Akbarzadeh, “Subjective Mental Workload and Its Correlation with Musculoskeletal Disorders in Bank Staff,” J. Manipulative Physiol. Ther., vol. 39, no. 6, pp. 420–426, 2014.
[4] Q. Sholihah, A. S. Hanafi, A. A. Bachri, and R. Fauzia, “Ergonomics Awareness as Efforts to Increase Knowledge and Prevention of Musculoskeletal Disorders on Fishermen,” Aquat. Procedia, vol. 7, pp. 187–194, 2016.
[5] B. Kaka, O. A. Idowu, H. O. Fawole, A. F. Adeniyi, O. O. Ogwumike, and M. T. Toryila, “An Analysis of Work-Related Musculoskeletal Disorders Among Butchers in Kano Metropolis, Nigeria,” Saf. Health Work, vol. 7, no. 3, pp. 218–224, 2016.
[6] J. Park, Y. Kim, and B. Han, “Work Sectors with High Risk for Work-Related Musculoskeletal Disorders in Korean Men and Women,” Saf. Health Work, pp. 4–7, 2017.
[7] S. Hignett and L. McAtamney, “Rapid Entire Body Assessment (REBA),” Appl. Ergon., vol. 31, no. 2, pp. 201–205, 2000.
[8] O. Karhu, P. Kansi, and I. Kuorinka, “Correcting working postures in industry: A practical method for analysis,” Appl. Ergon., vol. 8, no. 4, pp. 199–201, 1977.
[9] O. Karhu, R. Härkönen, P. Sorvali, and P. Vepsäläinen, “Observing working postures in industry: Examples of OWAS application,” Appl. Ergon., vol. 12, no. 1, pp. 13–17, 1981.
[10] J. S. Moore and A. Garg, “The strain index - A proposed method to analyze jobs for risk of digital upper extremity disorders,” AM. IND. HYG Assoc., no. 56, pp. 443–458, 1995.
[11] Y. Akao and G. Mazur, “The Leading Edge in QFD: Past, Present and Future,” Int. J. Qual. Reliab. Manag., vol. 20, no. 1, pp. 20–35, 2003.
[12] N. Machulenko, “Applying Axiomatic Design Principles to The House of Quality,” 2001.
[13] Y. Haik and Shahin. Tamer M., Engineering Design Process 2nd Ed. Stanford, USA: CENGAGE Learning, 2011.