WORK POSTURE IMPROVEMENT AT PLASTIC PRINTING PROCESS IN PLASTIC MANUFACTURING INDUSTRY

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ABSTRACT: Plastic printing workstations in the plastic manufacturing industry are still semi-automated exposing operators to various ergonomics risk factors. This study aims to redesign the existing plastic printing workstation for improving work posture to prevent the occurrence of work-related musculoskeletal disorders (WMSD). The ergonomics risk factors faced by ten plastic printing workstation operators were assessed using workplace observation, questionnaire survey and Rapid Upper Limb Assessment (RULA). The results showed the operators were subjected to frequent bending posture which may cause WMSD on the back, shoulder, and legs. A new workstation design concept was constructed and finalized using the House of Quality (HOQ). This study concluded that the new design of the workstation has improved the RULA score from 7 to 3. Further investigation is recommended on the productivity and product quality analysis, and muscle activity of the operators in the future study.

KEYWORDS: *Ergonomics Design; Work Posture; Manufacturing Industry; Workstation Design*

1.0 INTRODUCTION

The manufacturing sector has contributed to economic upgrading for many countries [1]. However, the manufacturing sector leads to a high number of workers exposed to repetitive and strenuous posture in non-ergonomic working environments. Strenuous work posture includes the improper alignment of bones, joints, muscles, tendons, ligaments, and nerves during task performance in any working environment. Excessive muscle exertion, heavy lifting and improper design of workstation are prominent factors of adverse work-related musculoskeletal disorders (WMSD) such as strain and sprain. An ergonomics assessment on occupational health in a manufacturing company found that 83 percent of workers suffered from WMSD especially in the shoulder, wrists and lower back [2].

WMSD such as neck pain and lower back pain are among the main reasons for presenteeism [3]. The workers suffering from WMSD endure pain interference with work, limiting the workers' performance and hence productivity [4]. Presenteeism work performance incurs a loss of $2225.8 billion per year [5]. Workers tend to take sick leaves to recover from the pain also reducing the company productivity [6]. Ignorance in the correct and ergonomic techniques in materials handling during the manufacturing process results in the prevalence of WMSD [7]. Without ergonomic solutions taken by the administration, the long-term nature of the pain costs substantial loss towards the industry. Hence, proper work postural evaluation is important to reduce the preventable loss of productivity while ensuring the physical and psychological aspects of the workers as evidenced by Sarkar et al. [8].

Ergonomics issues in plastics production remain to be a significant concern. To ensure high quality and quantity of plastic products, most of the routine tasks in plastics production are automated but some workstations are still semi-automated requiring constant manual labor simultaneously with machinery. The amount of manual labor required is very high since there is a constant demand for plastics from pharmaceutical, food and beverage and electronics industries [9]. Exposure to various ergonomics risk factors during plastic products manufacturing such as lifting and handling heavy loads, strenuous work posture, prolonged standing, and heat stress can cause the operators to experience occupational health problems such as back pain, neck pain, and shoulder pain. Fernandes [10] reported a 50.1% prevalence of WMSD, considering of all body parts among workers. As a consequence of these pains, the operators feel uncomfortable and unable to pay full concentration while operating the machines, hence slowing down the rest production processes of quality plastic products.

To improve occupational health of workers at the plastics industry, Sanjog [11] studied the statistical correlation among workstation design, working postures and work shift duration related to WMSD symptoms.

However, far too little attention has been paid to incorporate human factors and engineering design in the plastics production workstation. Hence, redesigning the plastics production workstation which considering workers' requirements to improve work posture has been identified by this study as the need-of-the-hour. The main objective of this study is to redesign the existing plastic printing workstations in a local plastic manufacturing company for work posture improvement.

2.0 METHODOLOGY

An ergonomics evaluation study was conducted at a small-scale plastics manufacturing company located in Melaka, Malaysia, involving nine plastics printing operators and one production supervisor. This study performed workplace observation, questionnaire survey and work posture assessment among the operators in the company. House of Quality (HOQ) was used to translate the operators' requirements into technical specifications when redesigning the current workstation for the plastic printing process. This study has three steps, started with an ergonomics assessment at the existing plastic printing workstation. The second step involved redesigning the existing workstation through the House of Quality. In the third step, work postures were simulated in 3D Computer-Aided Design (CAD) DELMIA® software (Dassault Systèmes, France) to evaluate the effectiveness of the modified workstation.

2.1 Workplace Observation and Questionnaire Survey

The plastic printing process and the work posture practiced by the operators were digitally captured using a smartphone. In an ergonomics observation worksheet, details concerning each process and their problems were described. Potential improvements and their procedures were included as possible solutions in the sheet.

The questionnaire form was divided into three sections. The first section highlighted the demographic information of the operators which consists of gender, age, nationality, height, weight, designation, working experience, and education level. The second section emphasized the problems and root causes in the plastic printing process, whereby the operators were asked to indicate health problems (for example, pain in the back and neck) that they experienced while performing plastic roll handling tasks in the workstation. Additionally, this section captured the root cause of the problems. The feedback of operators on the problem root cause was determined through 5-rating (strongly disagree: 1; disagree: 2; neutral: 3; agree: 4; strongly agree: 5). This includes physical factors of the workstation, task and workplace environment such as table height, the mass of load and lighting condition. The last section accentuated the solutions suggested by the operators to improve the work posture at the plastic printing process workstation. The suggestions for improvements were transformed as inputs for the proposed design of the workstation as part of the improvement to reduce the discomfort level of the operators. Questions in the second and third sections were rated from strongly disagree to strongly agree (1-5).

A pilot study of the questionnaire form was performed on the operators to validate the questions before the actual survey. By using data in the pilot study, Cronbach's Alpha test was carried out on questions in second and third sections of the questionnaire to determine the reliability of the questionnaire survey form by using Statistical Package for the Social Sciences (SPSS 16.0) software.

2.2 Work Posture Assessment at Existing Workstation

The work posture assessment was performed among four (out of nine operators) at plastic printing workstations. These four operators were selected based on their willingness and the permission of company management as the postural assessment process can have a minor effect on their productivity. Firstly, the anthropometry of the operators was measured using a measuring tape and the data were transferred to manikins in CATIA® software (Dassault Systèmes, France). The activities, tasks and work cycle of these operators in the workstation were recorded and simulated by using DELMIA® software (Dassault Systèmes, France). Using the latter software, the work posture was evaluated based on Rapid Upper Limb Assessment (RULA) score. RULA was developed to investigate the loads on the musculoskeletal system due to various angles of the body, magnitude of load and posture frequency [12].

2.3 Redesigning the Existing Workstation

The quantitative requirements were extracted from the third section of the questionnaire and transformed into customer requirements, which were adjustable height, easy to assemble the roller, less stressful leg in standing, and can sit or stand. These requirements were translated into quantifiable technical requirements, identified as height, number of pallets, number of stool and number of the anti-fatigue mat. A HOQ was constructed to depict their strength of the relationships with the customer requirements in a correlation matrix. In the triangular matrix of the HOQ, the interrelationship between technical requirement was depicted using symbols accordingly; double circle for a strong positive relationship, circle for a positive relationship, cross (x) for a negative relationship, double-cross (xx) for a strong negative relationship, and none for no relationship. Interrelationships between the customer and technical requirements were weighed on a four-point scale and represented in symbols designated as double circle scoring 9 for a strong relationship, circle scoring 3 for medium relationship, triangle scoring 1 for a weak relationship, and none scoring 0 for no relationship. Each technical requirement importance was calculated from the total of the products of the score and relative importance of customer requirement.

The highest importance is the strongest feature that should be emphasized in the design. Four possible solution tools were derived from the HOQ, namely stool, anti-fatigue mat, pallet, and mobile lift table. Then, a conceptual design was proposed based on the possible combination of these tools and finalized in a focus group discussion of the company administrative board members based on its practicability and preference. Furthermore, the proposed workstation was compared with the existing workstation in the HOQ ranking from 1 to 5 in the order from worst to best quality to determine the difference made based on each customer requirement. The final conceptual design of the workstation was constructed using CATIA® software (Dassault Systèmes, France) and its improvement to work posture was validated using RULA analysis in the software. No actual fabrication was made as the modification was restricted to digital human modeling and simulation using the software. A previous study pointed out that the application of digital human modeling software has recognized to correctly predict ergonomics issues associated with work postures at the workplace [13].

3.0 RESULTS AND DISCUSSION

3.1 Demographic of Study Participant

There were 10 participants involved in this study (nine printing operators and one production supervisor). Five of them were Malaysian. All participants were male, aged between 21 to 50 years old with working experience ranged between 1 to 19 years.

3.2 Findings of Workplace Observation and Questionnaire Survey

Through the workplace observation, two sequential processes in plastic printing were found: fixing 50 kg printing cylinder into the machine (Process 1) and fixing 20 kg rubber pressure roller into the machine (Process 2) as summarized in Table 1. Both processes were performed by two operators at the site to carry the heavy loads. The rubber pressure rollers were situated and assembled on an ankle-high pallet before their installment to the machine whereas the cylinders were placed vertically next to the pallet. The pallet should be rearranged as operators walked on it which might be a safety hazard and squatted when assembling the rollers with a hand hammer. No other tool was provided to mediate transport and installation of the cylinder and roller.

Table 1: Ergonomics workplace observation worksheet

Work Process	Problems	Potential solution
Process 1: Fix the printing cylinder into the machine No. of worker: 2 Load: 50 kg	No tool to transport the cylinder. Excessive time and effort to reach and drag the cylinder. Bending posture to install the cylinder.	Provide a tool to transport the cylinder. Plan the process. Avoid bending posture.
Process 2: Fix the rubber pressure roller into the machine No. of worker: 2 Load: 20 kg	No tool to transport the roller. Excessive time and effort to reach and pick the roller. Bending posture to install the roller.	Provide a tool to transport the roller. Plan the process. Avoid bending posture. Keep the roller closer to the body. Adjust the ankle-high pallet to the appropriate height.

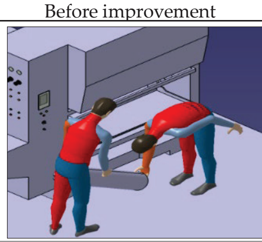
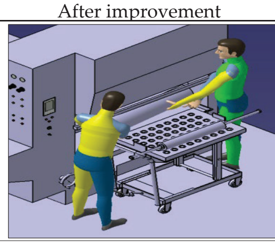
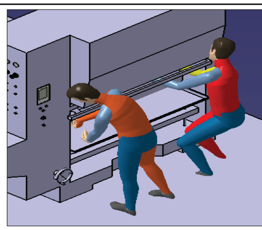
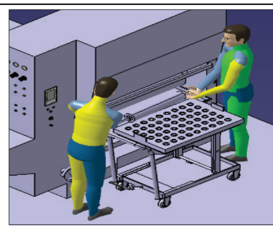
Results of the questionnaire survey revealed that working in an awkward posture, poor workstation design, and inappropriate working height were the main contributors to low productivity and occupational health problems at the plastic printing workstation. Among the root causes, working in awkward posture is the most critical root causes of low work yield and WMSD among the operators. The frequent bending during their work was slowing down the printing process due to the neck, back, and leg pain. Poor workstation design and inappropriate working height are related to the awkward working posture as shown in many ergonomic intervention studies [14-16].

3.3 RULA Score and HOQ Output

The final workstation design involves the incorporation of a mobile lift table, the addition of another layer of the pallet, and the rearrangement of cylinders and rollers on the pallet. The height of the mobile lift table is adjusted to the height of the new pallet height during the transfer of both materials simultaneously, reducing the repetition to retrieve them. Then, it is adjusted to a suitable working height during the assembly of the roller on it. Finally, the materials are transported by an operator using the mobile lift table and fixed into the machine by two operators accordingly.

Overall RULA score of work posture decreases from 7 to 3 after the work posture improvement for both Process 1 and Process 2. The RULA scores for the upper arm, neck, and trunk also decrease significantly. The virtual models simulated by DELMIA® software (Dassault Systèmes, France) in Table 2 shows that bending posture in both processes exerted the most physical stress on the neck, back and the legs of the operators. The color code on the models indicates decreasing severity of the stress from red to orange, yellow and green.

Table 2: Work posture at before and after workstation improvement

Work Process	Before improvement	After improvement
Process 1: Fixing 50 kg printing cylinder into the machine		
Process 2: Fixing 20 kg rubber pressure roller into the machine		

The HOQ in Figure 1 shows that the height of the workstation scores the highest importance at 64 due to strong relationships of height with two highest importance customer requirements which are adjustable height and easy to assemble the roller. The operators can assemble the rollers easier as they could transfer the roller onto the lift table before assembling it at adjusted height, reducing the repetition of bending posture assembling it on the pallet instead. The number of the pallet was added into the design to increase the reaching height of cylinders and rollers for their transfer to the table. A strong positive relationship was shown between the height and number of the pallet as the height of the workstation increases when the number of pallet increases in the diagram.

The number of stool was not added in spite of high importance because it is unpractical with the tasks upon discussion. In the benchmarking analysis in the HOQ, the proposed workstation improved significantly from the current workstation in two customer requirements of the highest importance; 1 to 5 for adjustable height and 2 to 4 for easy to assemble the roller. No significant difference between both designs could be deduced based on other customer's requirements.

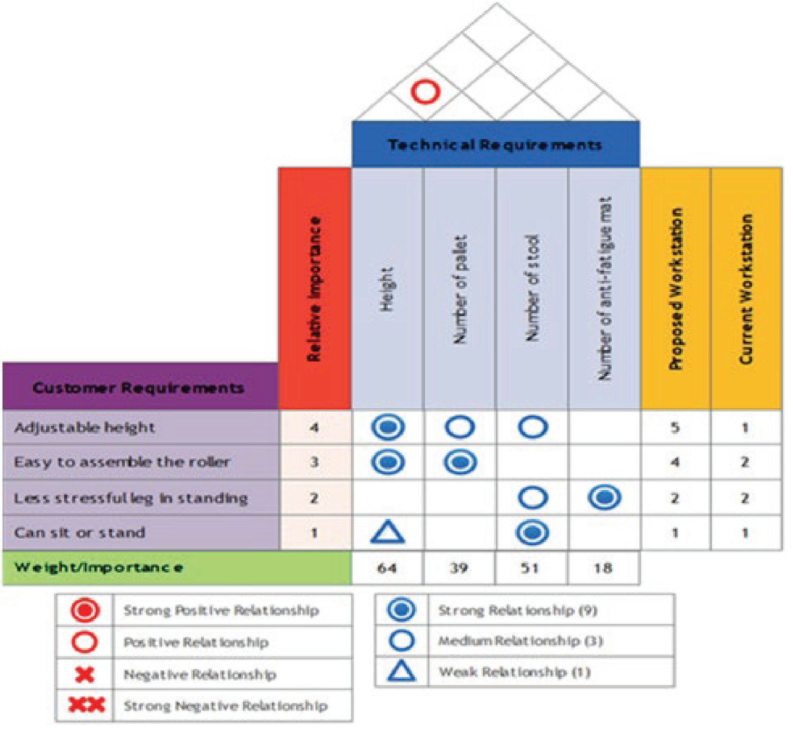


Figure 1: HOQ for analyzing operators' requirements to improve the existing workstation

Poor work posture such as bending, twisting and overreaching has been shown to cause WMSD among industrial workers [17]. Ghosh [18] found out that most workers suffered lower back and neck pain with 91 percent and 80 percent prevalence respectively when they were exposed to prolonged forward bending posture. Previous studies [19-20] have shown that poor work posture is highly correlated with the workstation design and occurrence of WMSD among workers. A study revealed that neglecting ergonomic principles of work posture in the workstation design may contribute to low job satisfaction, a decrease of work performance and production and numerous health effects [21]. RULA score of 7 indicates a high musculoskeletal loading and calls for engineering or work method changes to reduce WMSD risk [12]. The WMSD has a strong relationship with high RULA score so that precaution should be taken especially workplace design [17]. The score should be decreased as low as possible to minimize the risk. In this study, the existing plastic printing workstation leads to bending posture, thus increase the RULA score and caused most occupational health issues such as back, neck and foot pain at least twice per day as reported in the survey.

The ergonomics intervention proposed by this study shows work posture improvement based on the RULA analysis and simulated models. A decrease of overall RULA score from 7 to 3 indicated that working on mobile lift table improved work posture, especially for upper arm, neck, and trunk. The bending posture causes upper arm, neck and trunk scores to be high, thus improvement was focused on the upper limb by elevating the workstation to avoid bending posture. This study proposed adjustable equipment such as lift table as it has been reported to show positive effects on the upper body symptoms [22]. Gauthier [23] reported that the RULA grand score can be reduced from 7 to 4 when workers performed the task on an adjustable table. The adjustable height shifts work posture from bending or squatting to standing upright. Implementation such a tool has been demonstrated to effectively reduce the risk level of WMSD [24]. The mobility of the table facilitates the movement of the heavy loads minimizing the heavy lifting and subsequently musculoskeletal injuries [25]. The simulation of this study demonstrated better neck, shoulder, back, and leg postures after the improvement, reducing the risk during the installation of cylinders and rollers.

4.0 CONCLUSION

This study has performed an assessment of work posture among four operators at plastic printing workstations in a local plastic manufacturing company. The work postural assessment revealed that the existing plastic printing workstations required urgent improvement as shown by the high RULA score. Based on this indicator, this study developed a new conceptual design of the plastic printing workstations by incorporating a mobile lift table and added a layer of wood pallet for better working height. The working posture in the new design of workstation was simulated and the RULA score has reduced significantly. This study concluded that designing plastic printing workstations with a proper working height was able to improve the work posture of the operators. This study is limited to work postural assessment before and after workstation redesign. Further research should be conducted on productivity, product quality, and muscle activity to evaluate the effectiveness of the design on these factors.

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