Redesign of Squared-Profile Wood Sanding Machine for Work-Position and Productivity Improvement (Case study on Abu Production Handycraft, Pleret, Bantul, Yogyakarta)

Agung Kristanto *,1,2,3 **and Agung Saputra** 3
[1]Research Center in Back, Neck, Other Joint Pain and Human Performance (BNOJPH), Khon Kaen University, Khon Kaen
[2]Department of Industrial Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, Thailand
[3]Department of Industrial Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
Email: agung.kristanto@kkumail.com*

Abstract

Abu Production Handycraft was a small and medium enterprise (SME) that produced various types of handicraft products, such as tissue boxes, lamp cups, ashtrays, fruit baskets, flowerpots, flower vases, plaques, trays, souvenirs, and other types of wooden craft product. One of production processes was sanding process which was performed by the operator while in sitting position on a small bench for long time. It caused the worker worked with the back in bent position, head bowed, elbows and both legs include knees folded. Standardised Nordic Questionnaires (SNQ) revealed that the worker suffered from pain in the neck, shoulder, elbow, wrist, back, buttock, and knee. So, it could effect on the work productivity. The objective of this research was to redesign of squared-profile wood sanding machine for Work-position and Productivity Improvement. The concept of ergonomics was applied for work facilities designing. The discomfort perceived, standard time, and work productivity would be measured for comparing between pre and post redesigning conditions on this research. The anthropometric data was taken as reference for the dimension of sanding machine design which matched to the body dimension of the worker. SolidWorks software was used in this research for sanding machine designing. The result showed a decrease on the level of discomfort of 70% into 10%. Regarding to the standard time, the result showed 20.96 minutes/unit and 7.99 minutes/unit for initial and final condition, respectively. It indicated a decrease of 61.88% in term of standard time. Related to the standard output, it showed 3.00 units/minute for initial condition and 8.00 units/minute for final condition. It indicated that there was an increase of 166.67% in term of productivity when compared to the initial condition.

Keywords*: Anthropometry, Completion time, Discomfort level, Ergonomics in design, Productivity.*

1. INTRODUCTION

Indonesia includes to the group of developing country in the world. As the results of this, there are many industries that have grown rapidly in Indoensia. This growth occurs both in large scale industries and small and medium enterprises (SMEs). Relate to the SMEs, due to their important role as the economy backbone in Indonesia, so that Indonesian government has provided a lot of concern to them. The existence of SMEs takes part as much as 90 percent of total industries in Indonesia. They donate up to 57.9 percent to Indonesia's gross domestic product (GDP) and also engage up to 97.2 percent labors in SMEs sector (Declaration of Human Entrepreneurship, 2015).

The increasing number of SMEs has an impact on the increasing number of incidents and accidents on those SMEs. There were a lot of prior studies investigated about the most common injuries that occured in SMEs. The awkward body postures in working (e.g., bending or twisting) was frequently reported as the most common cause of back pain. It could occur due to the position of tools was lower than position of hand (Z. Sutalaksana and A. Widyanti, 2016). Another studies described the awkward working posture, such as knees folded due to the worker did the task in sitting position on a small work bench (Kristanto and D. A. Saputra, 2015), prolonged elbow bent (Kristanto and Y. Arifin, 2012), back bent caused by the position of workpiece was lower than the worker's hand (Kristanto and D. F. Fanany, 2014). The existence of dimensional gap in human-machine system in working became the major cause of all those incidents and accidents (Z. Sutalaksana and A. Widyanti, 2016). Eventually, It would affect the welfare (Z. Sutalaksana and A. Widyanti, 2016), health (J. L. Del Prado-Lu, 2007), comfort M. Mokdad and (M. Al-Ansari, 2009), labors safety (J. L. Del Prado-Lu, 2007), and labor productivity (D. Battini, M. Faccio, A. Persona, and F. Sgarbossa, 2011).

In Indonesia, One of SMEs that faces serious problem relate to dimensional gap in man-machine system is the handycraft industry. The sanding process is one of the production process in the handycraft industry. The dimensional mismatch can be observed on the sanding process. The sanding activity entangles an uncomfortable working position which the worker has to work in sitting position with the body in prolonged bent position, neck and back bowed and both legs and knees folded as shown in Fig. 1. According to a direct interview, it is revealed that the worker perceives pain in the neck, shoulder, elbow, wrists, back, buttock, knee, and legs, so it can influence on the work productivity.

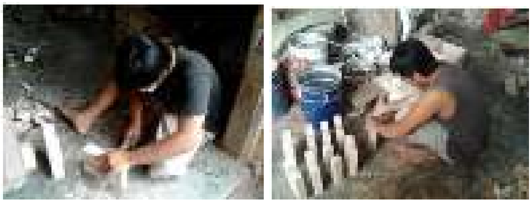

Figure 1. The initial sanding process posture (Courtesy : Abu Production Handycraft, 2014)

Based on the unergonomic working condition on Abu Production Handycraft SME, it indicates that the work facility redesigning which match to the anthropometry of worker is required to provide more comfortable and safer work environment. It indicates that the anthropometry database availability is very important.

Anthropometry is described as the human sciences that relate to the body measurements principally with body size, shape, strength and working capacity measurements (S. Pheasant, 1998). In SMEs, the significance of anthropometry data matching to workers is needed in the workplaces, equipments, and machines design in order to improve the comfort, safety, well-being, and health.

The objective of this research is to redesign of squared-profile wood sanding machine for work-position and productivity improvement The anthropometric data of Indonesian workers is measured in this research due to the requirement of dimensional match in human-machine system.

2. MATERIAL AND METHODS

2.1 Participants

Thirty male anthropometry data were collected in this study. It consisted of one anthropometry data of the real sanding machine operator and 29 additional Indonesian male anthropometry data. The consideration in selecting additional 29 Indonesian male data were based on the same in gender and age of which was located in the same age range to the real sanding operator. All anthropometry data was the data of Indonesian males in the age range of 20 – 30 years.

2.2 Measurement of anthropometry dimension

There were 8 body dimensions used in this research. They were sitting elbow height (SE), shoulder grip length (SG), span (SP), politel height (PH), buttock-poplitel length (BP), hip breath (HB), sitting shoulder height (SS), and shoulder breath (SB). The measurement methods of those dimensions can be seen in table 1.

Table 1. Anthropometry Dimension Measurement Methods

Dimension	Measurement method
SE	Vertical distance from the seat surface to the underside of the elbow (Fig. 2A).

SG	Distance from the acromion to the centre of an object gripped in the hand, with the elbow and wrist straight (Fig. 2B).
SP	The maximum horizontal distance between the fingertips when both arms are stretched out sideways (Fig. 2C).
PH	Vertical distance from the floor to the popliteal angle at the underside of the knee where the tendon of the biceps femoris muscle inserts into the lower leg (Fig. 2A).
BP	Horizontal distance from the back of the uncompressed buttocks to the popliteal angle, at the back of the knee, where the back of the lower legs meet the underside of the thigh (Fig. 2D).
HB	Maximum horizontal distance across the hips in the sitting position (Fig. 2E).
SS	Vertical distance from the seat surface to the acromion (i.e. the bony point of the shoulder) (Fig. 2A).
SB	Horizontal distance across the shoulders measured between the acromia (bony points) (Fig. 2E).

Source: Pheasant, 1998

2.3 Data collection

The completion task time, discomfort perceived by worker, and work productivity were taken as the parameters in this study.

The anthropometry dimension data was colleted by conducting a direct measurement for one real sanding machine operator using tape measure gauge and anthropometry chair. The rest 29 data were collected from the anthropometry database (Bank Data Antro Pria, 2014).

The prevelance of musculoskeletal disorders symptoms and the involved body parts identification was studied using the Standardised Nordic questionnaire (SNQ) (Kuorinka et al., 1987) which was modified to Indonesian version.

The completion task time was collected using continuous timing method by conducting a direct measurement using stopwatch.

2.4 Statistical analysis

The raw data colleted was input to the excel sheet and was imported into SPSS sofware for the statistical analysis. The Kolmogorov–Smirnov test ($p > 0.05$) was performed to check normality of the anthropometry data. The data uniformity and data adequacy test were applied to both anthropometry and observed time data. The Kolmogorov–Smirnov and data uniformity test were conduted using IBM SPSS Statistics 19 software. The data adequacy test was conducted using the formula decribed by Barnes (R. M. Barnes, 1980).

3. RESULTS

3.1 Anthropometry body dimensions

Table 2 displays the descriptive statistics of the gained measurements of the body dimensions of the subjects.

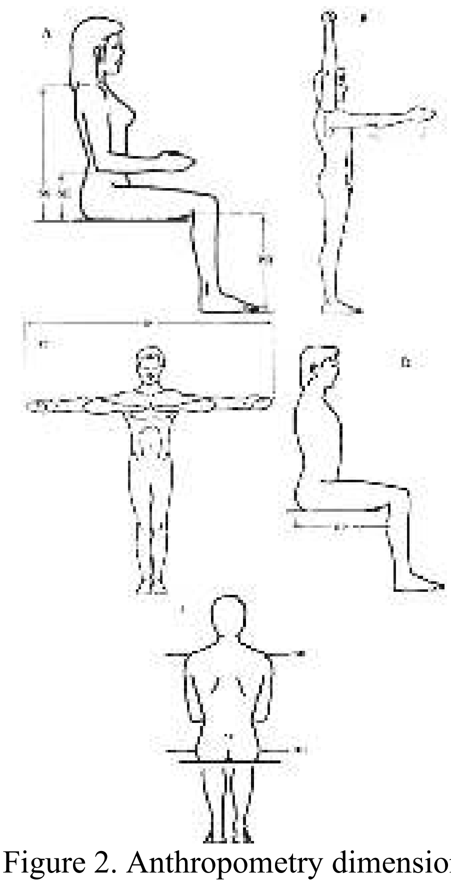

Figure 2. Anthropometry dimension

In order to ensure that the anthropometry data comes from a normal distribution, it is required to performed a the normality test using The Kolmogorov–Smirnov test. Table 3 displays the normality test result of anthropometry data.

Table 2. Anthropometric body dimensions of operator

No	Body dimension	Min	Max	Mean	SD	Percentile		
						5th	50th	95th
1	SE	21.00	27.80	24.35	1.72	21.55	24.00	27.47
2	SG	74.00	86.50	79.78	3.66	74.55	80.00	85.95
3	SP	161.50	186.00	171.51	6.33	161.50	170.50	183.80
4	PH	40.00	45.70	42.72	1.58	40.00	42.80	45.48
5	BP	43.00	52.30	46.98	2.82	43.00	47.05	52.14
6	HB	28.70	41.30	34.52	3.31	29.31	34.20	41.14
7	SS	56.60	62.50	59.55	1.55	56.82	59.50	62.23
8	SB	38.00	46.00	41.93	2.31	38.22	42.30	45.73

Table 3. The normality test using The Kolmogorov–Smirnov test

	SE	SG	SP	PH	BP	HB	SS	SB
p-value	0.286	0.571	0.637	0.861	0.222	1.00	0.486	0.666

Based on table 3. It can conclude that all anthropometry data comes from a normal distribution since the p-value for all data is greater than 0.05 (α-value).

The next statistical analysis for the anthropometry data is a data uniformity test then followed by a data adequacy test.

To ensure that there are no extreme data among the anthropometry data set, it is required to perform a data uniformity test. The data uniformity test results for the anthropometry data can be seen on figure 3.

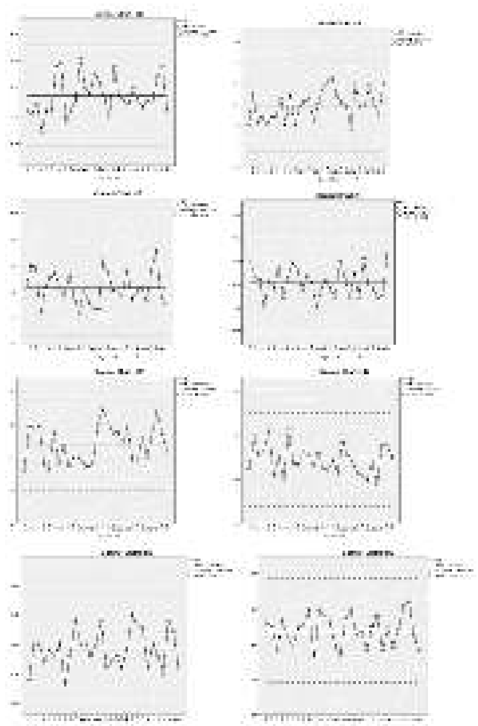

Figure 3. The data uniformity test results for the anthropometry data (A) SE, (B) SG, (C) SP, (D) PH, (E) BP, (F) HB, (G) SS, and (H) SB

It is showed that all data anthropometry are located between upper control limit (UCL and lower control limit (LCL). It can be concluded that all those data are uniform.

To ensure the number of data are enough to perform the further analysis, it is required to conduct a data adequacy test for the anthropometry data. Table 4 shows the results of adequacy test for the anthropometry data. It is taken the confidence level of 95% (confidence level index = 2) and error level of 5% for conducting the adequacy test.

Table 4. The adequacy test for anthropometry data

No	Body dimension	N’	N	Remark
1	SE	7.70	30	Adequate
2	SG	3.26	30	Adequate
3	SP	2.11	30	Adequate
4	PH	2.11	30	Adequate
5	BP	5.59	30	Adequate
6	HB	14.20	30	Adequate
7	SS	1.05	30	Adequate
8	SB	4.68	30	Adequate

N = number of observation data; N’ = number of theoritical data

It can be seen on table 4 that all anthropometry data have sufficient numbers in this study since the value of N’ is less than N.

3.2 Standard time determination

The statistical analysis for the observed time data is a data uniformity test then followed by a data adequacy test.

To ensure that there are no extreme data among the observed time data set, it is required to perform a data uniformity test. The data uniformity test results for the observed time data can be seen on figure 4.

Figure 4. The data uniformity test results for the observed time data (A) initial condition, (B) final condition

It is showed that all data of observed time are located between upper control limit (UCL and lower control limit (LCL). It can be conclude that all those data are uniform.

Then, it is needed to conduct a data adequacy test for the observed time data. Table 5 shows the results of adequacy test for observed time data. It is taken the confidence level of 95% (confidence level index = 2) and error level of 5% for conducting the adequacy test.

Table 5. The adequacy test for observed time data

No	Condition	N′	N	Remark
1	Initial	10.11	30	Adequate
2	Final	20.88	30	Adequate

N = number of observation data; N′ = number of theoritical data

It can be seen on table 5 that all observed time data have sufficient numbers in this study since the value of N' is less than N.

These observed time is adjusted by rating factor so that a qualified operator, working at a normal pace can easily do the work in the specified time. This corrected time is called the normal time. To this normal time are added allowances for personal time, fatigue, and delay, the result being the standard time for the task. The Westinghouse method is used as the performance rating system. The determination of performance rating factors refer to Barnes (R. M. Barnes, 1980). In order to determine allowances of operator, this is based on allowances that are recommended by International Labor Organization (ILO) (L. P. S. Hartanti, 2016). The performance rating factors and allowances for this study can be seen on table 6 and table 7, respectively.

Table 6. The performance rating factors for this study

Factors	Initial condition	Final condition
Skill	+0.06	+0.06
Effort	+0.05	+0.05
Condition	-0.03	+0.02
Consistency	+0.01	+0.01
Total	0.09	0.14
Performance rating (p)	1 + 0.09 = 1.09	1 + 0.14 = 1.14

Table 7. The allowances for this study

Variables	Initial condition	Final condition
Personal allowances	5%	5%
Standing allowance	2%	2%
Atmospheric condition	10%	0%
Close attention	0%	0%
Abnormal position allowance	7%	0%
Muscular energy	3%	0%
Bad light	2%	2%
Noise level	2%	2%
Mental strain	1%	1%
Monotony	1%	1%
Tediousness	0%	0%
Total allowances	33%	13%

The standard time for the task can be calculated using formulas as shown on table 8.

Table 8. The standard time calculation

Dimension	Formula	Initial condition	Final condition
Cycle time	$\frac{\sum \text{Observed time}}{N}$	12.89 min	6.10 min
Normal time	Cycle time x p	14.05 min	6.95 min
Standard time	Normal time x $\left(\frac{100\%}{100\% - \text{allowances } (\%)}\right)$	20.96 min	7.99 min

p = performance rating

3.3 Productivity determination

The standard time is used as the basis for work productivity calculation using the following formula.

$$\text{Standard output} = \frac{1}{\textit{standard time}} \qquad (1)$$

Then, refer to (1), the standard output for initial and final condition are 3 unit/hour and 8 unit/hour, respectively.

3.4 Discomfort perceived

Table 9 shows the comparison of pains in various body parts of the worker between pre and post designing conditions.

Table 9. Comparison of discomfort perceived

No	Part of body	Pre-designing condition		Post-designing condition	
		Comfort	discomfort	Comfort	discomfort
1	Wrist Neck		√	√	
2	Elbow		√	√	
3	Ankle	√		√	
4	Neck		√		√
5	Shoulder		√	√	
6	Back		√	√	
7	thigh	√		√	
8	Knee		√	√	
9	Hip	√		√	
10	Buttock		√	√	

3.5 Proposed solution

The recommendation of squared-profile wood sanding machine dimensions for the worker can be seen on table 10.

The anthropometric fits a sanding machine prototype with the proposed dimensions as can be seen on figure 5 and figure 6. It should be tested in the user population before making a final design recommendation. SolidWorks software was used in this research for work facilities designing.

Table 10. The recommendation work facility feature dimensions

Features	Anthropometric measurements	Design dimensions (cm)	Determinants
Sanding machine height	PH and SE	66.8	50%le of PH + 50%le of SE
Sanding machine width	SG	74.55	5%le of SG
Sanding machine length	SP	161.50	5%le of SP
Seat surface height	PH	42,80	50%le of PH
Seat surface width	HB	41.14	95%le of HB
Seat surface length	BP	47.05	50%le of BP
Backrest height	SS	59,50	50%le of SS
Backrest width	SB	42.30	50%le of SB

(A) (B)

Figure 5. Proposed work facilities (A) sanding machine unit, (B) work seat

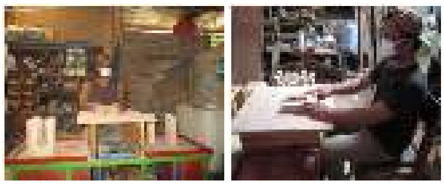

Figure 6. The final sanding process posture (Courtesy : Abu Production Handycraft, 2014)

4. DISCUSSION

Table 8 showed the comparison of standard time between initial and final condition. The standard time were 20.96 minutes/unit and 7.99 minutes/unit for initial and final condition, respectively. It indicated that the new design of sanding machine gave a decrease in standard time of 61.88% when compared to the initial condition. Before performing the time study, it was required to choose the operator who qualified and experienced to conduct a specific job or operation at normal pace. The worker should know the standardized method to finish the job or operation. The performance rating factor and allowance factor that used in this study are based on the judgment observation; thus, it was needed reviews and skills of work-study analysis to keep calibrating the standard times. Time standard as a result of time study might be used for cost control, scheduling and wage and budget estimation (L. P. S. Hartanti, 2016).

The purpose of ergonomics was to enable a work system to function better by improving the interactions between human and machines. Better functioning could be defined more closely, for example, as more output from fewer inputs to the system (greater 'productivity') (R. S. Bridger, 2003). This study also calculated the work productivity by using measured standard time. The work productivity calculation refered to research of (Kristanto and D. A. Saputra, 2015),(Kristanto and Y. Arifin, 2012), and (Kristanto and D. F. Fanany, 2014). Related to the standard output, This research showd 3 units/hour for initial condition and 8 units/hour for final condition. It indicated that there was an increase 166.67% in term of productivity when compared to the initial condition. This result was in accordance with previous research regarding to the work productivity improvement (M. Zare, M. Croq, F. Hossein-Arabi, R. Brunet, and Y. Roquelaure, 2016), (B. M. Deros, A. R. M. Yusoff, S. J. Ismail, and D. D. I. Daruis, 2016), and (S. A. Zakerian, E. Garosi, Z. Abdi, E. Bakhshi, M. Kamrani, and R. Kalantari, 2016).

Table 9 gives information about the discomfort that was perceived by the sanding machine operator. The operator felt discomfort on 7 body parts and 1 body parts of 10 total body parts for pre-designing and post-designing condition, respectively. It indicated that there was a reduction in term of discomfort perceived level of 60% between initial and final conditions. Many previous research also reported that the improvement of work facility layout could reduce the level of discomfort perceived in any production processes (Kristanto and D. A. Saputra, 2015),(Kristanto and Y. Arifin, 2012), and (Kristanto and D. F. Fanany, 2014). The Standardised Nordic questionnaire (SNQ) was used to measure the discomfort perceived by the operator on this research. However, the SNQ had some limitations on discomfort measurement, namely the SNQ only could be used to measure pain that happened over the past time on a certain time range, i.e., entire life, last 12 months, and previous 7 days, but the SNQ could not measure a spontaneous and instant pain. The other limitation of SNQ was only able to measure the pain qualitatively because it is typical of SNQ which was composed of binary (yes or no answer) questions (Kuorinka et al, 1987). It meant that the experience of the person who fills out the questionnaire may affect the results and recent and more serious musculosketetal disorders were prone to be remembered better than older and less serious ones (Kuorinka et al, 1987) and also the environment and filling out situation at the time of the questioning might also affect the results (F. R. Brigham, 1975) (M. A. Sinclair, 1975). The Visual Analogue Scale (VAS) was a common tool used by researcher to measure the pain perceived by the operator quantitatively. The VAS could measure a spontaneous and instant pain and also could be used for pain rating. The SNQ could be combined with VAS for measuring the discomfort or pain perceived by operator. It was confirmed by a prior study that develop a modified SNQ and VAS for pain measuring (K. Juntaracena, 2016).

This study still had some limitations. The limitation was the existence of discomfort or body pain perceived by the worker on the part of neck on post-redesigning condition. It indicated the potential risk of injury that may happened to the worker was still exist. It was required a further research that can eliminated the pain perceived by the worker on the neck.

5. CONCLUSIONS

Overall, the new work facility design have met the ergonomics requirement concept. The new work facilty design succeded to reduce the potential risk of injury and standard time and also increase the work productivity. There was a reduction in term of discomfort perceived level of 60% between initial and final conditions. The new design of sanding machine gave a decrease in standard time of 61.88% when compared to the initial condition. There was an increase 166.67% in term of productivity when compared to the initial condition.

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