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by Agung Kristanto

Research Article

Design of Ergonomic Work Facilities on Assembly Station of Mozaic Stone for Increasing The Work Productivity

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Abstract

Denta stone is a small and medium enterprise (SME) that fabricates mozaic stone ceramic using natural stone as the raw material. One of production processes is natural stone assembly which is conducted by the operator in sitting position on a small bench and using can with box shaped as the table. It causes the worker works with the body in bent position, head bowed and both legs folded. According to Standardised Nordic Questionnaires (SNQ), the worker suffers from pain in the neck, shoulder, elbow, wrist, back, buttock, and knee, so it can affect on the work productivity. This research applies RULA method to assess the postures of worker's upper limb in working. The concept of ergonomics is used for work facilities designing. The anthropometric data is taken as reference for the dimension of assembly work facilities design which match to the body dimension of the worker. SolidWorks software is used in this research for work facilities designing. The statistic computation is conducted by using SPPS software. The results show the RULA score for initial condition assessment is 7 that indicates investigation and changes are required immediately, meanwhile the final score assessment is 4 that indicates that further investigation is needed and changes may be required. Regarding to the standard time, the results show 1856 seconds/unit, 1109 seconds/unit, and 1045 seconds/unit for initial condition, first proposed layout condition and second proposed layout condition, respectively. Both of those layouts give a decrease in standard time of 40% and 44% respectively when compared to the initial condition. Related to the standard output, it shows 2 units/hour for initial condition and 3 units/hour for both proposed layouts condition. It indicates that there is an increase 50% in term of productivity when compared to the initial condition. A decrease also happens on the level of discomfortable of 80% into 30%. The second proposed layout alternative recommends a better improvement than the first one.

Keywords: Ergonomics; Work facilities; Productivity; RULA

1. Introduction

Indonesia is one of developing countries. Being as a rapid growing developing country, many large numbers of industries have been growth rapidly in Indonesia. This growth does not happen on large scale industries, but also on small and medium enterprise (SME). Associate with SMEs, Indonesian government has given attention since they play an important role as the backbone of economy in Indonesia. In Indonesia, It is approximately 99.9% industry are SMEs. They contribute up to 57.9% to Indonesia's GDP and employ up to 97.2% workers in SME sector [1].

The increase of number of SMEs lead to the increase of number of accident and incident on those SMEs. Some previous researches studied about the most common injuries that happened in SMEs. It was reported frequently about awkward body postures in working (e.g., bending or twisting) that leading to back pain. It was caused by the position of tools is lower than position of hand [2]. Another researches reported the uncomfortable working position, such as knees bent due to the operator worked in sitting position on a small bench [3], prolonged elbow folded [4], back bent due to the workpiece is located in the lower position than worker's hand [5]. The main cause of all those incidents and accidents was the existence of dimensional gap in man-machine system in working [2]. This influenced well-being [2], health [6], comfort [7], safety of the workers [6] and worker productivity [8] in the end.

In Indonesia, One of SMEs that encounters strenuous problem with dimensional gap in human-machine system is the industry of natural stone handycraft.The typical processes on this indutry includes raw material cutting process, smoothing process, sorting process, assembly process, and finishing process. The dimensional mismatch can be found on the assembly process. The assembly activity involves an awkward position which the operator works in sitting position on a small bench and using can with box shaped as the table as shown in Fig. 1. It causes the worker works with the body in bent position, head bowed and both legs folded as can be seen in Fig.2. According to Standardised Nordic Questionnaires (SNQ), the worker suffers from pain in the neck, shoulder, elbow, wrist, back, buttock, and knee, so it can affect on the work productivity.

Figure 1. The initial assembly work station (Courtesy : Denta Stone, 2015)

Figure 2. The initial operator's work position (Courtesy : Denta Stone, 2015)

According to the unergonomic drawn on natural stone SME, it showed that the workplace redesigning which fit to the anthropometry of worker is needed to provide more comfortable and safer work environment. It means that the anthropometry database availability very principal.

Anthropometry is defined as the human sciences that regarding to the body measurements: principally with body size, shape, strength and working capacity measurements [9]. In SMEs, the significance of anthropometry data fitting to labour is required in the work environment, tools, and machines design in order to enhance comfort, safety, well-being, and health.

This research aims to improve the design of work Facilities ergonomically on assembly station of mozaic stone for increasing the work productivity using anthropometry database approach. The measurement of anthropometric data of Indonesian workers is conducted in this study due to the need of dimensional match in man-machine system.

2. Materials and methods

3.1. Participants

Thirty females consist of 5 female operators and 25 Indonesian females were recruited to participate in this study. The consideration in choosing additional 25 females were based on the same in gender and the age of which is located in the same age range to the actual operators.

3.2. Measurement of anthropometry dimension

There are 7 body dimensions used in this research. They are shoulder-grip length (SG), politel height (PH), buttock-poplitel length (BP), hip breath (HB), span (SP), sitting elbow height (SE) and sitting shoulder height (SS).The measurement methods of those dimensions can be seen in table 1.

Table 1. Anthropometry Dimension Measurement Methods [9]

Dimension	Measurement method
SG	Distance from the acromion to the centre of an object gripped in the hand, with the elbow and wrist straight (Fig. 3A).
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. 3B).
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. 3C).
HB	Maximum horizontal distance across the hips in the sitting position (Fig. 3D).
SP	The maximum horizontal distance between the fingertips when both arms are stretched out sideways (Fig. 3E).
SE	Vertical distance from the seat surface to

	the underside of the elbow (Fig. 3F).
SS	Vertical distance from the seat surface to the acromion (i.e. the bony point of the shoulder) (Fig. 3G).

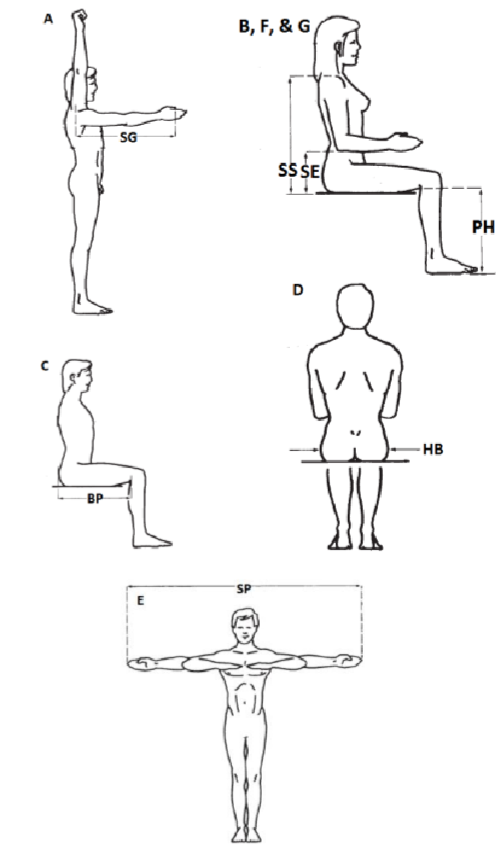

Figure 3. Anthropometry dimension

3.3. Data collection

The musculoskeletal symptoms prevelance and the affected body parts identification was investigated using the Standardised Nordic questionnaire (SNQ) [10] which was modified to Indonesian version.

The anthropometric dimension data was colleted by conducting a direct measurement toward all participants using tape measure gauge and anthropometry chair.

The ergonomic positioning data was measured using The Rapid Upper Limb Assessment (RULA) method [11]. RULA is an employee assessment worksheet that assess postures of neck, trunk, and upper limb loading [12].

3.4. 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 data.

3. Results

3.1. Discomfort perceived

Table 2 shows the comparison of pains in various body parts of the worker between pre and post designing conditions.

Table 2. Comparison of discomfort perceived

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

3.2. RULA assessment

The comparison between initial and final RULA assessment can be seen on table 3.

Table 3. The comparison between initial and final RULA assessment

	Initial condition		Final condition	
	Score	Remark	Score	Remark
Body posture part A : Arm and wrist analysis				
Upper arm	3	Makes angle of 60°	2	Makes angle of 35°
Upper arm adjustment	0	-	0	-
Lower arm	2	Makes angle of 130°	2	Makes angle of 115°
Lower arm adjustment	0	-	0	
Wrist	3	Makes angle of 30°	3	Makes angle of 28°
Wrist twist	1	Twisted in mid-range	1	Twisted in mid-range
Muscle arm	1	Repeated more than 4X/minute	0	Repeated less than 4X/minute
Force load	0	Load < 4.4 lbs (0.33 lbs)	0	Load < 4.4 lbs (0.33 lbs)
Total score A	5		3	
Body posture part B : Neck, trunk and leg analysis				
Neck	3	Makes angle of 40°	2	Makes angle of 15°

Neck adjustment	2	Neck is side bending	0	Good position
Trunk	3	Makes angle of 45°	2	Makes angle of 20°
Trunk adjustment	2	Twisted and side bending	1	Twisted or side bending
Legs	2	Not supported	1	Supported
Upper body muscle	1	Repeated more than 4X/minute	0	Repeated less than 4X/minute
Force load	0	Load < 4.4 lbs (0.33 lbs)	0	Load < 4.4 lbs (0.33 lbs)
Total score B		9		4
Final score		7		4

3.3. Anthropometric body dimensions

Table 4 shows the descriptive statistics of the obtained measurements of the body dimensions of the subjects.

Table 4. Anthropometric body dimensions of operator

No	Body dimension	Min	Max	Mean	SD	Percentile		
						5th	50th	95th
1	SG	63.4	69.0	66.21	1.67	64.46	66.21	68.95
2	PH	37.3	41.0	39.09	1.15	37.20	39.09	40.98
3	BP	39.5	43.6	41.51	1.09	39.70	41.51	43.29
4	HB	32.5	37.0	34.71	1.25	32.65	34.71	36.75
5	SP	148.0	154.0	151.04	1.64	148.35	151.04	153.74
6	SE	21.5	27.2	24.86	1.72	22.02	24.86	27.70
7	SS	52.0	58.2	55.06	1.61	52.40	55.06	57.70

3.4. Proposed solution

The recommendation work facility feature dimensions for the worker can be seen on table 5.

Table 5. The recommendation work facility feature dimensions

Features	Anthropometric measurements	Design dimensions (cm)	Determinants
Work table height	PH and SE	59	5%le of PH + 5%le of SE
Work table length	SP	148	5%le of SP
Work table width	SG	63	5%le of SG
Seat surface height	PH	37	5%le of PH
Seat length	BP	41	50%le of BP
Seat width	HB	37	95%le of HB
Backrest height	SS	55	50%le of SS

The anthropometric fits a prototype work facilities with the proposed dimensions as can be seen on Fig. 4. 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

Figure 4. Proposed work facilities.

This research developed two scenarios in term of work facilities layout. The purpose of those was to compare and figure out for the best work facilities layout. The two layouts can be seen on Fig. 5. The difference between first layout and second layout was the location of container of raw materials (small and big sized stone) and assembled products.

On the first layout, the container of pre and post assembly mall are located on the right and left side of the operator's chair, respectively. Whereas, the container of big and small sized stone are in right and left side on table area, respectively (Fig. 5a). The work operator's position using the first layout can be seen on Fig. 6.

On the second layout, the container of big and small sized stone are located on the right and left side of the operator's chair, respectively. Whereas, the container of pre and post assembly mall are in right and left side on table area, respectively (Fig. 5b). The work operator's position using the second layout can be seen on Fig. 7.

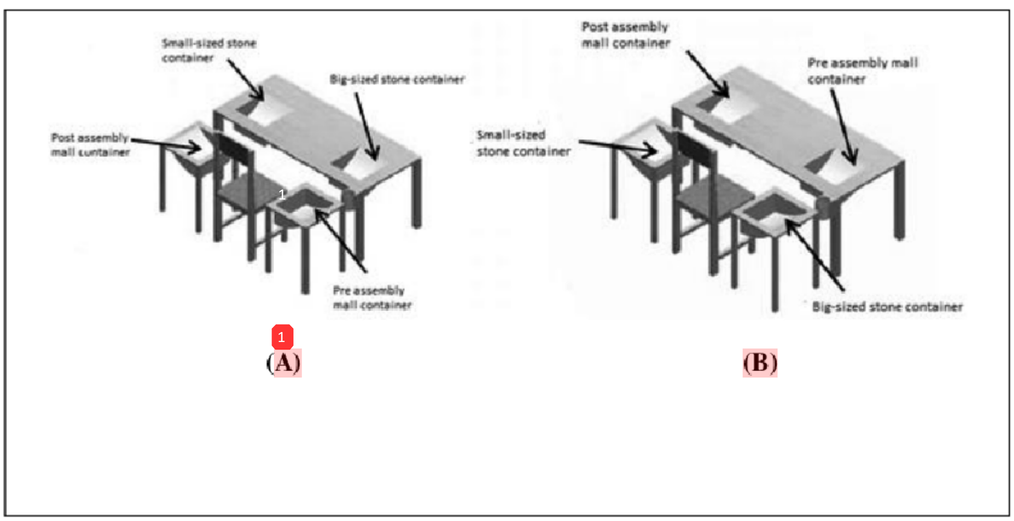

Figure 5. Work facilities layout (a) The first layout, (b) The second layout

Figure 6. Work operator's position using first layout (a) right view, (b) left view, and (c) front view (Courtesy : Denta Stone, 2015)

Figure 7. Work operator's position using second layout (a) right view, (b) left view, and (c) front view (Courtesy : Denta Stone, 2015)

3.5. The Completion task time

The completion task time would be measured for those two work facilities layouts. The learning process for worker was given before the factual completion task time was conducted. It was meant that worker become accustomed to new layout. The comparison of completion task time between initial, first proposed layout, and second proposed layout can be seen on Fig. 8.

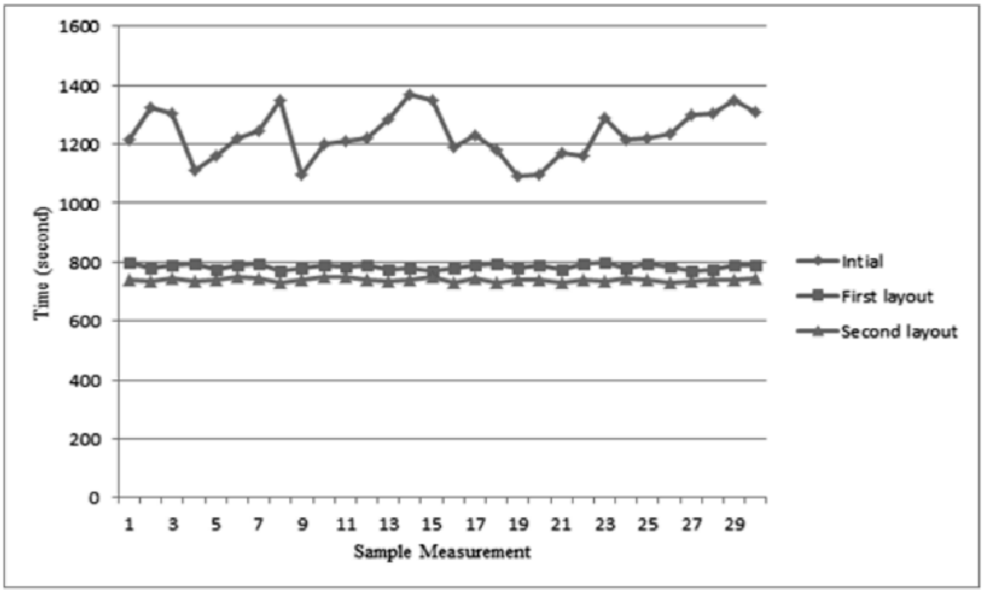

Figure 8. The comparison of completion task time between initial, first proposed layout, and second proposes layout

4. Discussion

Table 2 gives information about the level of discomfort that is perceived by the worker. The worker feels discomfort on 8 body parts and 3 body parts of 10 total body parts for pre-designing and post-designing condition, respectively. It indicates that there is a reduction in term of discomfort perceived level of 50% between initial and final conditions. Many previous research also report that the improvement of work facility layout can reduce the level of discomfort perceived in any production processes [3], [4], [5].

The operator still perceive pain on 3 body parts after using new work facility layout, namely elbow, wrist, and lower back. These findings are well-matched with the RULA assessment result for final condition displayed on table 3. Elbow is part of lower arm body. According to table 3, the lower arm on final condition makes angle of 115 degrees. So, the RULA assessment gives score of 2. It indicates that the posture is acceptable if it is not maintained or repeated for long periods of time. The wrist part on final condition makes angle of 28 degrees. It results RULA score of 3 which indicates that further investigation is needed and changes may be required. Lower back is part of the trunk part. The trunk on final condition makes angle of 20 degrees. The RULA assessment gives score of 2. It indicates that the posture is acceptable if it is not maintained or repeated for long periods of time. The final RULA evalution shows a score change from 7 to 4. It indicates that the the new layout design can reduce the potential occupational risk suffered by the worker but further investigation is needed and another changes may be required. This result is in accordance with previous research regarding to the ergonomics evaluation using RULA method [13].

Figure 8 shows the comparison of completion task time between initial, first proposed layout, and second proposed layout. This study will compare the standard time for each condition. The performance rating and allowance values detemination needed for standard time calculation refer to the research of [3], [4], and [5]. The standard time are 1856 seconds/unit, 1109 seconds/unit, and 1045 seconds/unit for initial condition, first proposed layout condition and second proposed layout condition, respectively. Both of those layouts give a decrease in standard time of 40% and 44% respectively when compared to the initial condition.

The purpose of ergonomics is to enable a work system to function better by improving the interactions between users and machines. Better functioning can be defined more closely, for example, as more output from fewer inputs to the system (greater 'productivity') [14]. This study is also calculate the work productivity by using measured standard time. The work productivity calculation refers to research of [3], [4], and [5]. Related to the standard output, This research shows 2 units/hour for initial condition and 3 units/hour for both proposed layouts condition. It indicates that there is an increase 50% in term of productivity when compared to the initial condition. This result is in accordance with previous research regarding to the work productivity improvement [15], [16], and [17].

This study still has some limitations. The first limitation due to the RULA assessment is only made on the new work facility design as a whole. Whereas on the new work facility design propose two model layouts as seen on Fig. 5, Fig. 6 and Fig. 7. It would be better if the RULA assessment is applied to both first and second proposed work facility layouts. Therefore, It can be seen the differences between those two proposed layout significantly. The second limitation is the existence of discomfort or body pain perceived by the worker on the part of elbow, wrist, and lower back on post-redesigning condition. It indicates the potential risk of injury that may happen to the worker is still exist. It is required a further research that can eliminate the pain perceived by the worker on the part of elbow, wrist, and lower back.

5. Conclusions

Overall, the new work facility layout have met the ergonomics requirement concept. The new wotk facilty layout succeds to reduce the potential risk of injury and standard time and also increase the work productivity.

According to the standard time and work productivity measurements, the second proposed layout alternative (Fig. 5b and Fig. 7) recommends a better improvement compared to the first one (Fig. 5a and Fig. 6).

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