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Jig Design, Assembly Line Design and Work Station Design and their Effect to Productivity

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Abstract

This report discussed the effect of workstation design, assembly design, jig design and working posture on the assembly of plugs. Two different designs of jig (vertical and rectangular) and two sets of assembly line design (one and two operators) and two set of workstations design (sitting and standing) were studied to observe their effects to productivity. Design of Experiments 2^3 with two levels of each factor is used to conduct an experiment for obtaining the most productive jig and assembly line design. Two groups of workers were employed to assemble the plug in 8 different ways. Number of replication is 32 for each setting and total of electric plugs produced by each group is 256 units. The results shows that jig design have the most significant effect to the assembly time. Furthermore, the other factors: assembly design and workstation design are also show significant factors to assembly time. However, interaction combinations of two or three factors were not significant to assembly time. The most productive assembly line design which achieved the lowest assembly time is the combination of one operator, with rectangular jig and work station design sitting. Meanwhile the working posture of workstation design that provides the lowest RULA score was sitting position, it provided score 2 which is safe.

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1. Introduction

An assembly line is designed by determining the sequences of operations to manufacture of components as well as the final product. Each movement of material is made as simple and short as possible, with no cross flow or backtracking. All operations performed along the line are balanced. Design of assembly line plays the important role in manufacturing which will directly influence its productivity.

Previous researchers [13], [19-20] explained assembly line is a widely used in production systems. The main objective of assembly lines designers is to increase the efficiency of the line by maximizing the ratio between throughput and costs. Chow [5] stated that "A simple process design criterion is to balance the assembly line so that each operation takes approximately the same amount of time. A balanced line often means better resource utilization and consequently lower production cost."

Jig is a special tool used for locating and firmly holding work piece in the proper position during the manufacturing or assembly operation. It also guides the tool or work piece during the operation. Jig is designed to increase the productivity of operation assisting worker to do job easier, faster and more comfortable.

Meanwhile, applying principles of ergonomics in the job environments such as improving working posture and workstation design as part of ergonomics efforts on enhance productivity and safe working condition have been extensively discussed by many authors [7] [8] [2]

[22]. The studies discussed ergonomics intervention may improve productivity, quality, operators' working condition, occupational health and safety (OHS), and even cost effectiveness. The areas of working environment studied include workplace layouts, working tables and chairs of appropriate height, fixing hand-tools, better lighting and job rotation and also working postures. This research studied several parameters afore mentioned: i.e. design of workstation, design of assembly process, design of jig, their effects to productivity in the assembly line of plugs. Other variables such as equipment and skill of worker which may contribute to productivity are assumed kept constant. The hypothesis to be tested that either one or more of the parameters or combinations of parameters contribute to better production performance in this case assembly time or cycle time.

Two designs of jig were introduced, one has rectangular shape and the other has line or vertical shape or vertical orientation. Two design of assembly were tested one with single operator and the other with two operators. Design of workstation was created by applying common industrial practices in assembly line i.e. standing or sitting position. For working poster assessment, RULA (Rapid Upper Limb Assessment) analysis was conducted to examine different workstation designs effect to safe working postures.

2. Methods

2.1 Product Design

For the purpose of this experiment an electric product was chosen as a case. This product was selected since it

widely used in the household, it was not a complex in design and components. The design of product is shown in Figure 1. This electric product is a plug product number BS 1363, it has 8 components. These are: base cover, neutral pin, earth pin, live pin, fuse holder, fuse, top cover and one screw. The dimension of the product is shown as Figure 1. Plug can assume as rectangular block (dimension 51mm X 49 mm X 21 mm) with 3 pin (earth, neutral and live terminal pin). The central point of live and neutral pin is located 22 mm below the central point of earth pin. The distance between central point of live and neutral pin is also 22 mm. Accuracy of position and dimension of the plug's pin are important when design the jig, this is to let plug able to locate and secure through the jig.
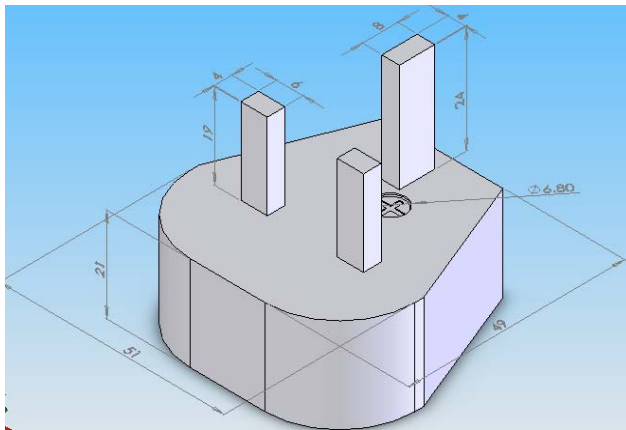

Figure 1 Plug design and dimensions

2.2 Design of Jig

The purpose of jig on this research is holding the plug's earth pin with cover in the proper position, other components locate and secure into the jig when the assembly process.

Two jigs were designed and produced by researchers, these designs were based on industry practice. The two were differentiated based on its orientation. The first one has orientation vertical shape in one line; the other has rectangular shape (see Figure 2). The size of the jig, the vertical one has 275 mm x 80 mm; the rectangular one has 136 mm x 145 mm. Both Jigs can accommodate 4 plugs at one time.
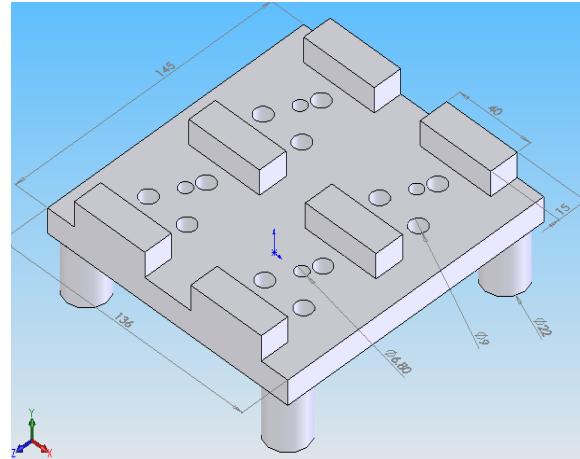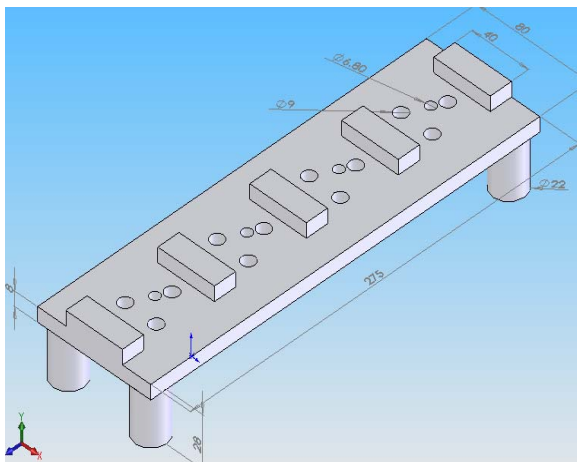

Figure 2 Two jig designs, a vertical shape and a rectangular shape

2.3 Design of Assembly line

Two designs of assembly line were created these were based on manufacturing practices one with single operator and the other with two operators. The process of designing assembly as follow: at the first stage was to recognize components and the second stage was to comprehend assembly processes of product which is BS1363. Once it has done, the assembly processes sequence were determined. These sequences as follow: put plug's base cover on the jig, insert the child components (neutral pin, earth pin, live pin, fuse holder and fuse) into the base cover. Then, assembly the top and base cover together by screw. For screwing process, the jig is flipped and tightens with the screw driver powered by air pressure. The sequence planning for the assembly process of electric plug is presented in the precedence graph below:
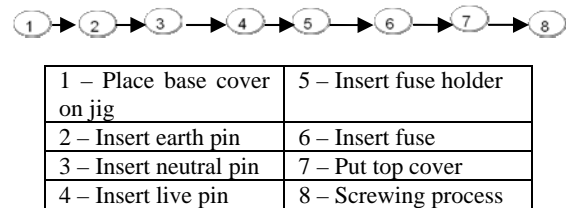

1 – Place base cover on jig	5 – Insert fuse holder
2 – Insert earth pin	6 – Insert fuse
3 – Insert neutral pin	7 – Put top cover
4 – Insert live pin	8 – Screwing process

Figure 3: Precedence graph of plug assembly

Table 1is shown the result of each assembly task based on the precedence graph constructed in Figure 3. To obtain the balance of time for two operators, the assembly tasks assigned for each operator should be equal for eliminating the waiting time of another operator.

Table 1: Average time of each plug assembly task for line balancing

Task No.	Assembly Task	Average time per plug (sec)	Cumulative Assembly Time
1	Place base cover on jig	0.83	0.83
2	Insert earth pin	2.52	3.35
3	Insert neutral pin	1.94	5.29
4	Insert live pin	2.46	7.75
5	Insert fuse holder	1.91	9.66
6	Insert fuse	2.30	11.96
7	Put top cover	2.02	13.98
8	Screwing process	5.02	19.00

According to the table above, the total time for assemble one electrical plug is 19.00s. The single operator did all the tasks from the beginning to the end of assembly processes. For design of two operators, in order to obtain a good line balancing for 2 operators, the total assembly time must divide equally into two, which is 9.5 sec. Hence, the most nearly cumulative assembly on Table 1 is on task 5 which is 9.66 sec. This means that the first operator will stop at the end of task 5 which is insert fuse holder. The second operator will start from task 6, insert fuse to final assembly. Assuming that there were work in process, therefore, the second operator did not required waiting for the first operator and could start the experiment at the same time.

2.4 Design of Workstation

Workstation design of an assembly line may contribute to performance of workers when he or she performed his/her job on position either standing or sitting. Grandjean [11] has made exploration on work surface height for different kinds of jobs. He proposed precision work for men should be set at 100-110 cm, light work around 90-95 cm and heavier work around 75-90 cm. Since the assembly of plugs is considered as a light work, the workstation design for assembly was set at the height 91 cm for either standing or sitting position.

2.4.1 Standing Position
Figure 4 shows isometric, and front side views, while performing the task with an operator and in standing position. The table height is fixed to 91 cm.
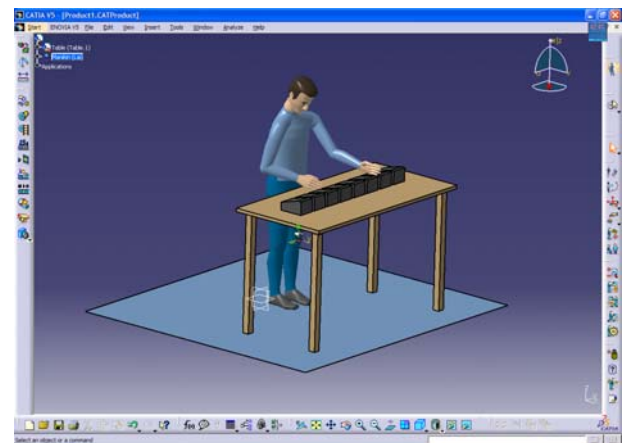

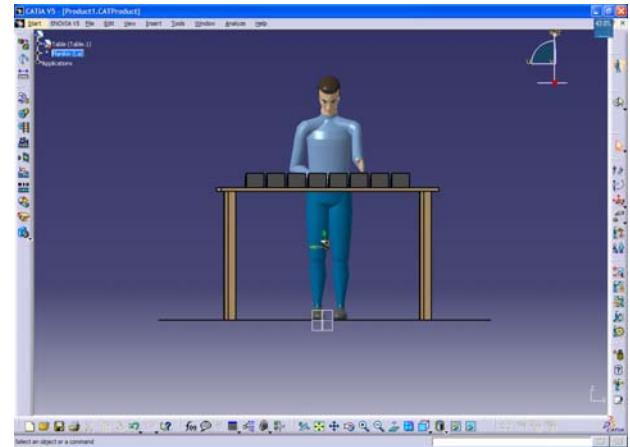

Figure 4: Standing position, isometric view and front view

2.4.2 Sitting Position
Figure 5 illustrates isometric and front side views of a subject performing the task with an operator in sitting position. The table height is fixed to 91 cm.
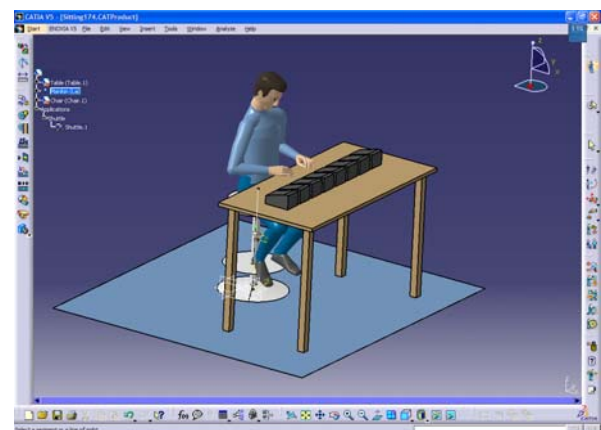
Figure 5: Sitting position, isometric view and side view

2.5 Design of Experiment

The design of experiment took three factors and two levels (2^3), the factors were jig design, assembly design and workstation design. The first factor, jig design, it has two different designs. The second factor, assembly design, it has two levels, one single operator and two operators. The third factor, workstation design, with two levels the first setting was sitting the second setting standing. Based on this design eight (8) different ways of assembling line were formed. Table 2 shows the design of experiment for assembly line.

Table 2: Summary of Design experiment

Position	One Operator		Two Operators	
	Vertical jig	Rectan-gular jig	Vertical jig	Rectan gular jig
Standing	X1	X2	X5	X7
Sitting	X3	X4	X6	X8

2.6 Experimental Procedure

Two groups of worker participate in this experiment. Each group has two subgroups, one with single operator and the other with two operators. These two groups will be compared and test whether their performance were the same, and whether the results of experiment were consistent.

Each group performed 8 different sets of assembly process according to the full factorial design. Thirty two repetitions for each different set of assembly were done. Each set was selected randomly, once it was selected, 32 plugs were produced. Hence, total of electric plug required to assemble for each group are 256 electric plugs.

Measurement of performance for this experiment was the assembly time required to finish one product. Before recording the assembly time, the performance of each group was tested to ensure their work has reached a consistent performance. The assembly time or cycle time was recorded by using stop watch. This assembly time became the dependent variable, while different factors were set as independent variables.

2.7 Subjects

The subjects participated in this experiment were young workers age in average 24 years old, all were male subjects. Their height is on range of 170 – 180 cm. They have experiences and involved in industrial works for less than a year. Training to assembly this product was given prior to the experiment. This was necessary to ensure that learning time has reached. Their time was recorded to ensure the consistent performance of their jobs.

3. RESULT & DISCUSSION

3.1 Group's Performance

The First test is to verify whether two groups of workers have different quality of work or performance. This is necessary to make sure the inferences made from the results may work for both groups. Hence, the F test and t-test were used to examine whether two groups showed different performance. The F test were used to verify whether the group has significant different in variance. Based on the F test result, these two groups then were tested for t-test: paired two samples for means.

Table 3: t-test: paired two sample means between two groups

	Group 1	Group 2
Mean	19.564	19.739
Variance	1.397	1.027
Observations	256	256
Pearson Correlation	0.255	
Hypothesized Mean Difference	0.000	
Df	255	
t Stat	**-2.080**	
P(T<=t) one-tail	0.019	
t Critical one-tail	**1.651**	
P(T<=t) two-tail	0.039	
t Critical two-tail	**1.969**	

According to t-test performed on Table 3, t Stat (2.080) is greater than t Critical one-tail (1.651) or t Critical two-tail (1.969). This result recommends reject the hypothesis that the two groups have the same means. It is shown that the assembly time for two groups is significantly different. Hence, the performance of each group has significantly different whereby the group 1 (19.564 sec) performed more productive than group 2 (19.739 sec). However, group 2 was more consistent in assembly time than group 1 because the variance of data for group 1 (1.397 sec) is greater than group 2 (1.027 sec).

Further investigation is to observe whether there is a significant different among the setting of experiments in each group of workers, Analysis of Variance (ANOVA) for single factor for group 1 and group 2 were used. The F Test for both groups suggest that there exist a significant different among the setting of the experiments, meaning jig design (jig's orientation), assembly design (different number of operators), and work station design (working position) are contribute to significant different to the response time (assembly time). Table 4 and 5 shows the ANOVA analysis for single factor of group 1 and 2.

Table 4 ANOVA for Single Factor for Group 1

Groups	Count	Sum	Average	Variance	
X1	32	638.84	19.96	0.69	
X2	32	615.08	19.22	0.40	
X3	32	598.64	18.71	0.75	
X4	32	587.44	18.36	0.62	
X5	32	670.8	20.96	1.09	
X6	32	651.48	20.36	0.75	
X7	32	632	19.75	0.77	
X8	32	614.16	19.19	1.04	
ANOVA					
Source of Variation	SS	df	MS	F	P-value
Between Groups	167.25	7	23.893	**31.346**	6.08 E-31
Within Groups	189.03	248	0.762		
Total	356.28	255			

Table 5 ANOVA for Single Factor for Group 2

Groups	Count	Sum	Average	Variance	
Y1	32	642.84	20.09	0.51	
Y2	32	626.64	19.58	0.46	
Y3	32	616.84	19.28	0.38	
Y4	32	603.68	18.87	0.68	
Y5	32	666	20.81	1.24	
Y6	32	646.76	20.21	0.90	
Y7	32	630.68	19.71	0.55	
Y8	32	619.8	19.37	0.99	
ANOVA					
Source of Variation	SS	df	MS	F	P-value
Between Groups	84.42	7	12.061	**16.853**	3.64 E-18
Within Groups	177.47	248	0.716		
Total	261.90	255			

Figure 6 shows mean statistics of different setting workstation design for group 1 (X). First assessment of the results shows that design of jig either vertical or rectangular provides the most significant different to assembly time by assuming other factors such as number of operator and workstation design are in the same set. This is shown column X1 and X3 for one operator the

average assembly time 19.96 sec, for vertical jig and 18.71 sec for rectangular jig. While with two (2) operators (column X5 and X7) provide 20.96 sec and 19.75 sec. The second greater significant different to assembly time is the number of operator either 1 or 2 operators with assuming other factors such as jig's orientation (jig design) and workstation design are in the same set. This shown by column X1 and X5 with vertical jig and standing position provides average assembly time 19.96 sec for one operator and 20.96 sec for 2 operators, while with sitting position (X2 and X6) provides 19.22 sec and 20.36 sec. Lastly, the result shows that workstation's design either standing or sitting provides the smallest significant different to assembly time by assuming other factors such as number of operators and jig design are in the same set. This shown by column X1 and X2 with an operator and vertical orientation of jig provides average assembly time 19.96 sec for standing position and 19.22 sec for sitting position, while with 2 operators (X5 and X6) provides 20.96 sec and 20.36 sec.

For group 2 (Y), the results is similar with group 1 which The orientation of jig provides the most significant different to assembly time, follows with the number of operator and the working position.
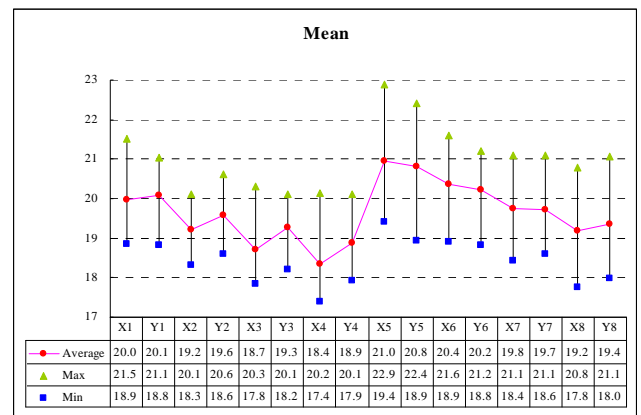

Figure 6: Mean for two groups with different set of factors

3.2 Analysis of Variance

Further analysis of variance, Table 6 illustrates the result ANOVA for each factor: Jig design, assembly design (number of operators) and workstation design, and its interaction of two ways and three ways to the response i.e. assembly time. The significant factors are determined by using the p-value (P) in the Factorial fit table. Using level of significant at 0.05, the main effects for number of operator, orientation of jig and design of workstation are statistically significant where their p-values are less than 0.05. Among the main effects, the most significant factor is the orientation of jig where its effect value is the greatest value, 1.1247. However none of combination factors are significant.

Table 6: Factorial fit for: assembly time versus number of operator, orientation of jig and design of workstation

Estimated Effects and Coefficients for Assembly Time (coded units)					
Term	Effect	Coef	SE Coef	T	P
Constant		19.5642	0.05457	358.54	0.000
Number of Operator	1.0034	0.5017	0.05457	9.19	**0.000**
Orientation of Jig	**-1.1247**	-0.5623	0.05457	-10.31	**0.000**
Design of Workstation	-0.5634	-0.2817	0.05457	-5.16	**0.000**
Number of Operator * Orientation of Jig	-0.0647	-0.0323	0.05457	-0.59	0.554
Number of Operator * Design of Workstation	-0.0172	-0.0086	0.05457	-0.16	0.875
Orientation of Jig * Design of Workstation	0.1097	0.0548	0.05457	1.01	0.316
Number of Operator * Orientation of Jig * Design of Workstation	-0.0866	-0.0433	0.05457	-0.79	0.428

For further confirmation of results of Table 6, the normal probability plot of the standardized effects were evaluated to observe which factors influence the response i.e. assembly time. As shown in Figure 7 significant factors are identified by a square such as number of operator, orientation of jig and design of workstation. Moreover, Figure 8 shows the main effects plot, it shows that assembly time is:

(a)   Increase from single operator assembly process to two operators.

(b)   Decrease from using the vertical jig to rectangular jig for jig's orientation.

(c)   Decrease from standing position to sitting position for workstation's design.
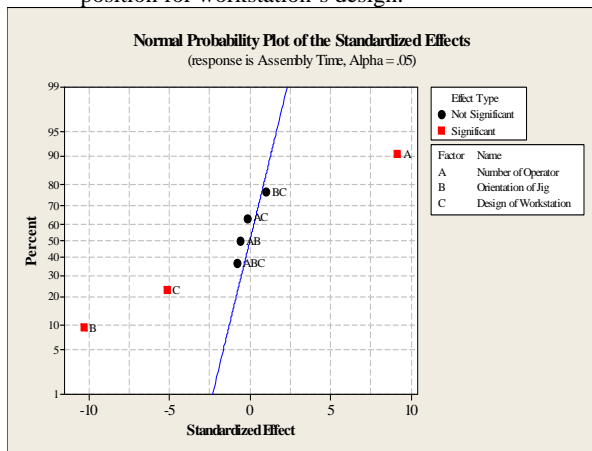

Figure 7: Normal probability of the standardized effects
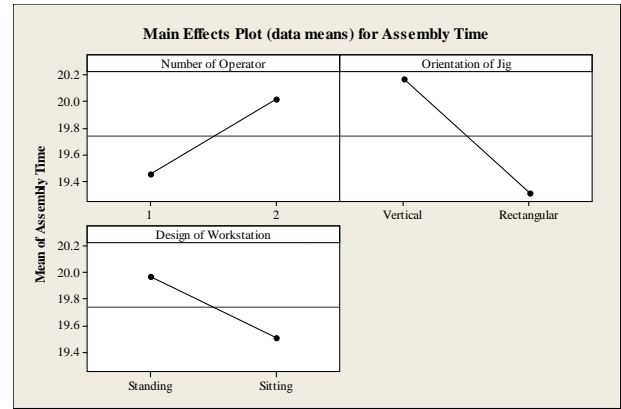
Figure 8: Main Effect plot for assembly time

Further investigation is on which setting of combination factors contribute to the lowest assembly time. Figure 9 Box plot of assembly time shows that the lowest Mean average assembly time is achieved at the assembly line design of 1 operator, rectangular orientation of jig and with the sitting working posture, the assembly time is 18.3575 sec. This combination also contributes the lowest assembly time which is 17.38 sec and the lowest upper bound is 20.15 sec.
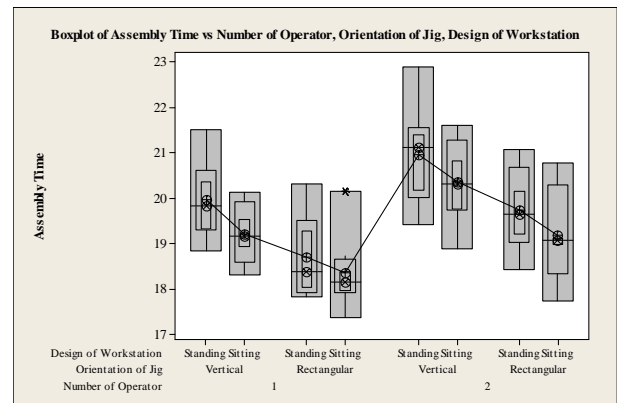
Figure 9: Box plot of assembly time

3.3 Working Posture Analysis

In a workstation, an operator may perform a task in various working posture. Working posture may expose to the hazards. Improper workstation design will expose to occupational hazards associated with awkward working posture. Therefore, an attention on working posture has priority to ensure it is safe to operators. There are various tools that have been introduced to analyze working posture; one of the common tools is RULA (Rapid Upper Limb Assessment) analysis.

For RULA analysis, this project assessed only a single operator from group 1 and group 2 with sitting and standing working posture. The factor of jig's orientation (rectangular or vertical) is assumed not significant affecting the results because jig is located at the normal working area which is 25cm from operator. RULA analysis is conducted by using CATIA software as shown in Figure 10. All dimensions required are according to the actual dimension such as anthropometry

of operator, 91cm height of table, 25cm work area and others to ensure the accuracy of results.

Figure 10 illustrates one of RULA analyses of an operator group 1 with standing position. As depicted in the figures, the column at the right hand side of dialogue box, it states the posture score of every part of the body. At the left hand side, the dialogue box recorded condition of posture (static, intermittent, and repeated); repeat frequency of the posture (< 4 times/minute or > 4 times/minute); condition of arm (supported, across body midline, and balance) amount of load handled by the subject; and the RULA Score.
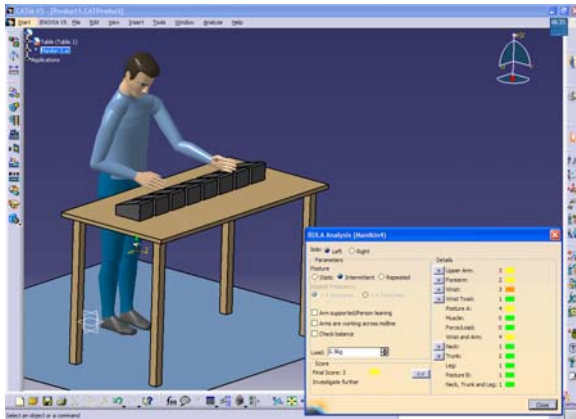

Figure 10: RULA analysis of an operator from group 1 with standing position

The results show the posture scores for every part of the body are in a range from 1 to 4. Orientation of forearm, muscles, neck, trunk and legs are considered safe, as the posture score 1 or 2. As illustrated in Figure 10, the score of wrist posture is 3 when the operator flexed his wrist at 15° while performing task in standing position. Hence, further attention and investigation should be carried-out because the final score reaches 3.
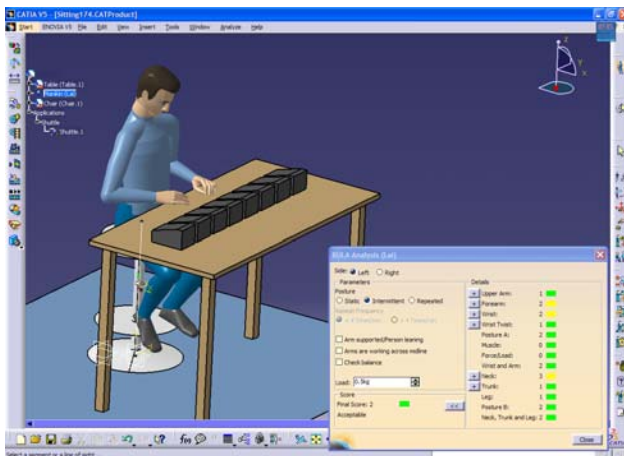

Figure 11: RULA analysis of an operator of group 2 with sitting position

Figure 11 illustrates one of the example RULA analyses of an operator from group 2 with sitting position. From the presented results, the posture scores for every part of the body are in a range from 1 to 3. Orientation of upper

arm, forearm, wrist, muscles, neck, trunk and legs are considered safe, as the score 1 or 2. As illustrated in Figure 11, the final score reaches 2 which mean that the sitting working posture is acceptable and safe on this assembly line.

Table 7: Summary of RULA analysis

Position	Group	RULA Score	Result	Indication
Standing	1	4	Working posture needs further investigation	Wrist is flexed at 15°
	2	3	Working posture needs further investigation	Wrist is flexed at 10°
Sitting	1	2	Working posture is acceptable	
	2	2	Working posture is acceptable	

Table 7 is shown that the summary of the result obtained from the RULA analysis. Based on the table, the sitting working posture is safer than the standing working posture with the table height of 91cm. Hence, the sitting position not only contributes the lowest assembly time but also provides the safe working posture for operators.

4 . Conclusions and Recommendations

The following findings are concluded:

(a) There is a significant different in the performance of two groups of workers. Group1 is performed more productive than group 2; however, group 2 is performed more consistent than group 1.

(b) For the both groups, among the single factors: Jig Design (Jig's orientation), Design of assembly (number of operators), and Workstation design (standing and sitting) have significant contribution to assembly time with significance level 0.05. The most significant factors that contribute to assembly time were: jig design (vertical or rectangular). The second most significant factor is the number of operators (1 or 2) and the smallest significant factor is the workstation design (standing or sitting).

(c) For combination of two or three factors, the results show that no evidence to claims there is significant contribution to the assembly time.

(d) The assembly time increase from single operator assembly process to two operators assembly process; Decrease from using the vertical jig to rectangular jig for jig's orientation; Decrease from standing position to sitting position for workstation's design.

(e) Among the setting of assembly line design, the most productive assembly line design is the combination of 1 operator, with jig design rectangular orientation and working posture is sitting. This set of assembly provides average

18.3575 second per product, with the lowest reached 17.38 second.

(f)   The sitting position working posture, is the most safe workstation design for this assembly line.

There are some areas that can recommend for the further study, among others are:

(a)   The design of jig such as the shape, material used, number of quantity in a jig may further be investigated.

(b)   Human variability such as gender, age, occupational, race and others which might contribute significant effect to the assembly line.

References

[1]   Antony, J., "Improving the Manufacturing Process Quality Using Design of Experiments: A Case Study." *International Journal of Operations & Production Management*. Vol. 21, No.5/6, 2001, 812-822.

[2]   Barker, T.B., "Quality by Experimental Design." 3rd Edition. Chapman & Hall, Boca Raton, 2005.

[3]   Baudin, M., "Lean Assembly: the Nuts and Bolts of Making Assembly Operations Flow." Productivity Press, New York, 2002.

[4]   Box, G.E.P. and N.R. Draper, "Empirical Model-Building and Response Surfaces." John Wiley & Sons, New York, 1987.

[5]   Chow, W.-M., "Assembly Line Design: Methodology and Applications." Marcel Dekker, New York, 1990.

[6]   Choobineh, A., Mostafa Hosseini, Mohammad Lahmi, Reza Khani Jazani and Houshang, "Musculoskeletal problems in Iranian hand-woven carpet industry: Guidelines for workstation design". Applied Ergonomics, Vol. 38, No. 5, 2007, 617-624.

[7]   Dellman, N.J. and Jan, D., "Sewing machine operation: workstation adjustment, working posture and worker perceptions. International Journal of Industrial Ergonomics, Vol. 30, No. 6, 2002, 341-353.

[8]   Dellman, N.J. ,"Pres Operation: Workstation adjustment, working posture, and workers' perceptions", Occupational ergonomics Vol.3, 2003, 153-164.

[9]   Goh, T.N., "Operating Frameworks for Statistical Quality Engineering." *International Journal of Quality and Reliability Management*. Vol. 17, No.2, 2000, 180-188.

[10]   Gursel, A.S., "Designing Parallel Assembly Lines." *Computers & Industrial Engineering*. Vol. 35, 1988, 467-470.

[11]   Hinkelmann, K., and O. Kempthorne, "Design and Analysis of Experiments. Volume I: Introduction to Experimental Design." John Wiley & Sons, New York, 1994.

[12]   Ismail, N. et al., "Improving Productivity and Efficiency of a Vehicle Seat Assembly Line in Manufacturing Company." *Student Conference on Research and Development Proceedings*, 2002, 94-97.

[13]   Khan, A. and Andrew, J.D., "A Knowledge Based Design Methodology for Manufacturing Assembly Lines." *Computers & Industrial Engineering*. Vol. 41, 2002, 441-467.

[14]   Montgomery, D.C., "Design and Analysis of Experiments." 6th Edition. John Wiley & Sons, New York, 2005.

[15]   P.H.P Yeow, and Rabindra Nath Sen," Quality, productivity, occupational Health and safety and cost effectiveness of ergonomic improvements in the test workstation of an electronic factory", International Journal of Industrial Ergonomics, Vol 32, No. 3, 2003, 147-163.

[16]   Pierre, D.L. et. al., "A New Philosophy for the Design of a Product and its Assembly Line." *International Symposium on Assembly and Task Planning*, 1999, 381-386.

[17]   Qian, H.W, "List Representation of Assembly Sequences." *IEEE International Conference on Industrial Technology*, 1996, 315-319.

[18]   Rekiek, B., "Designing Mixed Product Assembly Lines." *IEEE Transactions on Robotic and Automation*. Vol.26, No.3, 2000, 268-280.

[19]   Rekiek, B., "State of Art of Optimization Methods for Assembly Line Design." *Annual Review in Control*. Vol. 26, 2002, 163-174.

[20]   Resnick, M.L. and A.Zanotti, "Using Ergonomics to target productivity improvements", Computers & Industrial Engineering, Vol. 33 No.1/2, 1997, 185-188.

[21]   Saptari, "A Plug Assembly Line: An Assessment of Workstation Design and Working Posture, *Journal of Biomechanics*, Vol.40, *Supplement 2, 2007, Page S15.*

[22]   Zhu, X.W., "Sequence Planning to Minimize Complexity in Mixed Model Assembly Lines." *International Symposium on Assembly and Manufacturing*, 2007, 251-258.