Design of assembly tools at woodworking and upholstery workstations with PUGH's Method to improve productivity

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Abstract. This study is a research on manufacturing processes field, especially in the assembly process with a single workstation. This research was conducted on the implementation of manufacturing process of making lecture chairs at the Industrial Engineering Department at Sebelas Maret University. In this research, an assembly tool was designed to solve the problem of high time needed to complete the assembly process of the backrest and cushion seat components and work stations that are not ergonomic. The assembly tool design stages are based on a structured approach of Ulrich and Eppinger (2015) so that it's good to develop new products and concept selection using the PUGH method to find out the concepts with the highest ranking and best fit the design criteria. This research involved 3 stakeholders, namely operator, lecturer, and assistant. The alternative concept chosen using components are pull-push toggle clamp, gas spring, M6 bolt, multiplex, cam buckle tie down, self-aligning ball bearings, aluminum extrusion 3030. Data on work productivity were tested with Paired T-Test at a significance level of 5 percent. The results showed that by using an ergonomic assembly tool design on woodworking and upholstery workstations, assembly cycle time increased significantly by 63.78 percent.

1. Introduction

Currently, the development of the manufacturing industry is growing rapidly. This resulted in the increasingly fierce competition in the manufacturing industry. To be able to compete with other manufacturing industries, a company must be able to continuously improve its production process. One of the implementations of the manufacturing process was carried out at the Industrial Engineering Department at Sebelas Maret University Surakarta (PSTI-UNS) with a product in the form of a lecture chair. The manufacturing process starts from the design stage, material procurement, product manufacturing to the product marketing stage. The process of making chairs is done at six workstations namely workbench, milling, turning, welding, woodworking and upholstery, finishing. The lecture chair component consists of the frame, cushion seat, backrest, table, and end cap material. The most time-consuming jobs are found in woodworking and upholstery workstations. Work activities at this workstation are to combine the results of multiplex pieces, upholstery, and foam with the results in the form of cushion seat and backrest components.

The work at the woodworking and upholstery workstations takes 480 minutes. The elements of work in woodworking and upholstery workstations consist of measurement, cutting, tidying the edges, drilling, T-nut installation, gluing, cutting and assembling / upholstery. The job that requires the longest time is the assembly/upholstery process of 180 minutes. The inefficiency of time in the lecture chair manufacturing process is due to the absence of workstations specifically designed to implement the manufacturing process properly. According to documents published by the World Health Organization Regional Office for the Eastern Mediterranean with document number WHO-EM / OHC / 85 / E / L about Occupational Health: A manual for primary health care workers (2001), there is no appropriate work facility and wrong working attitude will be the cause of the decline in productivity and the occurrence of problems in the body of workers [1]. Marek and Hankiewicz in their research found that a factor that reduced productivity in upholstery furniture was musculoskeletal disorders caused by work performed in hazardous work positions [2]. In addition to the length of time required to carry out the assembly process, there are problems that arise due to the absence of work facilities to carry out the assembly process is the emergence of the risk of body parts exposed to the staple gun.

Time inefficiency is an activity that has no added value, so that the right production strategy is needed to effectively overcome time inefficiency [3]. According to Juan Carlos Hiba (1998) a well-designed workstation will increase productivity, minimize material handling, increase efficiency and reduce worker fatigue [4]. Preventing work accidents and increasing work performance / productivity can be done by designing ergonomic workstations [5].

The design of woodworking and upholstery workstations in this study was carried out with a participatory approach that involved operator, assistants, and lecturers as stakeholder entities [6]. The participatory approach is used to determine the criteria for the design of work stations that are in line with user needs include the proportion of students with work stations according to standard manual assembly operator work stations according to SEMTA (The Science, Engineering and Manufacturing Technologies Alliance). The design of workstations in this study is based on product development steps by Ulrich and Eppinger [7]. To determine the right design, concept selection is carried out using the Pugh Concept Selection Method [8].

The design of assembly tools at woodworking and upholstery workstations with PUGH methods aims to reduce assembly time and prevent the risk of accidents in the workplace. Reducing time and preventing the risk of accidents at work in the assembly process will have a positive impact in the form of efficiency and effectiveness in the use of time in manufacturing processes which will directly increase productivity [9].

2. Methodology

This study aims to determine the effect of treatment on two conditions before and after using the results of the design of the tool. Based on the design, the assembly time is measured using a stopwatch. Retrieval of user needs data is done by using a questionnaire. The questionnaire consisted of 16 statements distributed to 30 stakeholders consisting of 1 lecturer, 11 assistants, and 18 operators. The design is focused on 4 main design criteria, namely safety, performance, reliability, and features. The results of the identification of needs in the form of 13 sub-criteria are translated / decomposed into 18 technical needs and classified into 7 design functions consisting of supporting the tool, moving the tool, pressing the workpiece, adjusting the pressure of the tool, holding the pressure load, pulling the fabric and changing the position of the workpiece. The results of the technical needs classification are used to develop alternative concepts. There are 6 alternative concepts that were then selected using the PUGH concept selection method. The selection of alternative concepts was carried out by conducting focus group discussions on 10 stakeholders consisting of 1 lecturer, 1 manufacturer, 4 assistants, and 4 operators. Furthermore, making a prototype of the selected alternative concept results. Prototype assembly tools are then tested for assembly time to determine the level of significance by conducting the Paired T-Test.

3. Results and discussion

In this study, the identification of needs is done with a participatory approach. The participatory approach involves stakeholders, namely lecturers, assistants, and operators. Stakeholders fill out a questionnaire that is used to identify the needs for the design of assembly tools. The results of the identification of needs are shown in Table 1.

Table 1. Identification of needs.

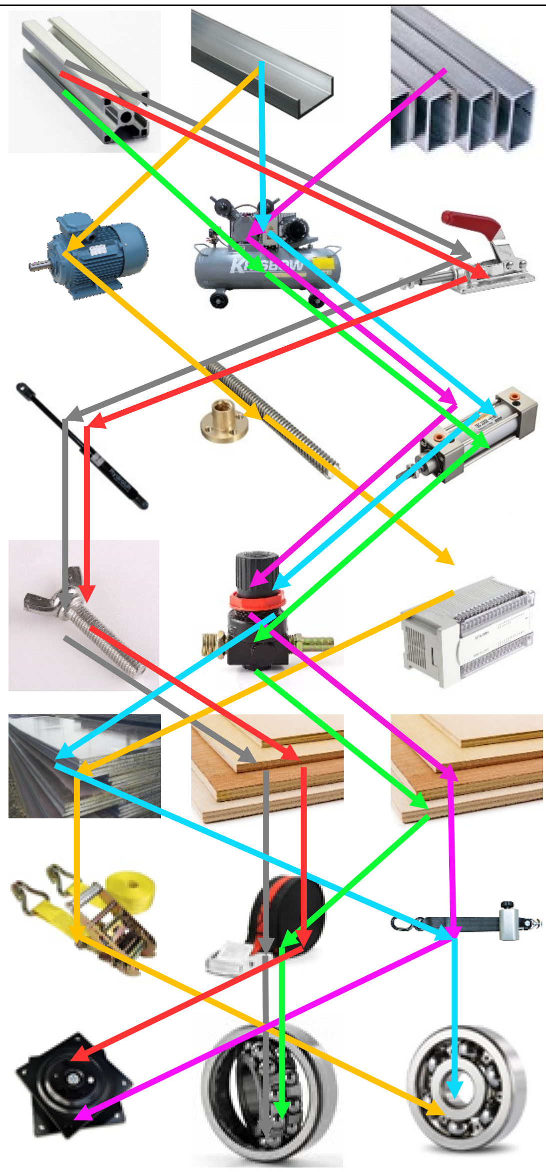
No.	Criteria	Statement
1	*Performance*	Assembly tools can provide enough pressure to hold the position of the workpiece
2		Assembly tools have a strong frame/construction formation
3		Assembly tools have a strong tabletop surface to withstand pressure loads during assembly
4		Assembly tools can be set-up easy
5		Assembly tools can help users to assemble quickly
6	*Reliability*	Assembly tools can be used with low physical effort
7		Assembly tools using a manual mechanism
8		Assembly tools prevent users from making complex movements
9	*Features*	Assembly tools have a rotatable table surface
10		Assembly tools have a feature to pull/hold upholstery
11	*Safety*	Assembly tools prevent the hands from being exposed to staples
12		Assembling tools prevent the risk of being pinched
13		Assembly tools do not damage the workpiece during the process

The design is focused on 4 main design criteria, namely safety, performance, reliability, and features (Fantahun, K, and M.S, 2017) [10]. Determination of specifications and dimensions of tool design is done by translated / decomposed into 18 technical needs and classified into 7 design functions consisting of supporting the tool, moving the tool, pressing the workpiece, adjusting the pressure of the tool, holding the pressure load, pulling the fabric and changing the position of the workpiece.

Table 2. Determining the specifications and dimensions of the workstation design.

No.	Identification of needs	Technical needs	No.
1	Assembly tools can provide enough pressure to hold the position of the workpiece	There are machine parts that can be used to put pressure on the workpiece	1
		There is an adjustment to measure enough pressure on the workpiece	2
2	Assembly tools have a strong frame/construction formation	Made of strong material	3
		Made from material that is easy to shape	4
3	Assembly tools have a strong tabletop surface to withstand pressure loads during assembly	The surface of the table has a flat surface to hold the workpiece	5
		The surface of the table is made of strong material	6
4	Assembly tools can be set-up easy	Assembly tool has features that make set-up easy	7
5	Assembly tools can help users to assemble quickly	Assembly tool can be operated quickly	8
6	Assembly tools can be used with low physical effort	The dimensions of the tool adjust the user's work posture	9
		Users do not need a big effort / energy to operate the equipment	10
7	Assembly tools using a manual mechanism	Assembly tool can be operated with human power	11
		Assembly tools can be used flexibly	12
8	Assembly tools prevent users from making complex movements	Reducing work done simultaneously	13
9	Assembly tools have a rotatable table surface	The area on which to place / position the workpiece can be rotated	14
10	Assembly tools have a feature to pull/hold upholstery	There are parts of the tool that can be used to pull / hold upholstery	15
11	Assembly tools prevent the hands from being exposed to staples	Assembly tools can keep the hand away from the tip of the staple gun	16
12	Assembling tools prevent the risk of being pinched	Assembly tools can keep the hand away from the press area	17
13	Assembly tools do not damage the workpiece during the process	There are several levels of pressure strength that can be adjusted to the physical properties of the workpiece	18

Table 3. Generating alternative concepts.

Technical Requirements	Design Functions	Component	Alternative 1	Alternative 2	Alternative 3
3, 4, 9	Supporting the tool	Frame			
8, 10, 11	Driving the tool	Drive			
1, 7, 10, 11, 13	Hold the position of the workpiece	Press tools			
2, 11, 12, 17, 18	Measure tool pressure	Pressure regulator			
5, 6	Withstand the pressure load	Table surface			
10, 11, 12, 13, 15	Pulling/retaining upholstery	Cloth puller			
10, 11, 12, 14	Rotating/changing the workpiece Position	Rotator			

There are 6 alternative concepts that were then selected using the PUGH concept selection method. The selection of alternative concepts was carried out by conducting focus group discussions on 10 stakeholders consisting of 1 lecturer, 1 manufacturer, 4 assistants, and 4 operators. PUGH concept selection method is presented in Table 4.

Table 4. The results of filtering concepts.

Criteria		Alternative Concepts					
		I	II	III	IV	V	VI
Performance	Pressure tool strength	+	0	+	+	0	0
	Construction toughness	+	+	+	+	+	0
	Table surface strength	0	0	0	+	+	0
	Ease of set-up	-	0	-	+	0	0
	Assembly time speed	0	+	+	-	0	0
Reliability	The amount of physical effort needed	+	+	+	-	0	0
	Manual	+	0	+	-	0	0
	Simplicity of movement	-	0	-	+	0	0
Features	Table rotation capability	0	+	+	0	0	0
	The ability to pull / hold fabric	+	+	+	-	0	0
Safety	The risk of staples is small	0	+	+	0	0	0
	The small risk of hand pinched	+	0	+	-	0	0
	The small risk of the tool damaging the workpiece	+	0	+	-	0	0
Amount +		7	6	10	5	2	0
Amount -		2	0	2	6	0	0
Amount of 0		4	7	1	2	11	13
Final score		5	6	8	-1	2	0
Ranking		3	2	1	6	4	5
Continue?		Yes	Yes	Yes	No	No	No

Table 5. Assembling tools assessment matrix.

Criteria		Weight	Concept I		Concept II		Concept III	
			Rating	Rated load	Rating	Rated load	Rating	Rated load
Performance	Pressure tool strength	9%	5	0.45	4	0.36	5	0.45
	Construction toughness	6%	5	0.30	5	0.30	5	0.30
	Table surface strength	4%	3	0.12	3	0.12	3	0.12
	Ease of set-up	5%	3	0.15	4	0.20	4	0.20
	Assembly time speed	6%	3	0.18	4	0.24	4	0.24
Reliability	The amount of physical effort needed	7%	2	014	3	0.21	2	0.14
	Manual	6%	5	030	3	0.18	5	0.30
	Simplicity of movement	7%	2	014	3	0.21	2	0.14
Features	Table rotation capability	12%	3	036	5	0.60	5	0.60
	The ability to pull / hold fabric	13%	5	060	5	0.60	4	0.60
Safety	The risk of staples is small	13%	3	039	4	0.52	5	0.52
	The small risk of hand pinched	6%	5	030	3	0.18	5	0.30
	The small risk of the tool damaging the workpiece	6%	5	030	3	0.18	5	0.30
Total			3.73		3.90		4.21	
Ranking			3		2		1	
Conclusion			No		No		Yes	

Based on the results of alternative assessments, concept III has the highest value compared to concepts I and II so that the alternative concepts chosen and developed next are alternative concepts III [11].

Alternative concept III has seven main functions. The first function is to support the device. To support the framing device used for assembly tools is aluminum extrusion 3030 to form a strong and tough frame construction to support the entire tool load. The second function is to drive the device. The drive system used is a pull-push toggle clamp 36020 with a holding capacity of 180kg so that it can be easily used to speed up the assembly process. The third function is pressing the workpiece. The pressure tool used is a gas spring with a force of 350N so that it can provide enough pressure to carry out the assembly process and is easy to set-up. The fourth function is to measure tool pressure. The pressure regulator used is the M6 15mm butterfly bolt with a knockdown mechanism that is paired directly with the toggle clamp so that it can be easily used and has flexibility in determining various sizes of pressure. The fifth function is to hold pressure loads. The surface of the table to withstand the pressure load used is a multiplex material with a thickness of 18mm so that it can withstand the pressure load of the tool on the table and is easily shaped. The sixth function is to pull the fabric. The cloth puller used is a 1-inch cam buckle tie down to avoid the user from the activities carried out simultaneously, namely pulling and holding the fabric. The seventh function is to change position. Position changes are made with a rotation system using the 2211K "ASB" self-aligning ball bearing with an inner diameter of 25mm in order to facilitate the process of changing the position of the workpiece when assembled. The alternative results of the design concept of assembly aids at woodworking and upholstery workstations are explained in Figure 1.

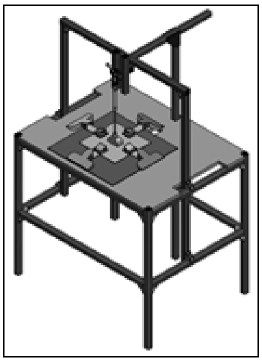


Figure 1. Alternative concepts chosen.

The design of assembly aids at woodworking and upholstery work stations is carried out using 3-dimensional anthropometric data, namely elbow height stand, reach hands forward, and eye height stand of 83 operators [12]. The results of anthropometric data processing are shown in Table 6.

Table 6. Body dimension calculation result data for data adequacy test, data uniformity test, and percentile on assistance tool design size at woodworking and upholstery workstations.

No.	Body Dimensions	Average	SD	Data Adequacy		Data Uniformity		Percentile		
				N	N'	BKA	BKB	P5	P50	P95
1	Elbow Height Stand	98.71	4.91	80	75	109.33	88.10	90.64	98.71	106.79
				adequate		Uniform				
2	Reach Hands Forward	76.45	3.55	80	68	83.57	69.34	70.60	76.45	82.30
				adequate		Uniform				
3	Eye Height Stand	146.99	7.08	80	77	161.16	132.82	135.33	146.99	158.65
				adequate		Uniform				

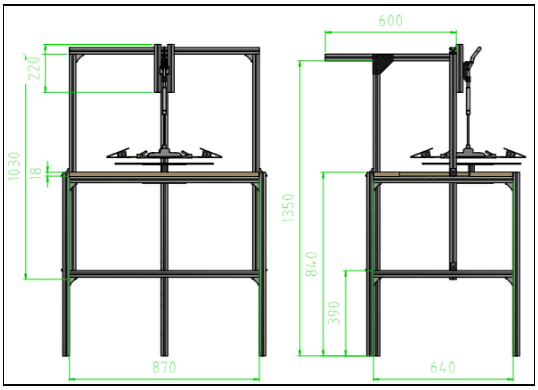


Figure 2. Workstation design 2D.

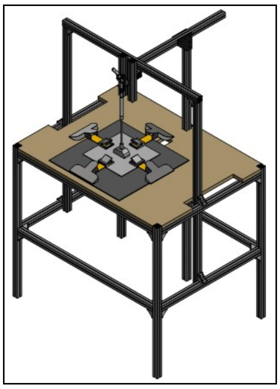


Figure 3. Workstation design 3D.

This study aims to determine the effect of treatment on two conditions before and after using the results of the design of the tool. Evaluation is done by measuring the cycle time of the backrest and cushion seat assembly without using tools and by using the design of assembly tools. After obtaining the average cycle time, then the paired T-Test statistic test is performed to determine the significance level of assembly time before and after using the design tool [13].

Table 7. Paired sample T-Test results.

Variable	N	Average	SD	Average difference	t-value	p-value
Before using assembly tools	4	15,218.25	82.947	9,707.25	234.058	0.001
Using the results of the design of assembly tools	4	5,511		(63.78%)		

Based on the results of the paired sample t-test data in Table 7, the p-value is 0.001. The initial hypothesis is H0: $\mu1 = \mu2$ (there is no significant difference between before using the tools and using the design tools). H1: $\mu1 \neq \mu2$ (there is a significant difference between before using the tools and using the design tools). If the value of $p > 0.05$, then Ho is accepted; H1 rejected. The value of $p < 0.05$ so that it shows that there is a significant difference between before using the tools and using the design tools that are equal to 63.78%.

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4. Conclusions.

Based on the previous discussion can be conclude some of the essence of research to answer the existing problems, as follows. By using PUGH concept selection method, the ergonomic workstation obtained a 63,78% increase in productivity. Assembly cycle time before using tools is 15218.25 seconds, while assembly cycle time after using tools design results is 5511 seconds. The work station is made of several components, namely aluminum extrusion 3030, pull-push toggle clamp, gas spring, M6 15mm butterfly bolt, multiplex, 1-inch cam buckle tie down, and self-aligning ball bearings.

5. References

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