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Design of Assembly Workbench in Industrial Engineering Practicum I Using Reverse Engineering Method

Ratnanto Fitriadi[1], Aditya Panji Kusuma[1], Munajat Tri Nugroho[1], Umar Surya Suryahatmaja[1]

[1] *Department of Industrial Engineering, Faculty of Engineering, University Muhammadiyah Surakarta, Indonesia*
e-mail: rf253@ums.ac.id

Abstract

The assembly process is a critical component of the manufacturing cycle. As an approach to learning in higher education, this can be conducted through laboratory practicals. Industrial Engineering Practicum (PTI) 1 is one of the courses focusing on the creation of technical drawings for a product, the development of process plans, and the manufacturing process—including the assembly process with the project being the creation of a toy car using PVC foam as the raw material. Based on the laboratory sessions that have been conducted, several issues were identified, particularly during the assembly phase, namely a relatively long assembly cycle time reaching 1.7 hours (107 minutes). This study aims to design an assembly workbench that can standardize the assembly process. It is expected that the cycle time will be shorter, the workstations will be more neat and organized, and the product results will be more precise. The research was conducted using a Reverse Engineering approach, beginning with an analysis of the requirements and characteristics of each product component. Subsequently, benchmarking was performed on the assembly table design and component layout, as well as the design drawings of the workbench tailored to the needs of the laboratory experiment. The designed workbench, after testing, was then prototyped for testing through actual assembly processes in the laboratory. Test results for the assembly workbench at PTI 1 under the new standardization show an assembly cycle time of 61 minutes (a 43% reduction) with a lower level of variability. Workstations were 64% more neat and organized, and 84% very satisfied with the assembly workbench based on questionnaires completed by 13 lab assistants.

Keywords: *Design, Assembly Workbench, Cycle Time, Reverse Engineering*

INTRODUCTION

Assembly is one of the processes in manufacturing where components that have previously been produced will be combined or assembled into a final product. The assembly process can also be interpreted as the stage of combining parts of a product so as to form a valuable finished product [1]. In the field of manufacturing, assembly is important because it greatly determines the final result of the product made. The right assembly process can make it easier operationally, and be more efficient in terms of time and tool needs [2]. In learning in higher education, it can be done on a practicum scale that is carried out in the laboratory. Industrial Engineering Practicum (PTI) I in Industrial Engineering UMS, is a practicum that studies the manufacturing process with the project

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of making toy cars with PVC Foam raw materials from sketches to finished products.

The assembly stage in the production process of the PTI I toy car is carried out manually on a table without any tools (fixtures) to hold the assembled components. Some practitioners even carry out this assembly process by sitting on the floor because there are no assembly aids on the workbench. In its implementation, several problems were found, namely lack of precision/precision in the assembly between components, work stations that are not neat and regular, and assembly cycle times that are too long with an average time of up to 1.7 hours. The lack of precision during assembly between components will lead to unsatisfactory final results (not neat according to the design in the engineering drawing). Meanwhile, too long cycle time will cause overtime or exceed the given production time limit, which is 8 hours.

From this problem, it is necessary to have an assembly workbench with a workpiece holder tool that is specifically for the assembly process of the toy car project at PTI I. This workbench will be designed with features that are tailored to the needs of the assembly process. So that with this workbench, it is hoped that the toy car assembly process will be more efficient in terms of place, time to the final result obtained. The Reverse Engineering method is used as the approach method used in the design of this assembly workbench. Reverse Engineering is a method used to identify components and their relationships in a system. In the industrial world, the concept of Reverse Engineering is used to develop a product using references from existing products. The design of this assembly workbench was made to facilitate the assembly process at the stage of the production process of the toy car project at PTI I, so that the level of product precision is better and the cycle time needed in this assembly is also shorter [3].

METHOD

The research was carried out at the Laboratory of Work and Manufacturing Systems, UMS Industrial Engineering Study Program, with an address at Jl. A. Yani No. 157, Pabelan, Kartasura, Sukoharjo, Central Java. The object of the research is the assembly process of the toy car project which is one of the phases in the Industrial Engineering Practicum I.

This research uses the Reverse Engineering approach which fundamentally refers to the process of solving an object or system to find out or extract knowledge of the object or system [4]. Reverse engineering is the activity of analyzing a system using the identification of system components and their relationships [5]. Reverse engineering has a wide scope, commonly used in software engineering, tool development, machine dismantling and other broader scopes. Reverse engineering activities are carried out in the following ways:

a. Product disassembly work (workpiece to be assembled),
b. Component assembly work,
c. Measurement activities,
d. Designing new products (assembly table with workpiece/component holder aids),

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e. Product prototyping (assembly table with workpiece/component holder aids) [6].

Benchmarking is a stage carried out in this study with the aim of comparing and looking for references related to similar products, namely assembly workbenches that are already on the market. Benchmarking is carried out by comparing three assembly workbench products and comparing the features and advantages of each product [7].

Time study is a measurement technique used to determine the standard duration required by a person to complete a certain job. Time study aims to find out the standard time needed to complete a job and to establish a standard that is used to plan and evaluate the efficiency of work [8] . Time study was first introduced by Frederick W Taylor (1856-1915) which was widely implemented to establish standard time [9]. In calculating the time study, it must go through several stages, including: Conducting Work Measurements, Collecting Time Data, Conducting Data Uniformity Tests, Conducting Data Sufficiency Tests, Determining Adjustment Factors, Determining Normal Time, Determining Relaxation Factors, Determining Standard Time or Standard Time [10] .

Data uniformity testing aims to verify whether the data from the time measurement shows a level of uniformity. Data uniformity can be shown by not finding data that is outside the control limits that have been set or calculated. The following is the formula for the data uniformity test:

$$UCL = \bar{X} + 2\sigma \qquad \text{... (1)}$$

$$LCL = \bar{X} - 2\sigma \qquad \text{... (2)}$$

Description:

UCL = Upper Control Limit,

LCL = Lower Control Limit,

$\bar{X}$ = Mean,

σ = Standard deviation [11].

The statistical procedure of the data sufficiency test is applied to verify or assess whether the data collected is sufficient and able to represent the population studied. The data sufficiency test is calculated with the following formula:

$$N' = \left[\frac{ks}{\sqrt{N}\sum x_i^2 - (\sum x_i)^2 \sum x_i}\right]^2 \qquad \text{... (3)}$$

Description:

k = Constant confidence level (95% = 2),

s = Desired level of accuracy,

N = Number of observations,

N' = Required number of observations,

x = Time data [12].

Cycle time is defined as the total length of time it takes for an operator to complete a series of activities or a unit of work from start to finish. The following formula is used to calculate cycle time:

$$CT = (\sum xi) / N \qquad \text{... (4)}$$

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Description:
CT = Cycle Time,
$\sum xi$ = Number of Observation Time,
N = Number of Observations [13].

This normal time is the result of normalizing the actual working time based on the operator's rating factor. This factor is used in the calculation of normal time to normalize the results of the work time measurement, considering the difference in the work rate or tempo during the measurement process. The formula used to determine normal time is:

$$NT = CT \times P \quad \text{... (5)}$$

Description:
NT = Normal Time,
CT = Cycle Time,
P = Rating Factor [14].

Standard time is defined as the standard duration required by a normally capable operator to complete a unit of work. The following is the formula used to determine standard time:

$$ST = NT \times \frac{100}{100 - allowance\ (\%)} \quad \text{... (6)}$$

Description:
ST = Standard Time,
NT = Normal Time,
$allowance$ = Allowance Factor [15].

RESULTS AND DISCUSSION

1. Early Stages of Research

The initial stage of research is to conduct field studies and literature studies. Field studies are conducted to directly observe how the assembly process takes place and the conditions of the workstation. Through this field study, the data needed for the research is obtained such as assembly cycle time data, toy car product specification data and assembly process sequence data. In addition, a literature study is also conducted to conduct research related to ideal assembly conditions in the manufacturing world. Literature studies are carried out by conducting research through sources such as journal articles, news and relevant books. The data obtained from the field study stage & literature study is used in designing assembly workbenches.

2. Reverse Engineering Stage

a. Product disassembly & analysis

The first stage in the Reverse Engineering (RE) method is product disassembly. In this study, toy car products are disassembled to find out all the parts or components that make up the product and its characteristics. Based on the disassembly carried out on toy car products, it is known that there are 35 parts that make up the product. Each part has a different shape and size and is divided into three categories, namely made, assembled and bought. For parts made of PVC Foam have a thickness of 1 cm, except for some parts

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such as Wheels & Axles which have a thickness of 3 cm, & Steering Hub with a thickness of 2 cm. The information from all these parts will later be used for the design of the assembly worktable. In addition, the disassembly of toy car products, measurements are also made for the workbench that is currently used. Based on the measurements of the old workbench, the length measurements were obtained which were 100 cm, width 60 cm and height 73 cm. This workbench will later continue to be used in the development of new workbench designs, so the size of the old workbench is very important for the development of design concepts.

PART NUMBER	DESCRIPTION	DECISION	QUANTITY
A	PTI I CARS	ASSEMBLED	1
A.1	CHASSIS	ASSEMBLED	1
A.2	BODY	ASSEMBLED	1
A.1.1	UNDERFRAME	CREATED	1
A.1.2	AXLE	CREATED	2
A.1.3	BACK AXLE	PURCHASED	1
A.1.4	LEFT STEERING HUB	CREATED	1
A.1.5	RIGHT STEERING HUB	CREATED	1
A.1.6	ROD SWEATER	CREATED	1
A.1.7	LEFT FRONT AXLE	PURCHASED	1
A.1.8	LEFT FRONT WHEEL	CREATED	1
A.1.9	RIGHT FRONT AXLE	PURCHASED	1
A.1.10	RIGHT FRONT WHEEL	CREATED	1
A.1.11	LEFT BACK WHEEL	CREATED	1
A.1.12	RIGHT BACK WHEEL	CREATED	1
A.1.13	BOTTOM LATCH	PURCHASED	4
A.2.1	LEFT FRAME	CREATED	1
A.2.2	RIGHT FRAME	CREATED	1
A.2.3	FRONT BUMPER	CREATED	1
A.2.4	ENGINE HOOD	CREATED	1
A.2.5	ROOF PANEL	CREATED	1
A.2.6	DECKMEMBER	CREATED	1
A.2.7	BACK BUMPER	CREATED	1
A.2.8	LEFT SELL	CREATED	1
A.2.9	RIGHT SELL	CREATED	1
A.2.10	TOP LATCH	PURCHASED	4
A.2.11	SPOILERS	ASSEMBLED	1
A.2.1.1	LEFT BODY	CREATED	1
A.2.1.2	LEFT HINGE	PURCHASED	1
A.2.1.3	LEFT DOOR	CREATED	1
A.2.2.1	RIGHT BODY	CREATED	1
A.2.2.2	RIGHT HINGE	PURCHASED	1
A.2.2.3	RIGHT BY	CREATED	1

Figure 1. Bill Of Material Product
Source: Author's own elaboration

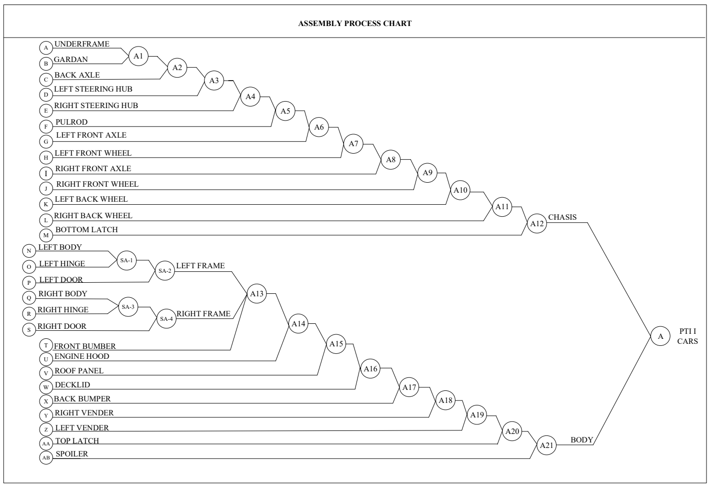

Figure 2. Assembly Process Chart Product
Source: Author's own elaboration

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b. Reassembly product

After the toy car product is disassembled and analyzed, the next stage is to reassemble. This reassembly is carried out to find out how the assembly process is carried out according to the Assembly Process Chart (APC) data. This stage is also carried out to evaluate the sequence of the assembly process and find out the relationship between parts. With this assembly stage, information is obtained for the design of a new assembly workbench.

c. Benchmarking

Benchmarking is carried out to obtain information from existing assembly workbenches, including features and specifications. There are three assembly bench products that are benchmarked. To provide a clearer picture of the comparison of products used as a reference, benchmarking data is presented in the form of a table containing product names, design visualizations, and reference sources from each of the analyzed assembly workbenches.

Table 1. Benchmarking

Product Name	Image	Source
Adjustable Tilt Electric Control Panel Mounting & Assembly Table (Red) - AMTE-300		https://controlpanelsupply.com/adjustable-tilt-electric-control-panel-mounting-assembly-table-red-amte-300/
Craftsman Clamping and Assembly Table		https://toolguyd.com/craftsman-peg-table/
Heavy Duty Industrial Workbench Assembly Table		https://www.indiamart.com/proddetail/heavy-duty-workstation-assembly-table-industrial-workbench-21158215791.html

Source: Author's own elaboration

d. Creation of assembly workbench design concept

Based on the results obtained from the previous disassembly, assembling and benchmarking steps, it can be developed into a workbench design concept with SolidWorks software. The design of the assembled workbench is divided into three sections, namely the main workbench (there are tools to hold the workpiece), the product part place, and the tool used place. The following is figure 3. which displays the design of the assembly workbench along with the section information in it.

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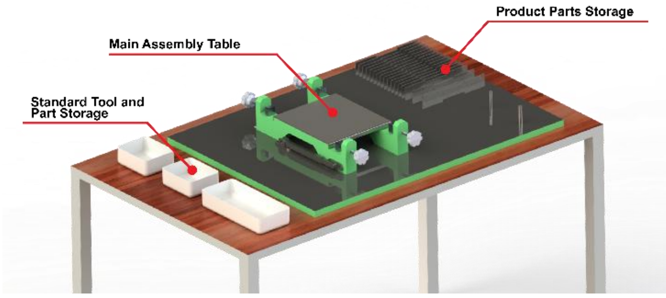

Figure 3. Design Concept of Assembly Workbench
Source: Author's own elaboration

e. Design testing

The design concept that has been developed is then tested to ensure that the design is in accordance with the characteristics of the product to be assembled. Testing is carried out on each section, starting from the main workbench to test whether it can be grippy and the adjustable feature that can be tilted up to 55°. The second and third sections are also tested whether they can fit according to the shape and size of each part or tool.

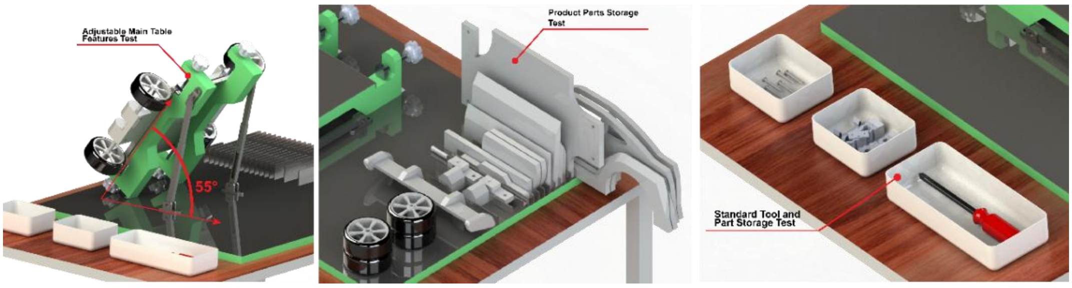

Figure 4. Product Testing
Source: Author's own elaboration

3. Assembly Workbench Testing

a. Analysis of time studies before and after the implementation of the assembly workbench

After the design that has been made is tested and declared passed, the assembly worktable is made. The finished assembly worktable is then tested on the time of the PTI I toy car assembly cycle. Data was taken from the assembly process carried out by 36 groups on March 4-7, 2026.

Table 2. Cycle Time with Assembly Workbench

Groups	Assembly Cycle Time (min)	Groups	Assembly Cycle Time (min)	Groups	Assembly Cycle Time (minutes)
1	73.9	13	56.84	25	59.2
2	53.46	14	59.42	26	56.63
3	64.02	15	53.42	27	58.65
4	69.19	16	52.19	28	68.88

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Groups	Assembly Cycle Time (min)	Groups	Assembly Cycle Time (min)	Groups	Assembly Cycle Time (minutes)
5	68.585	17	50.09	29	66.94
6	69.52	18	66.25	30	46.89
7	63.78	19	47.4	31	59.31
8	65.98	20	71.89	32	60.6
9	59.01	21	53.34	33	58.59
10	70.768	22	56.48	34	72.71
11	59.16	23	73.86	35	54.62
12	50.9	24	69.67	36	62.8

Source: Author's documentation

The assembly cycle time data obtained from PTI I 2026 was tested for data uniformity with formula (1) and formula (2) with the results as follows.

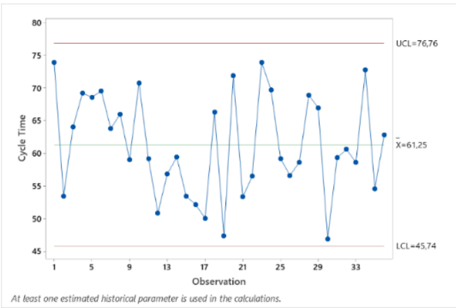

Figure 5. Uniform Test of Cycle Time with Assembly Workbench

Source: Author's own elaboration

Based on the graph above, no data passes through UCL & LCL so the data obtained is uniform. Next, test the sufficiency of the data with formula (3) and the results are obtained in the table below.

Table 3. Data Adequacy Test of Cycle Time with Assembly Workbench

Remarks	Value
∑X	2204.94
∑X^2	137152.82
(∑X)^2	4861773.63
N	36
N'	6.23

Source: Author's own elaboration

Because of the values of N' < N, the data can be concluded that the cycle time data is sufficient. Then the next step is to determine the rating factor & allowance factor to calculate normal time & standard time. The rating factor is determined based on the assessment of the operator's skill, effort, working conditions, and consistency, with a final

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result of 1.11 indicating that the operator's performance is slightly above the normal standard. Meanwhile, the allowance factor is calculated by considering working conditions such as power load, work attitude, movement, eye fatigue, and environmental conditions, with a total allowance of 20%.

The comparison of cycle time, normal time & standard time between before and after using the assembly workbench is calculated by formula (4), (5) and (6) and yields the following values.

Table 4. Result of Time Study before and after Assembly Workbench

Remarks	Before	After
Cycle Time	107,68	61,40
Normal Time	119,53	68,15
Standard Time	149,41	85,19

Source: Author's own elaboration

Based on the results of the time study comparison above, it can be concluded that the design of the assembly workbench has a significant impact on the efficiency of working time. This is shown by a consistent decrease in cycle time, normal time, and standard time of 43%. Thus, the designed workbench not only improves neatness, but is also able to increase the productivity and effectiveness of the overall assembly process.

b. The level of neatness and arrangement of workstations

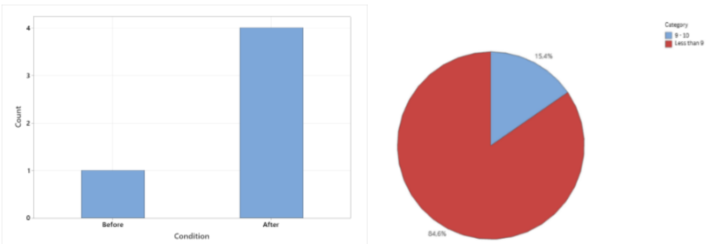

Figure 6. Questionnaire Data by the Lab Assistant

Source: Author's own elaboration

The results of the study also showed an improvement in the neatness of the workstation after the use of the assembly workbench. The results of the questionnaire filled out by the practicum assistant received an average score that increased from 1.49 to 4.68 with a percentage increase of 64%. This shows that the design of the assembly workbench is able to improve the system of arrangement of components and tools, the layout of the operator's position and the efficiency of finding components. In addition, as many as 84% of respondents gave a high rating (score 9–10), which indicates that the designed workbench is considered very effective in improving the neatness and arrangement of the workstation.

CONCLUSION

The design of the assembly workbench has been proven to be able to significantly increase the effectiveness of the work process. This is shown by the reduction of cycle time from 107.68 seconds to 61.40 seconds, or an increase in efficiency of 43%. In

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addition, the level of neatness and arrangement of the workstation also increased by 64% based on the results of the questionnaire filled out by the practicum assistant. A total of 84% of respondents gave an "excellent" rating to the designed workbench, indicating that the facility is considered effective in supporting the improvement of neatness and organization of the work area.

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