Enhancing process optimization through adaptive jig design in lean manufacturing: insights from Universitas Mercu Buana's laboratory

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ABSTRACT

This study aims to enhance efficiency in the Lean Manufacturing practicum at the Lean Manufacturing Laboratory of Universitas Mercu Buana by applying PDCA (Plan-Do-Check-Act) and TRIZ (Theory of Inventive Problem Solving) methods. The primary focus was the design and implementation of a flexible jig tool to reduce processing time and increase precision in the vacuum, trimming, and assembly stages designing and implementing. Results showed that the flexible jig reduced process time by 37.8%, from 1431 seconds to 890 seconds, and improved the level of automation from fully manual to the use of flexible tools. Further evaluation revealed significant gains in productivity. The study utilized tools such as Value Stream Mapping (VSM), Operation Process Chart (OPC), and the seven waste concepts within the PDCA framework to identify key issues in the manufacturing process. The application of TRIZ principles in tool design also significantly enhanced production efficiency. This research presents compelling evidence that systematic approach like PDCA and creative methodologies for instance TRIZ can substantially improve operational performance in light manufacturing practicums. Additionally, it highlights the important role of higher education in fostering technological innovation and industry collaboration to tackle evolving manufacturing challenges.

1. Introduction

The global manufacturing industry continues to undergo dynamic changes influenced by various factors, including technological advancements, shifts in market demand, and logistical challenges. In the era of digitalization, manufacturing companies face significant challenges and opportunities (Yaqub & Alsabban, 2023). Digital transformation and automation are some of the major trends impacting the operational methods of manufacturing companies (Kraus et al., 2021). Additionally, the COVID-19 pandemic has accelerated the adoption of new technologies and work models, highlighting the importance of resilient and adaptive supply chains. In response to these changes, the manufacturing industry must be able to adapt and innovate to remain relevant and competitive in the global market (Kapilan et al., 2021).

Amidst these challenges, lean manufacturing and technological advancements, particularly automation, have become key drivers of transformation in the manufacturing industry. Lean manufacturing focuses on reducing waste and improving operational efficiency by eliminating non-value-added processes (Buer et al., 2021). Through this approach, companies can increase productivity, reduce costs, and improve product quality. On the other hand, technological

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advancements in the form of automation enable production processes to become faster, more accurate, and more consistent (Herlambang et al., 2022).

In addressing the evolving needs of the industry, higher education institutions play a crucial role (Donald, 2024). Through relevant education programs that align with industry needs, these institutions prepare a skilled and knowledgeable workforce in modern production technologies and methods (Rosenbusch, 2020).

Laboratories play a very important role in supporting and advancing the manufacturing industry. As centers of research and development, laboratories are where new technological innovations and methodologies can be tested and refined before being implemented in the production process (Mohzana et al., 2023). Additionally, laboratories also play a role in workforce training and development. Through laboratories, universities and industries can conduct practical training programs that allow students and workers to gain hands-on experience with the latest technologies and equipment (Gamage et al., 2020). Overall, laboratories are an integral component of the manufacturing industry's ecosystem. With support from laboratories, companies can continue to innovate and build a skilled workforce ready to face the future.

The Lean Manufacturing Laboratory at Universitas Mercubuana serves as a practical application center for Lean Manufacturing principles. Activities conducted in this laboratory implement lean manufacturing principles, with one of the primary applications being in the production process of Tamiya cars, encompassing various stages such as heating, vacuum, trimming, press tire, assembling 1, assembling 2, assembling 3, quality control, and packaging. However, some stages like heating, vacuum, trimming, and assembling still face high processing times due to predominantly manual operations.

Therefore, the researcher is interested in designing a tool with a new approach to productivity in the laboratory, featuring capabilities that can significantly reduce processing time and improve the accuracy of cutting, assembling, and movement. Thus, the designed tool is expected to offer more effective and efficient solutions compared to the currently used manual methods. Furthermore, this research aims to prepare students to adapt to the continuously evolving manufacturing industry in line with technological advancements.

The research is limited to several stages of the Tamiya production process in the Lean Manufacturing Laboratory, namely heating, vacuum, trimming, and assembly. The aim of this research is to design a tool that improves productivity and accuracy at these stages, but it does not yet encompass full automation or advanced technologies outside this scope. The research is conducted in a laboratory environment, so the results may differ when applied to larger-scale industrial production. Long-term impacts, such as cost savings or energy efficiency, are not discussed. Further testing is required before industrial implementation.

With the implementation of tool design in the production process, this laboratory not only enhances operational efficiency but also provides relevant practical experience for students. This enables students to be better prepared to face the challenges and opportunities in today's manufacturing industry. Universitas Mercu Buana's Lean Manufacturing Laboratory is committed to continuous innovation and supporting technological advancements that can enhance the competitiveness of Indonesia's manufacturing industry on the global stage.

Lean Manufacturing, introduced by the Toyota Production System (TPS), is a systematic approach aimed at reducing waste in production without compromising productivity. This methodology emphasizes improving efficiency and production response time through various techniques such as Just-in-Time (JIT), Kaizen (continuous improvement), and Total Productive Maintenance (TPM). These principles have been well-researched and validated in modern production environments (Kumar et al., 2022). One of the essential tools in Lean Manufacturing is the Plan-Do-Check-Act (PDCA) cycle, which provides a structured approach to continuous improvement by identifying opportunities for enhancement, implementing changes on a small scale, and then evaluating and standardizing the improvements (Realyvásquez-Vargas et al., 2018).

A key visual tool in lean manufacturing is Value Stream Mapping (VSM), which is used to analyze the flow of materials and information throughout the production process (Ikatrinasari et al., 2019). VSM enables organizations to identify non-value-added steps and design more efficient workflows, supporting waste reduction and process optimization (Batwara et al., 2023). By focusing on these non-

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value-added activities, companies can streamline operations, leading to significant improvements in production efficiency.

Fig. 1 shows the symbols used in VSM. These symbols are essential tools for visualizing and analyzing the flow of materials and information throughout a manufacturing process. The detailed explanation of the common symbols typically found in VSM is presented in Table 1.

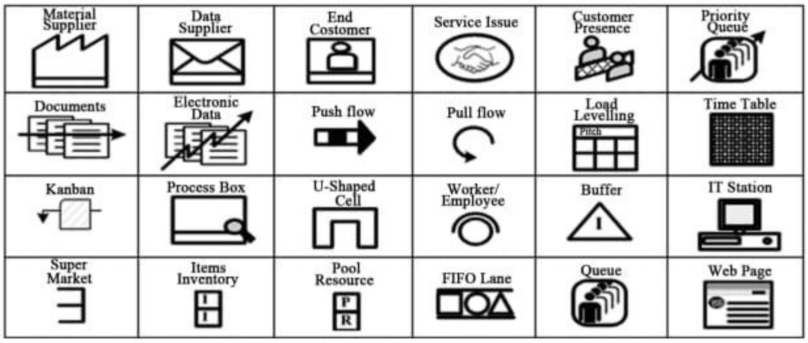

Fig. 1 VSM Symbols (Bonaccorsi et al., 2011).

Table 1 Detailed explanation of the common symbols typically found in VSM

No.	Symbol	Description	No.	Symbol	Description
1	Material Supplier	Indicates the source of raw materials or components needed in the production process.	13	Kanban	Symbolizes cards or signals used to manage material flow and production based on demand.
2	Data Supplier	Represents the source of data used in the production process.	14	Process Box	Represents processes, operations, machines, or departments where work is done.
3	End Customer	Symbolizes the final customer who receives the finished product.	15	U-Shaped Cell	Indicates a U-shaped production cell layout to improve efficiency.
4	Service Issue	Indicates service issues that may occur within the process flow.	16	Worker/Employee	Symbolizes workers or employees involved in the production process.
5	Customer Presence	Represents the presence of the customer in the production process.	17	Buffer	Shows a buffer to hold materials between processes.
6	Priority Queue	Shows the priority queue for certain processes or activities.	18	IT Station	Indicates IT stations that support the production process.
7	Documents	Symbolizes documents involved in the information flow.	19	Super Market	Symbolizes the storage area for finished goods before shipment to customers.
8	Electronic Data	Indicates electronic data used in the process.	20	Items Inventory	Indicates the inventory of items in the production process.
9	Push Flow	Shows push flow where materials are moved to the next process without demand signals.	21	Pool Resource	Shows shared resources used in multiple processes.
10	Pull Flow	Represents pull flow where materials are moved based on demand signals from the next process.	22	FIFO Lane	Indicates the FIFO (First In, First Out) lane for managing material flow.
11	Load Leveling	Symbolizes efforts to level the workload for more balanced production.	23	Queue	Symbolizes queues for specific processes or activities.
12	Time Table	Indicates the timetable for specific processes.	24	Web Page	Indicates web pages used in the information flow.

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Operation Process Charts (OPC) also play a crucial role in process analysis. OPCs map the sequence of operations, inspections, and delays, helping to identify inefficiencies. This graphical representation provides visibility into production processes and is especially effective when combined with digital tools, allowing real-time updates and better integration with other management systems (Permana et al., 2022).

Furthermore, the Seven Wastes (Muda) are a fundamental concept in Lean Manufacturing. These include overproduction, waiting, transportation, overprocessing, excess inventory, motion, and defects. Research highlights the detrimental effects of these wastes on production efficiency, and eliminating them is key to improving overall performance and reducing costs (Amrina & Fitrahaj, 2020a).

According to Fig. 2, these wastes include:

- Overproduction, producing more products than needed or producing them before they are needed. This leads to excess inventory and potential obsolescence.
- Waiting, Periods where work is stalled due to delays, such as waiting for materials, equipment, or approvals. This idle time adds no value to the product and reduces overall efficiency.
- Transportation, Unnecessary movement of materials or products between processes or locations. Excessive transportation increases lead times and risks damage or loss of materials.
- Over processing, performing more work or adding more features than necessary, which does not contribute to the value of the product from the customer's perspective. This can include redundant steps or unnecessary inspections.
- Inventory, Excess stock of raw materials, work-in-progress, or finished goods. High inventory levels can tie up capital and storage space, leading to potential waste through obsolescence or spoilage.
- Motion, Unnecessary movement of people or equipment during production. This can include workers walking long distances or handling tools and materials inefficiently, which contributes to wasted time and effort.
- Defects, Errors or defects in products that require rework or lead to scrap. Defects not only affect quality but also lead to additional costs and delays in the production process.

Fig. 2 Seven wastes (Pasha & Chin, 2024).

In lean manufacturing, the primary objective is to minimize or eliminate these wastes to improve efficiency, reduce costs, and enhance product quality (Amrina & Fitrahaj, 2020b). By focusing on the reduction of these seven types of waste, organizations can streamline their processes, optimize resource utilization, and better meet customer demands.

In addition to traditional Lean methods, the Theory of Inventive Problem Solving (TRIZ) offers a structured methodology for overcoming technical and non-technical challenges. TRIZ is based on the analysis of numerous patents and identifies common patterns in innovative problem-solving. The methodology encourages the resolution of system contradictions, where improving one aspect may deteriorate another, by applying creative and systematic solutions (Qiao et al., 2023). TRIZ has found widespread application in various industries, offering tools that enable companies to tackle complex challenges more effectively and innovatively (Sojka & Lepšík, 2020).

This research aims to improve the efficiency of the Lean Manufacturing practicum at Universitas Mercu Buana by applying the PDCA and TRIZ methods. The main focus of this research is the design

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and implementation of a flexible jig tool capable of reducing process time and increasing precision in the heating, vacuum, and trimming stages.

2. Methods

This research utilizes the continuous improvement method with the PDCA (Plan, Do, Check, Act) cycle to achieve optimal results, as illustrated in the Fig. 3.

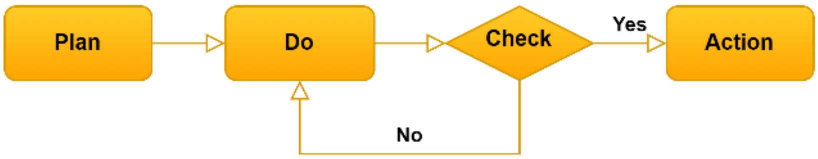

Fig. 3. Plan-Do-Check-Action.

Plan

In the preparation phase (Plan), several key steps are undertaken to establish a solid foundation for the continuous improvement process. The first step is mapping the VSM, which visually depicts the process flow of the lean manufacturing laboratory (Fog. 4). Explained again in Fig. 5, which is The Operation Process Chart (OPC), in this visual, each process stage has a different cycle time. The heating stage takes approximately 330 seconds, vacuum takes around 86 seconds, trimming takes about 190 seconds, press tyre takes about 140 seconds, assembling 1 takes 100 seconds, assembling 2 takes around 195 seconds, assembling 3 takes about 220 seconds, assembling 3 takes around 75 seconds, quality control takes about 75 seconds, and packaging takes about 20 seconds, as further detailed in Table 2.

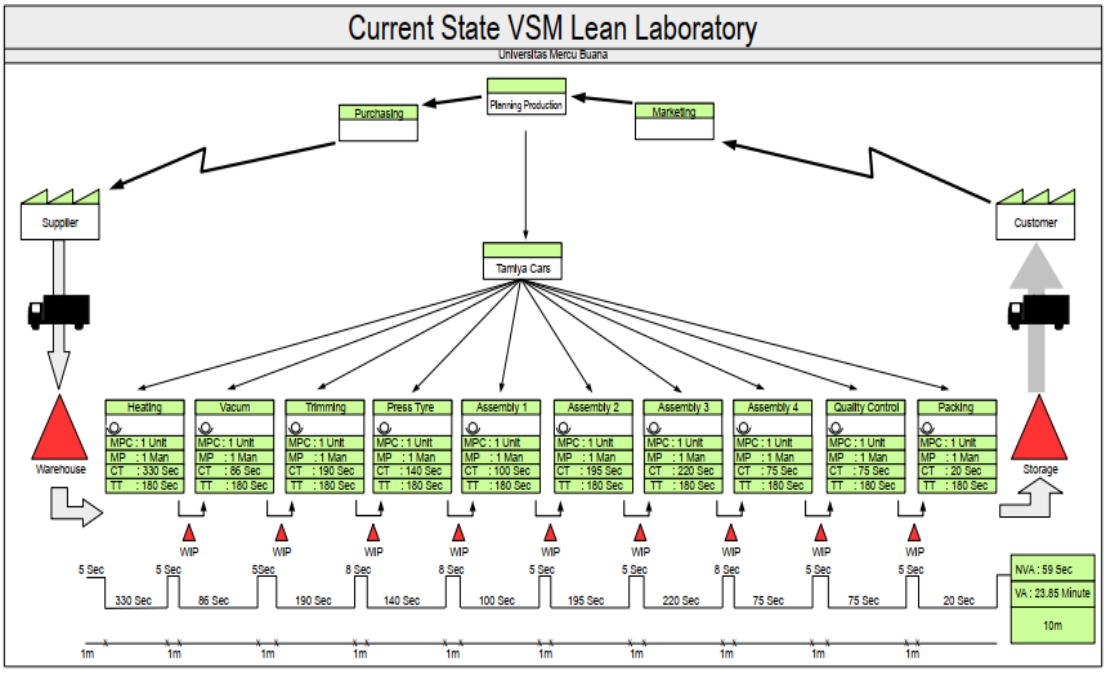

Fig. 4 Current state VSM Lean Manufacture Laboratory.

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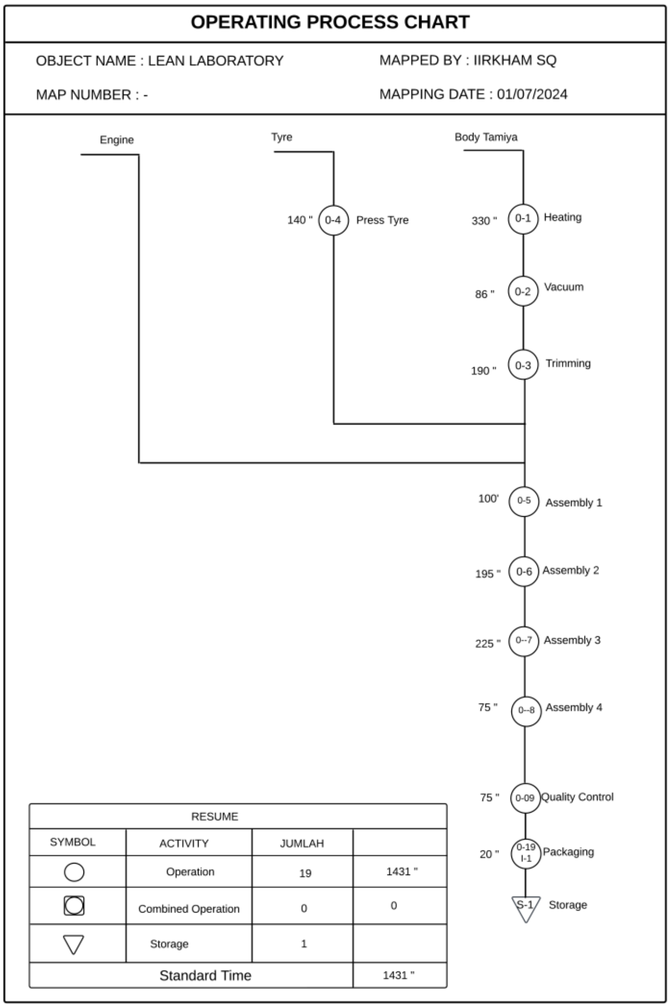

Fig. 5 Current state OPC Lean Manufacture Laboratory.

Table 2 Details process time

Station No.	Station Name	Cycle Time (seconds)	Takt Time (seconds)
1	Press Tyre	140	180
2	Heating	330	180
3	Vacuum	86	180
4	Trimming	190	180
5	Assembling 1	100	180
6	Assembling 2	195	180
7	Assembling 3	220	180
8	Assembling 4	75	180
9	Quality Control	75	180
10	Packaging	20	180

The research team also measured the number of people required per station and the distance between stations, as shown in Table 3, each station is handled by one person, and the distance between stations is 100 cm.

Fig. 6 is a graph that shows significant challenges in this laboratory process, particularly in the heating, vacuum, trimming, assembling 2, and assembling 3 stages. The cycle times for heating, vacuum, and trimming often exceed the determined takt time, with average times of 330, 86, and 190

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seconds, respectively, thus hindering the production flow. Similarly, assembling 2 and assembling 3 take 195 seconds and 220 seconds, respectively.

Table 3 Details people required station and the distance between stations

No.	Station Name	Man Power	Distance to Next Station
1	Heating	1	100 cm
2	Vacuum	1	100 cm
3	Trimming	1	100 cm
4	Press Tyre	1	100 cm
5	Assembling 1	1	100 cm
6	Assembling 2	1	100 cm
7	Assembling 3	1	100 cm
8	Assembling 4	1	100 cm
9	Quality Control	1	100 cm
10	Packaging	1	100 cm

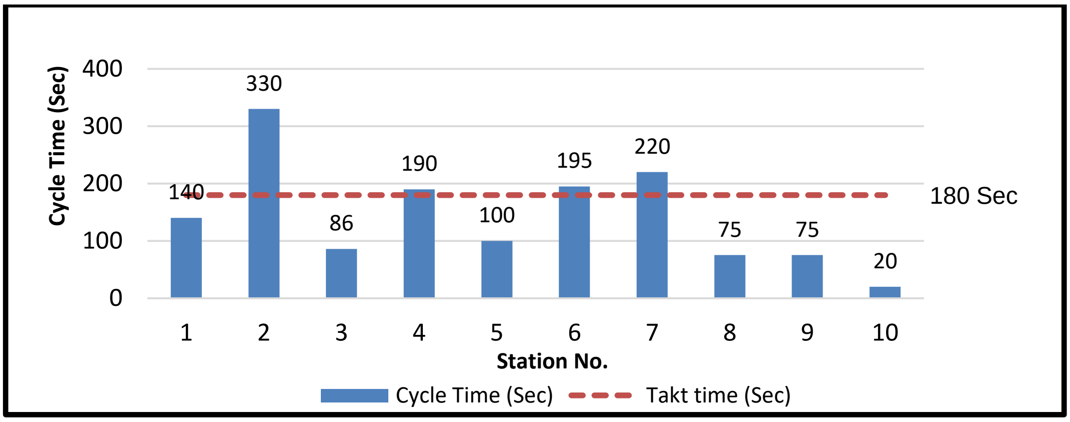

Fig. 6 Distribution of process time in lean manufacture laboratory.

Next, in the Plan phase, preparation involves gathering data on the Seven Wastes present in the lean manufacturing laboratory practicum. Identification and analysis of these Seven Wastes are crucial to pinpoint areas that require improvement and optimization. Detailed analysis, is outlined in Table 4.

Table 4 The seven wastes analysis in Lean Manufacture Laboratory

No.	Type of Waste	7 Wastes Analysis Observations
1	Transportation	The distance between workstations is 1 meter, leading to movement by hand and conveyor.
2	Inventory	-
3	Motion	• Workers need to move to retrieve raw materials and tools from other workstations. • Manual work processes cause unnecessary movements.
4	Waiting	There is waiting time at several workstations, such as during the heating of PVC sheets or while waiting for products to pass quality control.
5	Overproduction	-
6	Overprocessing	The product-cutting process at the Trimming station is still manual, leading to longer times. This could be improved with an automatic trimming machine to enhance precision and reduce time.
7	Defects	• There is allocated time for quality control to ensure products meet standards. • This indicates potential product defects that could lead to a waste of materials and time.

Do

In the Plan phase, the researchers have mapped out the Value Stream Mapping (VSM) and analyzed the Seven Wastes. Next, they can identify areas that require improvement and devise strategies to reduce or eliminate these wastes. The data obtained from this analysis will be utilized to design more efficient tools and methods in the Do phase using TRIZ.

Contradiction identification

a. Design criteria

Table 5 describes several design criteria focused on in this study: speed, precision, efficiency, safety, and cost. Each criterion is explained in the context of how the current manual process faces challenges related to each of these criteria.

Table 5 Design criteria

Criteria	Description
Speed	Processes take a long time.
Precision	Manual trimming is not always precise and consistent.
Efficiency	Slow and manual processes are inefficient.
Safety	Manual processes pose risks of workplace accidents.
Cost	Slow and manual processes can increase production costs.

b. Root Causes

Table 6 highlights the root causes behind the challenges identified in the design criteria. These include the use of outdated technology that is inefficient, the need for skilled operators for manual processes, and non-ergonomic and imprecise tool designs for manual trimming.

Table 6 Root causes

Root Cause	Description
Old Technology	Processes use inefficient old technology.
Operator Skills	Manual processes require skilled operators, which may be scarce.
Tool Design	Manual trimming uses non-ergonomic and imprecise tools.

c. Identification

Table 7 introduces contradictions that arise from the analysis of design criteria and root causes. These contradictions describe trade-offs or conflicts between various aspects such as speed vs. precision, precision vs. skill level, and efficiency vs. cost. Each contradiction is explained in the context of how improvements in one area can negatively impact other aspects.

Table 7 Identification

Contradiction	Description
Speed vs. Precision	Increasing speed in heating, vacuum, and trimming processes may reduce manual trimming precision.
Precision vs. Skills	Improving manual trimming precision requires skilled operators, which may be difficult to find.
Efficiency vs. Cost	Enhancing efficiency in heating, vacuum, and trimming processes can increase equipment costs and operator training.

Determination of inventive principles

Determination of Inventive Principles in Table 8. This table considers inventive principles that can be applied to address the identified contradictions. Each design criterion (Speed, Precision, Efficiency, Safety, and Cost) is paired with potential inventive principles to enhance the features that need improvement and reduce those that need worsening. General solutions are provided for each design criterion with specifications for both manual and semi-automatic cutting tools.

Table 8 Determine of inventive principle

Design Criteria	Improving Features	Worsening Features	Common Solution	Specifications
Speed	Ideality, Division	Contradiction Resolution, Dynamization	Manual and semi-automatic cutting tools	• Cutting speed depends on operator skill and effort. • Capacity to cut simple

Design Criteria	Improving Features	Worsening Features	Common Solution	Specifications
				shapes and basic patterns.
Precision	Adaptability, Lightness	Partial Changes, Nesting	Manual cutting tools with precision blades	• Cutting precision depends on operator accuracy and skill. • Limited capability to cut thin and brittle materials.
Efficiency	Division, Universality	Contradiction Resolution, Partial Changes	Manual cutting tools with ergonomic design	• Cutting efficiency depends on the operator's physical endurance. • Limited capacity to cut multiple parts simultaneously.
Safety	Lightness, Standardization	Dynamization, Nesting	Manual cutting tools with comfortable grips and blade guards	• Higher risk of workplace accidents due to manual cutting. • Limited capability to protect operators from blade hazards and debris.
Cost	Standardization, Nesting	Ideality, Dynamization	Manual cutting tools with simple construction and low-cost materials	• Lower initial costs.

Virtual design

Design Virtual involves translating the concepts and solutions generated from the analysis and identification stages using the TRIZ methodology into virtual designs. This phase ensures that potential solutions are validated before being implemented directly in the actual production environment. This design can be seen in the following Fig. 7.

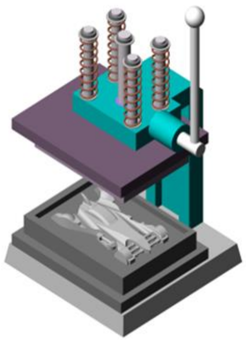

Fig. 7 Flexible jig.

Check

In the Check phase of the PDCA methodology, the results are assessed following the implementation of the flexible jig tool design in the lean manufacturing laboratory practicum. After designing and deploying the flexible jig tool, an evaluation is conducted to measure the achieved outcomes. This evaluation includes collecting data on the effectiveness of the new tool in reducing process time, improving precision, and enhancing overall workflow in the practicum. The evaluation results are used to determine whether the design of the flexible jig tool has successfully addressed previously identified issues and whether further adjustments or improvements are necessary before proceeding to broader implementation phases. The results are documented and can be observed in the following Table 9.

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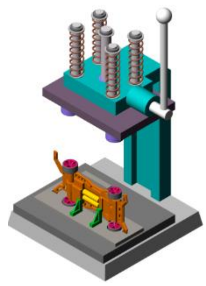
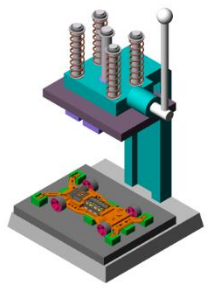
Table 9 Results of Flexible Jig Implementation

Activity Process	Before	After
Vacum & Trimming	Vacuum • Heat the PVC Sheet • Press on the Vacuum Jig • Turn on the Vacuum Machine • Remove the Workpiece • Inspect the Workpiece • Store the Workpiece Trimming • Take the Product • Marking • Cutting • Storage	• Loading the Workpiece • Lowering the Press • Performing the Operation • Removing the Workpiece
Time Reduction: 86% Process Reduction: 40%	Time: 276 Seconds Details: 2 Process (10 activities)	Time: 40 Seconds Details: 1 Process (4 activities)

Action

The Action stage in the PDCA methodology is where the steps tested and evaluated in the Check stage are implemented on a broader scale. In the context of expanding to Assembly 2 and Assembly 3 processes, this means that the results from implementing the flexible jig design have been evaluated and proven successful in addressing the challenges identified in the previous stage. The expansion of implementation can be seen in Table 10.

Table 10 The expansion of Implementation in Assemblies 2 and 3

No.	Activity Process	Before	After	Virtual Design
1	Assembly 2 (Tire Assembly) Reduction Time: 74% Reduction Process: 43%	• Assemble Product 1 • Install Shaft Bearing • Install 2x Shafts • Install 2x Tyre Assy Rear • Install Shaft Bearing • Install 2x Shafts • Install 2x Tyre Assy Front Time: 195 Seconds Details: 7 Activities	• Position Assemble Product 1 on the Press Assembly Jig, and install components • Press the Press Assembly Jig • Release Pressure and Check Time: 50 Seconds Details: 3 Activities	
2	Assembly 3 (Inner Cover Assembly) Reduction Time: 73% Reduction Process: 60%	• Assemble Product 2 • Install Power Terminal • Install Engine Power • Install Engine Power Cover • Install Engine Cover Time: 220 Seconds Details: 5 Activities	• Position Assemble Product 2 on the Press Assembly Jig, and install components • Press the Press Assembly Jig • Release Pressure and Check Time: 60 Seconds Details: 3 Activities	

These steps include integrating the tool into standard operating procedures (SOPs), providing training to the workforce to use the tool effectively, and ensuring that these changes support improvements in efficiency, and automation in the production processes. Additionally, the Action stage involves continuous monitoring of the performance of the newly implemented processes. Data is

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collected and evaluated continuously to ensure that the improvements achieved are sustainable and align with the objectives set in the previous Plan stage.

Thus, the Action stage is not only about implementing changes but also about ensuring the continuity and success of the improvements made in Lean Manufacturing practices at the Universitas Mercu Buana Laboratory.

3. Results and Discussion

After implementing a flexible jig tool in the light manufacturing practicum, the vacuum and trimming stations were combined into one station, resulting in the reduction of one manpower, as previously explained in Table 3 where each station is manned by one person. The observed results are shown in Table 11.

Table 11 The observed results

Station No.	Section Step	Cycle Time Before (Sec)	Cycle Time After (Sec)
1	Press Tyre	140	140
2	Heating	330	330
3	Vacuum	86	40
4	Trimming	190	
5	Assembling 1	100	100
6	Assembling 2	195	50
7	Assembling 3	220	60
8	Assembling 4	75	75
9	Quality Control	75	75
10	Packaging	20	20
Total (Sec)		**1431**	**890**
Total (Minute)		**23.9**	**14.8**

Table 11 explains that before the implementation of the flexible jig tool, the total cycle time was 1431 seconds or 23.9 minutes. After implementing the flexible jig tool, the total cycle time was reduced to 890 seconds or 14.8 minutes, showing a time reduction of 37.8%. This change can be seen in Fig. 8.

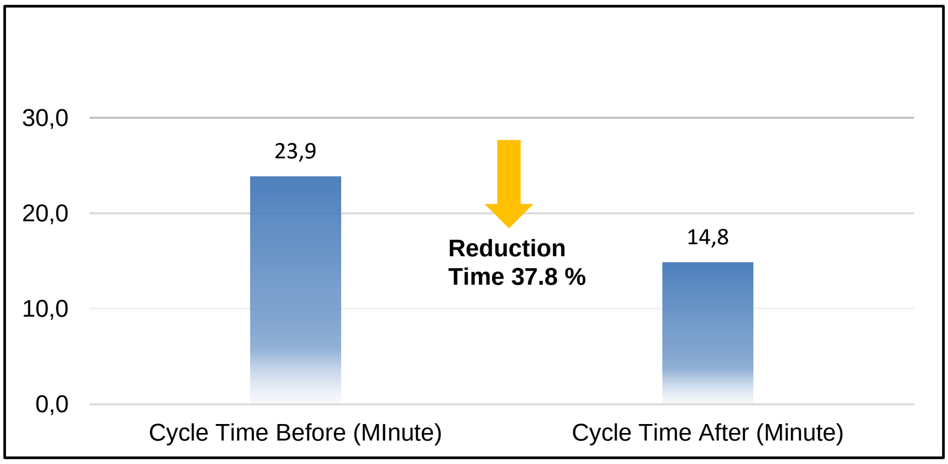

Fig. 8 Comparison between the cycle time before and after.

The implementation of tool design in this study significantly contributed to improving production process efficiency. The following steps provide deeper insights into the achieved outcomes:

- Problem Identification and Root Cause Analysis, In the Plan phase, researchers used tools such as Value Stream Mapping (VSM), Operation Process Chart (OPC), and the concept of Seven Waste to identify key issues in the manufacturing process. This approach helped uncover various time wastages and workplace safety risks caused by intensive manual processes. Through this analysis, researchers were able to understand the root causes of the problems and formulate more targeted improvement steps.

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- Solution Implementation: In the Do phase, the flexible jig tool was developed by integrating TRIZ principles to address identified contradictions. This tool enabled significant improvements in process efficiency and precision, especially in the Vacuum & Trimming stage.
- Evaluation and Continuous Improvement: The Check and Act phases of PDCA were used by researchers to evaluate the impact of the flexible jig tool implementation and expand its application. The evaluation results showed substantial enhancements in process productivity, which then extended its application to other assembly stages.
- Conclusion and Implications: The successful implementation of the flexible jig tool demonstrated its potential to enhance efficiency, reduce waste, and improve safety in the light manufacturing practicum. These initiatives not only optimized current processes but also laid the foundation for continuous improvement in future lean manufacturing practices.

The research is limited to several stages of the Tamiya production process in the Lean Manufacturing Laboratory, specifically heating, vacuum, trimming, and assembly. The aim of this research is to design a tool that improves productivity and accuracy at these stages, but it does not yet encompass full automation or advanced technologies outside this scope. While this research provides strong evidence that the implementation of tool design with systematic approaches like PDCA and creative methodologies such as TRIZ can significantly enhance operational performance, it is important to note that these findings are confined to a laboratory environment. Consequently, the results may differ when applied to larger-scale industrial production settings. Additionally, the study does not discuss long-term impacts, such as cost savings or energy efficiency, and further testing is required before broader industrial implementation can be considered.

4. Conclusion

The results show that the implementation of the flexible jig successfully reduced process time by 37.8%, from 1431 seconds to 890 seconds, and increased the Level of Automation from fully manual to the use of flexible hand tools. Further evaluation demonstrated significant improvements in process productivity.

The application of tool design using the PDCA method in this study utilized tools such as Value Stream Mapping (VSM), Operation Process Chart (OPC), and the Seven Waste concept to identify major problems in the manufacturing process. Additionally, the tool design using TRIZ principles significantly contributed to improving production process efficiency. However, this research has limitations that need to be considered. The focus of the research is only on specific stages of the Tamiya production process in the Lean Manufacturing Laboratory, namely heating, vacuum, trimming, and assembly. This research does not encompass full automation or advanced technologies outside this scope.

From the results, it can be concluded that the application of tool design with systematic approaches like PDCA and creative methodologies like TRIZ can significantly enhance operational performance in the context of light manufacturing practicum. Although the research was conducted in a laboratory environment, which may yield different results when applied to larger-scale industrial production, this implementation can serve as a reference for organizations aiming to achieve sustainable improvements in production systems.

In the future, further research can be conducted to develop applications of flexible jigs for automation purposes and explore the latest technologies that can be integrated into the Lean Manufacturing practicum. Universitas Mercu Buana is committed to continuous innovation, preparing students to face industrial challenges, and supporting technological advancements that can enhance the competitiveness of Indonesia's manufacturing industry on a global scale. The researchers hope that the results of this study can serve as a foundation for further research and practical applications in the industry, as well as contribute to the improvement of educational laboratories and student skills in the field of manufacturing.

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