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Integration of Lean Manufacturing and Information System for Productivity Improvement: A Case Study of the Electronics Industry in Thailand

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Abstract. Thailand's electronics industry has rapidly evolved over the past five decades. All manufacturers need to be ready to adapt the strategies to make competitiveness in the global market. Lean manufacturing is the manufacturing technique that is used to reduce lead times and operating costs and improve product quality to meet customer demand. Moreover, information system is a crucial part of any company of business as they monitor and manage to help the business be more efficient and productive. This study was to apply lean manufacturing and information system to improve the productivity of the electronics company in Thailand. The climate controller was selected in this study. It focused on the printed circuit board assembly (PCBA) process due to the longest processing time and the complete manual process. This study was done in 2 phases. First, it was to create standardized work and determine standard time. ECRS stands for eliminate, combine, rearrange, and simplify. This principle was implemented with standard operating procedure (SOP) to standardize the manufacturing process. Time study technique was applied to determine the standard time of the manufacturing process. Second, it was to develop the performance dashboard. Data visualization tool was used to monitor, control, and report the efficiency of manufacturing processes. The result showed that the productivity increased from 132 to 156 units per day. It raised by 18%. The performance efficiency rate of all operators tends to continuously increase.

Keywords: Lean manufacturing, Information system, Standardized work, ECRS, Data visualization

1. Introduction

Owing to productivity improvement being a critical success factor and the foundation of profitability [1], the increasing competitiveness between organizations means that they need to enhance effectiveness and efficiency, taking measures to reduce costs and increase their productivity [2]. Thus, productivity improvement is important to the organization to improve and maximize manufacturing efficiency, develop the production system by standardization, promote the company's performance through the competent use of its production resources, eliminate or reduce losses in the manufacturing processes, and maximize production capacity to be able to make competitiveness in the global market in order to meet the customer demand. Thailand's electronics industry has rapidly evolved over the past five decades. All manufacturers need to be ready to adapt the strategies to make competitiveness in the global market. Printed circuit board assembly (PCBA) is an essential process during the manufacture of electronic products, in which various electronic components and bare PCBs are connected [3]. Automated PCBA technologies have been introduced to expedite this process such as SMT, wave soldering, and robotic soldering machines but in cases where selective soldering or in small areas that are difficult to solder using automated machines, the hand soldering process is a better way for PCB assembly.

Lean manufacturing is a manufacturing technique that aims to minimize or eliminate waste from the root level to obtain productivity improvement and customer satisfaction. It was applied by Toyota during the 1950s which is famously known as Toyota Production System (TPS). At first, TPS was to improve

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productivity as well as to decrease the cost by eliminating waste or non-value added (NVA) activities [4]. Application of the TPS was guided by 5 principles starting with 1) specifying the value, 2) identifying the value stream, 3) making the value flow, 4) configuring the pull system by the customer, and 5) pursuing towards perfection [5]. Based on the TPS, Lean manufacturing consists of a set of tools and techniques that assisted in the identification and steady elimination of waste (Muda) such as 5S, just-in-time (JIT), PDCA, Kanban (Pull system), Andon, Kaizen (Continuous improvement), total productive maintenance (TPM), ECRS, value stream mapping (VSM) and standardized work [6], [7]. Overall Equipment Effectiveness (OEE), a part of the lean manufacturing tool kit, is an indicator for measuring manufacturing productivity. Lean manufacturing plays a significant contribution to the competitive manufacturing field. Ketchanchai, Tangchaidee, and Kongprasert [8] applied lean manufacturing to analyze, improve, and eliminate unnecessary activities through VSM in warehouse management of sugar manufacturing company.

Standardized work is one of the most important parts of the TPS. It has a purpose as a foundation for kaizen. It not only provides a standard way of doing the process but can analyze the processes that will reveal waste that should be eliminated as part of developing the standardized work. Operators are properly trained to work following the standardized work and should be encouraged to suggest changes that will improve the process and be reflected in revisions to the standardized work. Standardized work has been done through work study to provide standard methods of operation to the manufacturing activities [9] and time study establishes the standard time for operation improvement [10]. Standard time is the time that was taken by a qualified and trained operator to complete a certain job while working efficiently [11]. Creating standardized work documents by identifying the work steps. One of the most important parts is doing continuous improvement, and audits are used as a tool to detect deviations from standard work [12]. Vijay and Prabha [13] implemented standard operating procedure (SOP) and continuous improvement to standardize the manufacturing process, identified the critical time elements by using a stopwatch for time study, and adjusted the process by line balancing method. Sahebagowda, Kulkarni, and Gaitonde [14] studied standardized work of the critical workstation for determining value added (VA) and non-value added (NVA). Lean tools like kaizen and 5S techniques were used to improve the critical workstation along with ergonomics study, time and motion study.

Overall labor effectiveness (OLE) is an indicator to assess the productivity of a workforce where processes are manual. OLE is similar to overall equipment effectiveness (OEE) that focuses on the manufacturing productivity from machines. OLE is the analysis of the cumulative effect three workforce factors have on productive output: availability, performance, and quality. Availability is the percentage of time the workforce spends making effective contributions. Quality is the percentage of perfect or saleable products produced. Performance is the ratio of the actual output of operators to the expected output defined by the labor standards [15]. Laitinen [16] added that the most important performance information is associated with product profitability, company profitability, cost of activities, and customer profitability. Kuo, Dunn, and Randhawa [17] proposed that a good performance measurement system is necessity for company to grow by using productivity and attendance as evaluation criteria for operator performance.

Information systems (IS) are interrelated components working together to collect, process, store, and disseminate information to support decision making, coordination, control, analysis, and visualization in an organization [18]. There are different types such as management information system (MIS) and decision support system (DSS). Involving data visualization technology is used to analyze and keep track on production time, employee performance, and productivity in the manufacturing process. The major goal of data visualization is to provide the user with a qualitative and easy understanding of the information contents. The performance dashboard acts as an information management tool to track the key performance indicators (KPIs) and other key factors applicable to the specific process [19]. Kumar and Belwal [19] developed the performance dashboard for analyzing the business trends, operator performance, amount of profit, and much more. In order to present performance and to keep track of the department's capability to accomplish service level targets. Rezaei, Çelik, and Baalousha [20] developed a system to measure the operator performance and subsequently apply the obtained performance factor in order to create a motivation system for the company, which in-turn affects operators' performance and, consequently, company performance. Vilarinho, Lopes, and Sousa [21] developed and implemented a dashboard to improve the performance of productive equipment and processes, to be implemented at the shop floor level. Garrett, Saengphueng, and Kongprasert [22] and developed the inventory dashboard to increase the efficiency of inventory management of the industrial tool distributor in Thailand.

This study was to apply lean manufacturing and information systems to improve the productivity of the climate controller manufacturing process. It focused on the manufacturing process of climate controllers. It was done in 2 phases. First, it was to create standardized work and determine standard time. ECRS stands for eliminate, combine, rearrange, and simplify. This principle was implemented with standard operating procedure (SOP) to standardize the manufacturing process. Time study technique was applied to determine the standard time of the manufacturing process. Second, it was to develop the performance dashboard. Data visualization tool was used to monitor, control, and report the efficiency of manufacturing processes.

2. METHODOLOGY

The climate controller is the main product of this company. It has more than 20 models. Then, the climate controller was selected in this study. The manufacturing process of the climate controller consists of six processes: 1) material preparation, 2) printed circuit board assembly (PCBA), 3) PCBA inspection, 4) climate controller assembly, 5) inspection and functional testing, and 6) packaging, as shown in Fig. 1. The manufacturing process of the PCBA process was selected for productivity improvement because it was the longest processing time.

The PCBA process is composed of three processes: 1) surface mount technology (SMT) assembly, 2) robotic soldering, and 3) hand soldering, as shown in Fig. 2. Among those PCBA processes, the PCBA hand soldering process is a critical process due to the longest processing time and complete manual process. It is an important manufacturing process in case of SMT assembly process and robotic soldering process cannot solder the electronics components by using automated machines. Then, the PCBA hand soldering process was selected to improve productivity.

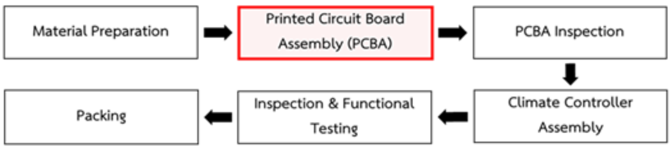

Fig. 1: The manufacturing process of the climate controller

Fig. 2: The PCBA process

In order to improve the productivity of the PCBA hand soldering process, this study was to apply lean manufacturing and information systems. It was done in 2 phases. First, it was to create standardized work and determine standard time. ECRS and SOP were implemented to standardize the manufacturing process. Time study technique was applied to determine the standard time of the manufacturing process. Second, it was to develop the performance dashboard. Data visualization tool was used to monitor, control, and report the efficiency of manufacturing processes.

2.1. Phase I: Create Standardized Work and Determine Standard Time

This phase was to create standardized work of the PCBA hand soldering process. It was done in 4 steps: 1) study the manufacturing process, 2) improve the manufacturing process, 3) create standardized work, and 4) determine standard time.

1) Study manufacturing process: This step was to study the manufacturing process of the climate controller. The climate controller T207 model was selected in this study because it was one of the top 5 best-selling products. It has 27 electronics components. This step found that

- The PCBA hand soldering process has 5 steps: 1) prepare materials (P), 2) insert component into a PCB through pinholes (I), 3) solder component (S), 4) trim pins (T), and 5) clean finished product (C).
- All operators assembled PCB in different procedures which affected the total processing times as shown in Table I.
- This model, SMT assembly and robotic soldering processes have standardized work, but the PCBA hand soldering process has not had standardized work.
- Operator C makes the assembly with the shortest processing time because she has more experience and skill than others.
- They collect the production data by using paper report. They take more time to analyze, summarize and report the performance of operator.

2) Improve manufacturing process: This step was to improve manufacturing process of the climate controller. ECRS and Standard Operating Procedure (SOP) were used to improve the manufacturing process. Five criteria were created to guide the head of operators to standardize the work process.

a) Component sizing: The smallest and shortest component will be chosen to be the first priority for assembly. They are the blue components (T, L and Y) as shown in Fig. 3.

b) Number of pins: The components that have more than 10 pins are selected to be the member of this group. They are the green components (IC and PW) as shown in Fig. 3.

c) Same category and same specification: The components that are the same category and same specification are chosen to assemble together. They are the red components (LED, SW, DP, C) as shown in Fig. 3.

d) Same category and different specification: The components that are same category and different specifications are not chosen to assemble together. For example, fuse 0.5A/1A/2A/4A, 7-segment red/green/yellow/white color, and diode.

e) Unwashed components: It is the special component that was chosen to assemble after cleaning PCBA to avoid being washed. It is the purple component (Z) as shown in Fig. 3.

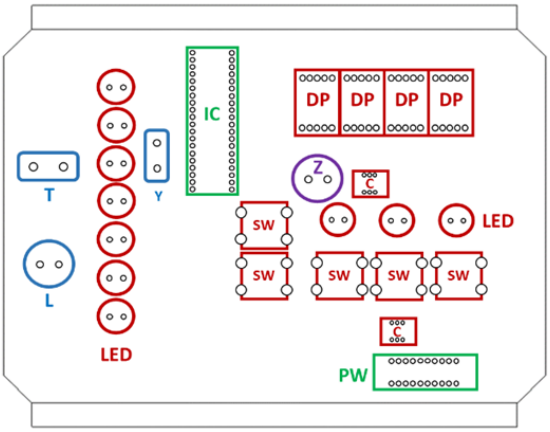

Fig. 3: The example of PCB drawing

3) Create standardized work: The main objective of standardized work is to convey to the operator how to perform the job efficiently by using Standard Operating Procedure (SOP) to standardize the process. The work sequence of operator C was selected to improve the manufacturing process by using 5 criteria and ECRS. The new work sequence was more efficient than the previous work sequence as shown in Table I.

4) Determine Standard times: To determine standard times, it was done in 3 steps: 1) record processing time, 2) calculate the standard time, and determine the standard time. Stopwatch was used to collect the data for Time study. The lot size for production was 30 units/time. The standard time was calculated by using the standard time equation as in [23].

2.2. Phase II: Develop the Performance Dashboard

This phase was to develop the dashboard by using the data visualization tool. It was done in 2 steps: 1) collect production data, and 2) develop the dashboard.

Fig. 4: Model of performance report system

1) Collect production data: This step was to collect the production data. Google Sheets were created to collect the production data as shown in Fig. 4.

2) Develop the dashboard: This step was to develop the dashboard. Based on the purpose of the performance dashboard. The main purpose is to summarize production data by using data visualization to report, monitor, and control the performance of manufacturing processes. This study was focused on the performance efficiency rate of OLE measurement methodology, the performance efficiency rate (P) was calculated by using (1)

$$P = (ST \times AOP) / TPT \quad (1)$$

where,

ST Standard time,
AOP Actual amount of Production,
TPT Total Production Time

Google Data Studio (GDS) is a data visualization tool that was used in this study. As shown in Fig. 4, the data source adds properties and functionalities, and chooses which dimensions and metrics to use in reports. The collected data need to be processed for information. GDS does not import the data, it uses a connector to get access to the data set. The report presented the output information.

3. results and discussions

The main goal of this study was to apply lean manufacturing and time study techniques for improving productivity and standardizing work of the PCBA hand soldering process. The result is summarized in the following:

3.1. Standardized Work of the PCBA Hand Soldering Process

The new standardized work of the PCBA hand soldering process was created as shown in Table I. It was summarized following this.

- The process of preparing materials for all sub-assemblies were combined into one time to reduce the preparation time. The cycle time of preparation material is 63 seconds.
- The process of sub-assembly was divided into 3 sub-assemblies. It followed the five criteria for guiding guide the head of operators to standardize the work process.
- Sub-assembly 1, consisted of 4 steps. First, the smallest and shortest components were chosen to be the first priority for assembly. They were T, L, and Y. Second, IC was selected because it has more than 10 pins. Third, component C has 2 items were the component in the group of the same category and same specification. They were selected to assemble before PW due to the position of both components located in the middle of PCB. It was difficult to solder after PW. The cycle time of sub-assembly 1 is 152 seconds.
- Sub-assembly 2, the components that were the same category and same specification were grouped in this sub-assembly. They were LED, SW, and DP. The cycle time of sub-assembly 2 is 426 seconds.

- Both processes for cleaning PCB were combined into one time to reduce the cleaning time. The cycle time of cleaning PCB is 68 seconds.
- Sub-assembly 3, the component that was avoided being washed was selected in this sub-assembly. It was Z. The cycle time of sub-assembly 3 is 15 seconds.

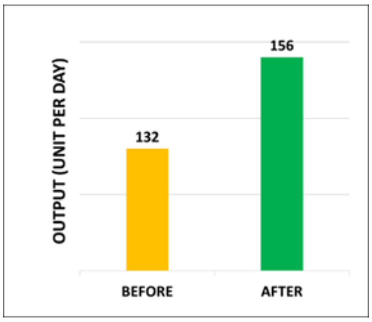

Fig.5: Comparison of the productivity between the previous and new work sequence

Fig. 5 illustrated the comparison of the productivity of operator between the previous and new work sequences. The total processing time has been decreased from 946 to 724 seconds. It reduced by 23%. The result showed that the productivity increased from 132 to 156 units per day. It raised by 18%

3.2. Report and dashboard

The dashboard was developed to report, monitor, and control the performance of the manufacturing process. The performance efficiency rate of each operator was shown in Fig. 6. It illustrated the average of performance rates and the monthly performance rates. The target performance rate is 80%. The average of performance rates was calculated to summarize the performance efficiency rate of each operator. The operator who has the highest performance, the result illustrated at the top of the chart.

The monthly performance rates showed the performance efficiency rate of each operator. During January to September 2021, it was time period before productivity improvement. It presented that the performance efficiency rate of each operator was inconstancy. During October to December 2021, it was time period after improving the standardized work of the PCBA hand soldering process. It presented that the performance efficiency rate of all operators tended to continuously increase. Moreover, the standardized work of the PCBA hand soldering process helped Operator A and B to perform nearly to Operator C.

Table 1: The Work Sequence of The PCBA Hand Soldering Process

BEFORE – Operator A		
TOTAL TIME (sec/unit)	946	
Process	Item(s)	Qty
Prepare material for Subassembly No. 1		
Subassembly No.1 (I +S+T)	T + L	2
	Y	1
	IC	1
	C	1
	PW	1
Clean PCB Front Side		
Prepare material for Subassembly No. 2		
Subassembly No.2 (I +S+T)	LED	10
	SW	5
Prepare material for Subassembly No. 3,4		
Subassembly No.3 (I +S+T)	DP	4
	C	1
Subassembly No.4 (I +S+T)	Z	1
Clean PCB Front and Back Side		

BEFORE – Operator B		
TOTAL TIME (sec/unit)	831	
Process	Item(s)	Qty
Prepare material for Subassembly No. 1		
Subassembly No.1 (I +S+T)	T	1
	L	1
	Y	1
	IC	1
	C	1
	PW	1
Prepare material for Subassembly No. 2		
Subassembly No.2 (I +S+T)	LED	10
	SW	5
	DP	4
	Z	1
	C	1
Clean PCB Front and Back Side		

BEFORE – Operator C				
TOTAL TIME (sec/unit)	755			
Process	Item(s)	Qty	ECRS	Criteria
Prepare material for Subassembly No. 1			C	-
Subassembly No.1 (I +S+T)	T + L + Y	3	-	a
	IC	1	-	b
	C	1	C	c
	PW	1	-	b
	C	1	C	c
Clean PCB Front Side			C	-
Prepare material for Subassembly No. 2-3			C	-
Subassembly No.2 (I +S+T)	LED	10	-	c
	SW	5	-	c
	DP	4	-	c
Clean PCB Back Side			C	-
Subassembly No.3 (I +S+T)	Z	1	-	e

AFTER – Standardized Work			
TOTAL TIME (sec/unit)	724		
Process	Item(s)	Qty	Cycle time (sec)
Prepare material for Subassembly No. 1-3			63
Subassembly No.1 (I +S+T)	T + L + Y	3	152
	IC	1	
	C	2	
	PW	1	
Subassembly No.2 (I +S+T)	LED	10	426
	SW	5	
	DP	4	
Clean PCB Front and Back Side			68
Subassembly No.3 (I +S+T)	Z	1	15

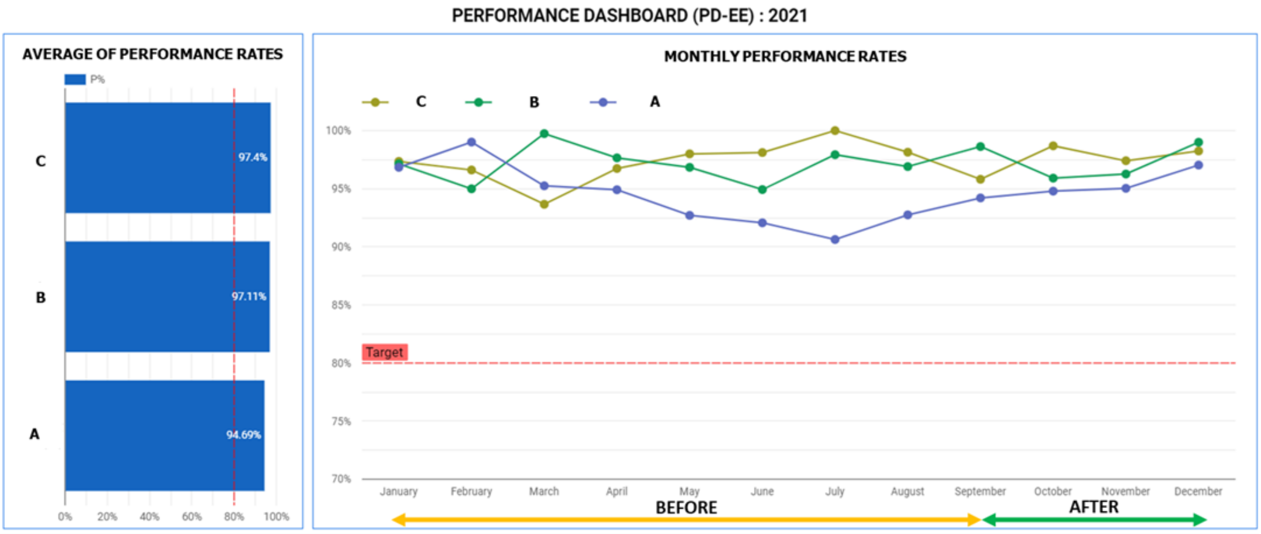

Fig. 6: Performance dashboard

4. Conclusions

This study applied lean manufacturing and information system to improve the productivity of the climate controller manufacturing process. It focused on the PCBA hand soldering process. It was done in 2 phases. First, it created standardized work and determined standard time. The previous work sequence was improved and created the new work sequence by using ECRS and SOP. Five criteria were created to guide the head of operators to standardize the work process. Second, it developed the performance dashboard. Google sheets were used to collect the production data. Google data studio was used to report, monitor, and control the performance of manufacturing processes. OLE was used to measure the performance efficiency rate. The result illustrated that the productivity increased from 132 to 156 units per day. It raised by 18%. The performance efficiency rate of all operators tended to continuously increase. Further work will focus on improving quality, availability, and overall labor effectiveness (OLE) in the PCBA hand soldering process, and developing dashboards for monitoring, controlling, and reporting.

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