Cycle Time Reduction for Coating Process in Manual Assembly Manufacturing Towards Economic Sustainability

Shamini Janasekaran¹, Vijaya Prakash Vijayasree² and Marcus K H Chong¹

¹Centre for Intelligent Manufacturing System, Department of Mechanical Engineering, Faculty of Engineering and Built Environment, SEGi University, Petaling Jaya, Selangor, Malaysia
²Faculty of Environmental studies, Universiti Putra Malaysia, Serdang, Selangor, Malaysia

shaminijanasekaran@segi.edu.my

Abstract. Lean manufacturing has been one of the techniques to eliminate waste in production to increase productivity. Improper usage of cycle time can extend lead-time of delivery for the production and incur more cost than needed. Determining sufficient cycle time is important to ensure the productivity of the each assembly line is within the delivery time span. Improvement of productivity contributes in maintaining sustainable environment that attracts customer and government supports. In this paper, a case study in a manufacturing assembly line was conducted to identify the operator’s motion waste as non-value added activity. As a result, the cycle time was reduced from 60 seconds to 50 seconds in a multiple engaging production activities besides improving the ergonomic posture of the operators. A double four stages rack was designed to reduce the cycle time by 16.7%, which leads to increment of 1000 units of products per month. The rack was built-in together within the assembly process and reduced movement of operators.

1. Introduction
In current era, customers are looking for higher productivity output at shorter lead-time without compensating the quality. Small and medium enterprises are eager to supply their products at short notice of delivery to compete within each other. Only by doing that, the SMEs can sustain for longer period in the business-oriented society. SMEs are slammed with challenges by the rapid changing market requirements where even seconds’ delay can contribute to the losses of business [1]. These SMEs industries are playing huge increasing role in Malaysia economy where they contribute 37.1% in 2017 compared to 36.6% in 2016. Their contribution is remarkable with RM435.1 billion in 2017 to Malaysia's economy with a real gross domestic product growth of 7.2% compared with 5.2% in 2016 [2]. Therefore, continuous improvement also known as kaizen is always been in demand through lean manufacturing. Kaizen activities include elimination of seven waste and 5S activities. These seven wastes include motion, waiting, overproduction, inventory, defects, over processing and transportation, which can be, eliminate by sorting Value Added (VA) activity and Non Value Added (NVA) activity. The NVA waste which is the vital obstacle for VA activity will definitely give customer non-satisfaction with the respective industry [3]. NVA categorized into seven wastes according lean manufacturing practices. They are wastes from overproduction, waiting time, transportation, inventory, over-processing, motion and defects. Despite the extensive knowledge and available lean resources, many SMEs are struggling to stay “lean”. The main intention in lean manufacturing are to reduce waste in human effort and inventory, which able products to reach market on time, while producing quality products in the most efficient and economical manner besides being responsive towards customer query [4]. Modification of current production process with implementation of lean will be...
leading path towards adoption of Industrial Revolution 4.0 (IR 4.0) within shorter lead time [5]. However, besides focusing on IR 4.0, the environment awareness plays high importance to all responsible manufacturers. For global scale, this considered as competitive when their production is aligned and adopted by sustainable techniques such as minimizing number of manufacturing steps. This can be done by employing alternative methods with minimizing energy consumption including human energy and ergonomically stable [6, 7]. The adaption of new techniques is important despite of all the effectiveness in the manufacturing due being instigated by the stakeholders such as customers, policy makers, regulatory authorities and society [8].

In this case study, motion of workers to turn at improper position has impact on the cycle time which can be categorized as NVA. Simplification of movement surely reduces the motion waste. From the previous research done by others [9-11], waste in production has been highlighted but specific studies on motion related to ergonomics and sustainability has yet to be conducted and presented clearly. Therefore, this research would propose one of the optimum designs of coating rack that improves the ergonomic motion of operators in aid to improve the productivity and reduction of cycle time for a particular process which leads to reduction of lead time overall.

2. Experimental Procedure

Conformal coating process is one of the essential processes in completion of loaded printed circuit board (PCB) in most of the manufacturing practice. Coating process eliminates the possibilities of the electronics components’ lead pin from touching unnecessary printed copper circuit lines on the loaded boards. This process cycle time is counted from the time the PCB taken from conveyor until it is laid again on conveyor after the coating and drying process complete. For this particular model, the longest process was coating and needs four operators to work simultaneously to get cycle time for 60 seconds.

Total time given was 240 seconds (this study was done separately using tact time studies adding each steps from taking the PCB to start to work on until it is placed back on the conveyor) even though the total value added activity only needs 190 seconds. This is because 50 seconds needed for the operators’ movement such as bending to take the uncoated PCB from the rack, which is placed beside the conveyor.

Coating liquid is applied in bidirectional at the bottom of each PCB as shown in Figure 1.

![Figure 1. Bi-directional coating orientation on bottom of PCB that takes 240 sec to complete](image)

Figure 2 shows the possible bending of 90° to 145° for every PCB. Eight PCB were kept on the waiting rack beside the conveyor at the left position of the operator. First, the operator needs to take the PCB, coat the bottom layer of PCB with adhesive liquid, and place it back on the rack for it to dry before sending it on the conveyor for next process. The repetitive movement distress the working ergonomic posture and tend to increase fatigue in the operator which can lead to poor performance and errors [12]. The most common error detected was placing not fully dried PCB on the conveyor, which will be categorized as defects if the coating is sticky for the next process. Previous studies had shown ergonomic issues can produce poor quality assembled products and defects to customers [13, 14].
3. Results and Discussion

3.1 Implementation of new coating rack

In this specific study, fixing the stages of PCB rack beside the coating chamber throughout the operation had reduced the motion involved. The ergonomically studied motion had reduced the cycle time to 50 seconds which overall increases the productivity. Figure 3 shows the best rack design obtained to reduce the operators’ movement for every PCB. In this proposal, operators need to turn slight (approximately $20^\circ$) left and right each time to grab a PCB to do the coating process. The operator takes uncoated PCB from left and proceeds for coating within 190 seconds and place the PCB at the right side of the coating rack for drying. Once it has dried, the operator placed it back to the conveyor for next process. The total process had reduced to the cycle time for the whole lot by 10 seconds from the time observation study. Initial rack position consumed operator 50 seconds to take and return the PCB meanwhile with new rack design, 40 seconds were reduced, which is 80% time reduction.
3.2 Improvement in productivity

The implementation of new coating rack has reduced the cycle time for the whole lot that can be calculated as shown in Equation 1-4. A lot of 5000 units of PCB were considered for one week production. The existing required cycle time (tact time) is 60 seconds which reduced to 50 seconds after implementation of 4 stages coating rack.

\[
\text{Time taken to produce number of } \frac{PCB}{\text{week}} = y \times \text{tact time}
\]  

From Eq 1, time taken for 5000 PCB was previously 300000 seconds and reduced to 250000 seconds per week. Considering the increment of PCB using same 300000 seconds per week will produce 6000 units (additional of 1000 units) using Equation 2.

\[
\text{New PCB units} = \frac{\text{Time taken to produce y PCB previously}}{\text{new tact time}}
\]  

The coating rack improvement has increased the productivity of the coating process by 1000 units, which can be converted into cost savings within the same period as shown in Equation 3.

\[
\text{Profit} = \text{cost per unit} \times \text{additional units}
\]

\[
\text{Cycle time reduction} = \frac{300000 - 250000}{300000} \times 100\% = 16.7\%
\]  

The detailed results have been tabulated in Table 1.

**Table 1.** Detailed results obtained before and after implementation of double four stages rack for coating process

| Details                               | Implementation of coating rack |
|---------------------------------------|-------------------------------|
|                                       | Before | After |
| Lead time for 4 PCBs coating (seconds)| 240    | 200   |
| PCB coated weekly (pieces)            | 5000   | 6000  |
| Cycle time for whole production line for each output (seconds) | 60     | 50    |
4. Conclusion
From this case study, following can be concluded:
a) Productivity had increased by 1000 units of product per month after elimination of non-value added activity such as motion.
b) The cycle time of the coating process workstation was reduced by 16.7% after implementation of double 4 stages rack.
c) Motion of operators during production can be manipulated to reduce the ergonomics discomfort such as repetitive bending and turning with 80% of NVA has been reduced.
d) Minimizing operators’ movement has proved manufacturers’ commitment towards economy sustainability.

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