Integration of Lean Six Sigma and Automation for Process Optimization in Surface Mount Technology (SMT) Assembly Line

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Abstract — This project was conducted in an Electronic Manufacturing Company that manufactures motor speed controllers for battery-powered and electric vehicles for airport, golf, material handling, and medical mobility companies around the United States and international countries. These motor speed controllers are composed of an assembled electronic circuit on several printed circuit boards (PCBs). One of the technologies used to assemble the electronic circuit is Surface Mount Technology (SMT). Applying Lean Six Sigma techniques, it is intended to optimize the process by decreasing cycle time and increase production rate by 50% by introducing a new automated machine onto a Surface Mount Technology line. New Automated Panasonic NPM-W Pick and Place Machine was implemented on Summer 2012 for process optimization and production performance improvement enhancing the surface mount devices placement throughput.

Key Terms — *Automation, Cycle Time Reduction, Process Optimization, Surface Mount Technology*

INTRODUCTION

Electric-powered vehicles today make it possible to generate less pollution than gasoline-powered vehicles, so they are an environmentally friendly alternative to the society.

An electric vehicle includes a motor speed controller, which generates a magnetic field and a battery pack that feed electricity to the motor. Although both powered alternatives provide the same effect in society: "transportation"; both powered alternatives use very different technologies.

The nature of electric motor speed controller begins in Surface Mount Technology (SMT) lines, platted Through-Hole Technology (THT) lines, or both. It is a concern how we can optimize the process so that they can meet the company's expectations.

In the electronic industries, unless both technologies can be used on the same board, Surface Mount Technology has replaced the Through-Hole Technology due to the smaller parts placed at the top/bottom board surface(s) using less space than a wire-leaded component.

Before implementing any alternative, it is good to review the SMT process. SMT process inputs consist in process design, printing (solder paste), placement (Pick and Place Machine), reflow oven (thermal profile), PCBs (design), solder paste (Sn62Pb36Ag2), and parts. We can control process design, printing, placement, and reflow oven. Due to high volume production, our major offender is the slowness on Pick and Place Machine combining Surface Mount Technology assembly line design. If the new Panasonic NPM-W is programmed ideally, and if we apply Lean tools to SMT process appropriately, the reduction in cycle time will improve the manufacturing productivity, impacting the company's expectative.

RESEARCH OBJECTIVES

The main objective of this project is to apply Lean Six Sigma techniques in Surface Mount Technology line by focusing on meeting our customers' demands on Product A and Product B, and to gain their full satisfaction keeping in mind that Product A and Product B provided to them has the highest quality.

Background Information

Design project was conducted in an Electronic Manufacturing Company located in Carolina, Puerto Rico. One of the main concerns the Company is facing about one year ago is the high customers' demand and not getting the desired results that the company has to comply with production expectations to be processed daily due to lack of top equipment engage with it. Most of these concerns refer to Surface Mount Technology production area, which have been encountered to be the main leading area during the printed circuit assembly manufacturing cycles after the product (speed motor controller) leaves the manufacturing site.

In the second half of the 1980s the fastest growing development in the printed circuit industry will be the use of surface-mounted devices [1]. The concept of surface-mounting was created due the need for more densely populated printed circuits.

If we compare surface mount technology and through-hole technology in board's components density, can be placed three times the amount of components than can be placed in platted Through-Hole Technology on the same board area (Figure 1). That saving of space on printed circuit boards (PCBs) makes the conversion from platted through-hole technology to surface technology increase rapidly.

The main differences between Surface Mount Technology assemblies are the methods and processes used to assemble components into PCBs.

Figure 1
Surface Mounted and Plated Through-holes Components

Surface Mount Technology, as the name suggest, refers to the method for constructing electronic circuits in which components are mounted directly onto the surfaces of the printed circuit boards assemblies [2]. Surface mount devices (SMD) are mounted onto the surfaces of the printed circuit board at predetermined locations on prepared solder pads. SMDs can be mounted on either side, side 1(top side) or side 2 (bottom side) or both of the PCB.

Surface Mount Technology has many undisputed advantages and forces behind it in contrast to plated Through-Hole Technology. These advantages are:

- Higher electronic speeds due to shorter delay-times.
- Increased density per area, which increase the possibility of circuitry sophistication
- Fewer external interconnections, which increase reliability
- Lower cost for materials, processes, and labor.

Despite these advantages, Surface Mount Technology has special assembly process requirements to attend. At difference to plated through-holes components that are mechanically fastened whereas the surface mount devices are merely placed into or, in some cases, onto the solder paste; therefore handling of the product is much more critical to prevent component movement and misalignment [1]. In the industry, it has replaced the plated through-hole technology construction method of fitting components with wire leads into plated through-holes (PTH) in the printed circuit boards.

Surface Mount Technology Process Flow Line

Surface Mount Technology is more profitable for large manufacturers. It gives them higher devices capability and it's streamlined to fit right into an automated assembly. Basically, Surface Mount Technology process is a complex situation; their implementation is not simple. Surface Mount process involves three manufacturing steps: solder paste printing, component placement system, and solder reflow operation (Figure 2). Other two activities were involved; one during the manufacturing step and other one after manufacturing steps were done. These activities are visual inspection once the PCB leave the component placement system, and QA visual inspection once the PCB leave the solder reflow operation. Each of the three manufacturing steps of the surface mount assembly process must be complementary to each other for yield and manufacturability certification [2].

- **Solder Paste Printing** - This technique is performed by an automated machine (screen printer), where an attached stencil in which the board's pads design are imposed on a fine stainless steel foil, and solder paste is transfer into the foil openings by a squeegee and onto the printing surface during the squeegee stroke. The key factors for good quality on Solder Paste Printing Step are parameter setting and support setup [3].
- **Component Placement System** - Commonly known as pick and place machine, consist of one or more automated machine used to place SMD onto a loading PCB once it has solder paste applied to its respective pads. The operation involves a conveyor belt, nozzle combination, component feeds and vision inspection system.
    - Conveyor belt - A transporter belt is attached through the middle of the machine, where along it traveling a printed circuit board. That PCB is clamped by a sensor signal detected.
    - Nozzle combination – A nozzle is a small device designed to picks up SMD. Various sizes and shapes of nozzles support various chips. Advances pick and place machine allows to programming the use of multiple nozzles to decrease the distance to travel between each component due the composition of different heads (16-nozzle heads, 8-nozzle heads, 6-nozzle head , and 3-nozzle heads) that works independently each other to further increase the throughput.
    - Component feeds - SMD are supplied on paper or plastic tape reels that are loaded onto feeders mounted to the machine. Once the nozzle picks up a component through vacuum pressure, the feeder feeds to a new component automatically allow the nozzle to pick another component from the same tape reel.
    - Vision inspection system - Once the PCB is inside the machine; nozzle carried out SMD from it respective feeders, the machine turns to recognize two or three fiducials marks (circuit pattern recognition marks used as a reference to allow all automated assembly equipment to accurately locate and place the components pattern onto the PCB [4]), depending on how it was programmed, on the PCB to measure it position accurately with a camera system mounted in the heads, for them begin the placement process on their respected position.

  The key factor for good quality on Placement Step is the accuracy of part placement in the centroid of their respective designed pad [3].
- **Solder Reflow Operation** - This process consist in introduce the PCB through an oven to reflow solder making a good joint between the SMDs and solder paste. The solder paste is a powdered metal suspended in flux. Solder paste is heated between a temperature increment; flux separates and flows to metal and beyond metal surfaces, creating a barrier to prevent oxides from reforming; then, metal goes to liquidous and wetting is achieved though capillary flow. Inside oven, PCB moves on a chain conveyor passing through multiple heating zones (130°C - 255°C) and a two cooling zones (75°C - 30°C). The key factor for a good quality on Solder Reflow Operation Step is the thermal profile. Depending on what solder paste alloy were used, depends the correct thermal profile in order to accomplish

with the temperatures specification required for solder paste, flux evaporation and each SMD. The key factors that will be observed during a thermal profile are ramping speed, peak temperature and time above liquidius (eutectic point) [3].

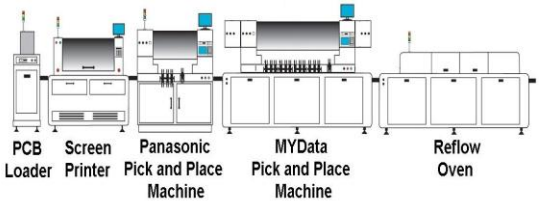

Figure 2
Surface Mount Technology Process Flow Line

Most of the PCBs assembled in Surface Mount Technology line are power boards (transfer power from the power source to the motor that ultimate propels the traction drive), logic boards (provides electrical connections for communication), and insulated metal substrate power base boards (provides superior heat transfer for increased reliability), which are used later on a final integration assembly line to obtain as a final result: a speed motor controller. They offer vehicle developers a highly cost-effective combination of power, performance, and functionality.

To focus on the problem being presented in this project, it is necessary to fully define the existent component placement system. Our SMT line consists of two different component placement system machines: a Panasonic CM202 Machine, and a MYData TP11 Machine. Let focus on the Panasonic CM202 Machine.

High Modular Speed SMD Placement Machine CM202, Model No.KXF-E24C (Figure 3) has four transfer heads, which transfer chips from the feeders to the board. Each head has 6-nozzle holders. Because it has a 6-nozzle head, six chips are scanned and recognizes all together by moving the head so that it will move across the line. The CM202 has two X-Y unit and Z-unit in total; each X-Y unit and Z-unit supports 27 (8 mm) tape width feeders. Using feeders above 8 mm tape width (12 mm, 16 mm, 24 mm, or 42 mm) will vary the amount of feeders per unit side, which affect the cycle time of each board due to the limited number of feeders placed.

Figure 3
Panasonic CM202 Pick and Place Machine

Electronic Manufacturing Company is concerned that the Panasonic CM202 machine works excellent but does not meet the company's expectations. Daily production numbers are under expectative due a high variety demand of increasingly Product X and Product Y, which is evident in the increased efforts to introduce a faster machine or another automated pick and place machine connected in series with the existing pick and place machine.

A pick and place machine is very expensive (US$300,000 to US$1,000,000) and yet the SMT assembly lines are typically designed such that the pick and place machine is the limiting resource or "bottleneck", which is the key issue for assembly line optimization. Since there are various types of pick and place machines, all which have characteristic and restrictions, the component pick and place scheduling is highly influenced by the SMD placement machine being used [5]. Company decided to focus on a high speed and multi-head machine.

Panasonic Factory Solutions Co. of America provide to the public one of its most prized products, the NPM-W. The NPM is part of Panasonic's award-winning NPM platform for expanding and evolving electronic assembly needs. Processing large board sizes and components while accommodating up to 120 feeder inputs make the NPM-W especially beneficial for high mix manufacturing. Additionally, the numerous available placement head combinations and supply methods make it versatile to any SMT manufacturing line – regardless of board sizes. Progressive changeover, gang nozzle exchange and feeder anywhere allow for near zero loss changeovers [6].

NPM-W Machine General Description

The NPM platform provides lean production and maximum productivity. Features and benefits most prove that this machine is able to carry out a production efficiently due to its advance technology. These features and benefits are divided into:

- ***High Productivity***
  Due the installation of new-style heads and new-style line cameras, and the development of high-speed multi-Head provide high-speed placement.
- ***Versatility***
  Combine the "16-nozzle Head", suitable for super-high speed placement of microchips.
  Combine the "8-nozzle Head", suitable for high speed placement of microchips to medium-size components such as capacitors, connectors, inductors and FET (field-effective transistors).
- ***Efficient Changeover***
  A multi-job production, meaning that only one time preparation enables productions of great many models, is supported. Also, the preparation for next models is possible while the machine is operating, and also an offline preparation can be performed.
- ***High-Quality Placement***
  Components are placed at high speed and high precision, through the newly developed recognition system, calibration feature, and high speed low vibration control.

RESEARCH METHODOLOGY

The methodology which will be followed is the principle of lean techniques and the acronym DMAIC Methodology, which stands for Define, Measure, Analyze, Improve, Control. Continuous flow and Kaizen are Lean Manufacturing techniques with the main goal of getting a production line optimally balanced with a little waste and an on-time production, increasing productivity by controlling manufacturing processes. DMAIC forms the five major phases of any Six Sigma project.

Lean manufacturing focuses on eliminating waste or non-value added activities in the process. Also, it's sought to improve process flow in the value stream focusing on delivering high quality products at the lowest price and at the shorter lead time possible. Lean's basic value proposition is that principles for improving workflow, decreasing setup time, eliminating waste, and conducting preventive maintenance will speed up business processes and return quick financials gains [7].

Six Sigma is a process disciplined methodology for eliminating defects or increase yield in any process. Six Sigma's basic value proposition is that principles for process improvement, statistical methods, a customer focus, attention to processes, and a management system focusing on high-return improvement projects result in continuous improvement and significantly financial gains [7].

Define

A project charter was proposed with the intention of understood the internal customer requirements establishing a project goal, and clear expectations keeping focus on the process optimization of the Surface Mount Technology assembly line.

Project Description

The purpose is to optimize the SMT assembly line of an Electronic Manufacturing Company (internal customer) that manufactures speed controllers for worldwide distribution.

Scope

The SMT production area consists of three assembly lines. These lines produce PCBs to be used then on final integration assembly lines. Due Product A and Product B are assembled in Line #3, just this line will be considered for the project.

Project Goals and Measures

In order to meet our customers' demands on Product A and Product B providing the highest quality, we consider:

- Reduce cycle time and increase production;
- Achieve a level of zero rejects in PCB's quality;
- Reduce unnecessary resources for the management of the PCBs such as reworking;
- Customers' satisfaction

Expected Business Results

The expected project goal is to optimize the process for:

- Increase production performance to enhance the company's expectative.

Support Required

In order to complement the expected results, we have to identify those points that will help to optimize the process. These points are:

- Revise strategies of maintenance;
- Encourage the investment necessary for process optimization in order to obtain a production rate improvement;
- Include work instruction procedures, policies, processes, infrastructure, and add/cut personnel if needed.

Expected Customer Benefits

Increase production performance while maintaining quality.

A highly level map or SIPOC diagram (Figure 4) is created in order to have a general view of the process. The suppliers and inputs are the following:

- Raw Material Warehouse: Material
- Alpha Metals: Solder paste
- PCB Suppliers: Printed Circuit Boards
- SMT Stocks: Operators
- Engineering: Training and Procedures
- Maintenances Department: Machine and Spare Parts

Any business needs to know the customers' needs and their perception about the product for what they are paying for. Figure 5 translates the Voice of Customer to the Critical to Quality of the process. Having one for the SMT area will help knowing what the customer are looking for, and what their needs and interest are. We take our customer's needs into account, adapting the process to what they expect.

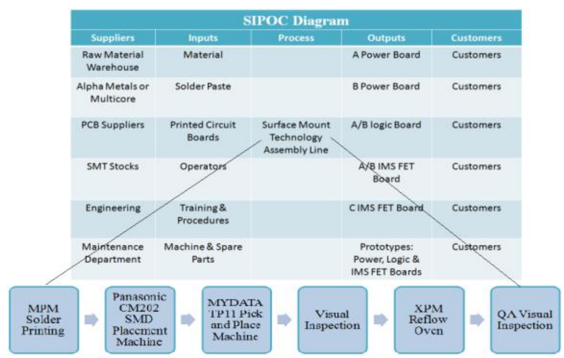

Figure 4
SIPOC Diagram

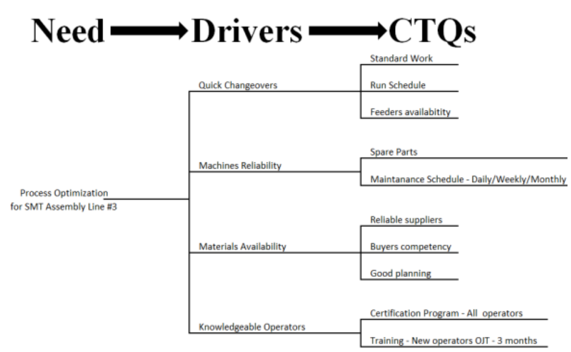

Figure 5
CTQ Tree

Measure

Gathered data on Surface Mount Technology line #3 was evaluated during December, 2011- June 12, 2012 using Panasonic CM202 machine, it is recognized that although the data shows a growth in production on March, 2012, machine capacity is not enough to achieve the planned orders. Gathered data showed in Figure 6 include total printed circuit boards produced during all three shifts including overtime using the Panasonic CM202 machine. These data include all PBs assembled in SMT line #3 to be used later on final integration assembly Product A and Product B (A power board , B power board , A/B logic board, and A/B IMS FET board), and part of Product C (C IMS FET board) lines. Figure 9 shows the layout when the data was gathered.

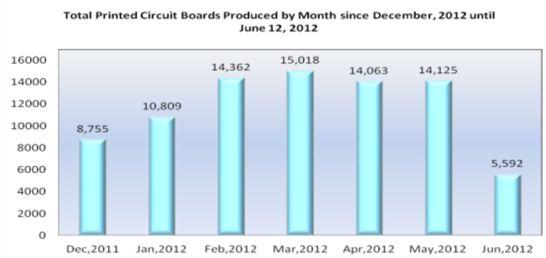

Figure 6

Monthly SMT Production Rate using Panasonic CM202 and MYData TP11 Machines (December, 2011- June 12, 2012)

Data clearly shows that process improvement techniques should be applied for increase the production rate and efficiency of the line. This is:

- Applying lean tools such as Quick Changeover, Kaizen, Continuous Flow, and Standard Work in order to increase production rate in SMT Line #3.

Analyze

In the Analyze phase, a kaizen team was created to determine the causes of the problem that needs improvement. Kaizen focus on people and process standardization. His practice requires a team of production personnel, maintenance technician, quality, engineering, buyers, and other employees that the team consider necessary. It aims to increase productivity by controlling manufacturing processes through: reducing cycle times, standardization of working methods for operation.

In order to analyzed all possible causes that were affecting that the production rate was not achieved, a cause and effect diagram (Figure 7) was completed to highlight opportunities for improvements.

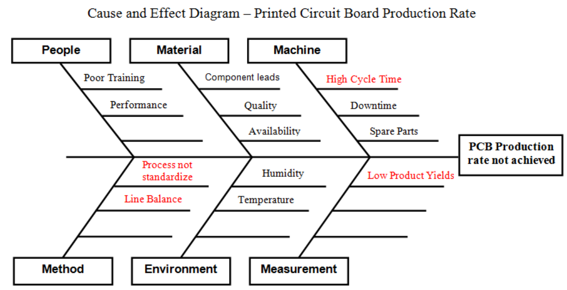

Figure 7

Cause and Effect Diagram

Data contributes to identify that integration of new equipment will be needed to optimize the process in order to reduce the production cycle to achieve a higher throughput. Our major offender was the higher cycle time in the Component Placement System (Panasonic CM202 Machine and MYData TP11 Machine) balancing. During a brainstorming, the team identified other waste throughout the process that will have to take into consideration to increase production rate (Refer to Table 1).

Table 1

Waste and Opportunities for Increase Production Rate and Reduce Setup Downtime

Waste	Opportunities
Waiting	Unnecessary waiting time for materials. When a part is needed to replenish machine, it was observed that sometimes was not available at SMT stock.
Transport	Used reels need to be re-stocked; this takes a lot of the operator time.
Over Processing	Setup steps are not standardizing. A Quick changeover analysis is needed in order to understand wastes in the process.
Motion	No exceeding walking found in the area.
Defect	Yield % data was analyzed since Dec-11. A fluctuation trend was observed. To avoid yield goal dropping machine must be calibrated.
Human Potential	Operator ideas are not properly documented and followed for actions.

Despite we have confronted problems with product quality due to out of pad components, data shows a yield fluctuation; machine must be calibrated due to avoid dropping the product yield goal of 98.5%. See Figure 8.

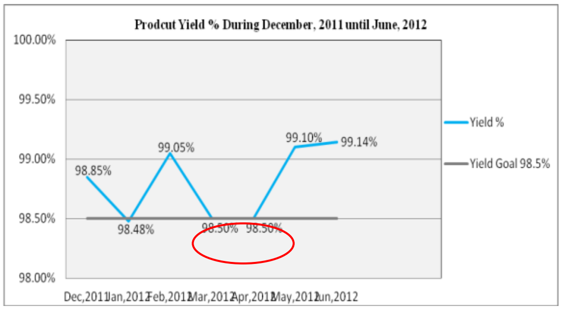

Figure 8

Yield % During December, 2011 until June, 2012 using the Panasonic CM202 Machine and MYData TP11 Machine

After a series of discussions, the team is now focused on addressing the action plan. All action documented are focused on two areas:

- Cycle time reduction
- Process work standardization

Improve

In this phase, we are ready to implement solutions. After brainstorming, the team identified some opportunities that have a positive contribution to carry out in the SMT line #3 to reduce cycle time while contribute on increase production.

Actions implemented during this improve stage are the following:

- New Automated Panasonic NPM-W Pick and Place Machine
- Reduction of setup downtime
- Magazines Setup standardization on MYData TP11 Machine

These actions were implemented after a Re-Layout of the SMT Line#3 (Figure 9). This Re-Layout was planned on April 16, 2012.

After the implemenation of these actions, we can see an improvemnet in cycle time reduction and production rate enhancement. As shown in Figure 10 to Figure 14, bars represent SMDs placement and lines represents cycle time reduction. Two different Y-axis also was deployed on graphs; left side for SMD placed on machines and right side for cycle time in minutes during SMD placed on machines. All products' cycle time were improved but not all were the same for each one. A Power Board cycle time were optimized into 1.35 minutes less enhancing process into a 49 %. B Power Board cycle time were optimized into 2.08 minutes less enhancing process into a 48 %. A/B Logic Board cycle time were optimized into 2.80 minutes less enhancing process into a 58.8 %. A/B IMS FET Board cycle time were optimized into 0.90 minutes less enhancing process into a 46.9 %. C IMS FET Board cycle time were optimized into 0.17 minutes less enhancing process into a 6.4 %.

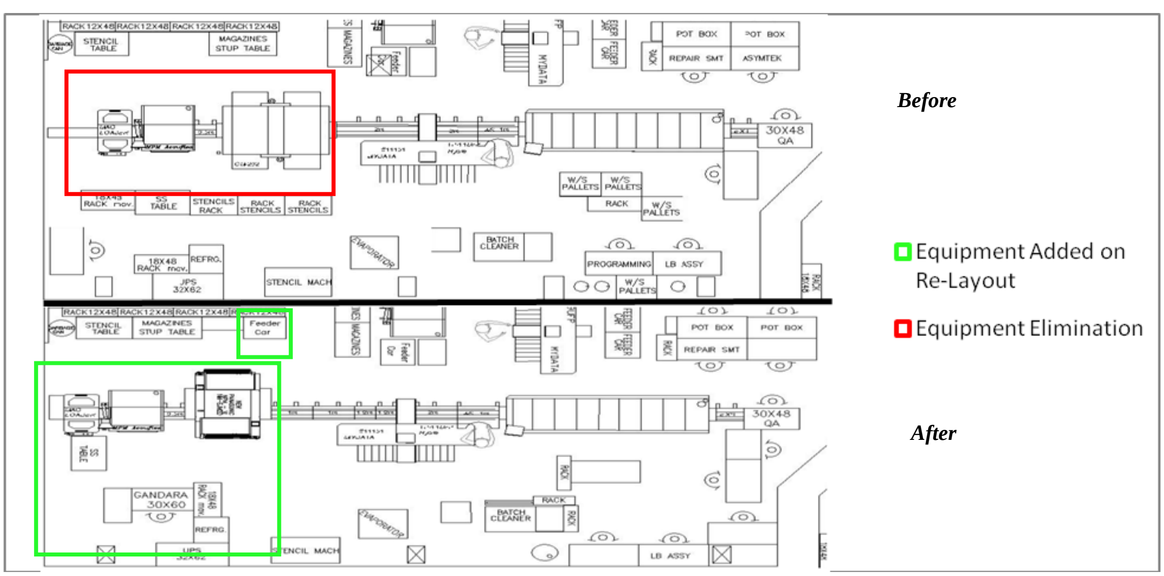

Figure 9

Layout when Panasonic CM202 Pick and Place Machine were on SMT Line #3 & Re-Layout for Integration Panasonic NPM-W Pick and Place Machine on SMT Line #3

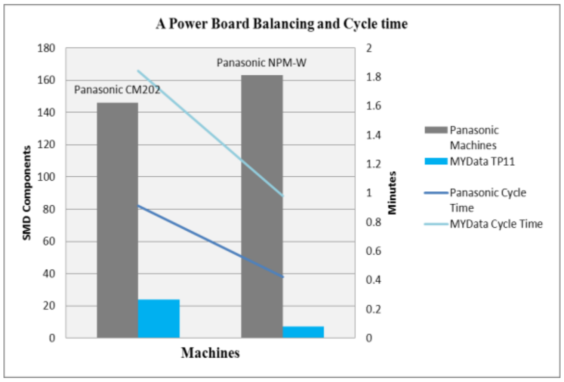

Figure 10
Cycle time reduction on A Power Board integrating new Panasonic NPM-W machine

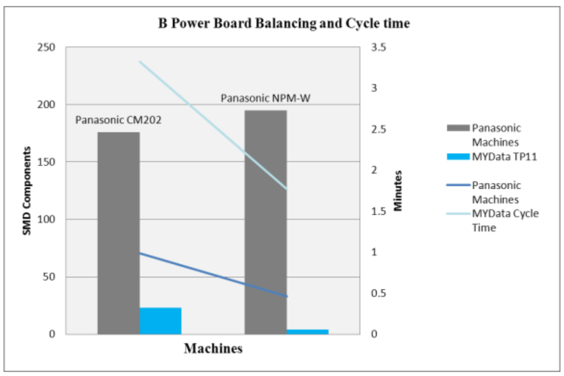

Figure 11
Cycle time reduction on B Power Board integrating new Panasonic NPM-W machine

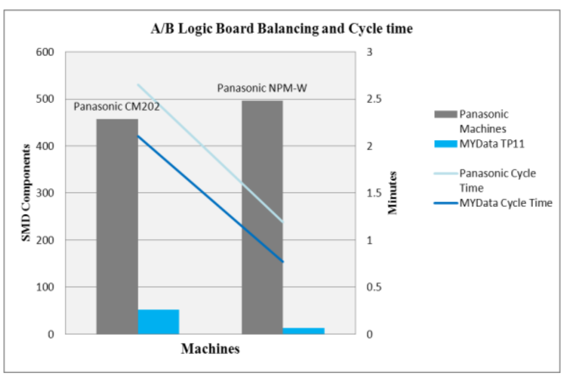

Figure 12
Cycle time reduction on A/B Logic Board integrating new Panasonic NPM-W machine

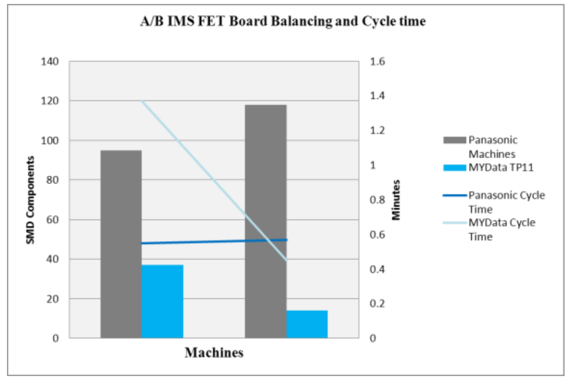

Figure 13
Cycle time reduction on A/B IMS FET Board integrating new Panasonic NPM-W machine

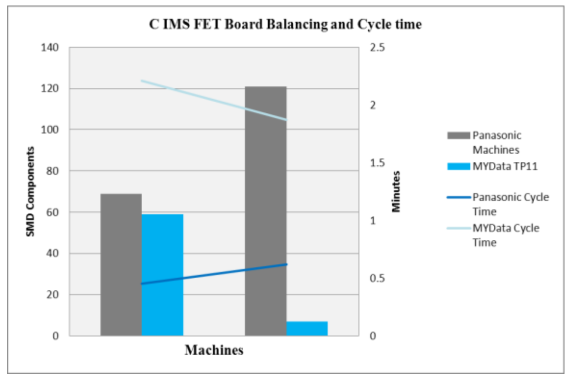

Figure 14
Cycle time reduction on C IMS FET Board integrating new Panasonic NPM-W machine

That improvement represents a 23% enhance in production rate. See Figure 15.

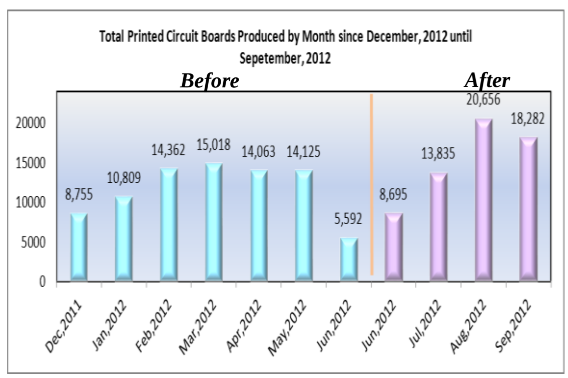

Figure 15
Monthly SMT Production using Panasonic CM202 Pick and Place Machine (December, 2011- September, 2012)

Due the high operating rate through components supplies during operations, a splicing tool system must be integrated. Splicing tool system is used to provide the feeder with a continuous supply (continuous flow) of components without stopping the machine on production process.

Furthermore, adaptation of a SUNSDA SBC-100A 1.5 meters conveyor between MPM200 Screen Printing Machine and automated Panasonic NPM-W Machine was placed to maintain a buffer for continuous flow.

Control

Production keeps running constantly, with the exception of suddenly technical problems or situations where the operator does not realize that a feeder is running out components and it need to stop production to recharge the feeders attached to the Panasonic NPM-W machine with a new tape reel.

Process engineer will monitor production of the products for the remainder of the engagement to ensure performance sustainability of the entire Panasonic equipments during production schedule.

Conclusions

In accordance with the objectives, enhance the production rate by 50%, and reduce process cycle time in minutes that takes to assembly a PCB in SMT line #3. These two aspects were completed and accomplished with the implementation of new automated Panasonic NPM-W Machine at Surface Mount Technology (SMT) line #3 applying Lean Six Sigma tools. The impact to the original scope must be clearly identified but needs some improvements.

Applying the DMAIC methodology to any non-conformed problem confronted in any aspect that affect a company's process and final product, you have the opportunity to go through an organize process using different tools for the finding of the solutions.

The main objective was to meet our customers' demand increasing the production rate by 50% but total increased production rate obtained was 23%. Our main goal was not completed as expected.

Otherwise, a cycle time reduction was seeing on the SMD placement machines; cycle time reduction is among 46% and 59%. In order to fulfill our main goal we are going to optimize product recipes on Panasonic NPM-W machine.

Future Projects

Although we did not reach our main goal, a great improvement was seen. For this reason, another innovative technology leaded from Panasonic NPM platform machine must be implemented in the SMT line #3 in a near future.

For now, we will focus in introducing a Component Verification Tool (CVT), which indicates to the operator when a component is running out. Thus, the operator will feel more comfortable to know when to do splicing. CVT and Panasonic NPM-W will be submitted to budget.

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