Improvements of Quality in SMT line through Overall Equipment Effectiveness

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Abstract

In the 21st century, everything is improving faster, and manufacturing sectors are not excluded. Technological advancements have exponentially improved the manufacturing sector in the past three decades and have also advanced in increasing the quality of products produced in a manufacturing industry. TPM, one of the most famous and used methodologies founded by Seiichi Nakajima has a quantitative tool called Overall Equipment Effectiveness (OEE), which gives the quantification of an industry's Total Productive efficiency. The electronics sector is a growing sector in India and this paper is an attempt to deliver a case study on the Improvement of OEE in an SMT line. In this case study, several quality tools from Lean Manufacturing have been integrated and incorporated for the OEE improvement. OEE data has been assumed from various articles on the Semi-conductor industry. The tools like VSM, Fishbone Analysis, FMEA are used to identify the main slow-down process and then the paper discusses the various methodologies that can be adopted for this specific SMT line so that the result would be an improvement in OEE.

Keywords. Total Productive Maintenance, Overall Equipment Effectiveness, Surface Mount Technology, Value-Stream Mapping, Fishbone analysis, Process-failure mode analysis.

1. INTRODUCTION

The rise of the industrial revolution in the 19th century and early 20th century led to technological advancements in the electronics sector and the growth of the global economy. European countries, Japanese, and many other countries were improving to be the industrialized nation and as a result, the technology saw a rapid advancement. The First World War adversely affected many countries, and they were forced to adopt different methodologies to be more efficient. The lean Manufacturing model from the Toyota Production System in 1930 gave a new insight into discrete manufacturing. This Lean Manufacturing focussed on eliminating wastages, speeder production, and cost-effectiveness. Later in the 1950s the Father of the Total Production System Seiichi Nakajima devised a quantitative measure to standardize the production efficiency called OEE i.e., Overall Equipment Effectiveness. OEE is a small part and a lean tool of this Lean manufacturing which deals with the equipment effectiveness, it takes the most common sources of manufacturing which gives us a measure to calculate the efficiency the manufacturing process. The three categories are Availability, Performance and Quality. Since the 1950s OEE has evolved in many ways for various kinds of manufacturing sectors. OEE consists of three attributes Availability, Performance, and quality. OEE is the product of all these three values. Nakajima also states that the losses while calculation of OEE can be grouped into six big losses which further helps us to classify the losses.

In the past two decades, Electronics Manufacturing Sector has been growing exponentially all over the world and countries like India which has a growing number of skilled workforces is a perfect place for this industry. Printed Circuit Boards are the building blocks of an electronic component, and these PCBs are manufactured using Surface Mount Technology. Developing VSM from the data gathered and identifying the bottleneck manufactured using Surface Mount Technology. Improvement of OEE[8] of SMT line is a continuous improvement strategy and This paper is a case study on the Linear Surface Mount Technology line. Single-sided PCBs are taken into consideration, so that model can follow a linear path and single workflow.

2. METHODOLOGY

Basic area to focus in improving OEE is to look after the major losses i.e., breakdown**,** setups and adjustment, small stops**,** reduced speed**,** startup rejects, production rejects and try to reduce it**.** This case study focusses on how to improve the OEE by focussing on the quality attribute and availability of the equipment unlike only on availability as discussed in [9], The prime objective of this study is to analyse the process flow of the SMT line, and to apply the quality tools over the gathered data about SMT line and finding out the bottleneck. Integration of quality tools like FMEA as mentioned in [7] and identification of appropriate methodologies for OEE improvement is the secondary goal is to be achieved. The proposed framework of the adopted methodology for the same is shown in Figure 1.

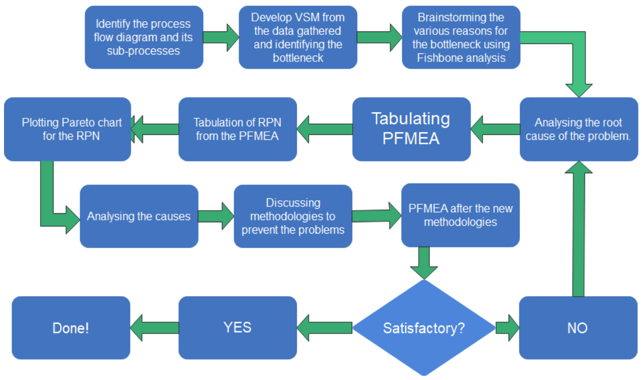


Figure 1. Methodology for this case study

The process workflow Figure 2 formulated in this paper is primarily focused on the linear model. The SMT line usually starts from the arrival of components, solder paste and other products to the warehouse, then it follows the major value-added processes and then unloading occurs which then proceeds for logistics or other processes depending upon the, if it is an automotive electronics manufacturer, it proceeds for ICEF testing processes. This paper has considered standard sized PCBs and the simple major value-added processes to the PCB boards. The machinery is arranged in a linear manner and connected to each other via conveyor belt.

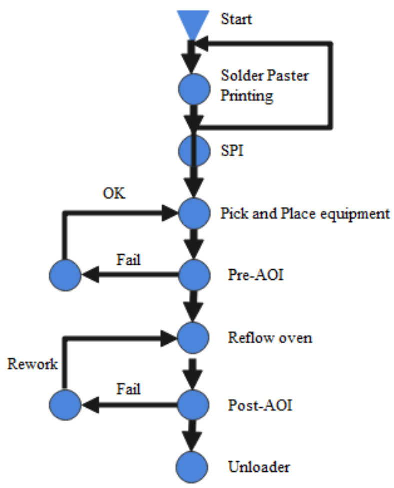


Figure 2. Process flow in considered SMT line

The Process workflow considered in this paper:

1. The Surface Mount Technology process starts from the loading of PCBs onto the loader, the worker loads the plain PCBs on to the UD/LD loader, which proceeds to push the PCBs onto conveyor belt.
2. This takes the boards to their first value-added process where the automated solder paste printer prints the solder paste. The PCB is placed under a Stencil and a squeegee moves left to right printing the Solder paste onto the board. This printing involves loading the raw solder paste in liquid or solid state into the machinery prior to the start of the processes, this involves different methods depending upon the industries.
3. After this printing process the conveyor belt takes this board to Solder Paste Inspection, this inspection is usually automatic because it saves a lot of time, and this machine can detect whether the print is applied or not but cannot detect the quality of the solder printing. If any fault is detected in the SPI the defective parts is excluded and sent to the buffer, it may be a vertical or horizontal buffer depending on the industry. The defective boards are then corrected and then set back in the conveyor belt.
4. The Board then passes to the major value adding process i.e., Chip mounting machinery or pick and place equipment. The considered environment is high-mix low volume, so this process is very crucial in the Surface Mount Technology line. Components like chips, resistors are loaded to the machine and this loading process is considered in downtime. The automated pick and place fit the components onto the board where the solder paste is printed.
5. After the chip mounting process, the board passes through the Automated Optical Inspection before entering the reflow oven, x-ray inspectors are used for this inspection. The Pre-AOI is placed right before the reflow oven to detect any missing part. This equipment is very essential in the entire process because once the fault is not detected before a board enters a reflow oven, rework cannot be done over the board and eventually the defective board will be discarded. I have considered an automated OI.
6. After this inspection the board enters the reflow oven, I have considered 8-layer reflow oven and a linear flow. The incomplete board then passes over the solder paste enters the reflow oven and gets heated up and the soldering is done.
7. When the board exits the oven, it is subjected to cooling or other trivial processes depending upon the manufacturers, but I have made a simple SMT line so, the board goes through the post-AOI which is the final process of my considered SMT line, Here the board is checked for every aspect. Same as the pre-AOI equipment, if any detect is found, it is sent to the buffer and the rework is done. Then the board are unloaded from the conveyor belt.

2.1 Developing VSM

Value stream mapping is a lean management tools which provides the big picture of the entire process. The conventional usage of this tool is by creating a current VSM, analysing the causes, implement new methodologies and implement future VSM. In this paper, two to three quality tools have been integrated for improvement of OEE. VSM helps visualise the entire process and quickly discover in which way it may go wrong and gives an idea for improvement. Data has been gathered for SMT line from [5] by Amir Azizia and Thulasi a/p Manoharan which was based on a PCB manufacturer in Malaysia and from other sources to implement the VSM. This

Data has been checked properly and considered after some recommended changes. The data has been displayed in the Table 1.

Table 1. VSM data for the considered line.

Process name	Solder Print	SPI	Chip mounter	Pre-AOI	Reflow oven	Post-AOI
Manual Cycle time	55.8	6	0	34	0	62.5
Machine cycle time	5	14	48	6	20	7.5
Changeover time	65	0	0	0	105	0
Batch size	300	300	300	300	300	300
Effective cycle time	61	20	48	40	20	70
Available time	50400	50400	50400	50400	50400	50400

2.2 Analysis of VSM

It indicates a main point that Manual Cycle time for post-Automated Optical Inspection is more than a minute for single board. The VSM has been attached as *Figure 3*. This is due to the importance of quality of the soldering. If the AOI detects any quality degradation it sends it to the buffer and a worker checks any rework is possible or else the board is discarded. So, the important reason for this rejection and increasing manual cycle time is Improper soldering in Reflow oven.

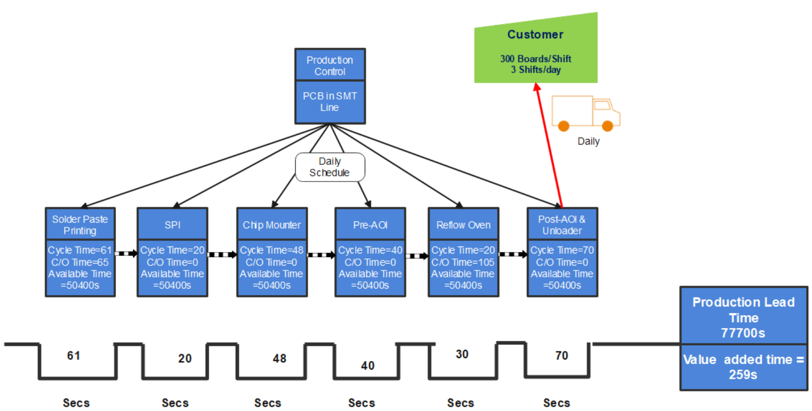


Figure 3. Current VSM for the considered line

2.3 Fishbone diagram and its analysis

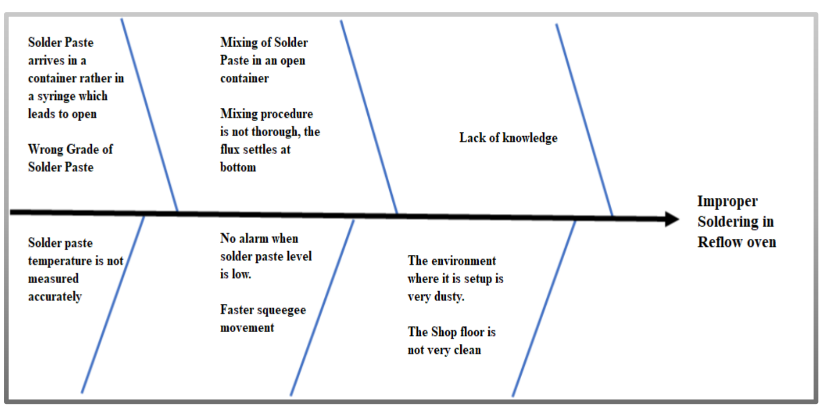
Figure 4. Fishbone analysis over the bottleneck

Fishbone analysis is a lean management tool and used to take all the causes for the main problem. The main purpose of this tool is to quickly factor out the major causes for the problem. The main effect should be discussed and clearly stated out.[8] The main effect is written at the right edge of the paper or sheet; a line is drawn from the effect in the middle and branches are drawn out of the line to factor out the causes. This resembles a fishbone with the main effect as the head. Hence it is also called as Fishbone analysis. The Fishbone analysis has been attached as *Figure 4*. Improper soldering from VSM has given us the main area to focus and it is a solid effect to be focussed on.

2.4 PFMEA

Failure mode effective analysis is a lean tool which quantifies the risk involved in a process or components [15] . Process-FMEA is formulated here because this tool helps identify the errors precisely and provides with a solution for that. This tool also helps to eliminate the unwanted processes in a manufacturing line. From the fishbone analysis the causes for the effects are known now PFMEA can be performed on the main value-added processes in SMT line to sort them out based on their stages. PFMEA is quantified by three attributes *Severity*, *Occurrence and Detection*. Product of these attributes gives us the Risk Priority Number. The limit set to RPN varies across manufacturing sectors. The Scale for the quantification of Severity, Occurrence and the detection varies across industries. The considered Scale here is designed by considering data from various sources.

Table 2. PFMEA over Solder paste printing



Process/Product

Potential Failure Modes and Effects Analysis

(FMEA)

Process or Product Name:	PCB						**Prepared by:**	Bharath									
Responsible:	Process Engineer						**FMEA Date:**	**(Orig.)**1/06/21	**(Rev.)** 10/08/21					**Page**		**of**	
Process Step/Input	**Potential Failure Mode**	**Effect**	**Potential Failure Effects**		**Potential Causes**		**Current Controls** **Prevent**	**Detect**			**Actions Recommended**	**Responsible**	**Actions Taken**				
What is the process step/input under investigation?	**In what ways does the input go wrong?**	**NP-NEXT PROCESS SP-SUBSEQUENT PROCESS OP-OTHER PROCESS**	**What is the impact on the Output Variables (Customer Requirements) or internal requirements?**		**What causes the input to go wrong?**		**What are the existing controls and procedures (inspection and test) that prevent/detect either the Cause or Failure Mode?**				**What are the actions for reducing the occurrence of the Cause, or improving detection? Should have actions only on high RPN's or easy fixes.**	**Who is responsible for the recommended action?**	**What are the completed actions taken with the recalculated RPN? Be sure to include completion month/year.**				

Solder Paste Printing	Improper attachment of components	NP		8	Low Temperature of the Solder	8	Using Solder Paste after 6 hours taken from refrigerator.	SPI	2	128	Poka yoke for Solder paste temperature and not based on hours	Engineer 03/06/2021	Poka yoke for Solder paste temperature and not based on hours.23/06/21	2	6	6	72
		SP								0							0
		OP	Rejection of Products							0							0
										0							0
										0							0
	Improper attachment of components	NP		5	Improper mixing of Solder paste	6	Stirring the paste before application	SPI	3	90	Employment of Solder Paste centrifuge machine	Engineer 16/06/2021	Employment of Solder Paste centrifuge machine. 30/06/2021	3	3	4	36
		SP								0							0
		OP	Rejection of Products							0							0
										0							0
										0							0
	Improper attachment of	NP		3	Paste stuck in Stencil	5	Replacement of Stencils	SPI	4	60	Usage of frameless stencils	Engineer 05/07/2021[1	Usage of frameless stencils 20/07/2021	3	2	2	12
		SP								0							0

	components	OP	Rejection of Products							0							0
										0							
	Improper attachment of components	NP		3	Faster Printing	2	nil	SPI	7	42	Slower Squeegee action	Engineer 27/07/2021	Slower Squeegee action 10/08/21	1	2	4	8
		SP								0							
		OP	Rejection of Products							0							0

PFMEA is a very tedious process and can be exceptionally long, PFMEA is updated whenever a new methodology is applied and for this case study, this paper has considered what can go wrong in SMT line and a PFMEA is made, a sample of PFMEA done over Solder printing has been attached as table 2. The main deduction from the PFMEA is the RPN. RPN has been segregated for three main Value-added processes in table 3 and pareto chart has been plotted for that in Figure 5.

Table 3. Compilation of RPN from PFMEA

Effect	RPN	Cumulative Percentage	Percentage
Sol.Print	320	38	38
Chip.Mt	288	72	34
Reflow Soldering	232	100	28

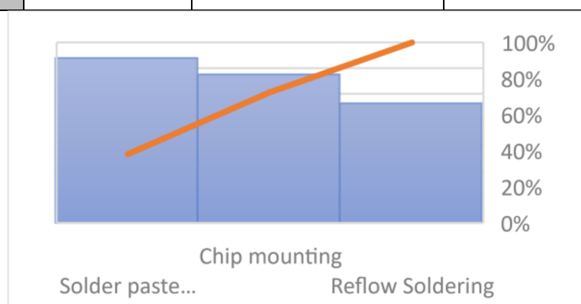


Figure 5 Pareto chart of RPN.

2.5 Pareto Chart

This Pareto is also a lean tool, and it is because 80 percent of disruption in a manufacturing line is caused by 20 percent of the process and the remaining 20 percent disruption is caused by 80 percent of the line. This helps to identify the main area to focus on terms of quantified risks. Pareto chart is combination of bar graph and a line graph. In this case the RPN for each process is plotted in bar graph and their cumulative percentages are plotted as the line graph.

3. RESULTS AND DISCUSSION

3.1 Quality

From the above performed quality tools it can be deduced, which area should be focused. PFMEA performed after this analysis quantified and allowed to visualize the various effects and their causes. The Pareto analysis clearly indicates where to focus the most and it is the pre soldering process followed by chip mounting process Following are the main factors:

Table 4: Methodologies for quality aspects

Problems	Methodologies	Implementation goals
Using Solder Paste after 6 hours.	Implementing poka-yoke [18] for the solder printing process.	Poka-yoke for Solder paste temperature.
Stirring the paste before application	Employment of Solder Paste Centrifuge machine.	This ensures the proper mixing of solder paste without any synthetic errors.
Paste stuck in Stencil, thickness of the stencil	Usage of frameless stencils	This is cheap and allows the operator to replace it without any hinderance.
Faster printing and Squeegee angle	Slowing done the action.	This ensures the proper solder printing.
Excess or Low solder paste volume	Employment of ML algorithms [16] to study the effect of temperature and volume of solder paste on the soldering process.	This has been proved to be a good methodology to identify the good solder paster type and their temperature operating window.

- Low temperature of the solder[4], improper mixing of solder paste, paste stuck in Stencil, thickness of the stencil, damaged stencil faster printing, squeegee angle, Wrong cleaning fluid in the printer,
- Oxidation of the solder paste and faulty heater.

The components are heat sensitive and undergo thermal stress, which causes the damage, should use appropriate mounter tools.

3.2 Availability

The VSM has given the data, and it indicates the availability of the machine. It clearly indicates the set-up time, break down considering change over time during solder paste printing and Reflow oven is more and it can be optimized. It can be also observed that all these processes can be made continuous by segregating and performing it as internal and external activities over time. SMED is a lean manufacturing tool, developed by Toyota in 1950s. Which eliminates the unwanted time. Motive of SMED is to reduce the change over time under 10 minutes. This directly reduces the lead time and reduces the idle time. SMED methodology can be applied to the entire process.

In a high-mix low-volume production changeover time is generally higher and it specifically caused during the components loading into the chip mounter. Above mentioned data considers only a single type of PCB board. Change-over time is considered under Down Time loss. We can reduce the change over time by implementing SMED. Two cases with use of DES software and WITNESS simulation over SMT line have been shown in [10]. For Case 1, the only maintenance strategy used is Corrective Maintenance. Hence, the maintenance is performed only when the machine breakdown. The breakdown of machine will cause stoppage to whole production line. As for case 2, PM is introduced to all machines. The maintenance task that should be done during PM and its frequency were decided qualitatively after discussion with the stakeholders. The PM was scheduled to be done daily. The time for adjustment and setup task during PM is 15 minutes.

The result proved that Preventive maintenance was much effective than the corrective maintenance. Though not all machines showed improvement under preventive maintenance the overall availability of the manufacturing line saw a decent increase. This concludes that SMT manufacturing line should adopt Preventive Maintenance strategy.

Preventive maintenance can also be improved by various methods. By installing sensors and a storage we can start gathering data as mentioned in [1] and [2], SMT line can produce rich data within a week giving us the needed information. We can employ machine learning algorithms to analyze the data and predict the model. This can be incorporated with Preventive maintenance strategies.

Table 5 Methodologies for availability aspects

Methodologies	Implementation goals
Labelling components (RFID)	We can reduce the time utilized for component search
Changing Warehouse layout to accommodate the above said changes	Improvising the shop floor towards [17] Industry 4.0
Preventive maintenance using gathered data	Installing sensors and tagging the boards to gather data and predict the equipment wear.

4. CONCLUSION

This report has accomplished the above-mentioned objectives with clear explanation. This Report has integrated the tools and have performed a valid case-study providing the insights of SMT line. The PFMEA can be performed after the chosen methodologies, and it can clearly give us the efficiency of our implemented methods. It can be quantified into numbers by RPN and paretto chart and since it is a continuous improvement strategy, we can periodically assess this and improve the manufacturing line. Growing trend of Industry 4.0 in India [11] is a point to be noted as all quality tools are data driven and integration of the lean tools with them will result in a more efficient production line. The methodologies provided in this paper may further studied in detail for future studies.

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