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DMAIC Methodology to Solder Paste Printing Process in Printed Circuit Boards

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***Abstract*— Nowadays, production of defective items is a crucial issue for manufacturers. In repetitive and mature processes with low defect levels, measured by defects per million opportunities (DPMO), it is difficult to reduce them even further. The purpose of this study is to reduce the defects rate in one key process, surface mount technology (SMT). The methodology is based on case study of an automotive supplier of electrical and electronic devices. It focuses on implementing Six Sigma tools, using the DMAIC to improve the solder paste printing process of Printed Circuit Boards (PCBs) in SMT. In the case study, solder paste volume defect is defined as the most common type of defect occurred in the process. The used method (proflow) was compared with a new selected method (squeegee) using statistical analyses. The volume defect was reduced over 50% and the sigma level was increased from 5.0 to 5.2.**

***Index Terms*— DMAIC; Six Sigma; Surface Mount Technology – Printing Process**

I. INTRODUCTION

Manufacturers of automotive electronic components have successfully implemented quality managements systems, quality tools and techniques to support systems. The prerequisites for improvement of manufacturing processes in the electronics field are the continuous growth of different methodologies; as well as the increasing level of quality requirements.

The environment associated with surface mount technology (SMT), has been successfully compatible with Six Sigma, it is a project based DMAIC methodology (the sequential phases Define, Measure, Analyze, Improve and Control) that make up the improvement cycle.

The use of Six Sigma detects and eliminates root cause of defects in a given system [1]. Various industries applied the Six Sigma for defect or problem reduction and sigma level improvement purposes [2], [3], [4], [5].

Six Sigma represents the idealized goal of a defect rate of 3.4 DPMO (defects per million opportunities), or 3.4 defective products on a sample of 1 million, which corresponds to a quality rate of 99.9997% [6].

If the customer dissatisfaction is measured as a defect, then Six Sigma indicates that there would be only 3.4 defects for every million opportunities, or near perfection [7]. The reason of choosing six sigma level is that the five sigma could not meet the customer satisfaction and the seven do not add significant value, as 3.4 DPMO is close the perfection, and that makes it a more attainable and realistic goal to achieve [8].

Specification limits associated to products are performance ranges that customers accept [9]. These limits are typically represented by: lower specification limit (LSL), upper specification limit (USL) and target value (T) (Figure 1).

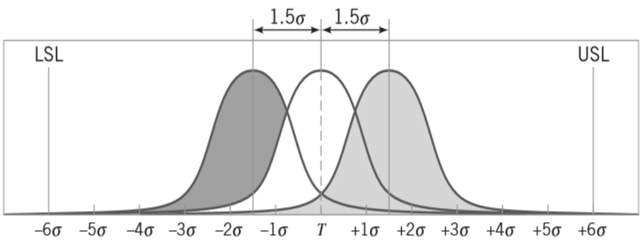

Figure 1. Normal distribution with the mean shifted by ±1.5 [7].

The process mean is to be kept at the target value in practice. However, the process mean during one time period is usually different from that of another time period for various reasons [9]. This means that the process mean constantly shifts around the target value. To address typical maximum shifts of the process mean Motorola added the shift value $\pm 1.5\sigma$ to the process mean. This shift of the mean is used when computing a process sigma level. The process mean can be drifted 1.5 sigma in either direction [10]. The area of a normal distribution, beyond 4.5 sigma from the mean is indeed 3.4.

DMAIC is used by Six Sigma as a generic problem solving methodology that applies across cultures, processes, functions, types of industry [11]. It has developed by using of this or similar approaches around the world in many different improvement circumstances.

The importance of SMT has been reflected in many published studies. They particularly focus on the application of the solder printing process because most of SMT defects are originated in solder paste printing process. The capability of solder paste printing process was improved by reducing the variation of solder thickness that may cause PCB failure in SMT [12]. In another study, DMAIC (Define, Measure, Analyze, Improve and Control) methodology was applied to improve the same and also by reducing thickness variations from a nominal value [13]. Another work [14] reported a reduction in the defective rate and increase of yield using Six Sigma in a printed circuit assembly line.

DMAIC methodology was used in Printed Circuit Board (PCB) manufacturing, particularly in the solder paste printing process, where product failures reduction and continuous improvement are key objectives and are the focus of this work in an assembly-manufacturing site for the automotive sector, located in Braga, Portugal.

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This paper is organized in four sections. After this introduction, section II presents SMT process and the main process focused on. In third section is organized according to DMAIC cycle. Types of defect are described and the root cause is designated. Previous method and the method of solder printing by calculating sigma levels. The comparison indicates improvement of process with statistical analyze. Finally, on the last section, the achievements are compared with pre-defined objectives and general conclusions are drawn.

II. Description of SMT Process

This work was developed in Delphi Automotive-Braga, which is an assembly-manufacturing site. Delphi Automotive-Braga manufactures PCB products mostly by using SMT) which is a technique of placing surface mount devices (SMDs) on the surface of a PCB.

The company strives to use the better existing technology; it is equipped with twelve fully automated SMT assembly lines to quickly and efficiently meet customer's expected product requirements. The study is in one of these lines (Figure 2).

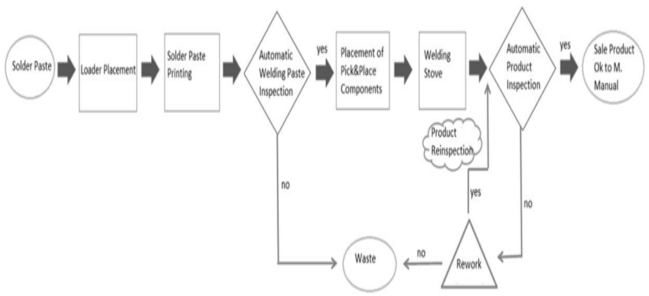

Figure 2. SMT Flowchart.

SMT production line consists of three manufacturing processes [12]: (1) solder paste printing process; (2) pick-and-place for SMT components and (3) reflow of solder paste.

PCB is placed in the operation line properly (loader placement). The next operation is the solder paste printing that puts the required paste down on a board and makes a deposition on a pad. Printed board is automatically inspected. The operation automatically runs by picking up components and placing them down into the solder paste. After the placement of components, the placed board goes through the reflow oven to melt solder paste and burn off flux. Then the solder paste is hardened to bond the components into place and form to electronic connection. Automatic product inspection is the last control. PCBs are analyzed and classified by properly trained and certified employees who decide, in case of defect detection, whether there is a possibility of rework or it is classified as scrap.

In the beginning of solder paste printing process (Figure 3), the checklist including stencil type, printing program and solder paste type is controlled by the operator. Then, solder paste is put in the PCB through the stencil. Since there are different PCBs, the program is adjusted for each board. In order to use the solder paste efficiently, it is kneaded in the machine before the printing. The solder paste is pushed through the stencil to fulfill the gaps. After the printing process, the stencil is removed and the place of the stencil is cleaned.

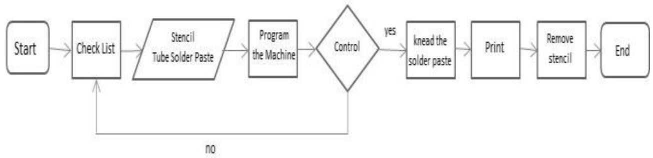

Figure 3. Printing process flowchart.

Solder paste printing is only the first step in the SMT process, and defects usually appear only after reflow soldering. If the printing solder paste inspection does not exist in the process or is not reliable, the process improvement gets difficult.

By focus on process improvement, the main objectives of this work are:

- Present and understand details of each step of the solder paste printing process;
- Identify the main type of defects;
- Identify each defect and respective root causes;
- Eliminate the root causes from the processes by developing and implementing new solutions;
- Control the impact of the changes performed.

III. Applying DMAIC Phases

A. Define

A team was formed and a project charter was defined (Table 1). This project was scheduled for three months between March and July 2017.

TABLE I. Project Charter of Printing Process

Project Charter	
Project Name: DMAIC Approach to Solder Paste Printing in Printed Circuit Boards.	
Problem Statement & Objective: Defects cause low performance in the printing process. DMAIC cycle is used to improve the solder paste printing process of Printed Circuit Boards (PCBs) in surface mount technology (SMT). The purpose of project is to focus on the reducing of defect rate in the process.	
Business Case: In the case study, solder paste defect is defined as the most common type of defect occurred in the process. The used method (proflow) can be compared with new selected method (squeegee) using statistical analyses.	
Team Members: Fernando Guedes Jorge Goncalves Diogo Leitão José Machado Beyza Nur Sezgin	Project Area: SMT Line / Solder Paste Printing Process Duration: 1/3/2017 - 15/7/2017

A team was formed and a project charter was defined (Table 1). This project was scheduled for three months between March and July 2017.

In order to detect the defects that may cause PCB failure, all types of defects were considered. The company has accepted these defects which are identified by inspection machine as a problem that should be reduced.

The standard limits and parameter values for printing process depend on the printing line, supplier recommendations and customer requirements. The types of defects that can be associated with each solder paste deposition in the PCB are defined as volume, position, bridging, height and area.

Volume: Two types of defect occur in volume defect; excessive is when the solder paste exceeds the upper specification amount of solder paste, and insufficient is when the solder paste falls below minimum level of volume.

Position: Position defect is defined as the solder paste that is deposited in an inaccurate position instead of at the pre-defined coordinates.

Bridging: Bridging defect occurs when the solder forms an abnormal connection between two or more adjacent pads to form a conductive path.

Height: Upper height defect is when the solder paste height is greater than the upper specification level; lower height is when the solder height is lower than a minimum specification level.

Area: High area defects occur on the board when the solder paste is outside the maximum area defined (the area is regarded as size of the stencil hole). If the area of solder paste is less than the minimum percentage, the result of inspection is a low area defect.

B. Measure

Since there were various types of PCBs in production, one of the production lines was selected to evaluate the data. This line manufactures different PCBs, each one with different number of pads, but the process is similar in all products. In this phase, Sigma level for each type of defect was calculated to measure the process quality level. Overall, PCBs with 35503890 pads were inspected during 10 days in April 2017 and defects were collected. As a result 9123 defects were found. The data and the sigma values calculated for each type of defect are shown in Table 2.

TABLE II. INITIAL SIGMA LEVEL

Defect Type	*Total Number of Pads*	*Number of Defects*	*PMO*	*Sigma Level*
Volume	35503890	8629	243.04	5.0
Position	35503890	95	2.67	Over 6
Bridging	35503890	380	10.70	5.7
Height	35503890	15	0.10	Over 6
Area	35503890	4	0.42	Over 6
Total	35503890	9123	256.96	5.0

Considering all types of defects, the corresponding sigma level is 5.0.

Pareto analysis (Figure 4) showed that volume defect is the most frequent type of defect, representing 94.6% of total defects occurred in solder printing process.

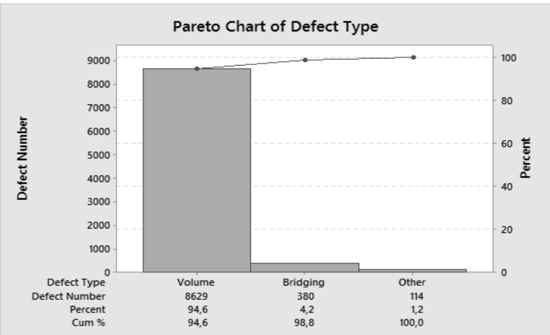

Figure 4. Pareto chart of defect types.

C. Analyze

According to sigma levels, the result showed that volume defect is the most frequent type of defect in the studied process. However, the consequences of different types of defects can be different. For example, some types of defects are easier, faster or cheaper to repair than others, while others may result in sending the PCB to scrap. Thus, the following method was used to clarify the criticality of the different types of defects.

First, the scale definition was created for pairwise comparison and decision-making using AHP scripting language in Table 3. A pairwise comparison matrix was created based on the cost of defect in the process. In this study, the key criterion used was cost. According to the effect of defects on process, the scales were assigned for comparing the criticality of different types of defects. The survey has done by operators according to pairwise comparison matrix. Operators selected the number for each comparison considering AHP scripting language.

TABLE III. DECISION-MAKING USING AHP SCRIPTING LANGUAGE

AHP Scale of Importance for comparison pair (aij)	*Numeric Rating*	*Reciprocal (decimal)*
Extreme	9	1/9
Very strong to	8	1/8
Very strong importance	7	1/7
Strongly to very strong	6	1/6
Strong	5	1/5
Moderately to strong	4	1/4
Moderate	3	1/3
Equally to moderately	2	1/2
Equal	1	1

The comparison matrices were circulated among the technical staff and operators of the printing operation. This method conducted pairwise comparisons across all possible combinations of parties.

Since there were five comparisons matter, 5 by 5 matrix was made and then the diagonal elements of the matrix were defined as 1, because it would correspond to a comparison with one type of defect with itself. The upper triangular matrix was filled up. According to survey result, the numeric rating and reciprocal values were put on the matrix (Table 4).

$$\begin{bmatrix} 1 & 9 & 1/5 & 1 & 4 \\ 1/9 & 1 & 1/7 & 1/7 & 1/2 \\ 5 & 7 & 1 & 7 & 8 \\ 1 & 7 & 1/7 & 1 & 4 \\ 1/4 & 2 & 1/8 & 1/4 & 1 \end{bmatrix}$$

TABLE IV. PAIRWISE COMPARISON MATRIX OF THE MAIN CRITERIA WITH RESPECT TO THE GOAL

	Volume	*Position*	*Bridging*	*Height*	*Area*
Volume	1	9	0.2	1	4
Position	0.11	1	0.14	0.14	0.50
Bridging	5	7	1	7	8
Height	1	7	0.14	1	4
Area	0.25	2	0.13	0.25	1
Total	7.36	26	1.61	9.39	17.50

In order to normalize the matrix, each column of the reciprocal matrix was summed and then each element of the matrix was divided with the sum of its column. The relative weight of the criticality of each defect type is presented by:

TABLE V. THE MATRIX DIVIDED WITH THE SUM OF ITS COLUMN

	Volume	*Position*	*Bridging*	*Height*	*Area*
Volume	0.14	0.35	0.12	0.11	0.23
Position	0.02	0.04	0.09	0.02	0.03
Bridging	0.68	0.27	0.62	0.75	0.46
Height	0.14	0.27	0.09	0.11	0.23
Area	0.03	0.08	0.08	0.03	0.06
Total	100	1.00	1.00	1.00	1.00

$$Weight = \frac{1}{5}\begin{bmatrix} 0.14+ & 0.35+ & 0.12+ & 0.11+ & 0.23 \\ 0.02+ & 0.04+ & 0.09+ & 0.02+ & 0.03 \\ 0.68+ & 0.27+ & 0.62+ & 0.75+ & 0.46 \\ 0.14+ & 0.27+ & 0.09+ & 0.11+ & 0.23 \\ 0.03+ & 0.08+ & 0.08+ & 0.03+ & 0.06 \end{bmatrix} = \begin{bmatrix} 0.19 \\ 0.04 \\ 0.55 \\ 0.17 \\ 0.05 \end{bmatrix}$$

The Consistency Ratio (CR) assesses the consistency between answers regarding relative importance of pairwise comparisons. Its value should be lower than 10%.

In order to calculate the CR the Principal Eigen value $(\lambda_{\max})$ was obtained from the summation of products between each element of Eigen vectors and the sum of columns of the reciprocal matrix.

$$\lambda_{MAX} = (7.36\times 0.19) + (23\times 0.04) + (1.93\times 0.55) + (7.40\times 0.17) + (15.20\times 0.05)$$

$$\lambda_{MAX} = 5.37$$

Thus for $\lambda_{\max}$ = 5.37 and n=5 (five comparisons), the consistency index (CI) is calculated as follows:

$$CR = \frac{\lambda_{\max} - n}{n-1} \quad (1)$$

$$CR = 0.0925$$

TABLE VI. RANDOM CONSISTENCY INDEX (RI)

n	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Then, Consistency Ratio, is given by equation 4.

$$CR = \frac{CI}{RI} \quad (2)$$

$$CR = 0.0826$$

The value of Consistency Ratio is smaller 10%, the inconsistency is acceptable. Table 7 presents defect relevance obtained by the multiplication of defect occurrence and defect criticality weight.

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TABLE VII. DEFECT WEIGHT OF PRINTING PROCESS

Type of Defects	*Number of Defects*	*Defect Relevance*	*Cumulative Count*	*Cumulative (%)*
Volume	8629	1624.33	1624.33	88.22
Bridging	380	210.65	1834.98	99.66
Position	95	3.53	1838.51	99.85
Height	15	2.49	1841	99.99
Area	4	0.22	1841.22	100.00

The Pareto analysis shown in Figure 5, based on data from Table 7, illustrates the list of occurring defects, which reveals that volume is the most relevant defect. The successive phases have concentrated on identifying the major root causes that contribute to this volume defect.

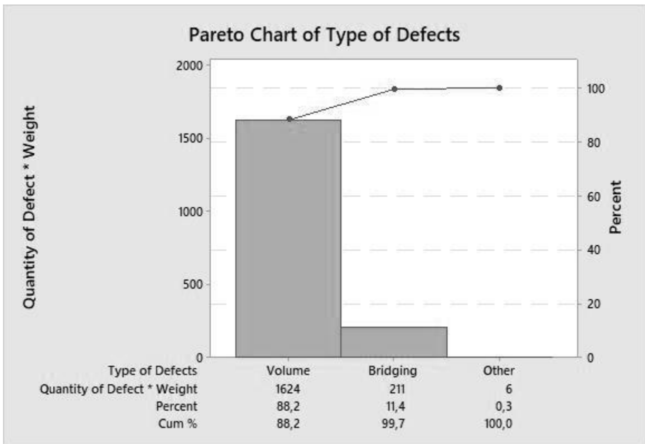

Figure 5. *Pareto analysis of "quantity of defect * weight".*

Based on the detailed Fishbone diagram, the project team members discussed factors that may cause a volume defect by using brainstorming, and summarized all the factors in the cause-and-effect diagram (Figure 6). It was concluded that the root cause in the process is the proflow printing method of depositing solder paste.

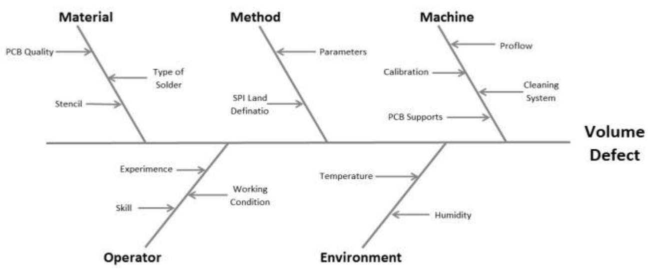

Figure 6. Cause and effect diagram for volume defect

This is the printing method (Figure 7) that the solder tube is attached to print carriages and is used to print various high viscosity materials which display non Newtonian characteristics based on pressure. During the print process the rotation of the conditioning grid, working together with the print medium pressure, forces print medium into the stencil's apertures. This is the most significant characteristic of proflow that is the way of deposition into the aperture of stencil.

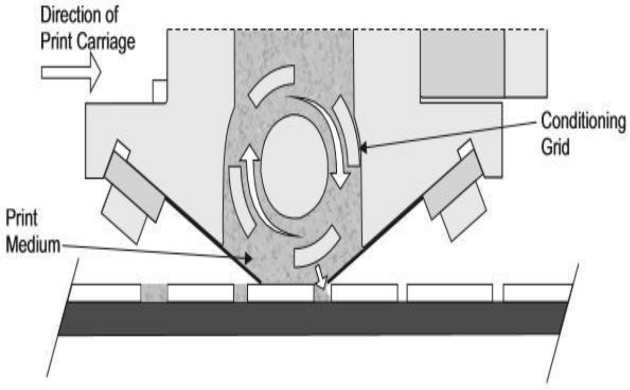

Figure 7. Proflow print medium and Conditioning Grid.

It was decided to analyze proflow process in different aspects. The main purpose of the analysis is to compare proflow method to an alternative printing method: squeegee. Considering technological evolutions and requirements evolutions, there is an alternative printing method that could be compared to proflow. Technically, this involves changing a tool in the solder past deposition machine.

The comparison was implemented in the same environment conditions such as temperature, humidity, noise, time, material lots, and parameters. The type of PCB used in this experiment is VW MIB*441A. This PCB contains 4457 pads. The pad is a point on the PCB where the solder paste is deposited. Printed paste on the pads is melted and bonded the components. Additionally, in order to examine volume effects on the pads, different pad sizes were considered such as the smallest, the biggest and the middle size (U29, C152, C137 and U66). One production line was decided to work on this analysis. The line has been worked with both proflow and squeegee methods. PASW Statistic 18 and Minitab 18 statistical software were used to analyze the difference between two printing methods.

The optimal volume value is calculated by using the pad length, width and the stencil height. Specification limits are defined as volume percentage relatively to the optimal volume value (100%). The amount of solder paste volume to avoid defects is between 40% and 180%, i.e., the amount of solder paste is between this range, the printing process is accepted as Good.

TABLE VIII. RANGES FOR SOLDER PASTE VOLUME

Range	*Amount Type*	*Impact on Quality*
0% - 40%	Insufficient	Defective
40% - 80%	Low Sufficient	Acceptable
80% - 120%	Optimal	Very Good
120% - 180%	High Sufficient	Good
>180%	Excessive	Defective

The company's experience showed that having a "high sufficient" volume is slightly better than a "low sufficient" volume.

1) Experience 1

The component U29 contains the smallest pads. The minimum pad size is 0.7 mm x 0.18 mm. Two samples were collected corresponding to two printing methods: Proflow and squeegee. Table 9 presents data of volume in these two cases. In the first observation; regarding to the data, 99.4% of data are good and 0.6% of data are error by using proflow method, while 99.9% of data are good and 0.1% of data are error by using squeegee in printing process.

According to mean numbers, it is demonstrated that squeegee deposits 16% more solder paste on the pads than proflow (Table 9).

TABLE IX. THE DESCRIPTIVE STATISTIC OF VOLUME% FOR PROFLOW AND SQUEEGEE USING PAD U29

Method Type	*N*	*Min*	*Max*	*Mean*	*S.D.*	*Cp*	*Cpk*
Proflow	216160	11.29	131.70	67.76	7.969	2.93	1.16
Squeegee	188654	6.31	242.95	83.92	7.106	3.28	2.06

Both printing methods show capability to produce within specification ranges because the Capability index Cp in both methods is bigger than 1.33. However, the Cpk is smaller in proflow indication that has a bigger difference from the volume average to volume nominal reference.

As a result it can be concluded that Squeegee method deposit the amount of solder paste required (between upper and lower limit). However, proflow method barely fell under lower limit. Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

2) Experience 2

Component C152 contains two similar pads and the pad size is 5.3 mm x 1.7 mm. Data are almost good by using squeegee method, while 99.8% of data are good and 0.2% of data are error by using proflow in printing process. It was observed that squeegee method does not cause error in the process.

Using the method squeegee can achieve 18.5% more volume then proflow method (Table 10).

TABLE X. THE DESCRIPTIVE STATISTIC OF VOLUME% FOR ROFLOW AND SQUEEGEE USING PAD C152

Method Type	*N*	*Min*	*Max*	*Mean*	*S.D.*	*Cp*	*Cpk*
Proflow	10808	77.31	269.23	97.55	6.97	3.35	2.75
Squeegee	9438	79,50	191.56	116.04	3.34	6.99	6.38

3) Experience 3

This component consists of two pins and pin size is 1.7 mm x 5.3 mm. It was observed that good frequency is 99.9% and error frequency is 0.1% when the squeegee method is used in the process. However, the proflow value is very close to squeegee results. The good frequency is 99.8% and the error frequency is 0.2%. The description statistic is shown that solder paste variation is deposited more by using squeegee method than usage of squeegee. The amount of volume difference is 15%. Cp values for both two methods are respectively 3.94 and 4.12.

TABLE XI. THE DESCRIPTIVE STATISTIC OF VOLUME% FOR ROFLOW AND SQUEEGEE USING PAD C137

Method Type	N	Min	Max	Mean	S.D.	Cp	Cpk
Proflow	8252	79.07	209.58	93.87	5.920	3.94	3.03
Squeegee	9447	3.70	141.94	108.40	5.660	4.12	4.03

4) Experience 4

The component which has one of the biggest pads and different shape was analyzed in the process. The descriptive statistic is shown that both of methods achieve to reach out optimal values considering mean value. Their amounts of volume are both between 80% - 120% and more than 100%. It might be proved that squeegee deposits 4% more solder paste into pads (Table 12). This situation is considered as an advantage.

TABLE XII. THE DESCRIPTIVE STATISTIC OF VOLUME% FOR ROFLOW AND SQUEEGEE USING PAD U66

Method Type	N	Min	Max	Mean	S.D.	Cp	Cpk
Proflow	5404	80.96	126.60	104.44	6.14	3.80	3.50
Squeegee	4460	24.47	249.91	108.39	7.95	2.94	2.87

5) Hypotheses for The Independent T-test

The independent samples t-test evaluates the difference between the means of two independent or unrelated groups.

In this study, it was evaluated whether there was a significant difference between the means in two unrelated groups. With the independent test sample t test, it was evaluated whether the mean value of the volume defect for one group 'proflow' differs significantly from the mean value of the test variable for the second group 'squeegee'. Null and alternative hypotheses were set up for each experiment of the pad type (U29, C152, C137, U66).

In order to compare the significant different between statuses, significance level (alpha) was set up as 0.05 which allows the analysis to either reject or accept the alternative hypothesis.

a) Hypotheses 1:

H_0: There was not a significant difference in volume defect of using U29 for ‘proflow’ and ‘squeegee’.

H_1: There was a significant difference in volume defect of using U29 for ‘proflow’ and ‘squeegee’.

b) Hypoheses 2:

H_0: There was not a significant difference in volume defect of using C152 for ‘proflow’ and ‘squeegee’.

H_1: There was a significant difference in volume defect of using C152 for ‘proflow’ and ‘squeegee’.

c) Hypoheses 3:

H_0: There was not a significant difference in volume defect of using C137 for ‘proflow’ and ‘squeegee’.

H_1: There was a significant difference in volume defect of using C137 for ‘proflow’ and ‘squeegee’.

d) Hypoheses 4:

H_0: There was not a significant difference in volume defect of using U66 for ‘proflow’ and ‘squeegee’.

H_1: There was a significant difference in volume defect of using U66 for ‘proflow’ and ‘squeegee’.

e) Interpretation of the Independent Sample T-test Analyze

In the difference between ‘proflow’ and ‘squeegee’ test, it was resulted in a Sig. (p) value that was less than significance level ($p < 0.05$). The null hypothesis was rejected, and the alternative hypothesis was accepted for each pad types shown in Table 13.

There was a significant difference in volume defect of using pad U29 for ‘proflow’ (M=67.76, SD=7.969) and ‘squeegee’ (M=83.92, SD=7.106) conditions; t (404812)=-676,58 ,p=0.00.

There was a significant difference in volume defect of using pad C152 for ‘proflow’ (M=97.55, SD=6.968) and ‘squeegee’ (M=116.04, SD=3.34) conditions; t (176977) =-166,85 ,p=0.00.

There was a significant difference in volume defect of using pad C137 for ‘proflow’ (M=93.87, SD=5.92) and ‘squeegee’ (M=108.40, SD=5.66) conditions; t (20244) =-235,37 ,p=0.00.

There was a significant difference in volume defect of using pad U66 for ‘proflow’ (M=104.44, SD=6.142) and ‘squeegee’ (M=108.39, SD=7.95) conditions; t (9862) =-27,87,p=0.00

TABLE XIII. THE SIGNIFICANCE OF VOLUME ACCORDING TO STATUS

Component Type	df	t	Sig.
U29	404812	-676,58	0,000
C137	176977	-166,85	0,000
C152	20244	-235,37	0,000
U66	9862	-27,87	0,000

D. Improve

The reason of the thoughts bases on previous experience in the company that always accepted as an advantage that the amount of solder paste is more on the board. Therefore, the squeegee printing method which deposits more solder paste than proflow printing method has been accepted as a new method to be used in improve phase. Statistical experiments on four different pads as shown:

- The analysis of the components named U29 which consists of smallest pads showed that squeegee deposits 16% more solder paste into the pads.
- According to analysis of named C152 component, its pads was filled 16% more solder paste into the apertures.
- Amount of solder paste was found 15% more solder paste in the squeegee method when the deposition was compared between squeegee and proflow.
- In the last observation of the last component named U66

showed that the results of the amount solder paste were close to each other. It was slightly more in the squeegee method.

Squeegee is one of the printing methods in the SMT line. The squeegee module allows the setting and monitoring of squeegee height and pressure during the print stroke.

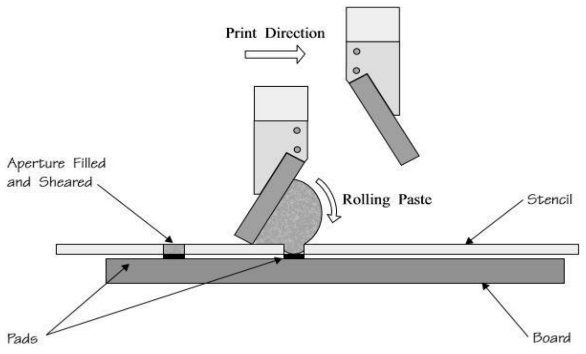

Figure 8. Squeegee printing method.

A quantity of paste is placed on the stencil in front of the traveling squeegee. Due to the angle of the squeegee blade the paste has a tendency to move in rolling motion. This rolling motion plays very significant part in the distribution of paste and the final print quality. During the rolling action the paste is worked into and fills the apertures in the stencil, thereby showing the importance of the paste rolling action during printing.

E. Control

In this phase, it will be proved that the performance of the new method and variation of volume error rates which are caused by using proflow and squeegee method. There are significant circumstances in the control phase to avoid the problems in the last phase. The control phase was applied according to these particular steps:

- Implementing ongoing measurement
- Standardizing the solutions
- Quantifying the improvement

In the first step, the sigma level was recalculated in the process that the squeegee was used. This result shows that the sigma level of process was increased by 0.2. This improvement percentage is an important value to raise the performance which aims to excellence production ideology.

TABLE I. THE NEW SIGMA LEVEL OF PROCESS USING SQUEEGEE METHOD

Defect Type	*Total Number of Pads*	*Number of Defects*	*PMO*	*Sigma Level*
Volume	13277760	1566	117.94	5.2
Position	13277760	38	2.86	Over 6
Bridging	13277760	116	10.70	5.8
Height	13277760	2	0.15	Over 6
Area	13277760	3	0.23	Over 6
Total	13277760	1725	129.92	5.2

The volume DPMO changed from 243.04 to 117.94. This result showed that the squeegee method reduced more than half the volume amount of solder paste defects (compared to the previously used proflow method), ending up with an improved sigma level of 5.2 (Table 14). The reason of using the same component in the analysis and control phases is to obtain a correct result in the process.

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IV. Conclusion

In order to reducing the defect rate and raise the sigma level, DMAIC methodology was implemented in this study. Five phases were successfully applied step by step. This consideration was crucial to identify the critical root causes for the mentioned problem as well as to improve the process.

The defects of soldering paste printing were identified, classified into five types of defects, and its frequency was analyzed. This study also used AHP, involving experienced workers, to assess the criticality of these types of defects, not assessing only its frequency, as it is reported in typical Six Sigma projects. The volume defect was considered the most critical defect to be minimized.

The root cause of volume defects in the soldering paste printing process was determined by brainstorming, cause-and effect diagram and Pareto chart. The printing method “proflow” could be changed to an alternative method: “squeegee”.

The new printing method (squeegee) was compared with current method “proflow”. According to amount of volume, it was observed the reachability to the optimal value. The comparison indicated that the performance of the new method (Squeegee) reduced defects from 243 to 118 per million opportunities. Afterward, Squeegee printing method was introduced in the improve phase.

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