Quality Improvement in Flexible Printed Circuit Board (FPCB) Using DMAIC Methodology: An Investigation in Semiconductor Industry

S N A Shamsudin¹, M S Jusoh¹,², A G M Rosli¹,², M S Ismail¹,², M S Hj Din¹

¹Faculty of Applied and Human Sciences, Universiti Malaysia Perlis, Kangar, 01000, Perlis, Malaysia.
²Center of Excellence Social Innovation & Sustainability, Universiti Malaysia Perlis, Malaysia

Email: shahar@unimap.edu.my

Abstract. Continuous Process Improvement is methodology to solve the defect problem by increasing the effectiveness and efficiency of the business performances. DMAIC (Define-Measure-Analysis-Improve-Control) is a data improvement cycle designed for business process to find flaw or inefficiencies particularly resulting in defect or reject. This study was conducted at Company A and used DMAIC method to reduce the open defect for the circuit on the Flexible Printed Circuit Board (FPCB) from 0.6% to 0.3%. Part 13236 which has the highest open defect problem was chosen as the project improvement main focus. Imaging area was the main focus in this project because of its process forming the circuit. DMAIC methodology are initiated by problem identification through the past record of the open defect. The result observed for period of four months. After improvement, Part 13236 that have the highest defect decrease from 0.68% to 0.28% while the overall open defect decreases from 0.6% to 0.3%. The decline on product defect rate helps the company to improve the effectiveness and efficiency of business performances. It also results in cost saving which improves company’s profit margin in the long term.

1. Introduction

Six Sigma originates from 19th Century mathematical theory, but became known in the 1980s in the today’s mainstream business world through the efforts of an engineer at Motorola. Six Sigma seeks to improve business processes by removing the causes of errors that lead to defects in a product or service [1]. This is accomplished by setting up a management system that systematically identify error and provide method for eliminating them. DMAIC (define, measure, analyse, improve, control), one of Six Sigma methodologies, is one of the leading methodological practices used to improve customer satisfaction and business processes. DMAIC process is an improvement system for existing processes falling below specification and looking for incremental improvement [2]. DMAIC is used to find out the problem, and generates sustained success of the related problem. Besides, a performance is crucial because each function, business unit, quality control, and individual have different targets and standard. The effectiveness and efficiency of business performances have relationship with the rapidly changing in the technology and business environment. The improvement on business should be linked to a process, whether manufacturing or non-manufacturing and the capability of these process obviously influences an organization’s achievement [3]. Therefore,
in this project, continuous improvement tool DMAIC was used to improve quality, reduce defect at a faster and cheaper cost. It improves company effectiveness and efficiency through the scientific and statistical quality assessment. The study is based on the actual manufacturing data of Company A. The defect rate is very important to help increase the quality of the product and company profit. The objective of study is to reduce the open defect problem and to propose series of method that can be used by the company. In the manufacturing process for formation of circuit, the open defect is always the main effect for the circuit formation. The main root cause was accessed using Ishikawa Fishbone diagram and perform the implementation of solution to reduce the open defect.

2. Literature Review

2.1 Lean Six Sigma DMAIC Methodology
Six Sigma was developed by Motorola in early to middle 1980’s based on quality management fundamental, after that it become a popular management approach at General Electric (GE) in the early 1990’s. It is a systematic methodology aimed at operational excellence through continuous process improvements. It has been successfully implemented worldwide for over 20 years, producing significant improvements for many large and small organisations. It is a data-driven philosophy of improvement for several of defect problem. It drives customer satisfaction and bottom-line results by reducing variation, waste, and cycle time, while promoting the use of work standardization and flow, thereby creating a competitive advantage [4]. It applies anywhere variation and waste exist, and every employee should be involved. DMAIC provide a stepwise procedure, a collection of techniques, concepts and classifications such as Critical-to-Quality (CTQ). DMAIC is a closed-loop process, which aim to eliminate non-value-added step and focus on new measurements and applies technology for continuous improvement. In ensuring the DMAIC accomplishment, this study applies following processes;

2.2 Phase I - Define
Stage to define the problem, project goals, scope of the project and customer both internal and external deliverables.

i. Project charter - To define the focus, scope, direction and motivation for the improvement team.

ii. Voice of Customer - A process used to capture the requirement and feedback from the customer to provide the customer with the best product quality of product. It can be done in variety of way such as direct discussion, focus group, customer specifications, observations, observation, warranty data, field report, complaint logs

iii. Process Flow chart- A flow chart is a picture of the separate steps of a process in sequential order. Element that maybe include are: sequence of actions, materials or services entering or leaving the process (input and output), decision that must be made, people who become involved, time involved at each step and/or process measurement [5].

2.3 Phase II- Measure
Measure phase is the process to determine current baseline performance, to understand what the problem is and in what condition it exists. At this stage, initial process measurement can be conducted to understand the voice of the current process and begin developing Y=F(x) relationship. Two mostly used tools in this phase are Pareto chart and control chart. According to the Lean training course, Pareto chart is a series of bar whose heights reflect the frequency or impact of problems. The bars are arranged in descending order of height from left to right. This means the categories outlined by the tall bars on the left are relatively more vital than those on the right [6]. The Pareto chart use 80-20 rule to prioritize the contributors which make the biggest impact on a problem, or which represents the largest areas of opportunity. The principle of 80:20 states that 80% effect comes from 20% of the causes.
Control chart is a graph used to study how a process changes over time. The data are plotted in time order. A control chart has a central line as index of average, an upper line for the upper limit control and a lower line for lower control limit. These lines are determined through historical data. By comparing it with current data to these lines, a conclusion whether the process variation is consistent (in control), or is unpredictable (out of control, affected by special causes of variation) as shown in Figure 1.

![Control Chart Example](image)

**Figure 1.** Example of Control chart: Out-of-control Signal

### 2.4 Phase III - Analysis

Analyse the data to understand the Voice of the Customer and to evaluate why the problem is occurring and what the potential root cause(s) of the defects are. At this stage, the focus is to narrow down the many ‘X’s’ (or causes) to the vital few. A fishbone diagram is a tool that can help to perform a cause-and-effect analysis for a problem. This type of analysis enables the user to discover the root cause of a problem [7]. This tool is also called a cause-and-effect diagram or an Ishikawa diagram. These names can be used interchangeably. Dr. Kaoru Ishikawa, a Japanese quality control expert, is credited with inventing the fishbone diagram to help employees avoid solutions that merely address the symptoms of a much larger problem.

### 2.5 Phase IV - Improve

Improve the process by eliminating defects and the root causes to the problem. Performing design of experiments, and possible solutions, verifying whether these solutions work, and eradicating the root causes [8]. Most improvements will require a careful plan to ensure they are implemented correctly and can be measured to evaluate their performance. Otherwise, it would be like scattering seeds over unturned soil and hoping for the best.

### 2.6 Phase V – Control

Create the new standard process, which captures the new way of working, and control future process performance. Process analysis is critical here, to understand the new process capability and control, ensuring that the new process is indeed capable and in control. Closing the project out also means that project cost savings should be calculated and verified and all transfer plans/processes created. Lastly, celebrate the success and communicate to the business [8]. Control Plan is created during the improve phase. In essence, a Control Plan would present a summary of all the information relevant to a given project so that the quality specialist is able to ascertain if the project is on track and, in case of deviations, delays, and wasteful overheads, is able to take corrective action. As such, the Control Plan is kept updated to reflect any changes to the process.
3. Methodology

3.1 Project Implementation Flow

![Process roadmap of DMAIC](image)

**Define**
- Develop the project area and problem statement
- Performance standard - Process Map
- Identify the possible causes the problem of open defect

**Measure**
- Measure the current situation and observe the changes through trend chart
- Find main part to focused for improvement
- Draw a tree diagram to differentiate the cause of open defect

**Analysis**
- Perform evaluation on the selected sample based on the process flow (Visual Inspection)
- Construct the fishbend diagram to find out the root cause

**Improve**
- Reduce the open defect by implement the solution for the root cause

**Control**
- Collect data and check whether the method can help to reduce the open defect
- Standardize method of improvement and sustain the improvement

**Figure 2. Process roadmap of DMAIC**

i. **Define Phase** - During the selection of the project, the problem face by that process, and goal need to be clearly determined. We have to decide whether the process or the product needs to be improved. Company A produce Flexible Printed Circuit Board (FPCB) and Moulded Interconnect Substrate (MIS). This project focus on Single-sided Printed Circuit Board. In the imaging process of the circuit, there are some defects occur such as Open defect, short defect of the circuit, and this is the problem always complaint by the customer and have high demand compared to MIS.

ii. **Measure Phase** - Measure phase involves more data analysis than define phase. In this phase, the performances of the manufacturing process of single-sided FPCBs for past eight month is analysed through the Visual Inspection Report. Those baseline data is collected for being able to measure the baseline process performances. The overall trend chart is plot, and figure out the top 5 highest of defect rate for single-sided Flexible Printed Circuit Board, and choose the highest part for focus on improvement. Then the process mapping for the study process is draw and figure out the process that to be focus for that part. Mapping the process can help to identifying each step in the process helps selecting what to measure, where and how to focus on actual process. Besides, process mapping also help to visualise the process.

iii. **Analyse Phase** - Pareto analysis is used to prioritize the direction and focus on the vital process instead of aiming all the process flow. By using Pareto analysis, it can help to break a big problem into specific root cause to identify the most significant factors and show which part focus for the implementation plan. Pareto analysis chart communicate the principles of 80/20 rules, which state that 80% of an effect comes from 20% of the causes. The main causes of Open defect for single sided FPCBs were discovered and the tree diagram for causes was develop.

iv. **Improved Phase** - After figure out the possible root cause for occurrence of the Open defect from the Analysis phase. All the group member especially those who was experienced in the manufacturing process in FPCBs will identify possible improvement
action, prioritize them in, test the improvements, and finalize the improvement action plan. Based on the identified root causes, directly address the causes with the improvement.

v. Control Phase- Full scale implementation of the improvement action plan, set up controls to monitor the system so that gains are sustained. Control plan needed to monitor ongoing performance to ensure that the improvement plan fully implemented.

4. Results and Discussion

4.1 Phase I- Define
The company have various type of flexible printed circuit board, but single-sided is the main study in this project as single-sided is high demand product and have higher customer orders compared to other types of circuit board. Figure 3 depicts the manufacturing process flow for single-sided flex circuit was from material issue, drilling, pre-treatment, dry film lamination, exposure, developing, etching, stripping, post treatment, immersion nickel gold plating, target punch, routing, rinsing & drying and electrical test. Open defect is known as the highest reject for single-sided board.

![Diagram of Manufacturing process flow of Single-sided Flexible Circuit](image)

**Figure 3.** Manufacturing process flow of Single-sided Flexible Circuit

4.2 Phase II- Measure
In this phase, the past record of open defect from January 2020 until August 2020 was analysed and part with the highest number of open defects was chosen for this improvement project. Figure 4 shows the graph of overall trend chart for defect rate of single sided FPCB. The target of the defect rate is set at 0.5% but the actual average defect rate of the open defect is around 0.6%. The production for single-sided FPCBs for one day are 23 lot, 1 lot have 80 panel, and 1 panel have 512 pieces. So, the production volume for single sided FPCBs for one day is 942,080 pieces. Since the production volume is large so the difference of 0.1% would able to help company to save cost and improve the quality of the FCBs in the market.
Based on the calculation of yield report for open defect of five type of single-sided FPCBs, in Figure 5 it shows that the ascending order of part that have the highest Open defect were started with part 13236, 11078, 13650, 13539 and 13541. The total number of defects for part 13236 are 15127 pieces. While for part 11078 have 6717 pieces. 6363 pieces for the part 13650, part 13539 have 3778 pieces. Lastly, for the part 13541 have 3205 pieces of defect. Part 13236 was chosen for the improvement plan as the part have the highest open defect compared to others.

The trend chart in Figure 6 shows the performances of defect rate for part 13236 before the improvement stage. The blue line is the target (indicator) of Open defect that set by the company. While the red colour indicates the actual situation of defect rate. From the trend chart, the open defect percentage was always higher than the target rejects except in August due to no part running on that particular month. Manufacturing process that mainly contributed to this issue is starting from material issue until develop process. Process flow from material issue until developing process involved in this study then flow to In-Process-Quality-Control (IPQC) to record the defect rate and detect the error or defect during manufacturing process to minimize the error. It is able to detect any abnormality immediately and at the same time indicate action that needed to fix the problem.
From Figure 7 above, after the IPQC inspection, the scope of occurrence of open defect are narrow down to focus on imaging area. This is because imaging is a process of forming the circuit which is the fundamental process of FPCB, thus this project focus on imaging area compared to post treatment process which is the open defect reject that occurred after the forming of the circuit. The defect under imaging mostly has two types which is contamination and pin hole problem. The causes of contamination and pin hole caused by the exposure of glass contaminant, existing of dust particle on the panel and existing of dry film chip.

4.3 Phase III- Analysis

Twenty panels equivalent to 10240 pieces of single-sided FPCBs were evaluated on the process from Pre-treatment, Dry film lamination, exposure, develop and IPQC to figure out the process that contribute to the contamination. The process uses visual checking and IPQC. Fishbone diagram was used to figure out the root cause of open defect. The table is the record of data for checking process from process step pre-treatment, dry film lamination, exposure, developing and at the last have IPQC. The data is from 20 panel of sample that total are 10240 pcs to do analysis as depicts in Table 1 to find which area contribute to the contamination and to figure out the difference of contamination after the panel cleaning. After drilling process, visual checking was performed before the pre-treatment process, found out 16 panels out of 20 panels have contaminant that 80% of defect. Visual checking after the pre-treatment process found 0% of contamination and arrange those panel with Separator. After that, have the visual checking and 10 panels found contamination out of 20 panels which means 50% contaminated. Then, panel cleaning process and visual checking performed again and found there are 0% of contamination. At this moment, the root cause is the separator that contribute to the contaminants.
Table 1. Evaluation record for checking Open defect of 20 panel of sample

| Process          | Activity                                | Test Result                                      | Defect % | Date  | Time  | Remark                                      |
|------------------|-----------------------------------------|--------------------------------------------------|----------|-------|-------|---------------------------------------------|
| Visual checking  | before Post Treatment                   | 16 out of 20 panels found contamination          | 80%      | 9/1   | 8pm   |                                             |
| Post Treatment   | - Visual checking after post treatment  | No contamination                                | 0%       | 9/1   | 9pm   |                                             |
|                  | - Arrange panels with Separator         |                                                  |          |       |       |                                             |
|                  | - Remove Separator and Visual check     | 10 out of 20 panels found contamination          | 50%      | 9/1   | 9.30pm|                                             |
| Panel cleaning   | After panel cleaning, visual checking   | 0 contamination                                 | 0%       | 9/1   | 11pm  |                                             |
| Dry Film Lamination | After Dry Film Lamination              | 0 contamination found dent mark                 | 0%       |       |       | Panels arranged in tray/bin. Found not clean has cured dry film chips |
| Exposure         | Visual checking after exposure          |                                                  |          | 10/1  | 12.30am|                                             |
| Develop          | After develop IPQC checking             |                                                  |          |       |       |                                             |
| IPQC             | FOUND OPEN: 17 pcs                     | 0.16%                                           | 10/1     | 8am   | 17 OUT OF 10240 PCS OPEN                    |

Visual checking performed after dry film lamination process and none contamination found except for some dent mark. Before the exposure process, the panels are taken out from Bin and have visual checking. At this time, there are 11 panels found dry film chips stick on the surface of the panels, after go through the exposure process and develop process and have the IPQC checking, there are 17 out of 10240 pieces had open defect problem. Through this evaluation, the main focus is due to the separator issue that can cause contamination and also the existing of dry film chip after taken out the panel from the Bin. Figure 8 shows acceptable versus open defect board.

Figure 8. Acceptable versus open defect board
Fishbone diagram in Figure 9 is to figure out the possible cause for the contamination in every causes [9,10]. The symbol of alphabet and the bolded yellow colour are the main causes that will be focussed on implementation of the solution for reduce the contamination that led to open defect of the circuit.

This diagram shows that the effect of dirty separator for existing of contaminant. From the evaluation above, improper handle of dirty separator can cause seriously contamination problem and directly cause the open defect.

4.4 Phase IV- Improve
Fishbone diagram in Figure 10 shows that the main cause for open defect was caused by the existing of contamination, and those few types of causes from the fishbone diagram before was gathered in the action plan. For the action plan shown in Table 2, the main cause under category of method is improper cutting method. The short-term action taken after different of testing for feasibility is changing the cutting knife every three lots.
Table 2. Action plan for implementing the solution

| Defect | Category | Cause | Short term Action | Control (Standardisation) | PIC | Long term | PIC |
|--------|----------|-------|-------------------|---------------------------|-----|-----------|-----|
| Method | Improper cutting method | A | To change knife every 3 lots | Recording in first Piece Checklist | Kalai/Yaakob/Alim | To fix auto cutting machine | Yap |
| Contamination | Dirty separator | B | Implement separator cleaning by cleaning | Recording in separator Cleaning Checklist | Production (Mariappan/Sanjeev/Sim) | To fix separator cleaning machine | Tew |
| Material | Panel contamination | C | Go through panel cleaning machine | Recording in Panel Cleaning Checklist | Kalai/Yaakob/Alim | NA | - |
| | Dirty tray/bin due to dry film chips | D | Imaging PM-tray/bins cleaning | Recording in Tray Cleaning Checklist | Kalai/Yaakob/Alim | NA | - |
| Man | Exposure glass not clean every 10 cycle | E | To fix cleaning glass every 10 cycles | To record in Expose Glass Cleaning Checklist | Kalai/Yaakob/Alim | To modify machine-add in buzzer to trigger every 10 cycles of exposure | Yap |

Figure 11 shows the overall trend of open defect reject starting from January until December. The reject decrease from 0.6% to 0.3% after the improvement project. The target reject was also reduced by 0.1% which is from 0.5% to 0.4%. This is good signal as it showing that the process improved and reduced in reject trend.

Figure 12 shows that the defect rate of open defect start decrease from September after those action of improvement is taken. From overall, can conclude the improvement from the highest 0.73% on February decrease to the lowest 0.28% on December. Besides, the target of open defect also reduces from average 0.5% to 0.4%.
Figure 12. Open Defect Reject Rate Before and After Improvement Project for Part 13236

Figure 13. The cost saving before and after improvement and forecasting for future cost saving

The Figure 13 above show the trend of improvement of the part 13236. The part that has open defect from the highest 3836 pieces in April decrease to the lowest 907 pieces in December and forecast the reject rate will keep decrease with the improvement plan implementation in place. Besides, in term of cost also there is cost saving recorded from -RM255.9392 in January increase to RM853.33 in December.

4.5 Phase V- Control

This stage is to ensure the action plan in improve phase is able to maintained and implemented. The aim of this phase, it is necessary to standardize and document procedures, make sure all the employees are trained and communicate the project’s result. In this phase, One Point Lesson (OPL) or Attention Note is created. OPL is a simple operational tool used to educate operators in a company and help to improve the quality of the product and service quality. The main uses of OPL are achieving single standard of work among operators and shift. The next is to develop a detail learning of the process, machine and line for the worker. The second thing will conduct in this phase is will create a new work instruction of tray cleaning procedure and separator sheet cleaning procedures. Work instruction are developed to guide operator in four key areas which is training, reference, problem solving and continuous improvement. Besides, a checklist was prepared to record which shift of the operator in charge on the process of checking the condition of separator. This is to ensure the daily, weekly and monthly tasks was performed effectively.

RoHS is meant to restrict the way that certain substances are used in electronic products. These include lead, cadmium, mercury, hexavalent chromium and other heavy metals, as well as similar elements that can be hazardous to human health and the environment. Figure 14 is
the Work Instruction (WI) created for tray and separator cleaning work station. With the WI, despite new operator or experienced operator will be able to perform the cleaning process using the right method.

![Figure 14. Work Instruction of Separator Sheet Cleaning Procedure](image)

**Figure 14. Work Instruction of Separator Sheet Cleaning Procedure**

![Figure 15. Checklist for condition of separator](image)

**Figure 15. Checklist for condition of separator**

5. **Conclusion and Recommendations**

The purpose of this study is to improve the performance of business by reducing open defect of the single-sided flexible printed. All the improvement process was done by using the Lean Six Sigma DMAIC technique. Six Sigma is powerful and useful methodology to oppose quality related problem and to achieve customer satisfaction. The Six Sigma approach is customer driven. The target for six sigma approach for a company is continuous improvement
in all process within the organisation. The benefit of lean six sigma approach are reduction in defects, work in progress, cycle time, improvement in customer satisfaction, productivity and increase in product quality. In this research, the main focus for improvement is open defect of manufacturing process which involved various phases namely material issue, drilling, pre-treatment, dry film lamination, exposure and developing process. Some control method such as work instruction and checklist are created as a control for the improvement. Contributions from this study is that Part 13236 that have the highest defect rate decrease from 0.68% to 0.28% while the overall open defect decrease from 0.6% to 0.3%. The decrease on the defect rate of product can help company to improve the effectiveness and efficiency of business performances and also results in the total accumulated saving cost of RM853.33. This helps the company to increase the profit margin in the long term. As for the suggestion for future study, the company can use Poka Yoke method of the cleaning process of the separator for Non-RoHs and RoHs separator, to improve and maintain the performances of the product. Next recommendation is the company should give training to the supervisor, operator and technician related to their job scope and position. Well trained employees will be able to perform their job effectively and efficiently.

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