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The Application of DMAIC to Improve Production: Case Study for Single-Sided Flexible Printed Circuit Board

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Abstract. In this study the DMAIC (Define, Measure, Analyse, Improve and Control) technique is applied at a company producing Flexible Printed Circuit Board (FPCB) in Malaysia. It is an initiative for continuous improvement by the company. The aim of the study is to reduce the number of open defects during the production of the single sided FPCB which has substantial impact on the profit margin of the company. The study examines one of the production line which has the highest defect rate. The study has utilised the Six Sigma tools such as brainstorming, process mapping, fish bone diagram, Pareto chart and control charts. From the analysis, it is found that the major contributor to the open defect problems are contamination of the separator during production. The causes of the contamination were identified and action plans were implemented. These actions have resulted in an overall reduction of defect rate and cost saving for the company. For the duration of the study, the overall defect rate for the particular line was reduced from 0.6% to 0.37% with a total saving of RM 1423.60. The case study showed that DMAIC process is an effective approach that can solve what seems to be a major problems using simple solutions. If conducted properly and efficiently, it has the potential to give good returns to the company.

1. Introduction and Background

Manufacturing company all around the world are facing the turbulent economic condition which include global competition, customer demand for high quality product and reduced in lead time. To remain competitive companies are continuously looking for ways to reduce production cost, enhance productivity and improve product quality. In response to these needs, companies need to have improvement strategies that utilise the available resources efficiently and effectively [1]. Many leading companies are leveraging on lean tools and techniques to enhance productivity and quality performance. One of the widely used performance strategy improvement is the utilisation of Six Sigma. Six Sigma efforts are directed towards the minimisation of waste and non-value added activities (NVA) and maximising customer satisfaction. Six Sigma drives on substantial improvement to the bottom line by designing and monitoring everyday business activities [2]. The DMAIC Six Sigma has the potential to realise cost savings and improved quality on the shop floor [3]. The DMAIC methodology follows the phases of: define, measure, analyse, improve and control. The Six Sigma DMAIC process is an improvement system for existing processes falling below specification and looking for incremental improvement. Although, the DMAIC stage model is a structured problem solving device, with the original task of variation reduction, the method are now popular for more general tasks, such as quality improvement, efficiency improvement, cost reduction, and other pursuits in operations management, and beyond manufacturing in services, healthcare, and other types of operations [4].

The Japanese word 'Muda' meaning waste is referred to the human activities that exploit the resources in the company but does not create any profit or value. This concept of 'Muda' in the

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manufacturing industry was presented by Taiichi Ohno, a Toyota executive [5]. In particular, he defined seven classes of waste that typically affect a manufacturing process:

Table 1. Seven Waste of Lean Manufacturing

Types of waste	Explanations
Over processing	Adding more value to a product than the customer actually require such as painting area that will never be seen or be exposed to corrosion.
Waiting	It is the act of doing nothing or working slowly whilst waiting for a previous step in the process. How many times you seen operators stood waiting for a previous operation, a delivery products to arrive or just slowly working for lengthen the time since run out of material.
Transportation	It is the movement of products from one location to another. Eg: This could be from the machining shop to the welding shop, or from the production facility in china to the assembly line in America. This transportation add no value to the product.
Inventory	Is the raw materials, work in progress (WIP) and finished goods stock is held, we often hold far more than is required to produce goods and services when the customer wants them using Just In Time (JIT).
Motion	Waste being a process step that is not value adding, moving is not necessarily working. The main causes of the waste of motion are with regards to cell layout, placing product at floor level on pallets, poorly arranged space, tools that are disorganized, lack of space and organization for component parts and so on.
Defect	Defect are when products or service deviate from what customer requires or the specification. Defect can be cause by many kind of problems, some should be avoidable with a little thought when designing the product, non-standard operation, different in the way that processes are undertaken by different operator on different shift.
Overproduction	Overproduction is making products in too great a quantity or before it is actually needed leading to excessive inventory.

In this project, DMAIC (Define- Measure- Analysis- Identify- Control) tool is utilise at the production floor. DMAIC is a very structured approach with a very detail analysis process of implementing the improvement. DMAIC also provides a business road map for solutions. This helps the business to solve the problems from the start of the manufacturing process till finish while producing bottom line results. Besides, DMAIC also support an analytical approach, allowing the business to use the collected data. This help the business ensure the accurate baseline. This paper aims to investigate the non-value added activity and waste of the single sided flexible Printed Circuit Board process using DMAIC. The aim is to reduce open defect from 0.5% to 0.4% by end of December 2017 and to propose a standardise documentation for the control of the open defect for the single-sided flexible circuit board.

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2. DMAIC methodology

DMAIC is a closed-loop process, which aim to eliminate those non-value added step and focus on new measurements and applies technology for continuous improvement [6]. Figure 1 shows the DMAIC methodology.

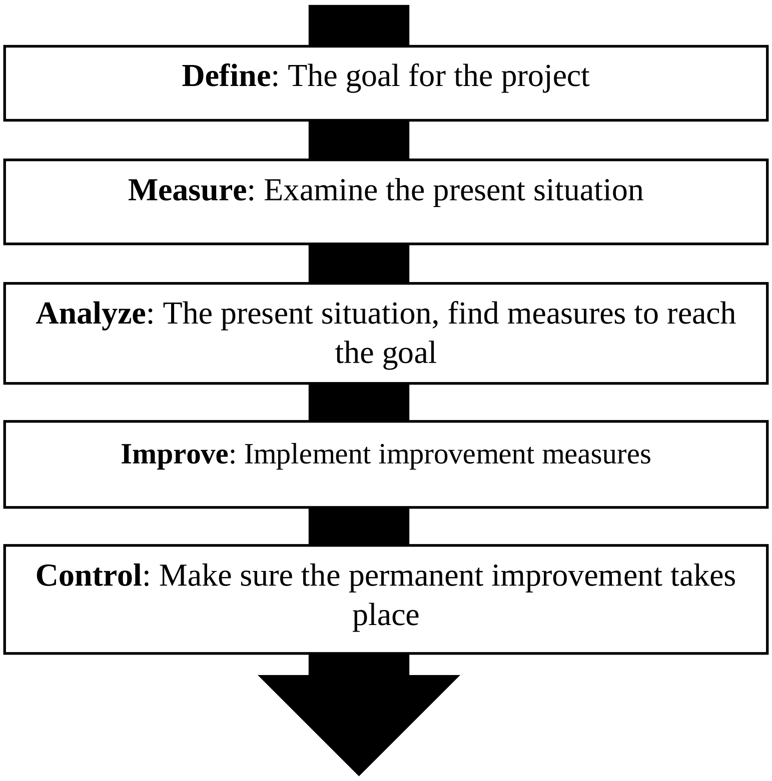

Figure 1. DMAIC methodology

DMAIC is regulated under five phases [7-8] as:

1. Defining the goal and its requirements: Identifying the problem which needs a solution and ends with understanding the issues.
2. Measuring the current process: Understand all the processes in organization, customers' expectations, suppliers' specifications and identification of the possible places where a problem may occur
3. Analysing the results of measurements, determining the causes of process imperfections and possible solutions for them: confirm the analysis some samples should be performed and potential problems have to be proven to be real problems.
4. Improving the process, implementing the changes, which eliminates the imperfections: to take necessary information to create and develop an action plan in order to improve the functioning of the organization, financial aspects and customer relationship issue.
5. Controlling of the improved process, monitoring the results in a continuous way: controls the future state of the process in order to minimize deviation from the objectives and ensure that the correction is implemented before it would have bad influence on the result in the process.

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3. DMAIC Implementation at Case Study Company

The DMAIC methodology is performed via the Roadmap of DMAIC as shown in Figure 2.

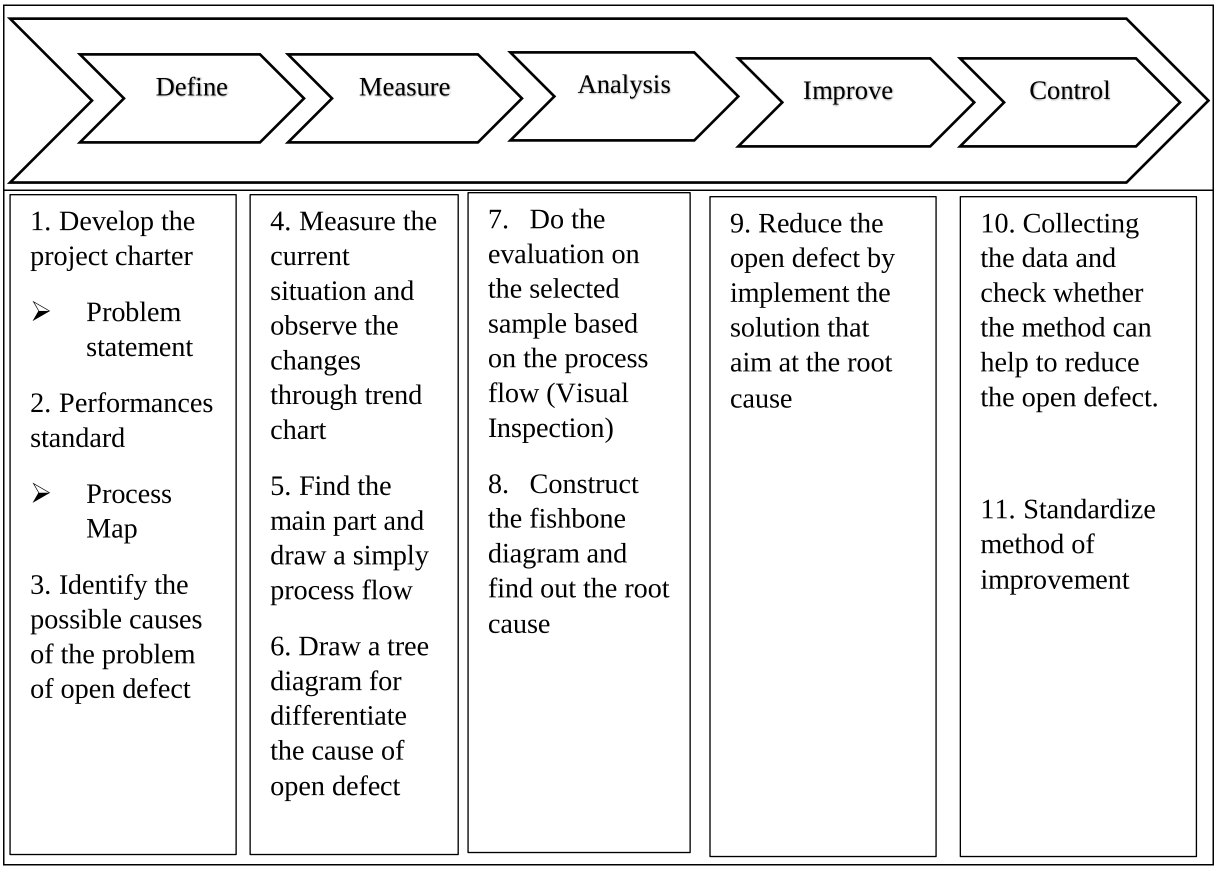

Figure 2. Process roadmap of DMAIC

Define Phase

When implementing the Six sigma DMAIC approach, the most important thing is to define the scope of the problem. The production line that has the highest number of defect was chosen for process improvement. Firstly, a project charter was developed. The project is led by the project manager and the team member consists of line leader and six team members. The smart goal of the project was to reduce open defect from 0.57 % to 0.4 % by end of December 31st 2017 with start date of July 1st during this stage, to further understand the process, Gemba walk was performed. Figure 3 shows the process flow of the production of the single sided FPCB.

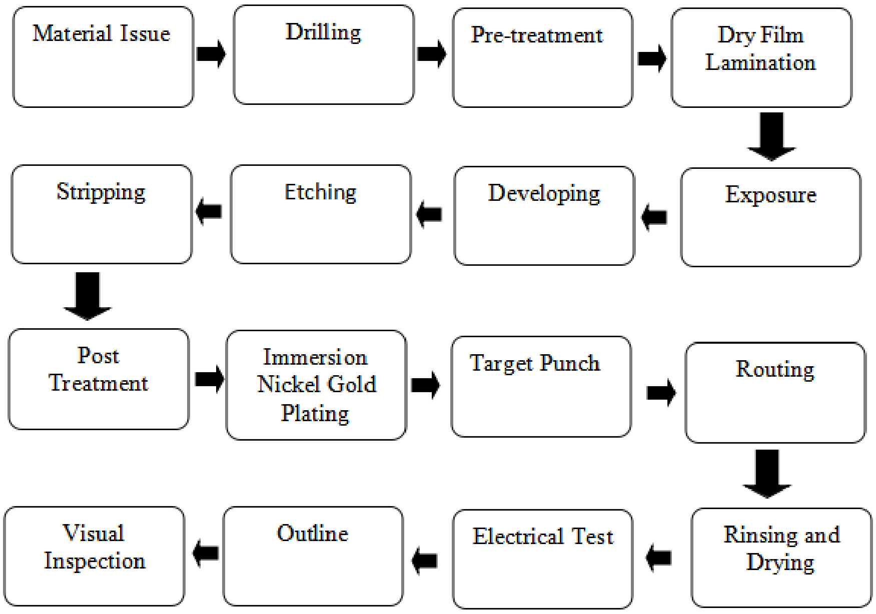

Figure 3. Process flow of the manufacturing process of single sided

Measure Phase

In this phase, the performances of the manufacturing process of single-sided FPCBs for the past 8 months is analysed using the Visual Inspection Report. The overall trend chart was plotted and shown in Figure 4.

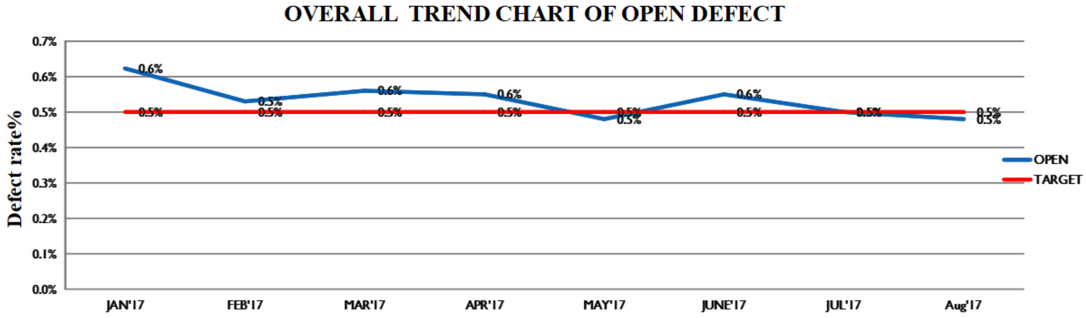

Figure 4. Graph of Overall Open defect of Single-sided FPCBs (Day &Night Shift) for January 2017- August 2017

From the graph, the rate for target of the defect is set at 0.5% but as we can see from the graph the average defect rate of the open defect is around 0.62% from January 2017 till August 2017. The production for Single-sided FPCBs for 1 day is 23 lots, 1 lot have 80 panels, and 1 panel have 512 pieces. So the production volume for Single sided FPCBs for every month is round 28262400 pieces. It is interesting to note that, since the production volume is large so the difference of 0.1% can help company save cost and improve the quality of the FPCB.

Based on the calculation of the yield report for open defect of single-sided FPCBs from January 2017 until August 2017, a Pareto chart was plotted as shown in Figure 5. Part 13236 is chosen as the main focus on reducing the rate of open defect. Then, the trend for the performance of the open defect rate for part 1326 was plotted as shown in Figure 6.

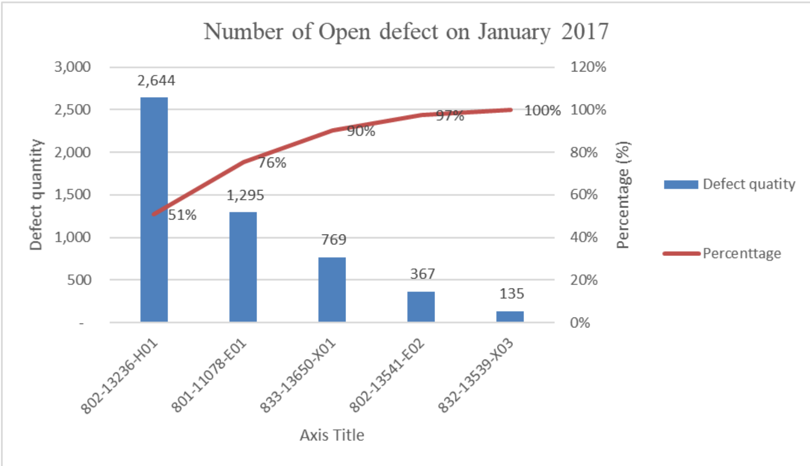

Figure 5. Pareto chart of Open defect for 5 types of single-sided FPCs for January 2017

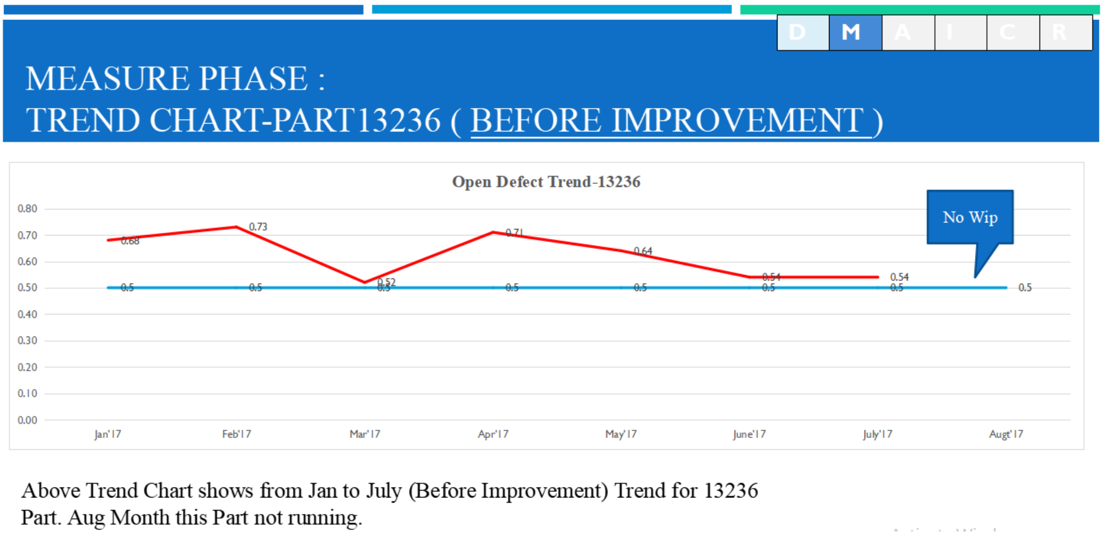

Figure 6. Trend chart of Open defect for parts 13236 for January 2017

The trend chart of Figure 6, shows the performances of defect rate for part 13236 from January 2017 to August 2017. The straight line is the target (indicator) of open defect that is set by the company. Whilst, the fluctuating line indicates the actual situation of defect rate from January 2017 until August 2017. The fluctuation of the data, shows that the process is not stable. Hence, these process can be further improved.

In the next step, process mapping for part 13236 was performed and presented in Figure 7. Process mapping is one of the most effective tools for the improvement of production and business performances. Mapping the process can help the team to identify each step in the process, help in selecting what to measure, and where (and how) to focus on actual process. Besides, process mapping also helps to visualise the process. In this project from the 17 activities, we will focus on the first 7 activities as shown in Figure 6. The In Process Quality Check (IQPC) activity is able to detect any error of abnormality during manufacturing process. The number of defect at every process from activity 1 to 6 were recorded and results from July 2017 to Oct 2017 are as shown in Figure 6. It is observed that the Open defect of the circuit for part 13236 have 2 main causes; problem of contamination (0.57%) and pin hole (0.53%). Since, contamination problem has a higher percentage of defect, thus this project would focus on problem of contamination.

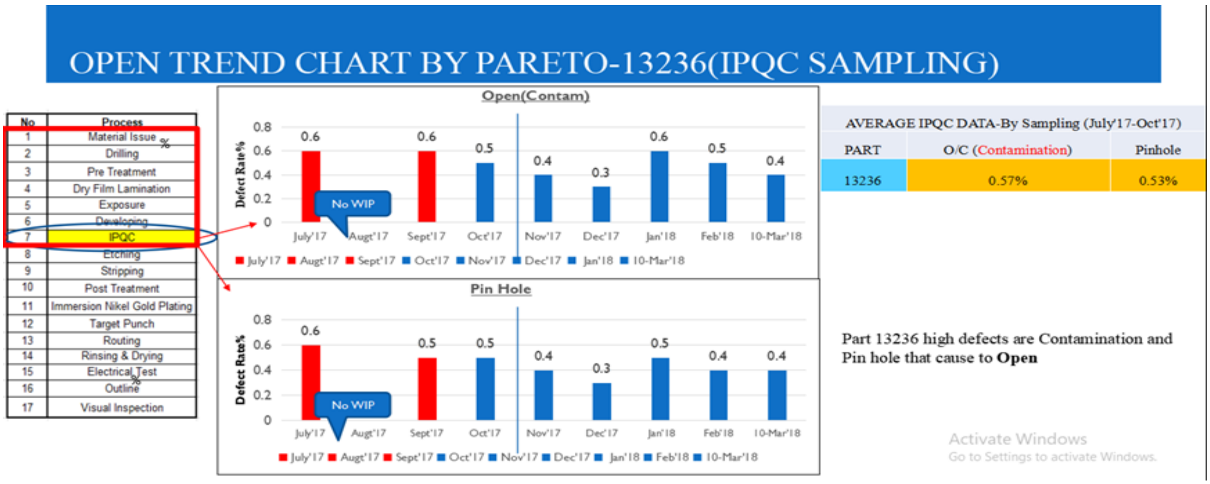

Figure 7. The process mapping and the IQPC results

Analyse Phase

The evaluation is conducted on 20 panels (10240 pieces) of the single-sided FPCBs. The process includes Post treatment, Dry film lamination, exposure, develop and IPQC. From this evaluation we can identify the processes that are contaminated. The process uses visual checking and IPQC (In-Process-Quality-Control). Table 2 shows the results of the evaluation.

Table 2. Evaluation record for checking open defect of selected 20 panel (sample)

Process		Activity	Test Result	Defect %	Date	Time	Remark
		Visual checking before Post Treatment	16 Pnls found contamination out of 20 panels	80%	9/1	8pm	
Post Treatment		-Visual checking after post Treatment -Arrange panels with Separator	No contamination	0%	9/1	9pm	
		-Remove Separator and Visual check	10 panels found contamination out of 20 panels	50%	9/1	9.30pm	
	Panel Cleaning	After panel cleaning, visual checking	0 contamination	0%	9/1	11pm	
Dry Film Laminatio n		After Dry Film lamination, visual checking	0 contamination, found dent mark	0%			Panels arranged in Tray/bin. Found bin not clean –has cured dry film chips
		Before exposure panels taken out from Bin, visual checking	11 Panels found dry film chips stick on Panel surface	55%	9/1	11.30pm	
Exposure		Visual checking after Exposure			10/1	12.30am	
Develop		After Develop IPQC checking					
IPQC			FOUND OPEN: 17pcs	0.16%	10/1	8am	17 PCS OUT OF 10240 PCS OPEN

From Table 2, it is seen that after drilling process, the visual checking results before the post treatment process, established that 16 panels (80%) out of 20 panels were contaminated. After the post treatment process, the visual checking results found 0% contamination and the panels were arranged with the separator. After visual checking, it was found that 10 (50%) panels were contaminated. The panels were cleaned and visual checking found that no panels were contaminated. The separators were identified as one of the causes of contamination. The 20 panels were arranged back in the Bin for the next process. Before the exposure process, the panels were taken out from Bin and visual checking was conducted. Dry film chips stick was found sticking on the surface of 11 panels. All the panels underwent the exposure process and the developing process and IQPC checking was conducted. It is found that 17 out of 10240 pieces have Open defect problem. From this evaluation, the contamination that occurs at the separator is the main issue that needs to be addressed.

Brainstorming session was conducted to demine the main causes of the contamination at the separator. There were many possible causes of contamination at the separator and they are described in a fishbone diagram as shown in Figure 8.

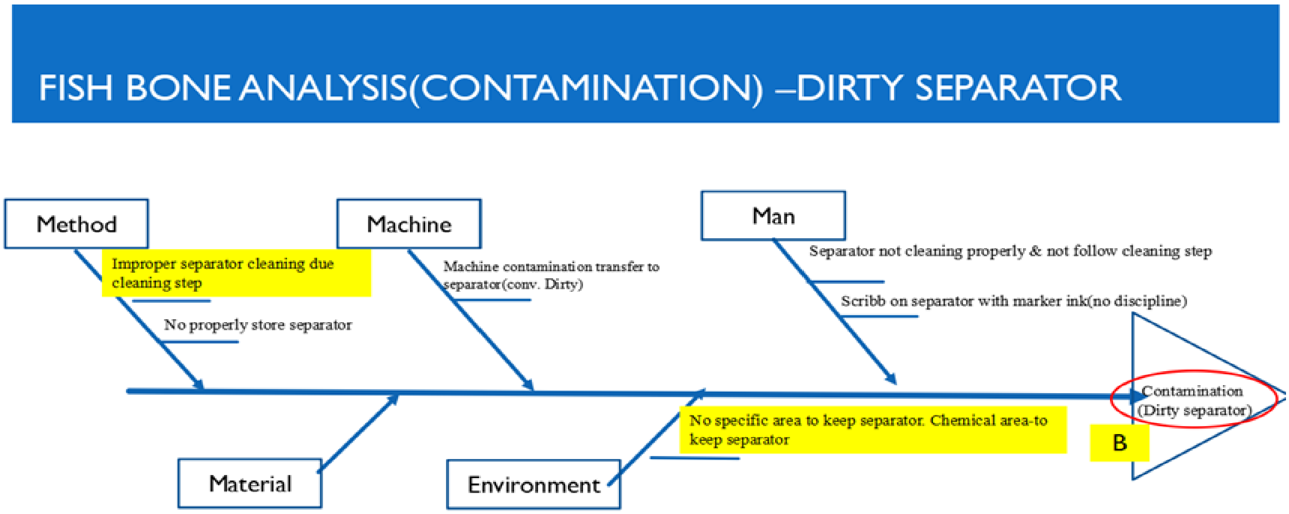

Figure 8. The fishbone diagram for causes of existing contamination at the separator

Improved Phase
The next step is to determine the action that needs to be taken to reduce the open defect due to contamination of the separator. All the group members especially those who have experience in the manufacturing process in FPCBs identified possible improvement actions, prioritize them, tested the improvements, and finalize the improvement action plan. Table 3 shows the action plan that were implemented by the group. Based on the identified root causes, suitable improvements were proposed. A structured improving effort can lead to innovative solution that can improve the baseline measure. Figure 10 shows the improvement with a substantial decrease in defects with highest in February 2017 to the lowest in February 2018. The overall open defect has decreased from 17781 units (0.6%) in January 2017 to 4766 unit (0.37%) in January 2018. Whilst part 13236 which has the highest defect also decreases from 2644 units (0.68%) to 132 units (0.26%). Besides, the setting target was reduced from 0.5 % to 0.4 %. The accumulated cost saving for the company from September 2017 till March 2018 is RM 1423.60. This is as shown in Figure 10.

Table 3. Action plan for implementing the solutions

IMPROVEMENT :
ACTIONS PLAN TAKEN

D M A I C R

Defect	Category	Cause	Short term Action	Control (Standardisation)	Date Start	PIC	Long term Action	PIC	Date
Contamination	Method	A Improper cutting method	To change cutting knife every 3 lots	Recording in First Piece Checklist	4-Oct'17	Kalai / Yaakob/ Alim	To fix auto cutting machine	Yap	2nd week Mar'18
	Material	B Dirty Separator	Implement separator cleaning by daily	Recording in separator cleaning Checklist	12-Oct'17	Production (Mariappan/ Sanjeev/Sim)	To fix separator cleaning machine	Tew	TBA
		C Panel Contamination	Go through panel cleaning machine	Recording in Panel Cleaning Checklist	6-Sept'17	Kalai / Yaacob/ Alim	NA	-	
		D Dirty Tray/Bin Due to dry film chips	Imaging PM – Tray/Bins cleaning by weekly	Recording in Tray Cleaning Checklist	14-Oct'17	Kalai / Yaacob/ Alim	N/A	-	
	Man	E Exposure glass not clean every 10 cycle	To fix cleaning glass every 10 cycles	To record in Expose glass cleaning checklist	22-Jan'18	Kalai/Yaacob/ Alim	To modify machine- add in buzzer to trigger every 10 cycles of exposure.	Yap	End of Mar'18

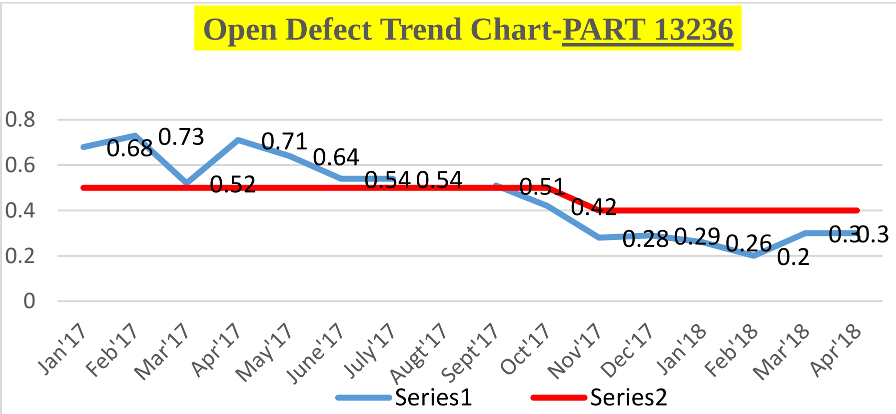

Figure 9. Open trend chart of part 13236

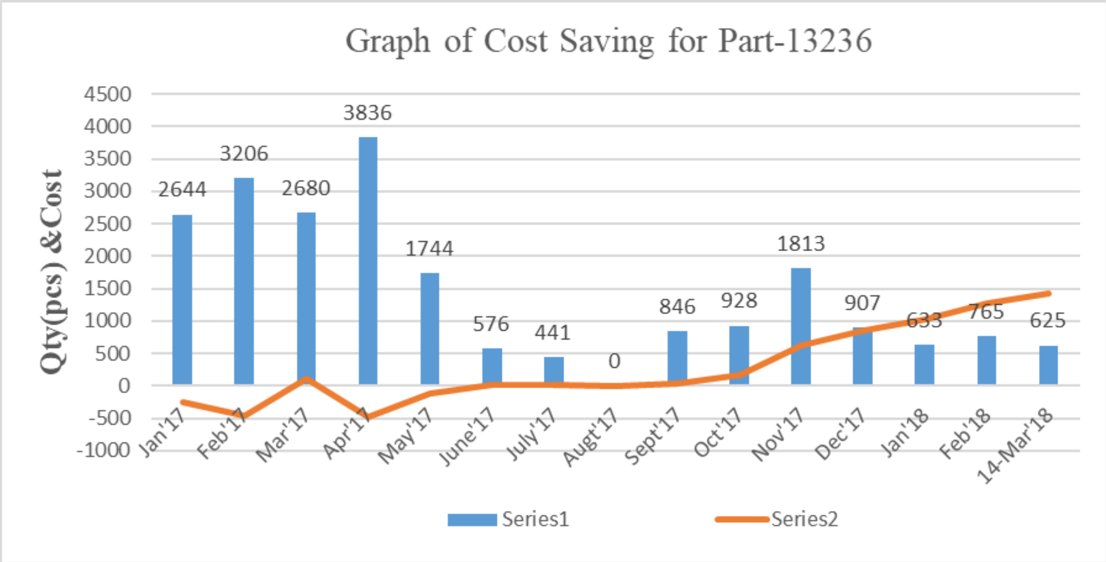

Figure 10. Graph of the cost saving from January 2017 until March 2018

Control Phase

In the phase, we need to ensure that the full-scale implementation of the improvement action plans are carried out. Controls need to be set up controls to monitor the system so that gains are sustained. Specifically, in this phase, a new work instruction was created for separator sheet cleaning procedures. Work instruction are develop to guide operator in 4 keys areas that are training, reference, problem solving and continuous improvement. A check list needs to be prepared to record the operators who are in-charge on the process of checking of the condition of separator. This can help supervisors, identify operators that need to be given more trainings.

In this phase, one point lesson (OPL) or Attention Note was created. OPL is a simple operational tool used to educate operators in a company to help to improve the quality of the product and service quality. The main aim of OPL is to achieve the similar standard of work among operators and shift. Detailed working procedures would be provided so that it can be a guideline for the operators. This is necessary as some improper production processes would be eliminated and some new procedures or steps are introduced. Operators that are more familiar with the old process steps may need some times to fully follow the new changes. A control plan was also provided to monitor the ongoing performance using statistical tools. This is to monitor the stability of the new process.

4. Conclusion

DMAIC technique is a strategic tool to improve the business performance by improving the manufacturing or operation process through effective application of both statistical and non-statistical tools/techniques. The study has demonstrated that the widely promoted DMAIC technique is able to improve the performances of case study company and achieve customer satisfaction. As overall, the defect rate has decreased whilst it has also deliver cost savings to the company. The DMAIC is an excellent continuous improvement technique that will succeed if supported by top management. However, companies need to train staff to conduct DMAIC as projects chosen for implementing DMAIC need to justify the investments, time and effort put into the project. If conducted properly and efficiently, it has the potential to give good returns to the company.

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