# NON-WETTING DEFECTIVE REDUCTION IN PRINTED CIRCUIT BOARD ASSEMBLY PROCESSES

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# การลดของเสียตะกั่วหลอมละลายไม่สมบูรณ์ในกระบวนการผลิตแผงวงจรอิเล็กทรอนิกส์

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According to the company's current situation, the case study company has been encountered with a large amount of non-wetting defects within the production process leading to a higher defect rate and cost over a several years. Therefore, this research is aimed to reduce non-wetting defective rate of location L7 on PCBA during Surface Mount Technology (SMT) process by applying Six Sigma DMAIC methodology accompanying with quality control tools and focus on experimental design. There are separated into five significant phases. The first is Define phase, which related to the studying of current process of manufacturing PCBA and also gathering historical data of defects for one year in order to use as a basic data to analyse in this research. Moreover, this phase is also set scope of the research and the purpose. The second is Measure phase that is brainstorm to find factors affecting non-wetting defect by using cause-and-effect diagram. In addition, using cause-and-effect matrix to prioritize the factors. Attribute Agreement Analysis (AAA) also has been applied to determine the accuracy and precision of the operators in order to judge the non-wetting defect. The third is Analyse phase which is mainly related to applying Design of Experiment (DOE). This research has been applied full-factorial with centre points design to test the significance of selected factors and find the optimal setting parameters. Then, conduct experiment and collect experimental data. Analyse the results of experiment and

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Nitcha Sangkhapanit

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# Chapter 1

# Introduction

This chapter provides an overview of this research that is composed of the current state of Thailand’s Electronics industry. Following by a brief background of the studied company used as a reference for case study. In addition, the problem statement, research objective, research scope, expected outcomes, expected benefits and research methodology will be shown in this chapter.

## 1.1 The Current State of Electronics Industry in Thailand and Global markets

Nowadays, it is inevitably accepted that product of electronics assembly has been a part of almost every technological stuff in which people are using. For example, smart phones have a Printed Circuit Board Assembly (PCBA) which is used to control and operate following any program order. Moreover, computers also need to have main board in order to perform and evaluate data owing to each user. Besides, medical devices in nowadays have been applying the latest technology using for treating the patient to recover and retreat such as Insulin pump, which is used to balance insulin level in diabetes patient by using a PCBA to automatically control and measure the level of insulin. Therefore, it can be stated that PCBA is used as a key component in various manufacturing industries i.e. household devices, gadget, automotive electronic, electric appliances and etc. As a consequence of this various demand for electronics products, it can be stated that electronics industries are important to everyone’s life in order to support people to have better lives.

Recently, there is a report regarding to electrical and electronic manufacturing market in 2017, which stated that electronics industry is expanding throughout the global market and it is expected to reach three trillion dollars by 2020. Moreover, the report also states the first five trends for the upcoming five-year forecast period in the electronics industry. The first is related to Original Equipment Manufacturer (OEM) which is mentioned in the above. There is an increase in OEM and also Electronic Manufacturing Service (EMS) which are partners of OEM. EMS companies are design services for assemblies and finish goods (FGs) to serve the requirement of OEM and more importantly for customer. The second is virtual reality in electronic manufacturing. This trend is created for the electronics companies that would like to see some simulation prior to decide for making orders. The third is about robotics and automation, which are mostly used in automotive industry. It is mostly used for productivity to reach high target in a short period of time with the highest accuracy. Next, demand for smart TVs. This is a combination between televisions and computers which use complicated PCBAs to control every function such as for integration of internet. In addition, there is a rise trend of using smart TVs and it is estimated to reach 134 million by 2020. Lastly, Internet of Things (IoT) technology driving smart household appliances. This is related to electronics household devices such as smart TVs, refrigerators, air conditioners, microwave, ovens, washing machines, and etc. By using IoT technology, it will make clients lives more comfortable and convenient. (Sindhu, 2017)

Most electronics industry in Thailand is considered to be Original Equipment Manufacturer (OEM) which produces parts or finish goods (FGs) to supply Value-Added Reseller (VAR). VAR is usually a customer that defines need and specifications of the products to OEM. Therefore, there are many competitors of electronics industries that try to compete over others in terms of profit, quality, and also production quantity.

Additionally, Thailand’s smart electronics industry has been continuously evolved over the past five decades and Thailand was ranked in the 14th largest electrical and electronics (E&E) exporter in the world in 2016. The E&E export revenue was reach USD 55 billion in 2016 as indicated in Figure 1. Furthermore, Thailand’s export value of E&E was accounted for 15% of Thailand’s total export value.

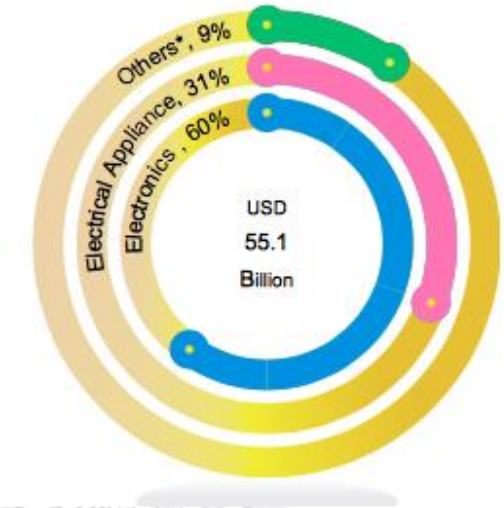


**Figure 1:** Electrical and Electronics (E&E) export values in 2016
Source: Thailand Board of Investment (2017)

In Thailand, there are many types of electronics industries. For instance, (i) hard disk drives which have the highest market shares of electronics devices in Thailand, (ii) Integrated circuits (ICs) manufacturing comes in the second place, (iii) Electrical appliances such as air conditioners, cameras and parts, refrigerators, circuit breakers, washing machine, (iv) medical devices which will be focused in this research. Medical devices are gradually growing on the world markets, partly due to rapidly growing of population and mostly become in elderly aged; thus, medical devices play an important role for life essentials for people. As stated by Krungsri research (2018), there is an increase trend of the global sales of medical devices in 2010 – 2016 as seen in Figure 2. The total values of the global market between imports and exports of medical devices in 2016 were THB 71.13 trillion with an average growth rate at 3.8%.

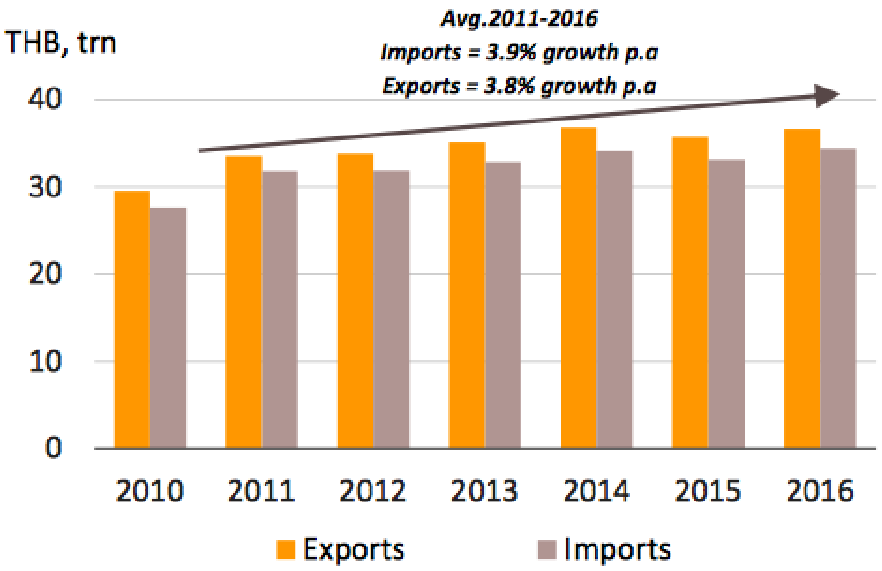


**Figure 2:** Global Sales of Medical Devices
Source: Medical Device Intelligence Unit (MeDIU)

Referring to Krungsri research (2018), the ASEAN top 5 markets for medical devices in 2016 is illustrated in Figure 3 and it can be stated that Thailand has the highest amount of market shares of medical devices sector, with export and import value split in the ratio of 73:27, following by Singapore, Malaysia, Indonesia, and Philippines.

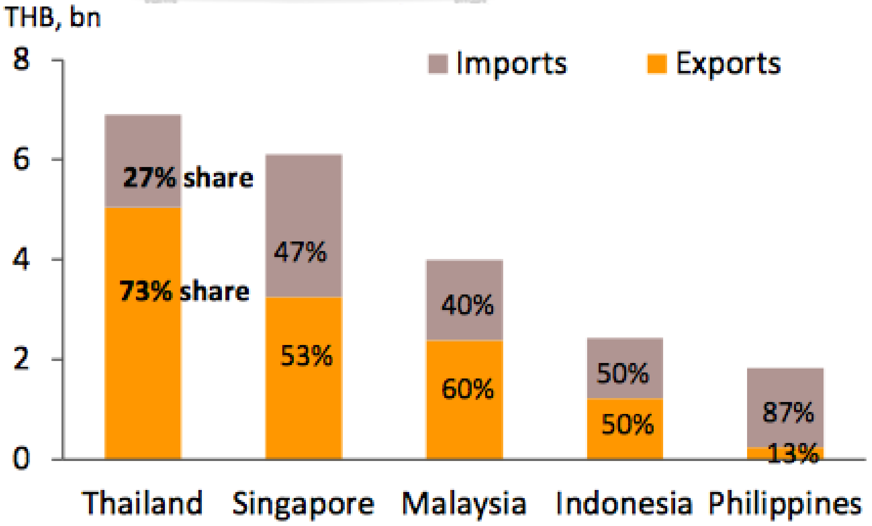


**Figure 3:** ASEAN Top 5 Markets for Medical Devices (2016)
Source: MeDIU

Thailand's forecast an average growth of 9.5% increase in year on year (YoY) by sales and exports of medical devices (Figure 4). It will also depend on the government's policies, demand and supply growth.

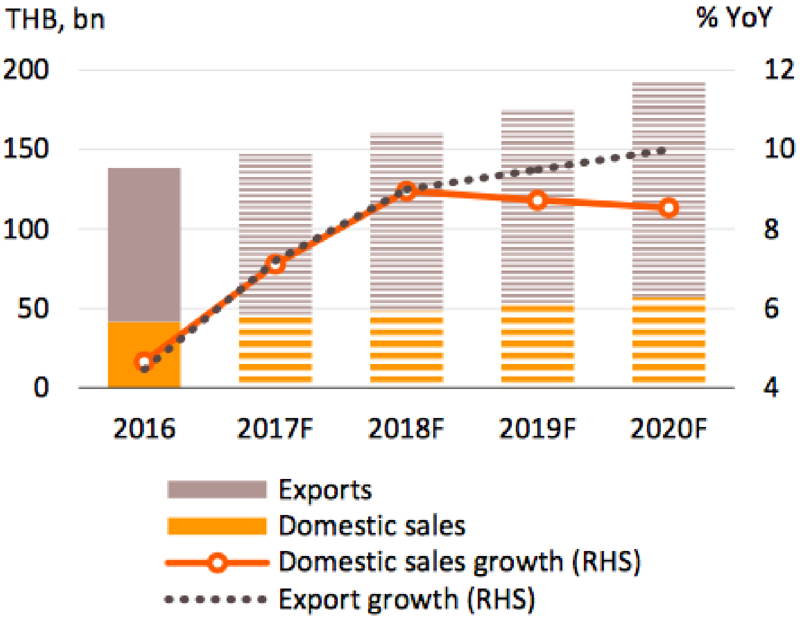


**Figure 4:** Thai Sales and Exports of Medical Devices
Source: Business Monitor International (BMI)

As continuously increase in the demand of electronics product, a consequence of the rapid consumption of electronics is the massive amount of electronics waste of both final devices and in-process manufacturing. Nowadays, electronics waste is estimated to be 64,400 tonnes per year, but in the first five months of 2018, the amount of electronics waste has already reached 52,200 tonnes (Bangkok Post, 2018).

In order to reduce electronics waste of work-in-process manufacturing, process improvement is necessary applied to control waste that might be occurred during the production process. This will also decrease operating cost by reducing non-value added which mainly is defect. Therefore, this research will focus on the reduction of defects in Printed Circuit Board Assembly (PCBA) process so as to enhance company productivity.

## 1.2 Company Background

According to electronics industries in Thailand, there are many manufacturing companies based mostly on the central part of Thailand such as Ayutthaya and Pathumtani provinces. Generally, as the demand of the electronics assembly increases, resulting in a massive production and finally effect to a high number of defect rate. For the chosen company, which mainly manufacture medical devices of PCBA in which mainly deliver to abroad such as the United State of America and Japan. As the production quantity continuously rises together with the demand; thus, the case study PCBA need to be immediately improved in order to serve the essential demand with a full percentage of good product. As a consequence, this PCBA will be selected to be the case study of improvement.

The case study company is located in Ayutthaya, Thailand and was established in 2002. There are several types of PCBA applications by the case study company, which shown in Table 1.

**Table 1:** Case Study Company's Product

| Type of PCBA applications | Characteristic |
|---|---|
| Medical devices | Appliance used specifically for diagnosis, prevention, monitoring, treatment, or alleviation of disease purposes and intended to be used for human beings |
| Telecommunications | Transmission of signals, messages, sounds, images or any information by using wire, radio or other devices and it will transfer information from one place to another place |
| Aerospace device | Device used for aerospace field |

## 1.3 Problem Statement

As mentioned earlier, a case study company is encountered with high defect rate during production processes. Thus, the historical data of the PCBA has been collected through one year from November 1st, 2016 to October 31st, 2017.

The historical data gathered included the number of outputs, number of defects, and defect rate. It can be calculated the percentage of defect rate by applying the following equation;

$$\text{Defect rate} = \frac{\text{Number of Defect (ea)}}{\text{Total output (ea)}} \tag{1.1}$$

$$\text{Percentage defect rate} = (1.1) \times 100\% \tag{1.2}$$

It can be seen in Figure 5 of defective quantity for one year of the PCBA which the study company is facing. It indicates that defective rate was quite high and approximately an average of 10%. The lowest defective rate was at 5% whereas the maximum defective rate was at 17% of total productions over one year.

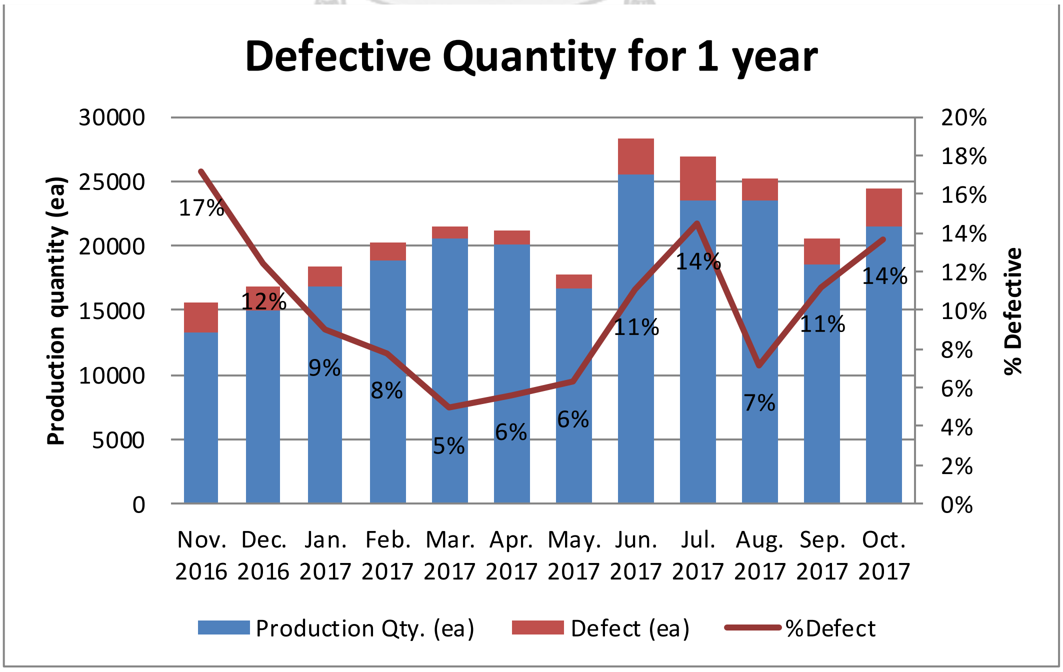
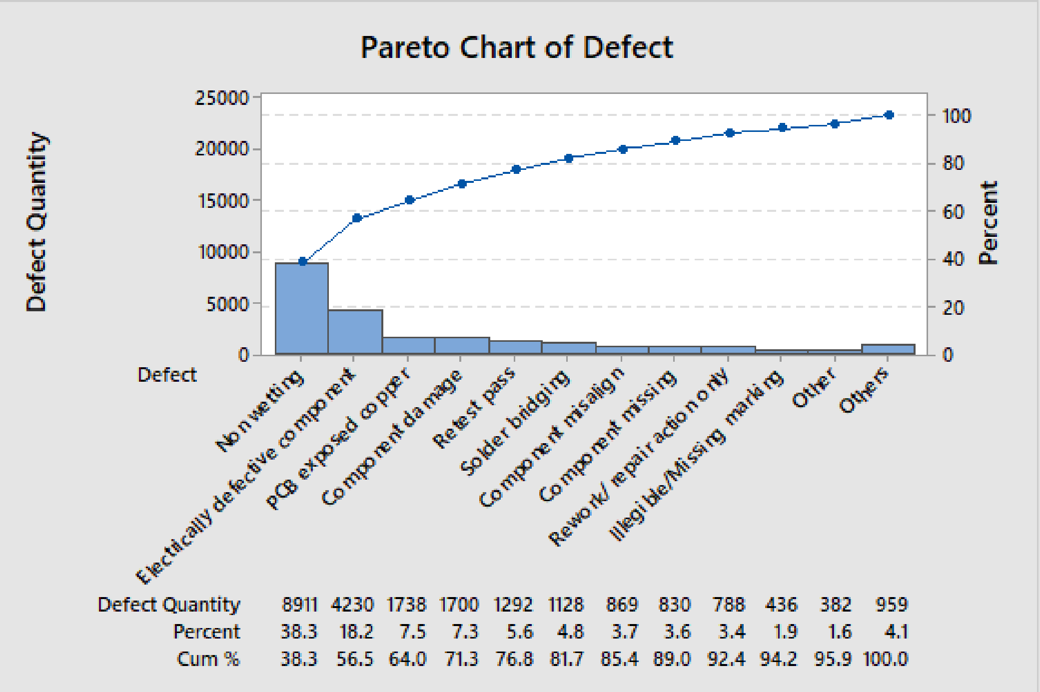


**Figure 5:** Defective quantity for 1 year of PCBA

Focusing on each station of SMT and TLA processes, found that the highest defective rate was Non-wetting defect in which consume 38.3% of total defective quantity over one year operation as illustrated in Figure 6, Pareto chart of defect code. Non-wetting is described as the inability of melted solder to form a metallic bond with the base metal. Thus, component terminal joints/ leads are not able to attach with the base metal or PCB pads during reflow soldering process. Follow by defect codes of electrically defective component, PCB exposed copper, component damage and etc.



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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Defect Quantity | 8911 | 4230 | 1738 | 1700 | 1292 | 1128 | 869 | 830 | 788 | 436 | 382 | 959 |
| Percent | 38.3 | 18.2 | 7.5 | 7.3 | 5.6 | 4.8 | 3.7 | 3.6 | 3.4 | 1.9 | 1.6 | 4.1 |
| Cum % | 38.3 | 56.5 | 64.0 | 71.3 | 76.8 | 81.7 | 85.4 | 89.0 | 92.4 | 94.2 | 95.9 | 100.0 |

**Figure 6:** Pareto chart of defect of PCBA

In addition, considering at the total production quantity as indicated in Figure 7 below. It can be seen that good production of PCBA is 90.1%, while non-wetting defect was estimated at 3.8% of total production. Follow by electrically defective component (1.8%), PCB exposed copper (0.7%), and component damage (0.7%), respectively.

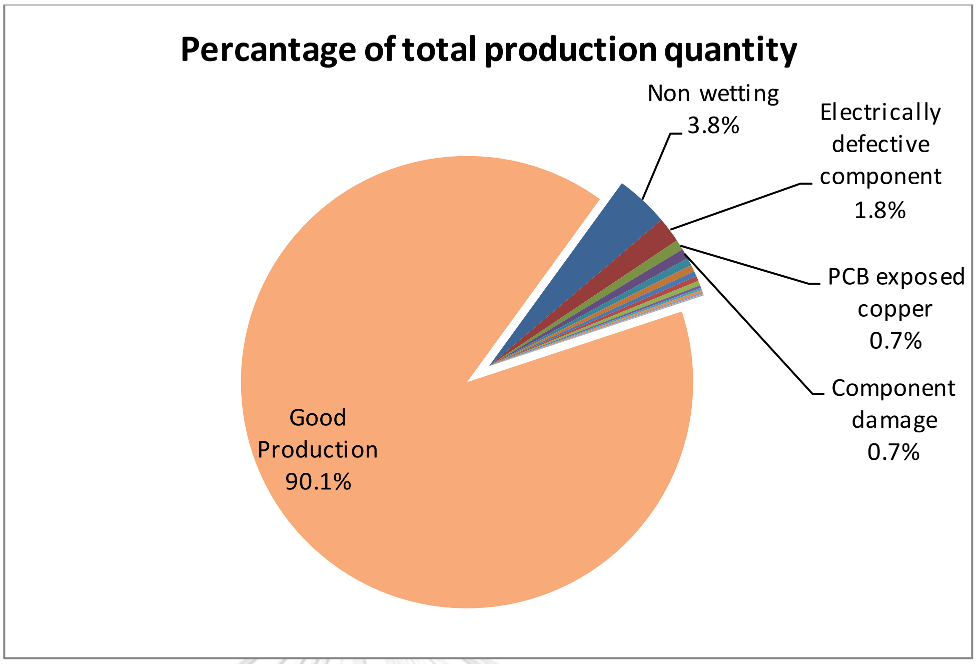


**Figure 7:** Pie chart of percentage of total production quantity

Additionally, when consider at each defect cost as shown in Table 2 below. It can be stated that non-wetting has the highest number of defect cost at 9,262,985 baht per year which consider being the highest amount of defect found from focused PCBA. This cost is calculated from 70% rework of non-wetting and 30% scrapped of non-wetting.

**Table 2:** Total defect cost of PCBA for one year

| Defect | Total Defective Quantity (ea) | % Defect of Total Production | Rework cost (Baht/year) | Total scrap cost (Baht/year) | Total defect cost (Baht/year) | %Defect cost |
|---|---|---|---|---|---|---|
| Non wetting | 8911 | 3.8% | 3,087,662 | 6,175,323 | 9,262,985 | 36% |
| Electrically defective component | 4230 | 1.8% | 1,465,695 | 2,931,390 | 4,397,085 | 17% |
| PCB exposed copper | 1738 | 0.7% | 258,093 | 2,810,346 | 3,068,439 | 12% |
| Component damage | 1700 | 0.7% | 504,900 | 1,570,800 | 2,075,700 | 8% |
| Solder bridging | 1128 | 0.5% | 335,016 | 1,042,272 | 1,377,288 | 5% |

| Defect | Total Defective Quantity (ea) | % Defect of Total Production | Rework cost (Baht/year) | Total scrap cost (Baht/year) | Total defect cost (Baht/year) | %Defect cost |
|---|---|---|---|---|---|---|
| Component misalign | 869 | 0.4% | 258,093 | 802,956 | 1,061,049 | 4% |
| Component missing | 830 | 0.4% | 246,510 | 766,920 | 1,013,430 | 4% |
| Rework/ repair action only | 788 | 0.3% | 234,036 | 728,112 | 962,148 | 4% |
| Retest pass | 1292 | 0.6% | 639,540 | - | 639,540 | 2% |
| Illegible/Missing marking | 436 | 0.2% | 129,492 | 402,864 | 532,356 | 2% |
| Other | 382 | 0.2% | 113,454 | 352,968 | 466,422 | 2% |
| PCB damage | 334 | 0.1% | 99,198 | 308,616 | 407,814 | 2% |
| Component mount wrong | 252 | 0.1% | 74,844 | 232,848 | 307,692 | 1% |
| Side/Toe/End Overhang | 84 | 0.0% | 29,106 | 58,212 | 87,318 | 0% |
| Tombstone | 137 | 0.1% | 67,815 | - | 67,815 | 0% |
| Wire damage | 90 | 0.0% | 44,550 | - | 44,550 | 0% |
| Assembly not clean | 62 | 0.0% | 30,690 | - | 30,690 | 0% |
| Total | 23263 | 9.9% | 7,618,694 | 18,183,627 | 25,802,321 | 100% |

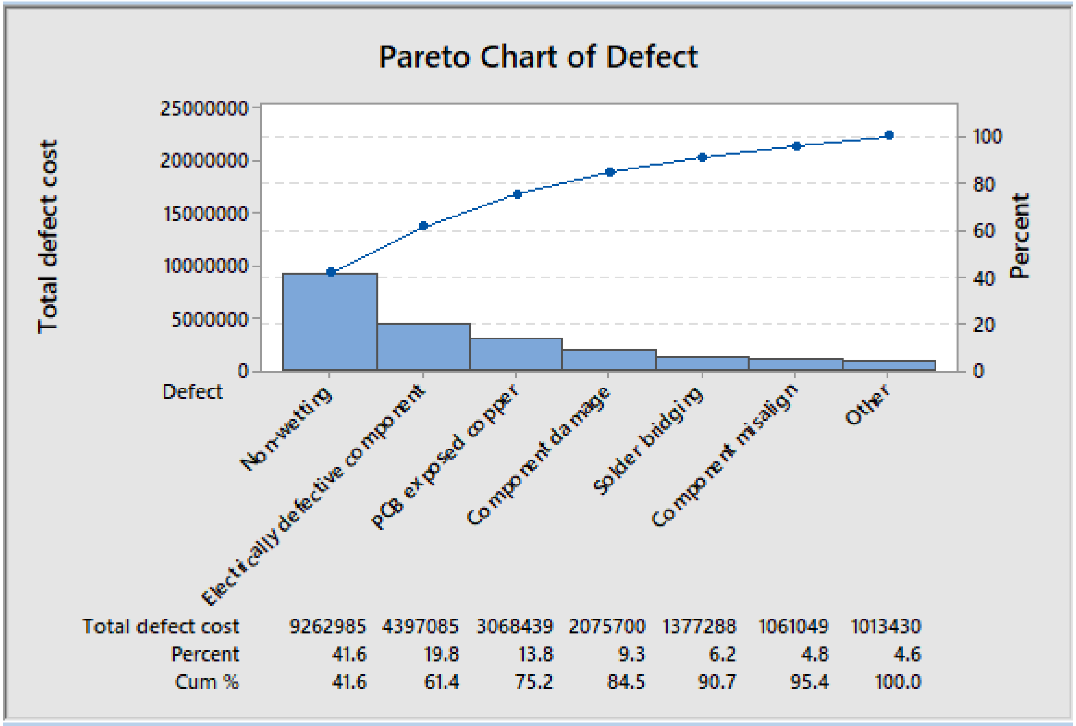


**Figure 8:** Pareto chart of total defect cost

When consider on a Pareto chart of total defect cost in Figure 8, it indicates that the highest amount of defect cost was non-wetting which estimated to be 41.6% of total defect cost. However, the second defective quantity and cost is electrically defective component which is related to component failure and it results in quality of the component from supplier. Therefore, in the manufacturing of PCBA cannot control quality of component, but it will have further improvement from supplier. The third and the forth defective quantity and cost are PCB exposed copper and component damage which are mainly related to handling method during manufacturing processes and it is estimated to be 14.8% of total defective quantity. Due to two defects are related to handling, it will be re-designed handling tray for further quality improvement. Moreover, considering to percentage of defect cost, non-wetting has much higher than other defects and there would be used different methods to solve the problem.

Therefore, other defects will not be considered in this thesis. Thereby, this research will mainly focus on defect code of non-wetting.

Furthermore, in order to know which location that mostly occurs this kind of defect, the in-depth analysis was performed through historical data of one year. As a consequence, location L7 has the highest number of defective items due to non-wetting (75%) as illustrated in Table 3. In addition, total defect cost of non-wetting at L7 location will be calculated from 75% of L7 non-wetting times with total cost of non-wetting (9,262,985 baht per year) which has a result of 6,947,238 baht per year. As a consequence, this research will mainly focus on non-wetting defect at L7 location of PCBA.

**Table 3:** Total defective quantity due to Non-wetting

| **Month** | **Non-wetting** | **L7** | **J1** | **J5** | **J2** | **B1** | **U8** | **Others** |
|---|---|---|---|---|---|---|---|---|
| Nov. 2016 | 1248 | 1215 | 0 | 0 | 3 | 9 | 0 | 21 |
| Dec. 2016 | 1259 | 1189 | 0 | 0 | 1 | 19 | 10 | 40 |
| Jan. 2017 | 661 | 584 | 3 | 0 | 0 | 19 | 20 | 35 |
| Feb. 2017 | 371 | 301 | 0 | 0 | 0 | 10 | 33 | 27 |
| Mar. 2017 | 270 | 200 | 0 | 0 | 6 | 7 | 16 | 41 |
| Apr. 2017 | 235 | 180 | 0 | 0 | 1 | 8 | 2 | 44 |
| May. 2017 | 173 | 96 | 1 | 0 | 0 | 17 | 16 | 43 |
| Jun. 2017 | 502 | 298 | 26 | 0 | 1 | 14 | 38 | 125 |
| Jul. 2017 | 1594 | 267 | 767 | 244 | 223 | 29 | 4 | 60 |
| Aug. 2017 | 686 | 585 | 20 | 1 | 0 | 10 | 3 | 67 |
| Sep. 2017 | 771 | 680 | 5 | 0 | 0 | 5 | 0 | 81 |
| Oct. 2017 | 1141 | 1092 | 0 | 0 | 0 | 3 | 0 | 46 |
| Total Defect Qty. | 8911 | 6687 | 822 | 245 | 235 | 150 | 142 | 630 |
| **Percentage of Defect** | | **75%** | **9%** | **3%** | **3%** | **2%** | **2%** | **7%** |

From the previously analysed data, it illustrates that non-wetting defect occurred at location L7 must be improved immediately so as to decrease defect cost since it results in the highest defect rate and also loss the large number of production value.

In a short summary, currently a PCBA has 75% of defective rate on L7 component due to non-wetting defect which impacts on lower productivity and decreased profit. This historical data was collected from November 1st, 2016 to October 31st, 2017 which is one year period. Total cost of rework and scrapped L7 component due to non-wetting was estimated to be 6,947,238 baht per year of total defective cost and rework. Therefore, an appropriate method needs to be applied in order to solve this problem.

The sample of non-wetting defect of L7 location on PCBA manufacturing line is shown in Figure 9 and 10. Non-wetting in this research is described as the inability of melted solder to form a metallic bond with the base metal during reflow soldering process. This defect is not accepted per IPC-A-610, which is worldwide standard of electronics specification.

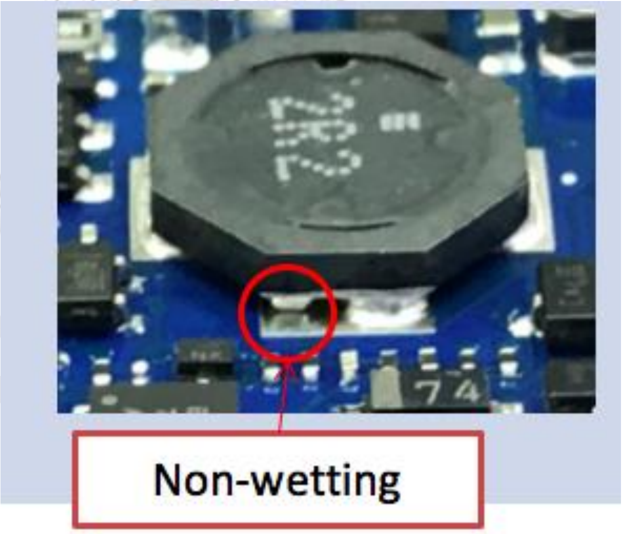


**Figure 9:** The sample of Non-wetting defect on L7 location (1)

**Figure 10:** The sample of Non-wetting defect on L7 location (2)

Figure 11 displays the sample of good wetting on L7 component after going out from reflow soldering machine, in which solder is wetted completely to components' legs and PCB pad for both legs of the component.

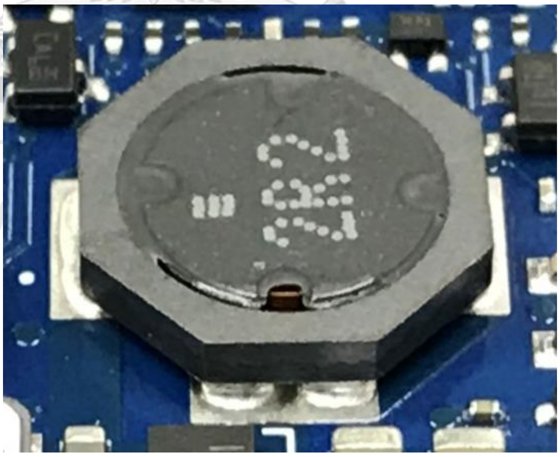


**Figure 11:** The sample of good wetting on L7 location

## 1.4 Research Objective

The objective of this research is to reduce non-wetting defective rate on PCBA.

## 1.5 Research Scope

1. This research focuses only on non-wetting defective reduction on L7 component of focused PCBA which has the highest defective rate of total defective found.
2. This research studies only SMT process which is related to non-wetting defect. The remaining manufacturing processes will not be studied due to they are not related to this type of defect.
3. Using MINITAB 18 programme to support statistical analysis.

## 1.6 Expected Outcomes

1. The equation between the defective rate due to non-wetting defect and significant terms of factors that impact on L7 non-wetting defective.
2. Optimal setting of significant factors which helps reduce the defective rate due to non-wetting defect.

## 1.7 Expected Benefits

1. A reduction of defect rate due to non-wetting of PCBA.
2. A decreased touch up rate of solder over a defect of non-wetting on PCBA.
3. An increase in yield of PCBA for the overall processes.
4. The method of solving this problem can be applied to decrease defective rate of non-wetting on other electronics products.

## 1.8 Research Methodology

The research methodology will follow the DMAIC processes of Six Sigma methodology in order to achieve the best results for this research. There are five major phases in the research execution as the following;

A) Define phase

1. Study current process of electronics assembly including studying occurrence problem

   The existing electronics assembly processes of PCBA will be studied in order to deeply understand related processes and it will be used as primary information to use for further analysis. Then, the defects that occurred along the production process will be analysed to find potential causes of the defects by gathering historical data of non-wetting defective rate for one year.

2. Gather historical data of defects for one year

   This step is to study historical data of defects in electronics assembly of PCBA for one year which indicates in section 1, introduction. The objective is to identify the defect which occurred the most during the manufacturing.

3. Define scope of problem, objectives, expected outcomes, expected benefits and planned activities of the research.
4. Study theory and related literature review such as Six Sigma and Design of Experiment so as to apply for this case study.

B) Measure phase

1. Perform Attribute Agreement Analysis to appraise the accuracy and the precision of the inspection of non-wetting defect.
2. Brainstorm factors affecting non-wetting defect using cause and effect diagram.
3. Prioritize the factors to be studied further using cause and effect matrix.
4. Design experimental plan.

C) Analyse phase

1. Design experiment to test the significance of selected factors and find the optimal setting by using MINITAB Program in a section of Design of Experiment (DOE).
2. Conduct experiment and collect experimental data.

3. Analyse the experiment results by finding the relationship equation and the optimal setting.
4. Make conclusion.

D) Improve phase

1. Perform confirmation experiment using the optimal setting for one month.
2. Conclude about improvement results by comparing non-wetting on L7 defective before and after improvement.

E) Control phase

1. Update Work Instructions of related processes.
2. Update control plan

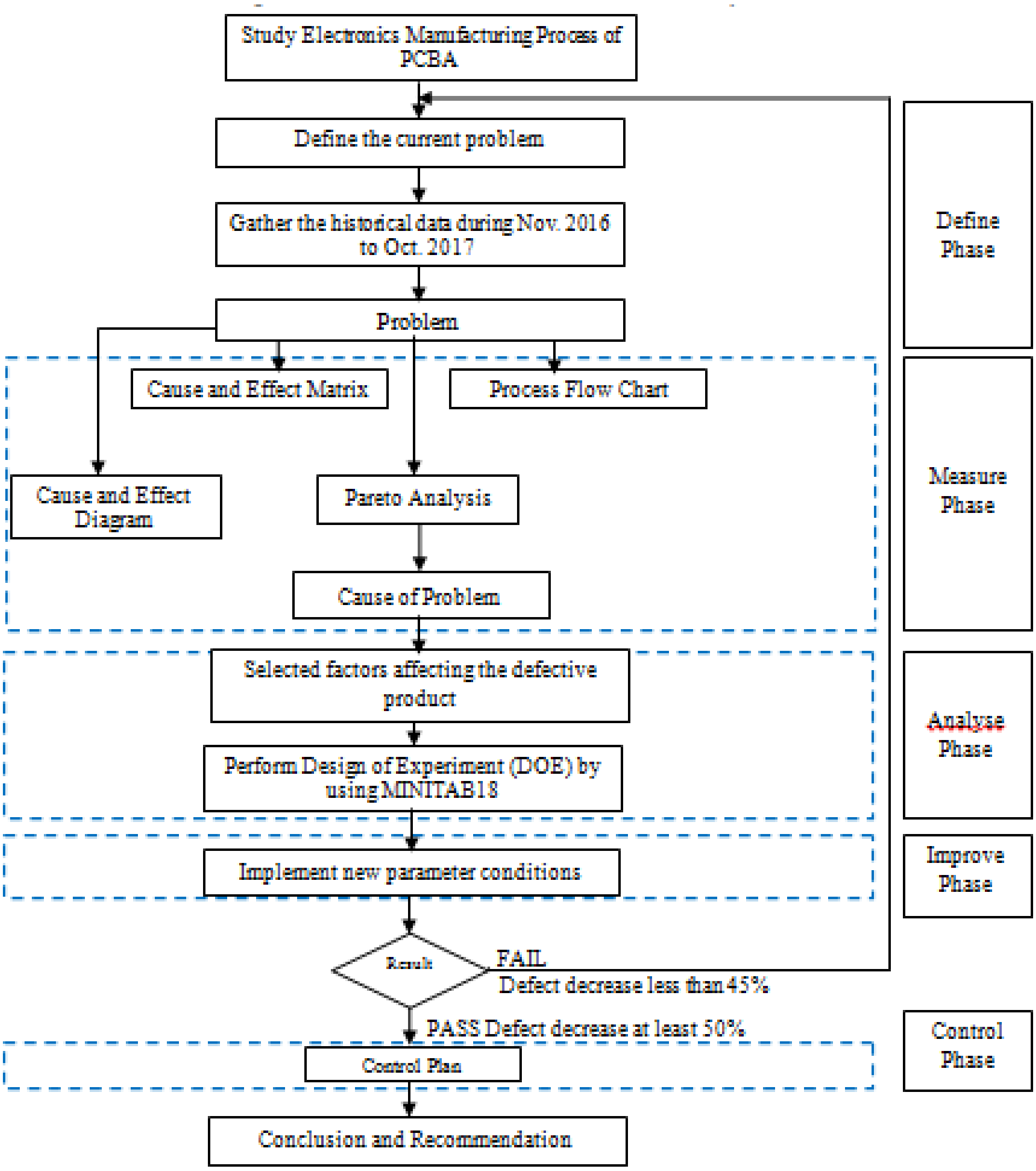


**Figure 12:** Roadmap of research project

## 1.9 Planned Activities

Gantt chart of Planned Activities and Estimated Duration for Conducting the Research Project

| Step | Activity | Mar-18 |  |  |  | Apr-18 |  |  |  | May-18 |  |  |  | Jun-18 |  |  |  | Dec-18 |  |  |  | Jan-18 |  |  |  | Feb-19 |  |  |  | Mar-19 |  |  |  | Apr-19 |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 1 | Study current process of Electronics assembly | 🟦 | 🟦 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 | Study occurrence problem |  | 🟦 | 🟦 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 | Study research and related theories |  |  |  | 🟦 | 🟦 | 🟦 | 🟦 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | Define Phase |  | 🟦 | 🟦 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 5 | Measure Phase |  |  |  |  | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 | Analyse Phase |  |  |  |  |  |  |  |  |  |  |  |  | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |  |  |  |  |  |  |  |  |  |  |  |  |
| 7 | Improve Phase |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 🟦 | 🟦 | 🟦 | 🟦 |  |  |  |  |  |  |  |  |
| 8 | Control Phase |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |
| 9 | Conclusion and recommendation |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 🟦 | 🟦 | 🟦 | 🟦 |
| 10 | Thesis book completion |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 🟦 | 🟦 | 🟦 | 🟦 |

# Chapter 2

# Literature Review

Since the PCBA is one of the major product that can make a lot of money over the others in the same electronic industry; thus, in order to reduce any defects which occurred in the production process will be the most critical thing that need to be done as soon as possible. The defects occurred during SMT process has attracted a number of academic researchers in this industry to study and research key findings to be able to discuss.

This literature review is separated into many sections, beginning with the manufacturing processes of electronics industries related to SMT process. Next, the causes of non-wetting defect were reviewed. Moreover, Six Sigma methodology has been researched and studied about DMAIC approach. Essential tools were reviewed, which were process flowchart, Pareto chart, cause and effect diagram, cause and effect matrix, Design of Experiment (DOE), and control chart.

## 2.1 Reflow in Surface Mount Technology (SMT)

There are many factors related to reflow soldering in which can generate defects on electronics product during the process. Hirox-USA Inc. (2009), described factors related to reflow soldering. For example, temperature profile which has a major effect on SMT process. Temperature profile needs to be controlled following solder paste type used and also component types. Preheating step is an initial step that lead temperature from room temperature of PCB, components and solder paste to melting point of solder; hence, it is an important step because if wettability of solder is poor, it is mainly from this first step of preheat. Therefore, temperature profile is critical to studied and analysed the way it reacts to see the result of solder wetting after getting out of reflow. Moreover, David Bao (2011) stated that to minimize defects of electronics assembly is to adjust reflow profile. It is described in many factors owing to reflow profile steps showing as a graph. It consists of preheating zone, soaking zone, reflow zone, and cooling zone. Each step can generate different kinds of defects. Hence, in order to reduce all kinds of defects, reflow profile need to be studied and adjusted to optimize it.

## 2.2 Non-wetting defect during SMT Process

IPC-A-610 standard (2001) defined non-wetting as molten solder cannot be formed a metallic bond with the base metal during reflow soldering process. Thus, component terminal joints/ leads are not able to wettability contact with the base metal or PCB pads owing to functional failures later.

During SMT process especially reflow soldering, poor wetting or non-wetting can be occurred as one of the major defects found. This insufficient wetting can result from unbalanced thermal profile. Peter B. *et al.* (2011) proved that non-wetting can be prevented when create an initial step to find reflow profile for the entire board. All component packages need to be measured the profile to ensure there will not have any defects such as solder balls, bridging, voids, tomb-stoning, and also non-wetting.

However, Peter B. *et al.* (2011) also stated that when non-wetting defect occur after reflow soldering, there probably causes from too low solder paste reaction, too high preheat temperature, long time of preheat, excessive oxidation under the parts to be joined with PCB pads. In addition, the defect will be related to solder paste types that have been used for different products as well as different PCB surface finish types.

Bittele Electronics (2008) analysed possible root cause of non-wetting as the following;

- The oxidation of PCB pads or components' leads/ joints, which prevent the contact between solder and metal base.
- Too low preheat temperature and flux is inactive leading to oxide layer on the pads or leads cannot be effectively removed.
- Expired solder paste causes flux does not activate.
- Small component sizes can be resulted in too fast evaporation of flux and it affects to wettability has not completed.
- Contaminated solder paste or flux.

## 2.3 Six Sigma strategy

Methodology of Six Sigma aimed at distinctive improvement to achieve, maximize, and sustain the industry to success. In statistical strategy, there is a unit of measure called sigma that is used to reflect process capability in any industries. There are total six scales of sigma to measure the capability of process. In general, most industries are standing at three sigma which is good, but it actually is not good enough especially in dangerous process it requires the most powerful safety to ensure the process will be smoothly completed. Therefore, capability of process will be monitored and controlled to be the best process. This will use six sigma scales to control it, stated by Edward W. *et al.* (2018).

Normally, six sigma process focuses on four main points which are customer want, centre around target, reduce variation, and reduce defect. There are entirely five steps of six sigma in order to reach the target. It consists of Define, Measure, Analyse, Improve and Control phases.

Define phase is an overview of an issue. Measure phase is about to identify cause and effect of the issue, mapping process, identifying Measurement System Analysis (MSA) via variable or attribute data and also process capability. Then, Analyse phase is related to inferential statistics, confidence interval, hypothesis testing, sample size and also any statistical tools to analyse the existing data of the issue. Improve phase is including Design of Experiment to create an experiment to test potential factors to find root cause and solve that issue. Finally, Control phase is used to control process that is experimented by using Statistical Process Control (SPC) as well as create control plan and sustain the gains, stated by Smetkowska M. *et al.* (2018).

## 2.4 DMAIC Methodology

Linderman et al. (2003) defined Six Sigma approach as "an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates." While Jeroen *et al.* (2011) stated that Six Sigma and DMAIC approach combined and developed in practice through some quality control tools. Six Sigma can be defined as a methodology of problem solving and emerging with DMAIC of Define, Measure, Analyse, Improve, and Control phases.

**Figure 13:** DMAIC Phase

DMAIC approach can be described in individual as the following Table 4.

**Table 4:** The Definition of DMAIC Phase

| DMAIC Methodology | Description |
|---|---|
| Define | Selection of a problem and analysis of the benefits. It is about to define a problem and focus on goal in order to improve it and also limit the level of improvement. |
| Measure | Problem is translated into a measurable form which is known as Critical to Quality (CTQ) and current situation assessment. This phase can provide an overview of the system through various quality tools such as macro process map, process flow diagram, cause and effect analysis, detail process map, process capability, variable repeatability and reproducibility, attribute repeatability and reproducibility. |
| Analyse | At this phase, the result of measurable data is used to analyse to find cause of the variation in the process. It also includes hypothesis test to eliminate the problem. There are several methods applied to support this phase such as Design of Experiment (DOE), and Regression. It can be stated in a short summary that analyse phase is to analyse specification of affected factors and causes which determine the CTQ's behaviour. |
| Improve | Adjustment implementation of the process in order that improve the CTQs performance. Improve phase is also help to develop performance and effectiveness of the process. There are several strategies applied for this stage which are |

| DMAIC Methodology | Description |
|---|---|
| | brainstorming technique, process optimisation, standard operating procedure (SOP). |
| Control | Maintain of the improvement to sustainable the process management of the new standard level. This control phase is sued some quality control tools to help manage the new process optimise to maintain the process value to be in the optimal process range as long as possible. (tu.ac.th, 2012) |

## 2.5 Process Flowchart

The process flowchart is one of a tool to present the steps in a process. Flowchart of a process can be represented in a graphical which is top-down process steps from start to end (Tallfy, 2018). There are many advantages for creating process flowchart. For example, flowchart can provide the overall picture of the manufacturing process. It can also provide a crystal-clear understanding of the process. Moreover, it helps to conduct teamwork and communication (MoreSteam, 2013). The following Figure 14 is an example of a flowchart template.

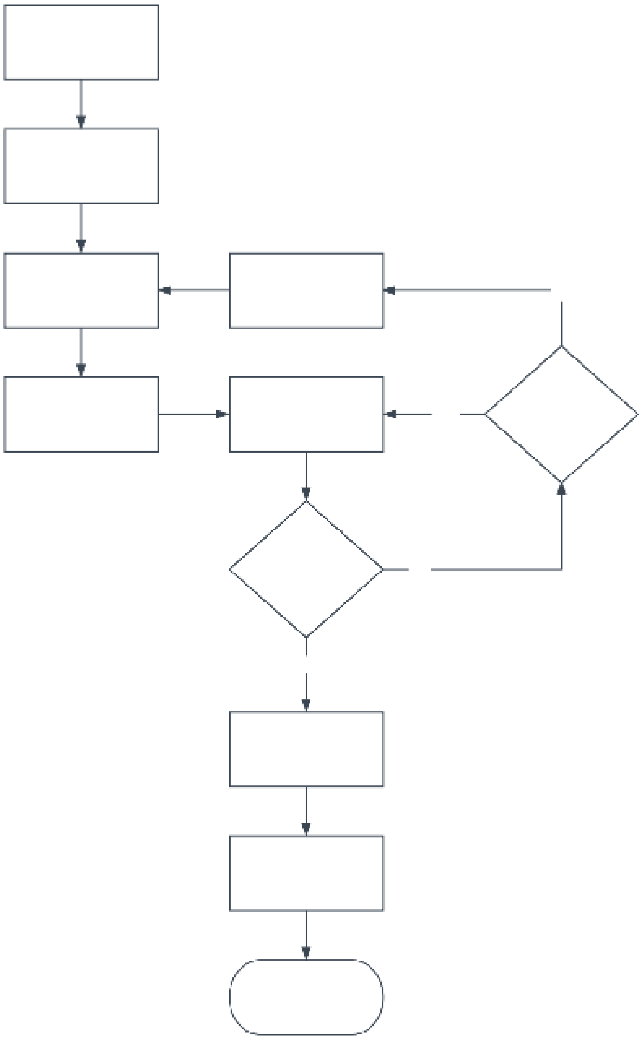


**Figure 14:** Process Flowchart Template (Lucidchart, 2016)

## 2.6 Pareto Chart

There is a basic rule of the Pareto chart principle which is about "80% of the total problems incurred are caused by 20% of the problem causes", stated by Vilfredo Pareto. Thereby, in order to eliminate the majority of the defects (80% of the defects), it is necessary to focus on the main problem which is first 20% of the overall problem. This principle rule of 80/20 was occurred by Vilfredo Pareto in 1906 and adopted by Dr. Joseph M. Juran in 1940s.

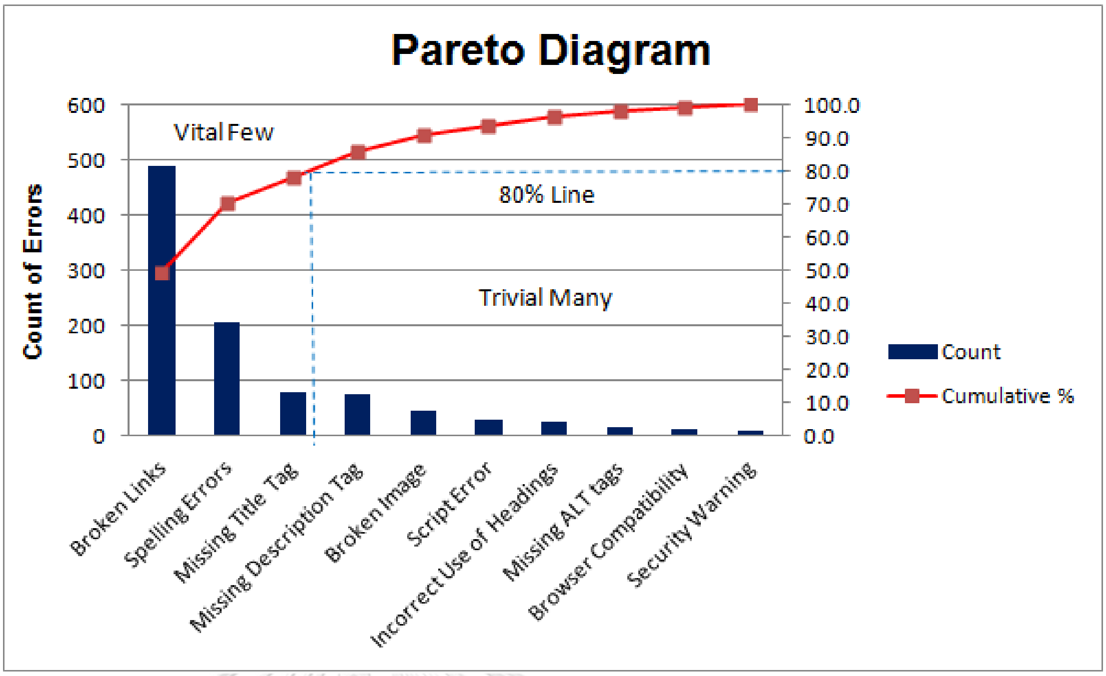


**Figure 15:** Pareto chart of Browsing Website

Figure 15 indicates an example of the problem of browsing website ordering from the highest number of the problem (broken links) to the least number of the problem (security warning). According to 80/20 rule of Pareto chart, it can be seen that the first 20% of the problem which are broken links, spelling errors, and missing title tag have covered almost 80% of the overall problem. If this first 20% can be reduced, it will decrease the majority of the problem of browsing website.

## 2.7 Measurement System Analysis

An objective of measurement system analysis is to analyse a source of variance in the measurement system so as to confirm the accuracy and precision of data before performing experiment. In general, Gage Repeatability and Reproducibility (GR&R) is applied to test the accuracy and precision of the measurement system and it can be separated into 2 types which are repeatability and reproducibility.

Repeatability means there is variances around the expected value of the measurement system by using the same production personnel and the same group of sample data for repeating measure. Thus, there is variance from production personnel and related environment.

Reproducibility is related to variances from the difference between production personnel for measurement, which is known as Appraiser Variation (AV).

### 2.7.1 Measurement system analysis for Attribute data

Attribute data can be measure variances of the data and appraiser by using Attribute Agreement Analysis (AAA). There are several steps in order to ensure that the appraisers are able to inspect and confirm the defect accurately and precisely.

(1) Select experienced inspectors who are able to discriminate the quality of product between good and bad product.

(2) Provide three different groups of product samples which are known good samples, known bad samples, and accepted known bad samples.

(3) Select 2-4 skilled appraisers who are trained and passed the testing course of inspection product and can discriminate the difference between good and bad product.

(4) Identify sample size of AAA as shown in the following table;

| Number of Appraisers | Number of minimum samples | Number of minimum replication |
|---|---|---|
| 1 | 24 | 5 |
| 2 | 18 | 4 |
| $\geq 3$ | 12 | 3 |

Source: Fasser and Brettner (1992)

(5) Randomly test each appraiser to inspect product samples and record result. Continue to repeat testing appraisers.

(6) Evaluate the results of inspection referring to the following;

% Repeatability of inspectors = $\frac{\text{Number of the same result}}{\text{Total sample inspection}}$ (1)

% Non-biased of inspectors (%Attribute score) =

$$\frac{\text{Number of the same result and accuracy}}{\text{Total sample inspection}} \quad (2)$$

% Repeatability effectiveness of inspection (%Screen effective score) =

$$\frac{\text{Number of the same repeatability result of all appraisers}}{\text{Total sample inspection}} \quad (3)$$

% Non-biased effectiveness of inspection (%Attribute effective score) =

$$\frac{\text{Number of the same repeatability result of all appraisers with accuracy}}{\text{Total sample inspection}} \quad (4)$$

(7) If all evaluation criteria have 100%, it means that the appraisers are able to inspect and discriminate between good and bad product.

## 2.8 Cause-and-Effect diagram

Ishikawa diagram also known as cause-and-effect diagram, it is used for identify the potential root causes of the problem. There is a relationship between an effect and all related factors that influence the effect or outcome (Brassard, M. (1988).

Figure 16 illustrates an example of a basic structure of cause-and-effect diagram which has an effect side and causes side. Firstly, a problem or effect has to be identified in order to scope the problem. Secondly, all main causes have to be listed which normally consist of people, process, equipment, materials, environment, and management. Thirdly, each possible cause can be deeply separated to be primary and secondary cause.

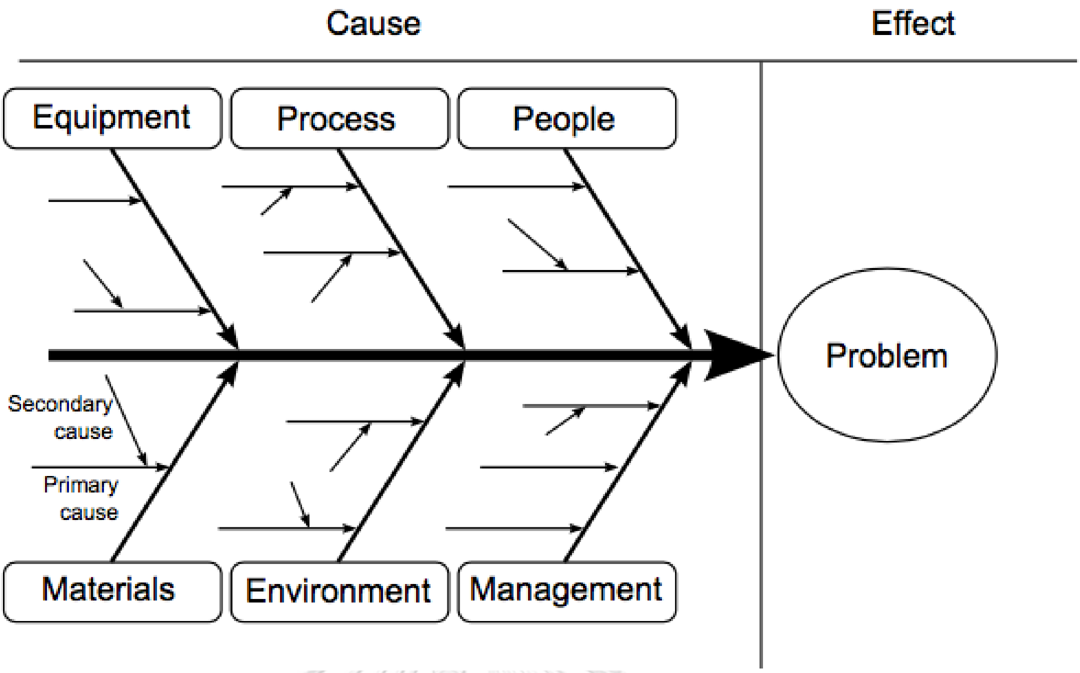
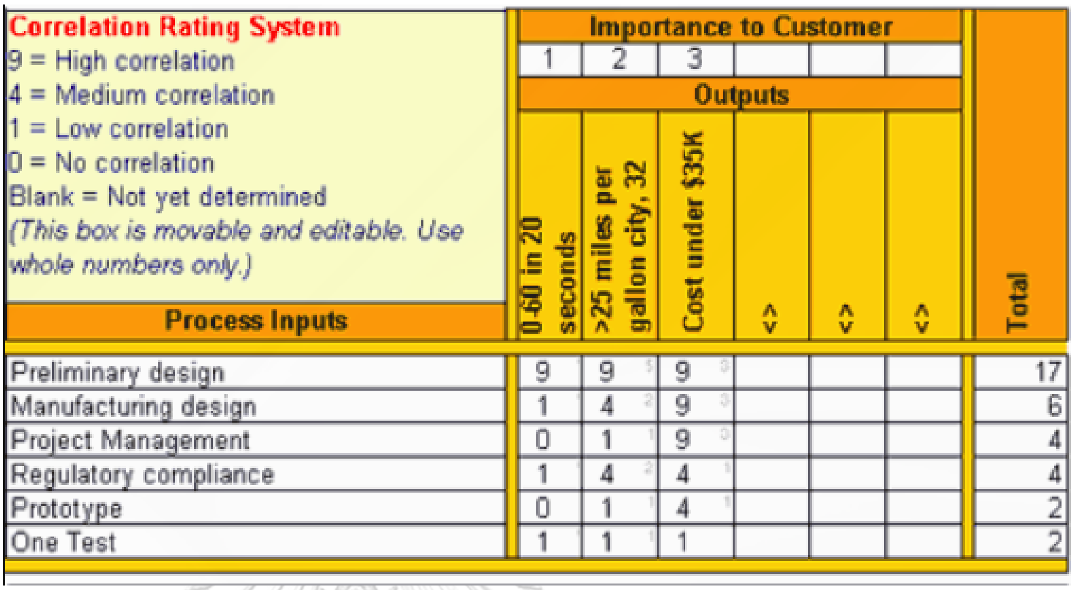


**Figure 16:** Cause-and-Effect diagram

There are several advantages by using cause-and-effect diagram. (1) Root causes determination. (2) Orderly and easy-to-read structure. (3) Scope areas for collecting data and etc.

## 2.9 Cause-and-Effect matrix (C&E matrix)

Jegatheeswaran T. *et al.* (2008) stated that cause-and-effect matrix is created from process measurement analysis. It is used to identify the key process input variables that must be affected to key process output variables, Michael L. *et al.* (2005). It consists of process factors which shown in column and a score of importance rating from 1-10. Process factors come from customer requirements. The row represents process inputs which has correlation to the outputs. Then, rate each input against each output based on the strength of their relationship. Finally, calculate the relationship between inputs and outputs by cross-multiply correlation scores with priority scores and add across for each input. The highest number will be represented the highest potential of process inputs that affect the outputs.



| Correlation Rating System<br>9 = High correlation<br>4 = Medium correlation<br>1 = Low correlation<br>0 = No correlation<br>Blank = Not yet determined<br>*(This box is movable and editable. Use whole numbers only.)* | Importance to Customer | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | | | | |
| | Outputs | | | | | | |
| **Process Inputs** | **0-60 in 20 seconds** | **>25 miles per gallon city, 32** | **Cost under $35K** | **<>** | **<>** | **<>** | **Total** |
| Preliminary design | 9 | 9 | 9 | | | | 17 |
| Manufacturing design | 1 | 4 | 9 | | | | 6 |
| Project Management | 0 | 1 | 9 | | | | 4 |
| Regulatory compliance | 1 | 4 | 4 | | | | 4 |
| Prototype | 0 | 1 | 4 | | | | 2 |
| One Test | 1 | 1 | 1 | | | | 2 |

**Figure 17:** Cause-and-Effect matrix

## 2.10 Design of Experiment (DOE)

The design of experiment is one of a methodology that is well-defined and well-structured for the experimental design. It contains the study between input parameters and the output (response variables) together with different interactions in the input variables. Most experimental designs are generated in a form of matrix, which columns indicating the independent variables regarded to the study, and rows illustrating samples or runs of experiment. The result of experimental design is known as responses, which refer to an optimisation process or the maximisation of yield, stated by Peigen *et al.* (2017). Moreover, an experimental design is a changes input parameters to consider the effect on output variables. It is aimed at testing main effects, interaction effects including process improvement.

Figure 18 indicates flowchart of experimental design which consist of 9 steps. Beginning with (1) state objective to set target of the experiment, (2) select output responses to scope the expected result, (3) select input factors to determine input variable, (4) select design to optimise the experiment, (5) develop strategy to confirm the experimental design, (6) run experiment, (7) fit and diagnose model to analyse the result, (8) interpret model to make conclusion, and (9) confirm model to find optimal parameters setting.

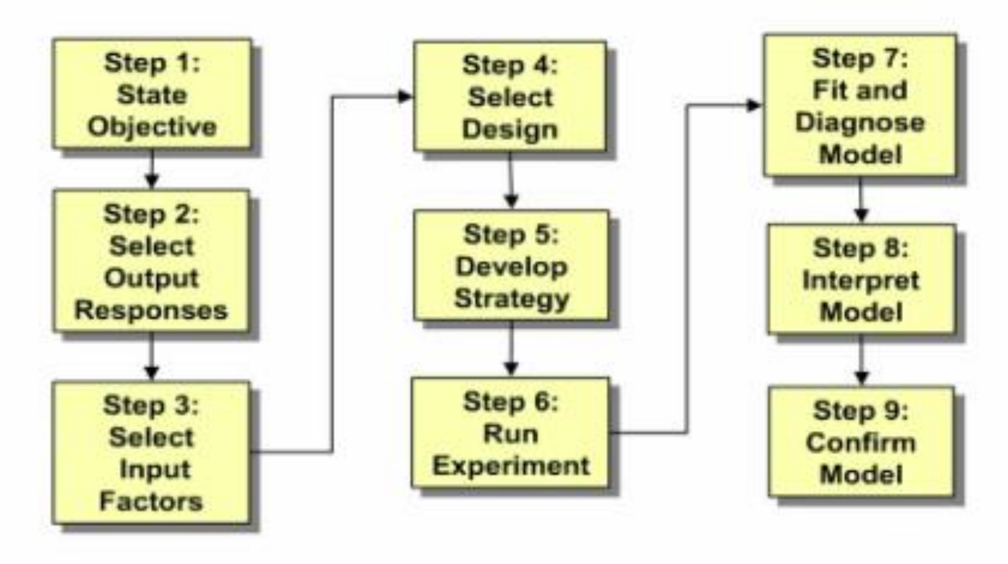


**Figure 18:** DOE Flowchart
Source: Process Quality Associates (2010)

## 2.11 $2^k$ full-factorial design with centre points design

One of the experimental designs is known as $2^k$ full-factorial design with centre points design, in which mainly used for optimisation studies in general processes. $2^k$ full-factorial design with centre points design is useful in defining the correlation between responses and control factors (Kaur et al., 2009; Kumar et al., 2014) which is consisting of a $2^n$ factorial runs added with centre runs ($n_c$) for measure experimental error. One of an advantage of $2^k$ full-factorial design with centre points design is it is able to provide the opportunity for testing curvature. Moreover, it is suitable for the experimental design that have potential factors less than or equal to 4.

Following equation (5) has illustrated the number of runs required for the $2^k$ full-factorial design with centre points design.

$$N = 2^n + n_c \qquad (5)$$

where *N* is a total number of factorial experimental run

$2^n$ is factorial point with its origin at the centre

$n_c$ is number of centre points that provide replicates run at the centre

## 2.12 Control Chart

Control charts are one of useful tools of statistical process control that widely used in the control phase of six sigma. This tool has a key point in monitoring the improvement levels within processes. In general, control chart consists of a centre line and two control limits, which are lower control limit (LCL) and upper control limit (UCL).

Base on Figure 19, Y-axis is represented measurement value and X-axis is represented time. There is a centre line which is process average (blue line). Whereas the upper control limit and the lower control limit are presented as dash line (red dash line). In normal operation and condition, each point of process variable will be in a control limit area, but when there is a special cause, at least one or more process variable will be out of control, which mean there are outside the UCL and LCL.

Control chart is mainly used for maintain stability of the process, which also stated as a certain of consistency from the past and continue to the future. Furthermore, control chart has several advantages. For instance, it will help to monitor process variation over time. Discriminate between common cause and special cause variation.

There are two significant types of control charts, which are attribute data and variable data. For attribute data, the result is presented in a form of pass/ fail, good/ bad, or accepts/ reject of a defect. While variable data, the values is measured from the continuous variable such as variable result of time, temperature, pressure, and quantity.

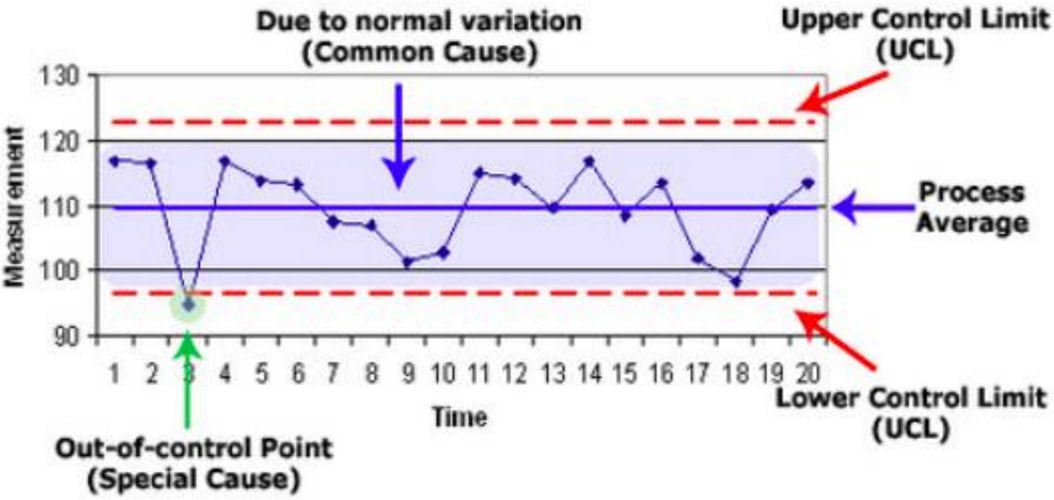


**Figure 19:** Control Chart
Source: Andrew F. (2010)

## 2.13 Past Studies

- Using six sigma DMAIC to improve the quality of the production process: a case study by Monika S. and Beata M. (2017)

In order to improve quality on product and customer satisfaction, six sigma DMAIC has been applied to use in organization and also to help reduce ineffectiveness and the number of errors. Moosa and Sajid, 2010 described the definition of Sigma as the distance of standard deviation around the mean value and they defined six sigma as six times the distance of standard deviation. In theory, the number of defects cannot more than 3.4 parts per million which is a principle of six sigma. A case study is started with an analysis of the total manufacturing process. After overall review, observed that there are some bottlenecks connected with visible downtime in the production process. A machine called Kolbus BF 511 was specified and found the process of connecting blocks and covers on the machine, which result in lower effectiveness than any other machines. For this case, six sigma DMAIC has been applied by first collecting historical data and plot an efficiency graph of machine BF 511 for at least one year. Then, analyse the main cause by first brainstorming method and analyse step by step until the most possible root cause can be found. This case was too long changeovers time of the machine. Next is improvement proposition which is reducing the changeovers time and set up during manufacturing time. Finally, control phase that is creating a control plan and also work instruction to conduct the production process in order to reach the target. It can be concluded that the application of DMAIC that is a part of quality improvement method used in six sigma can increase the effectiveness and reduce any non-conformance occurred on the processes.

- Enhancing effectiveness of Shell and Tube Heat Exchanger through Six Sigma DMAIC phases by K. Srinivasan *et al.* (2014)

This case study is related to effectiveness of shell and tube heat exchanger in furnace manufacturing process, in which six sigma DMAIC has been applied to help improve the overall efficiency of the furnace. In define phase, using Pareto chart for identify furnace performance. For measure phase, using Pareto chart for specify heat exchanger defects. Then brainstorming ideas to identify the major factors that affected shell and tube heat exchanger effectiveness through cause and effect diagram in analyse phase. Following by improve phase, in which the idea and result of the analysis has been concentrated and use for the current production process. Lastly, control phase to create a control plan to continuous improve the effectiveness of the heat exchanger.

- Using Six Sigma Methodology to Improve the Assembly Process in an Automotive Company by Adrian P. *et al.* (2015)

According to automotive manufacturing company, six sigma methodology has been considered to be the best selection for improving quality, decreasing waste in term of better products and services, faster and cheaper, stated by Pyzdek and Keller, 2010. Six Sigma methodology has two approaches: DMAIC (D-Define, M-Measure, A-Analyze, I-Improve, C-Control), which is applicable to an existing product or process to be improved, and DMADV (D-Define, M- Measure, A-Analyze, D-Design, V-Verify) which is applicable to new products or processes, to be designed and / or implemented in a manner that will provide a Six Sigma performance. In Automotive production process, apart from six sigma DMAIC, there is several tools applying such as cause and effect diagram, to find critical factors and 5 Whys analysis. In control phase, control chart (LSL vs USL, LCL vs UCL, and X-bar chart) have been performed.

# Chapter 3

# Define Phase

Define phase is the first step of Six Sigma DMAIC method. This phase is related to identify the problem and limit boundaries of the research in order to go through the point which is the defects occurred on the manufacturing process. This phase starts with studying a current process of electronics assembly industries based mainly on the case study project. In order to have a better understanding, process flow chart has been illustrated including the process explanation in each step. Moreover, Pareto chart is used to scope to the significant defect to be solved and find the location in which the defect occurred by using the principle of 80/20 as well as the defect costs of rework. Lastly, the project charter will be developed to summarise the crucial points of the research project.

## 3.1 Process Improvement Team Formation

In order to achieve the goal to reduce non-wetting defect on PCBAs, brainstorming is necessary to use to help create innovative solutions for solving the problems. Hence, process improvement team has been set up. The team consists of 5 members who are highly experienced in electronics PCBA manufacturing process and also related defects.

**Table 5:** Case study companies' improvement team

| Number | Position | Experience |
|---|---|---|
| 1 | Process Engineer | 10 Years' experience |
| 2 | Quality Engineer | 7 Years' experience |
| 3 | Equipment Engineer | 10 Years' experience |

| | | |
|---|---|---|
| 4 | Supervisor | 8 Years' experience |
| 5 | Researcher (Nitcha Sangkhapanit) | |

As indicated on Table 5, process improvement team of this research project will be the same members until the project is completed. This will include all operators who are working in the related manufacturing processes and also quality inspectors. For this research project, the researcher is responsible as a project leader who is setting up the working plan, conducting the meeting, creating experimental design, analysing and summarising the results, and also controlling the plan within the time period.

## 3.2 Production Processes

There are many operations to run in order to complete and get outputs known as Printed Circuit Board Assembly (PCBA) delivering to customers. There are two main operations. The first operation is surface mount technology (SMT) which consists of screen printing, solder paste inspection (SPI), surface mount devices (SMD), reflow soldering, visual inspection, auto optical inspection (AOI) and X-ray inspection stations. The second operation is top level assembly (TLA) which consists of the integration of assembly throughout final inspection including packing and finally shipping finish goods to customers. In addition, there are several processes for inspection solder in hidden areas or under components and also testing function of PCBA to prevent any failures before delivering to clients.

However, as electronics assembly run in massive volumes, which can be estimated that there are a lot of defects, occurred during the production processes. Defects are one of the major issues for electronics industry; thereby, all defects need to be eliminated or reduced so as to increase productivity and yield of manufacturing.

In this research, an electronics product known as PCBA has been used as an example to be demonstrated the defective rates and the solutions to prevent any unconformities. The reason for selecting this PCBA is because there is high demand forecast and high defective quantity in terms of manufacturing processes which will be described further in this research. Six Sigma strategy will be used in order to find root cause and solve the problem of a specific defect. Therefore, when operating production processes, there is inevitably generated unconformity or it can be known as defects. The defects can be occurred at any operations. Thus, defects are able to define and analyse to see which stations generate the most unconformity.

Based on PCBA that has been selected covers two main operations which are SMT and TLA processes. Beginning with receiving raw material from suppliers and start processes with solder paste screen printing to screen solder paste onto PCB pad. Then, PCB with solder paste on top pass to solder paste inspection (SPI) to measure solder volume with define the specification of solder volume. After that, PCB passes to SMD mounting machine that automatically place component onto PCB. Then, PCB will enter to reflow soldering machine to melt solder paste attached to component leads and PCB pads for each location of component. It controls temperature and time for reflow soldering. After that, PCB will be inspected by operators to inspect any defects that might occur during reflow soldering process. Then, PCB will be cleaned to eliminate solder paste or flux residues that might remain on the PCB. Flux is a substance mixed with solder to help solder melting completely with component leads. Next process is auto optical inspection (AOI) to inspect any unconformities such as component missing, component misaligned, non-wetting, etc. Then, PCB will be sent to X-ray to inspect solder under component to see whether it is short during the manufacturing processes. These processes are sub-processes of SMT process. For the second part, TLA process, it consists of de-panel which cuts PCB panel into single board of PCB. Then, single board will enter to functional test to test work function of the PCB such as functional test of each component and overall working process. After that, boards will be sent to under fill process to apply adhesive onto specific component to attach those components onto PCB and cure boards to dry the under fill. Then, boards pass to final inspection 2 to inspect any defects from de-panel, under fill and oven cure. Next is hand soldering for specific location that are not place at SMT process and then boards will be assembled other parts at hardware assembly and finally final inspection to ensure there is no defect boards deliver to customers.

Process flow of the PCBA manufacturing can be identified into two main operations which cover from receiving raw material to shipping to customer. In addition, two main operations can be separated into 20 processes. Each process can be explained as the following;

### 3.2.1 Receiving (Raw Material)

The first step is receiving raw material from various vendors and visual inspect each raw material before sending to production line. For the case study of PCBA, there are many raw materials such as Printed Circuit Board (PCB), components used to assembly onto PCBA, solder paste, adhesive used for under fill, etc. All these raw materials need to be inspected batch lot, date of manufacture and expire date in order to follow FIFO method. Apart from this, components need to be buyoff for 5 each to measure physical dimension compared to component drawing. If found physical dimension misalign with drawing, need to feedback to vendor and is not allowed to use at production line.

### 3.2.2 Solder paste screen printing

This process is to screen solder paste onto PCB pad by using stencil which specify aperture match with PCB pad. In order to screen solder paste onto PCB pad, screen printing machine has been used with a stencil and press solder paste along a stencil by proper squeegee size. At this step, pressure and speed of squeegee have been applied so as to press solder paste onto each aperture. Setting parameters between pressure and speed have been set up.

**Figure 20:** Screen Printing Machine

### 3.2.3 Solder paste inspection (SPI)

After PCB pass through solder paste screen printing, PCB with solder paste on top will be transferred to SPI machine.

In this process, solder paste %volume is inspected whether it is in specification of 50-180%, which is a standard used for inspect solder paste %volume. It is automatically detected by first programming its PCBA. Apart from solder paste %volume inspection, SPI can detect other kind of criteria such as solder bridging, insufficient solder, excessive solder, solder misalignment, and mismatch shape. If any of these criteria has defected, it will be alarmed and show a position of defect. If it is good, PCB will come out of the machine and ready to go to next step.

**Figure 21:** SPI Machine

### 3.2.4 SMD mounting

When PCB comes out of the SPI, it will be continuous to SMD mounting machine which are used for mount SMD components onto PCB by programming and named it. This machine will automatically pick up each component using various nozzle sizes. Each component comes with different package types such as tape and reel, tube, or tray. Electrical engineering team will set up the program to align with each package types and also component size. Moreover, this machine uses a concept of pick and place component which means there is a pressure when place component onto PCB. If the pressure does not appropriate, it will result in several kinds of defect such as non-wetting issue, bridging solder, component missing and etc.

**Figure 22:** SMD Mounting Machine

### 3.2.5 Reflow soldering

After PCB with component on top comes out of SMD mounting, it will enter to reflow soldering machine to melt solder paste attached to component leads and PCB pads for each location of component. It controls temperature and time for reflow soldering. At this process, PCBA will be good if setting parameter between temperature and time are appropriate. In contrast, if parameters are not appropriated, PCBA will show any of defects such as non-wetting solder, de-wetting solder, and tombstone.

**Figure 23:** Reflow Soldering Machine

### 3.2.6 Visual inspection after reflow

Once reflow soldering has been completed, PCB with component on top needs to be inspect in order to find any unconformities which might occur such as bridging solder, missing component, misaligned component, reversed polarity, non-wetting, and etc. This can be inspected by using luxo lamp or microscope.

### 3.2.7 Cleaning

In this step, PCBA is sent to clean by Saponifier cleaning which is one of a chemical used in order to eliminate any contamination such as flux, solder paste residues, dust and other small impurities.

### 3.2.8 Auto optical inspection (AOI)

Next, PCBA is passed to AOI machine which uses for inspect any criteria such as bridging solder, reversed polarity, insufficient solder, excess solder, missing component, component misaligned, de-wetting, non-wetting, loss of metallisation, and etc. In order to automatically inspect, the program of PCBA has been set up first; hence, when insert PCBA into the machine, it will be automatically inspected following the set-up program. If the machine notifies for a false call, operators need to justify by visual inspection so as to ensure whether it is defect or not.

### 3.2.9 Auto X-ray inspection (AXI)

To ensure any unconformities will not be missed, another auto-inspection machine is used which is called AXI machine. It is programmed to inspect solder characteristic under a component or known as hidden joints and also any locations that AOI cannot inspect. If the machine notifies for a false call, operators need to justify by visual inspection so as to ensure whether it is defect or not.

### 3.2.10 De-panel

Then, PCBA is entered De-panel machine to de-panelise panel PCBAs into single board. In this step, de-panel fixture has been used to support a panel and using a router from de-panel machine to cut each point following the set-up program.

### 3.2.11 Functional test (FCT)

Next, PCBA is tested function by follow the schematic of the product. Test software is programmed to test almost all components located on the PCBA to test work function and confirm whether the soldering process is completed and no defect occurs.

### 3.2.12 Under fill

Under fill process is to add adhesive around the selected component in order to prevent any contamination hide under the component. At this step, specific components have been applied adhesive by under fill machine such as BGA component type. Firstly, this machine is set up program. Then, it will run automatically after enter PCBA onto the machine. After under fill is applied, PCBA will come out and has been inspected by operators to see the shape of under fill.

### 3.2.13 Oven cure

After PCBA is inspected by operators, it is sent to oven to cure the adhesive for a specific temperature and time.

### 3.2.14 Final inspection 2

In this step, PCBA has been inspected again after oven cure in order to ensure there is no defects occurred during under fill and oven cure by using microscope before sending PCBA to next process.

### 3.2.15 Hand soldering

Hand soldering process uses for manual hand solder a specific location. For this PCBA, it uses to hand soldering Piezo using no-clean solder wire.

### 3.2.16 Hardware assembly

Once PCBA has been hand soldering, it is stacked with another board to be completed for the finished PCBA.

### 3.2.17 Final inspection

This step is to visual inspecting the whole PCBA by using microscope to confirm the PCBA is good prior deliver to customer. If any defects are found, operator will inform supervisor, process and quality engineers to help find root cause and solve the problem.

### 3.2.18 QA final inspection of PCBA

To confirm defects can be detected by randomly inspect some PCBAs prior to pack into shipping box.

### 3.2.19 Packing

This step is to pack finished goods of PCBAs into shipping box.

### 3.2.20 Shipping

Finally, PCBAs are delivered to customer.

The electronics manufacturing processes of case study PCBA can also be concluded as process flowchart as displayed in Figure 24.

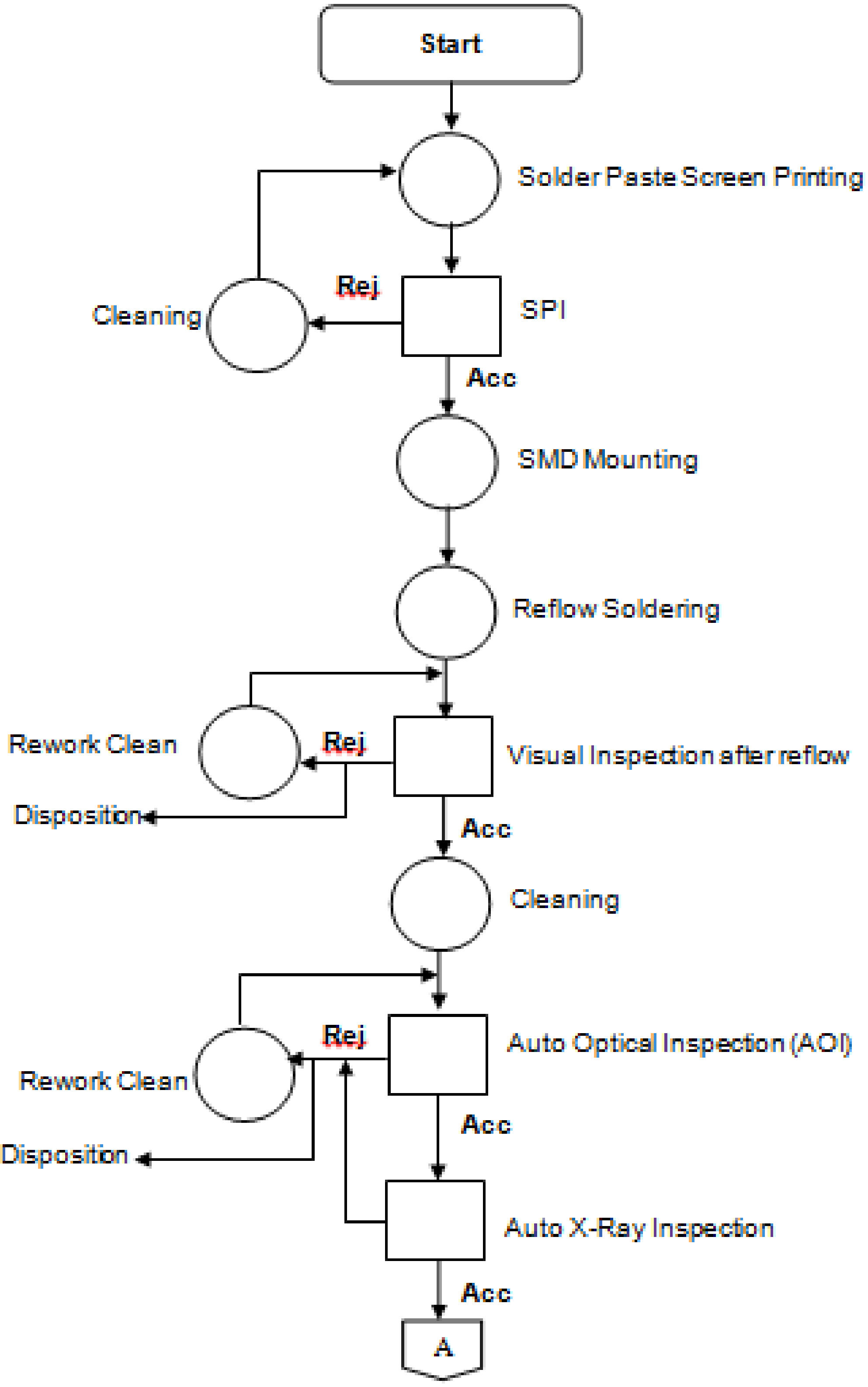


**Figure 24:** Process Flow chart of PCBA

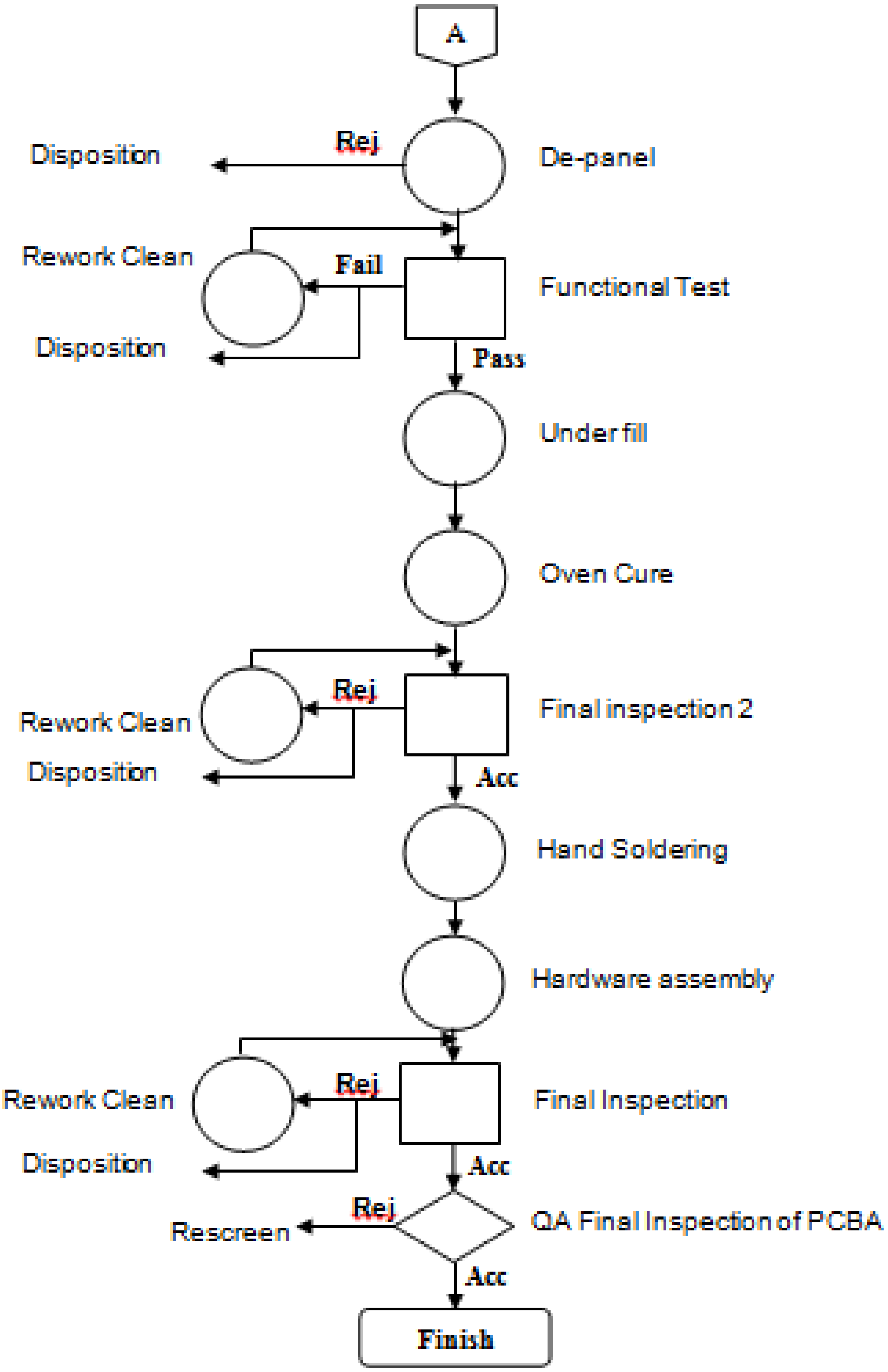


**Figure 24:** Process Flow chart of PCBA (Cont.)

## 3.3 Current Problem

### 3.3.1 Defect characteristic selection

As mentioned in the introduction chapter, the historical data of one year period from November 2016 to October 2017 indicated that the defective rate in PCBA manufacturing was accounted for an average of 10%. It can be illustrated in pie chart of total production in which separating between good production and defective types (Figure 25).

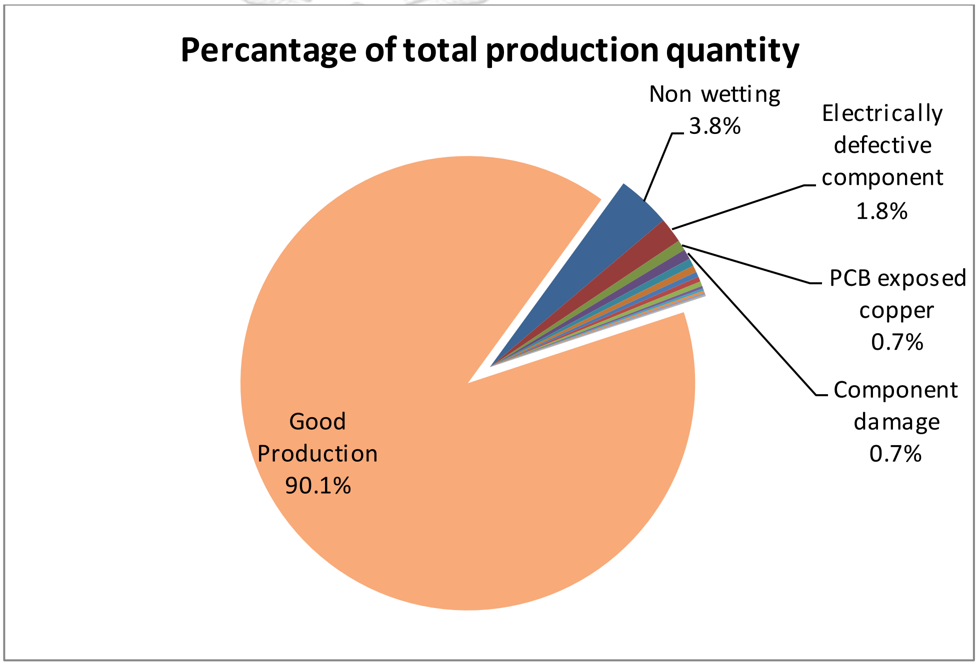


**Figure 25:** Pie chart of percentage of total production quantity

Good production is accounted for 90.1%, while non-wetting defect which is the highest defect found is accounted for 3.8%, following by electrically defective component (1.8%), PCB exposed copper (0.7%), and component damage (0.7%), respectively. Furthermore, Figure 26 shows a Pareto chart of total defect cost, which non-wetting has the highest number of defect cost at

9,262,985 baht per year of total defect cost, estimated to be 41.6%.

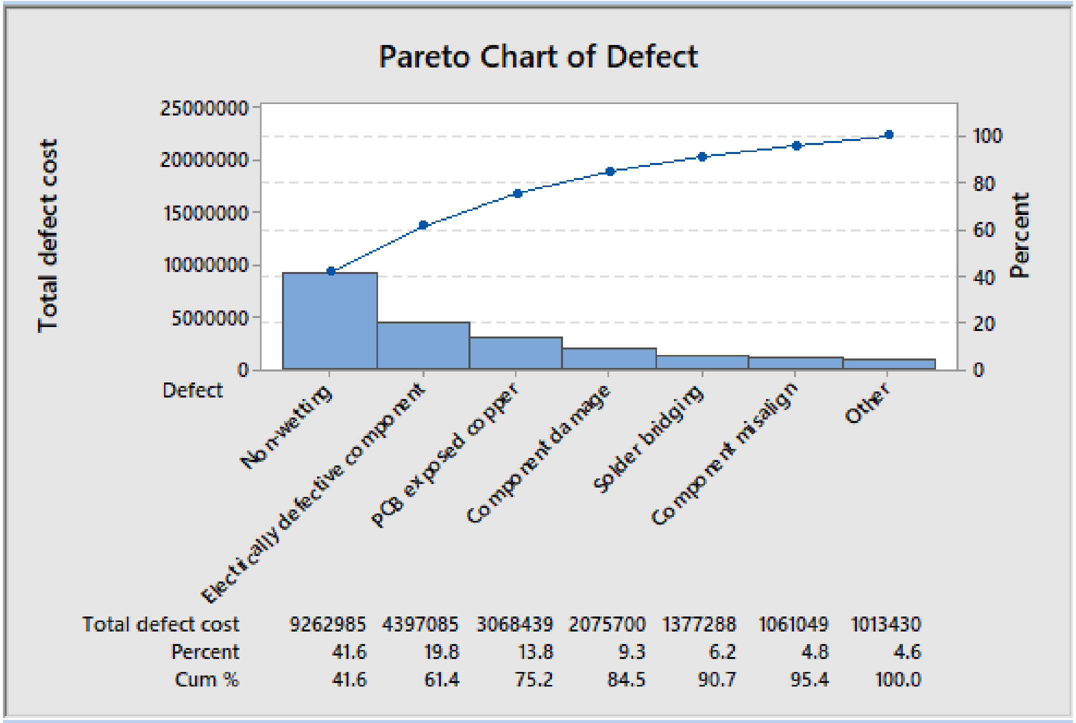
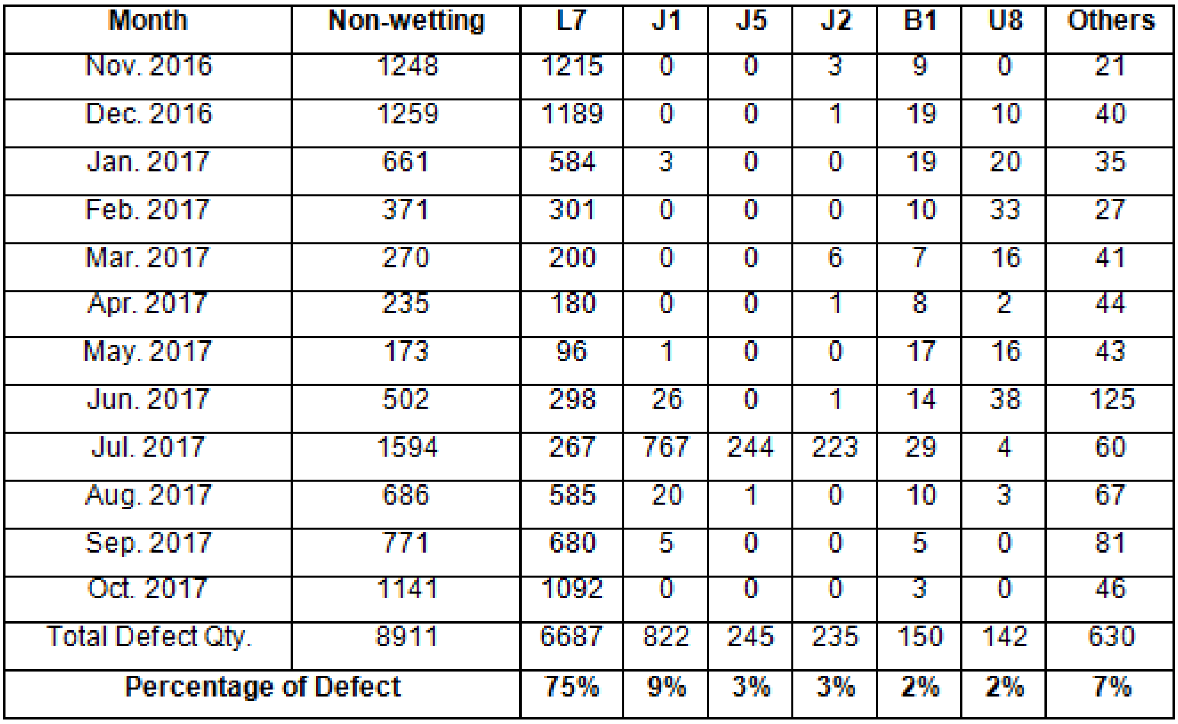


**Figure 26:** Pareto chart of total defect cost

It can be stated that non-wetting defect has much higher than other defects and there will be considered in this research project for the solving method of this defect in PCBA manufacturing process.

Apart from non-wetting defect found, there was an analysis of location of non-wetting on PCBA, it was found that the largest amount of non-wetting occurred at location L7 as illustrated in Table 6, which can be estimated for 75% of total non-wetting occurred at the PCBA. Therefore, this research will be specifically focus on non-wetting defect at L7 location of PCBA.

**Table 6:** Total defective quantity due to Non-wetting



| Month | Non-wetting | L7 | J1 | J5 | J2 | B1 | U8 | Others |
|---|---|---|---|---|---|---|---|---|
| Nov. 2016 | 1248 | 1215 | 0 | 0 | 3 | 9 | 0 | 21 |
| Dec. 2016 | 1259 | 1189 | 0 | 0 | 1 | 19 | 10 | 40 |
| Jan. 2017 | 661 | 584 | 3 | 0 | 0 | 19 | 20 | 35 |
| Feb. 2017 | 371 | 301 | 0 | 0 | 0 | 10 | 33 | 27 |
| Mar. 2017 | 270 | 200 | 0 | 0 | 6 | 7 | 16 | 41 |
| Apr. 2017 | 235 | 180 | 0 | 0 | 1 | 8 | 2 | 44 |
| May. 2017 | 173 | 96 | 1 | 0 | 0 | 17 | 16 | 43 |
| Jun. 2017 | 502 | 298 | 26 | 0 | 1 | 14 | 38 | 125 |
| Jul. 2017 | 1594 | 267 | 767 | 244 | 223 | 29 | 4 | 60 |
| Aug. 2017 | 686 | 585 | 20 | 1 | 0 | 10 | 3 | 67 |
| Sep. 2017 | 771 | 680 | 5 | 0 | 0 | 5 | 0 | 81 |
| Oct. 2017 | 1141 | 1092 | 0 | 0 | 0 | 3 | 0 | 46 |
| Total Defect Qty. | 8911 | 6687 | 822 | 245 | 235 | 150 | 142 | 630 |
| **Percentage of Defect** | | **75%** | **9%** | **3%** | **3%** | **2%** | **2%** | **7%** |

### 3.3.2 Production line selection

In the PCBA manufacturing process, there are totally 20 SMT production lines, which manufacture various electronics assemblies. Since this research project will focus on PCBA of focused product, SMT line 11 was selected as it is the only production line that manufactures this PCBA. All machines used for manufacturing must have preventive maintenance (PM) every month in order to maintain and check machines before any failures occur. Thus, it can be confirmed that all SMT production lines will have a good condition prior to run in every batch.

## 3.4 Baseline measurement

This research will be evaluated the percentage of defect rate which is the number of non-wetting defect divided by total number of units tested.

## 3.5 Summary of Define phase chapter

In conclusion, define phase is the beginning of this research in which the historical data of one year from November 2016 to October 2017 has been gathered. It is indicated the defects occurred during the production of PCBA were accounted for 10% and among this number of defective rate, there is 3.8% which accounted for non-wetting defect that is the highest defect found of PCBA. When deeply look into the non-wetting defect, 75% of this defect were occurred at a component of L7 and its defect cost was estimated to be 6,947,238 baht per year of total defective cost and rework. As a consequence, the problem of non-wetting at L7 location must be solved immediately as the sales volume of this PCBA tends to increase every year. Moreover, this project will focus on only SMT line 11 that manufacture this PCBA. If this issue is not solved immediately, it will cause the company having a critical situation and eventually having a negative financial performance in the future.

# Chapter 4

# Measure Phase

In measure phase of Six Sigma DMAIC methodology, the aim is to identify causes of non-wetting defect through several quality tools. Beginning with Attribute Agreement Analysis (AAA) through Gage R&R. Then, perform cause and effect diagram, following by cause and effect matrix to prioritise sub-root causes of problems and also applying Pareto chart. The scores obtained from the cause and effect matrix will be summarised before experimenting through DOE.

## 4.1 Attribute Agreement Analysis

Attribute Agreement Analysis (AAA) is a useful tool used to evaluate the agreement between the ratings done by the standard and appraisers. It can also be used to determine the accuracy of the assessments made by operators in manufacturing. In general, AAA is used to classify things into two types, which are good/bad or pass/fail. It is used for visual assessment, go/no go testing or when results are being categorized. In addition, the case study of PCBA which determine the quality of products in terms of attribute data of good/bad or accept/reject; thus, the Attribute Agreement Analysis has been created to ensure that the results have an accuracy and precision.

### 4.1.1 Visual inspection of PCBA after reflow soldering process

PCBA will be inspected by operators under microscope as shown in Figure 27. This visual inspection will be performed before sending to wash. If any defects were found, the defect unit will be scanned reject and identify the defect cause before sending to wash. Visual inspection will be performed 100% of overall PCBA through microscope and refer defects from IPC standard which is the acceptability of electronic assemblies.

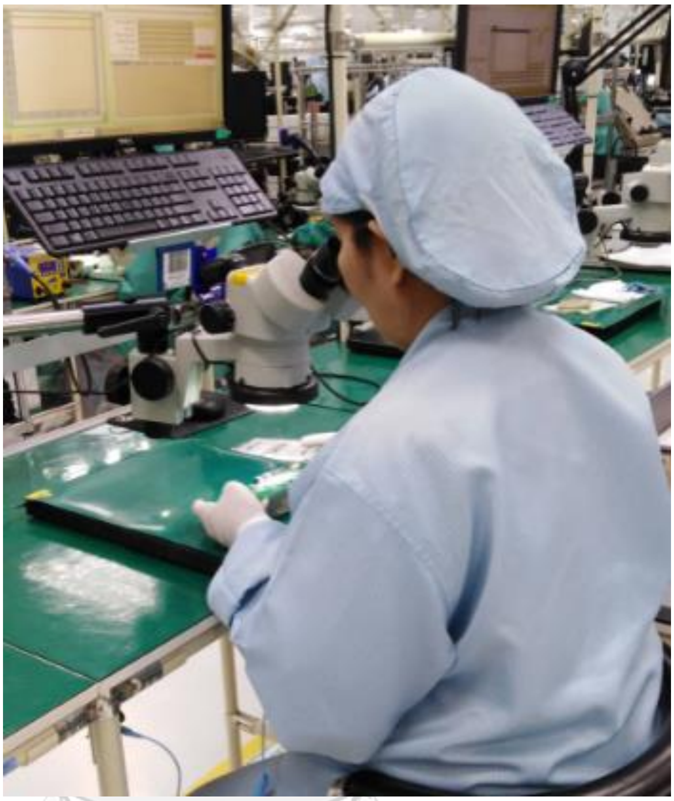


**Figure 27:** Visual Inspection

### 4.1.2 Automatic inspection machine (AOI)

In order to ensure that the defect will not be sent to customer, there is an automatic inspection machine to help inspect the PCBA by first programming the software and fine tune to real PCBA for inspection. In the program, there have a lot of defects criteria that referring to IPC standard. Non-wetting defect is one of the defects that can be inspected by AOI machine.

### 4.1.3 Attribute Agreement Analysis (AAA)

4.1.3.1 Select 3 operators who have duty to inspect non-wetting defect that occurred on L7 of PCBA.

4.1.3.2 For 3 operators based on the sample size suggested by Fasser and Brettner, 1992, 40 PCBA samples were needed 3 replicates and can be categorized into 3 types which are 14 good samples, 14 non-wetting defect samples, and 12 accepted non-wetting defect that refer to IPC standard.

4.1.3.3 Acceptance criterion standard will be inspected by visual inspection by referring to Table 7.

**Table 7:** Acceptance criterion standard

| Index | Acceptance criteria |
|---|---|
| % Repeatability of inspectors | 100% |
| % Non-biased of inspectors (%Attribute score) | 100% |
| % Repeatability effectiveness of inspection (%Screen effective score) | 100% |
| % Non-biased effectiveness of inspection (%Attribute effective score) | 100% |

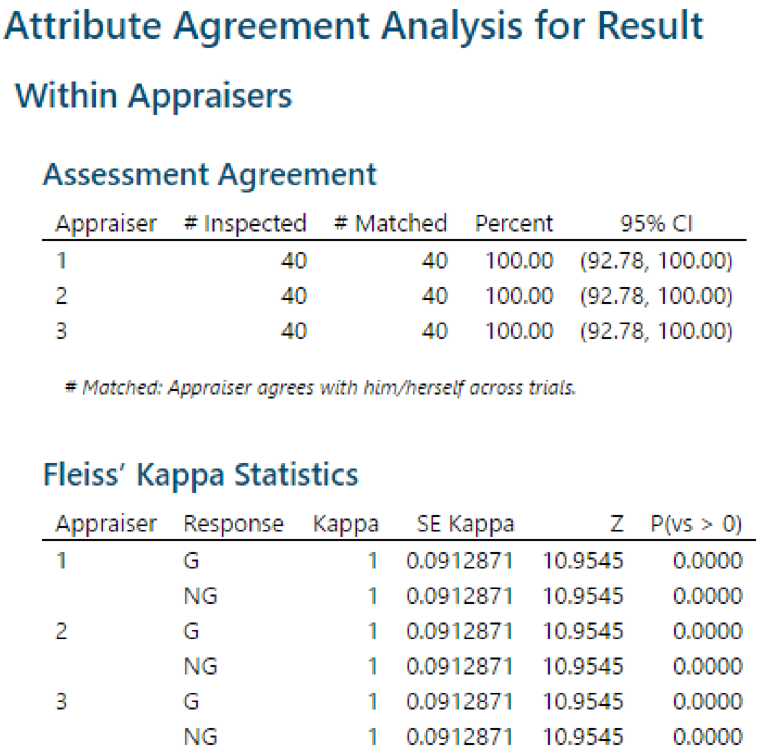
The inspection results of 3 inspectors are shown in Table 8 below.

**Table 8:** Inspection results by AAA method

| Sample No. | Referenced unit | Inspector 1 | | | Inspector 2 | | | Inspector 3 | | | Results of 3 operators are the same | Results of 3 operators are correct |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | | |
| 1 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 2 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 3 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 4 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 5 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 6 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 7 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 8 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 9 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 10 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 11 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 12 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 13 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 14 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 15 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 16 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 17 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 18 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 19 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 20 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 21 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 22 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 23 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 24 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 25 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 26 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 27 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 28 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 29 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 30 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 31 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 32 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 33 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 34 | G | G | G | G | G | G | G | G | G | G | Y | Y |

| Sample No. | Referenced unit | Inspector 1 | | | Inspector 2 | | | Inspector 3 | | | Results of 3 operators are the same | Results of 3 operators are correct |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | | |
| 35 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 36 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |
| 37 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 38 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 39 | G | G | G | G | G | G | G | G | G | G | Y | Y |
| 40 | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | Y | Y |

**Table 9:** Analysis results of AAA method by Minitab



Attribute Agreement Analysis for Result

Within Appraisers

Assessment Agreement

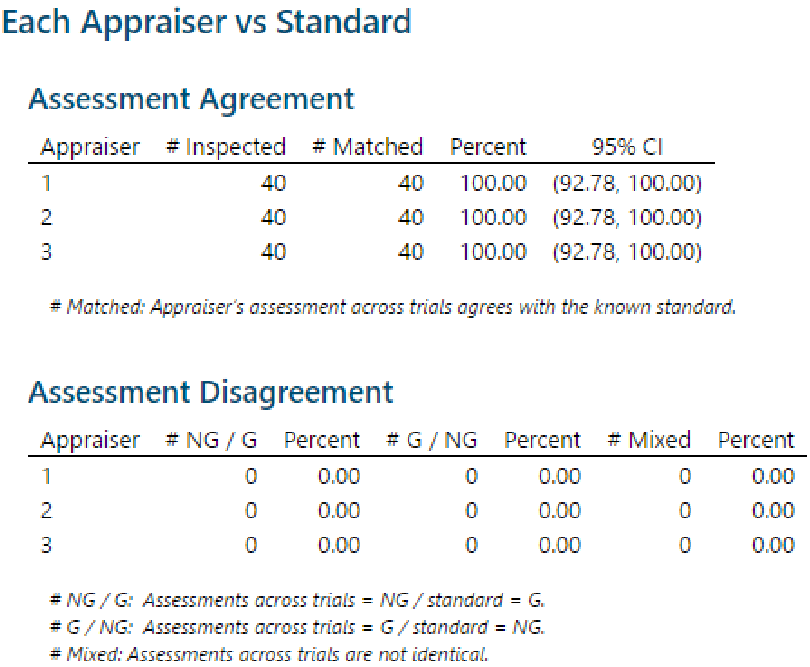
| Appraiser | # Inspected | # Matched | Percent | 95% CI |
|---|---|---|---|---|
| 1 | 40 | 40 | 100.00 | (92.78, 100.00) |
| 2 | 40 | 40 | 100.00 | (92.78, 100.00) |
| 3 | 40 | 40 | 100.00 | (92.78, 100.00) |

*# Matched: Appraiser agrees with him/herself across trials.*

Fleiss' Kappa Statistics

| Appraiser | Response | Kappa | SE Kappa | Z | P(vs > 0) |
|---|---|---|---|---|---|
| 1 | G | 1 | 0.0912871 | 10.9545 | 0.0000 |
| | NG | 1 | 0.0912871 | 10.9545 | 0.0000 |
| 2 | G | 1 | 0.0912871 | 10.9545 | 0.0000 |
| | NG | 1 | 0.0912871 | 10.9545 | 0.0000 |
| 3 | G | 1 | 0.0912871 | 10.9545 | 0.0000 |
| | NG | 1 | 0.0912871 | 10.9545 | 0.0000 |

**Table 9:** Analysis results of AAA method by Minitab (Cont.)



## Each Appraiser vs Standard

### Assessment Agreement

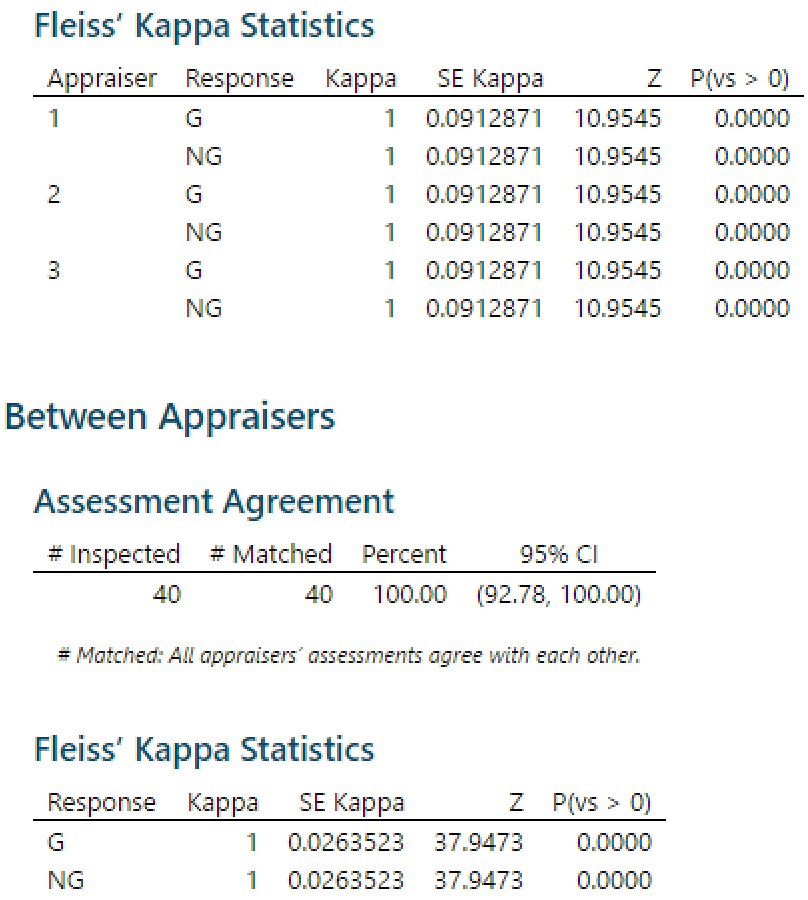
| Appraiser | # Inspected | # Matched | Percent | 95% CI |
|---|---|---|---|---|
| 1 | 40 | 40 | 100.00 | (92.78, 100.00) |
| 2 | 40 | 40 | 100.00 | (92.78, 100.00) |
| 3 | 40 | 40 | 100.00 | (92.78, 100.00) |

*# Matched: Appraiser's assessment across trials agrees with the known standard.*

### Assessment Disagreement

| Appraiser | # NG / G | Percent | # G / NG | Percent | # Mixed | Percent |
|---|---|---|---|---|---|---|
| 1 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| 2 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| 3 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |

*# NG / G: Assessments across trials = NG / standard = G.*
*# G / NG: Assessments across trials = G / standard = NG.*
*# Mixed: Assessments across trials are not identical.*



### Fleiss' Kappa Statistics

| Appraiser | Response | Kappa | SE Kappa | Z | P(vs > 0) |
|---|---|---|---|---|---|
| 1 | G | 1 | 0.0912871 | 10.9545 | 0.0000 |
| | NG | 1 | 0.0912871 | 10.9545 | 0.0000 |
| 2 | G | 1 | 0.0912871 | 10.9545 | 0.0000 |
| | NG | 1 | 0.0912871 | 10.9545 | 0.0000 |
| 3 | G | 1 | 0.0912871 | 10.9545 | 0.0000 |
| | NG | 1 | 0.0912871 | 10.9545 | 0.0000 |

## Between Appraisers

### Assessment Agreement

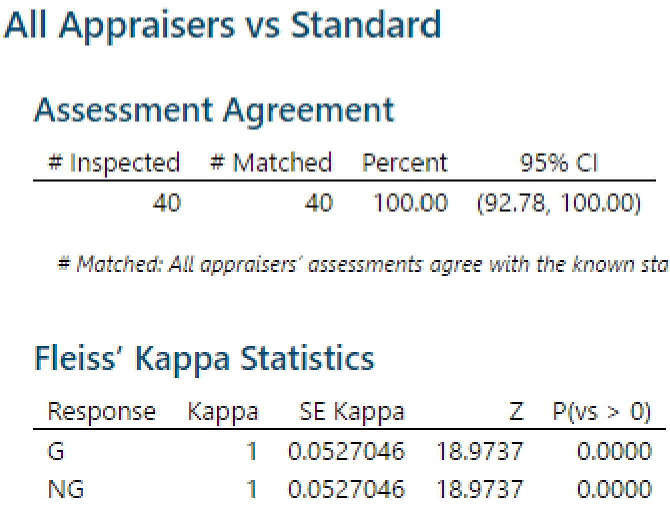
| # Inspected | # Matched | Percent | 95% CI |
|---|---|---|---|
| 40 | 40 | 100.00 | (92.78, 100.00) |

*# Matched: All appraisers' assessments agree with each other.*

### Fleiss' Kappa Statistics

| Response | Kappa | SE Kappa | Z | P(vs > 0) |
|---|---|---|---|---|
| G | 1 | 0.0263523 | 37.9473 | 0.0000 |
| NG | 1 | 0.0263523 | 37.9473 | 0.0000 |

**Table 9:** Analysis results of AAA method by Minitab (Cont.)



## All Appraisers vs Standard

### Assessment Agreement

| # Inspected | # Matched | Percent | 95% CI |
|---|---|---|---|
| 40 | 40 | 100.00 | (92.78, 100.00) |

*# Matched: All appraisers' assessments agree with the known standard.*

### Fleiss' Kappa Statistics

| Response | Kappa | SE Kappa | Z | P(vs > 0) |
|---|---|---|---|---|
| G | 1 | 0.0527046 | 18.9737 | 0.0000 |
| NG | 1 | 0.0527046 | 18.9737 | 0.0000 |

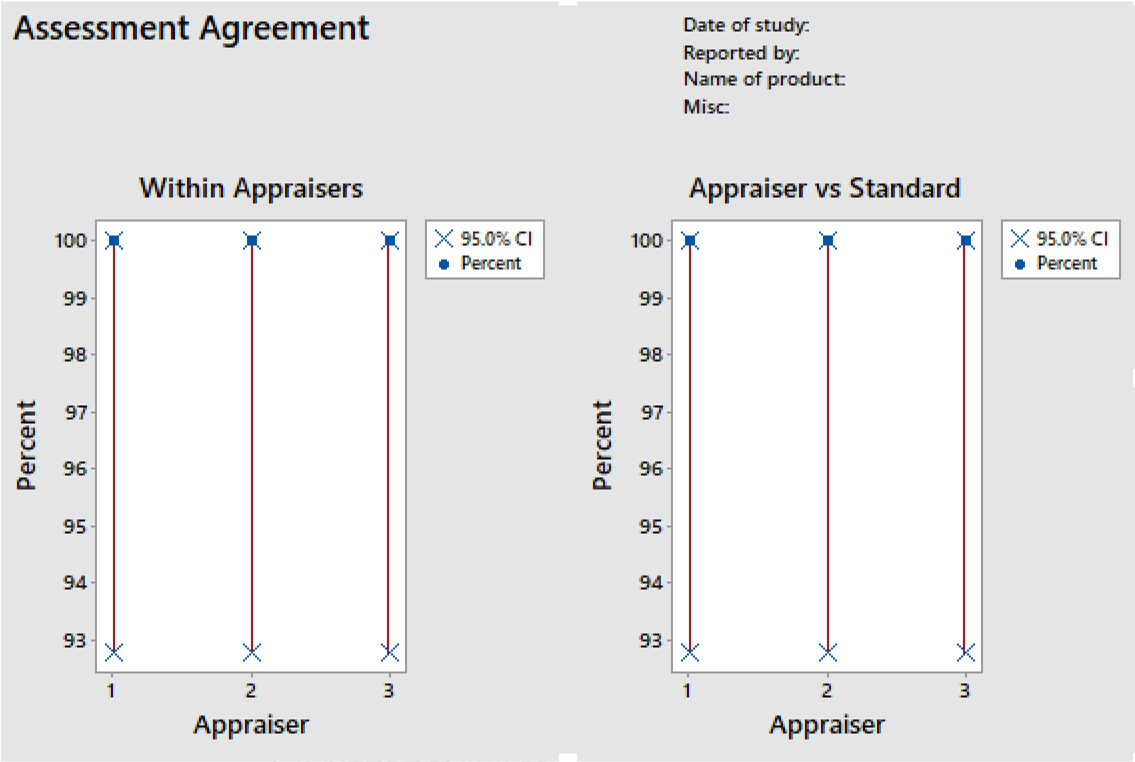


**Figure 28:** Attribute Agreement Analysis result

It can be concluded from the AAA as the following;

1. Percentage repeatability of inspector 1, inspector 2, and inspector 3 are 100%.
2. Percentage of non-biased of inspector 1, inspector 2, and inspector 3 are 100%.
3. Percentage repeatability effectiveness of inspection is 100%.
4. Percentage non-biased effectiveness of inspection is 100%.

As a consequence, it can be summarised that the Attribute Agreement Analysis has been completed and all inspectors are able to inspect non-wetting defect accurately within first time. Thereby, next step of finding potential causes of non-wetting defect will be considered.

## 4.2 Cause and effect diagram

In order to identify causes of non-wetting defect, cause-and-effect diagrams has been generated and it can be shown in Figure 29 below. It can be seen that there are many factors that are being investigated. The first is related to man who are operators working on this product. They might not follow work instruction and also does not properly clean manufacturing line, leading to contamination mixed with solder paste, flux and component. Moreover, if there are new operators working for the PCBA, they still have no experience to operate each machine, which finally results in defects occur.

The second is about machine being used on PCBA which are screen printing machine, solder paste inspection machine, SMD mounting machine and reflow soldering machine. All these machines can be one of the root causes of the problem due to operating error or malfunction, reading parameters do not match with setting parameters, machines do not usually perform preventive maintenance and long-time used machine causes efficiency drop.

The third is related to material used; contaminated component, solder paste or flux is contaminated and also expired solder paste. Besides is different qualification of raw material; for instance, using different batch lot or different supplier.

The final potential factors are about method of the manufacturing. Unsuitable setting machine of preheat temperature and preheat time in reflow soldering machine. Inappropriate setting parameters of pressure and speed in screen printing machine also have an effect on non-wetting defect. Inappropriate pressure of component placement. Insufficient solder volume at the non-wetting point and not enough flux for wetting.

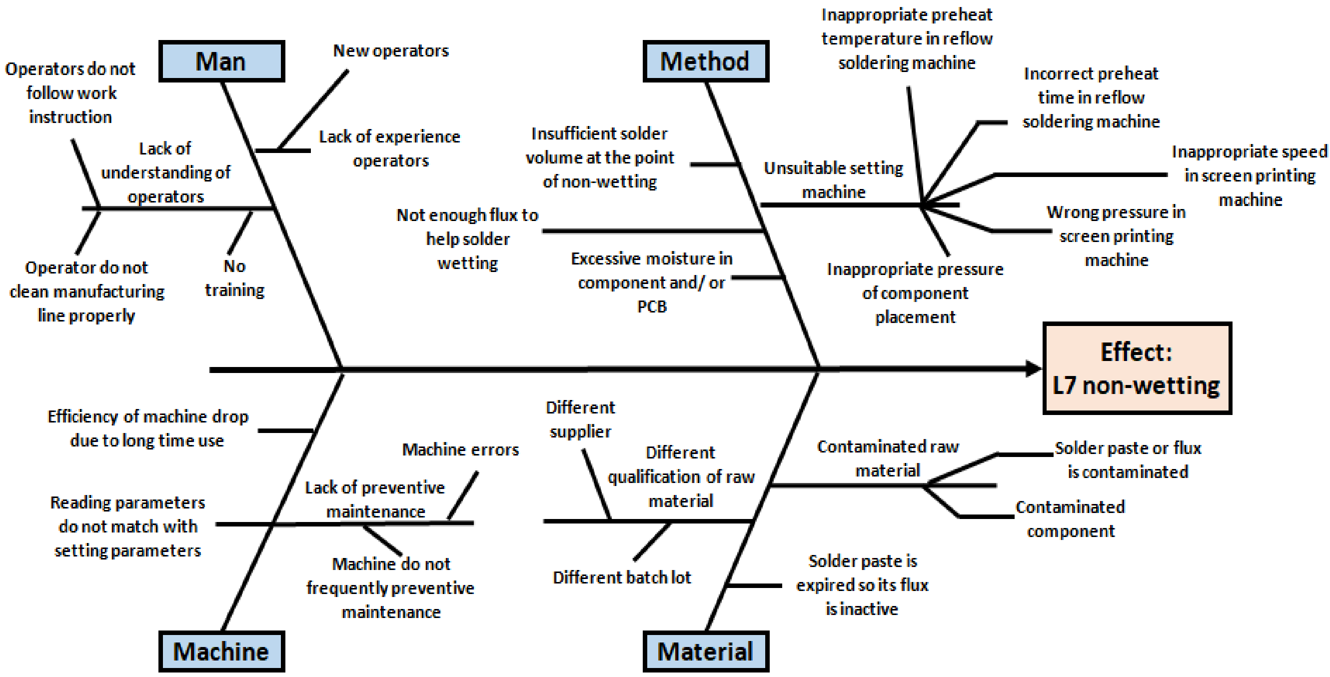


**Figure 29:** Cause-and-effect diagrams of L7 non-wetting

### 4.3 Cause and effect matrix

The most possible root causes of non-wetting defect can be analysed by using the principle of cause-and-effect matrix (C&E matrix) which stated in Table 10. It can be seen from cause-and-effect matrix that potential causes of non-wetting defect have been identified and analysed from cause-and-effect diagram. Cause-and-effect matrix was weighted the score by using 5 operators to weigh score of a correlation between each potential cause and non-wetting defect. If there is high correlation, a score of 9 will be weighted. If there is medium correlation, a score of 4 will be placed and if there is no correlation, a score of 0 will be weighted.

**Table 10:** Cause and Effect matrix of non-wetting defect

| Process Inputs | Opr. 1 | Opr. 2 | Opr. 3 | Opr. 4 | Opr. 5 | Total Score |
|---|---|---|---|---|---|---|
| **Man** | | | | | | |
| Operator do not clean manufacturing line properly | 4 | 4 | 4 | 1 | 1 | 14 |
| Operator do not follow work instruction | 4 | 1 | 4 | 4 | 4 | 17 |
| No training | 4 | 4 | 4 | 1 | 4 | 17 |
| New operators | 9 | 4 | 4 | 4 | 9 | 30 |
| **Machine** | | | | | | |
| Efficiency of machine drop due to long time use | 1 | 4 | 1 | 1 | 4 | 11 |
| Reading parameters do not match with setting parameters | 4 | 4 | 9 | 4 | 4 | 25 |
| Machine do not frequently preventive maintenance | 4 | 4 | 1 | 1 | 4 | 14 |
| Machine errors | 1 | 4 | 4 | 1 | 4 | 14 |
| **Material** | | | | | | |
| Solder paste or flux is contaminated | 9 | 4 | 9 | 4 | 4 | 30 |
| Contaminated component | 4 | 4 | 9 | 9 | 4 | 30 |
| Solder paste is expired so its flux is inactive | 4 | 4 | 9 | 4 | 4 | 25 |
| Different batch lot of raw material | 1 | 1 | 4 | 1 | 1 | 8 |
| Different supplier of raw material | 1 | 1 | 1 | 4 | 4 | 11 |
| **Method** | | | | | | |
| Pressure of squeegee in solder paste screen printing | 9 | 9 | 9 | 4 | 9 | 40 |
| Speed of squeegee in solder paste screen printing | 9 | 9 | 9 | 4 | 9 | 40 |
| Preheat temperature in reflow soldering machine | 9 | 9 | 9 | 9 | 9 | 45 |
| Preheat time in reflow soldering machine | 9 | 9 | 9 | 9 | 9 | 45 |
| Pressure of component placement in SMD mounting machine | 4 | 9 | 4 | 4 | 9 | 30 |
| Insufficient solder volume at the point of non-wetting | 4 | 4 | 9 | 9 | 4 | 30 |
| Not enough flux to help solder wetting | 4 | 4 | 9 | 4 | 4 | 25 |
| Excessive moisture in component and/or PCB | 4 | 4 | 4 | 1 | 4 | 17 |

**Relation Rating System**

9 = High relation

4 = Medium relation

1 = Low relation

0 = No relation

It can be assumed that the highest score means process input has the highest impact on non-wetting. In contrast, the lowest score means process input has the lowest impact on non-wetting. It can be seen from Table 10 that process inputs which related to method which are pressure of squeegee in solder paste screen printing, speed of squeegee in solder paste screen printing, preheat temperature in reflow soldering machine and preheat time in reflow soldering machine have high impact (score 45 and 40) on non-wetting defect.

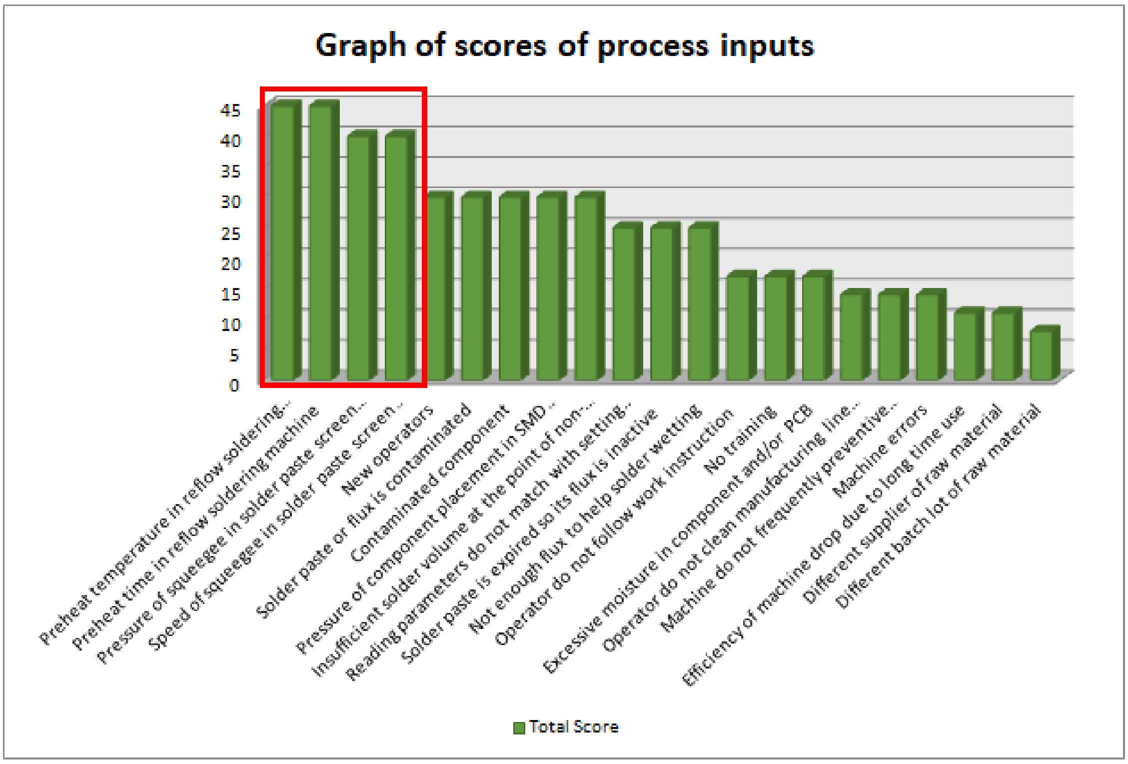


**Figure 30:** Graph of scores of process inputs

Moreover, there is a gap between these four process inputs and other inputs as seen from the graph; thus, this research will mainly focus on the first four factors and find out the suitable levels of these factors, which are pressure of squeegee in solder paste screen printing, speed of squeegee in solder paste screen printing, preheat temperature in reflow soldering machine and preheat time in reflow soldering machine in order to find the factors affect non-wetting defective rate.

The first is temperature. For example, if preheat temperature in reflow soldering machine is too low, it will generate non-wetting because solder paste has not completely melt at the contact area between component terminal and PCB pads.

The second is preheat time in reflow soldering machine. Long preheat time can cause an inappropriate temperature for chemical reaction between solder paste and flux at the point of melting, which initiate non-wetting defect. Furthermore, if temperature is too high, it will make flux evaporate. Flux is a solvent in solder paste used to help solder completely wetting. If flux is evaporated, there is no flux to help solder wetting which finally lead to non-wetting.

The third is squeegee pressure in screen printing machine. If there is an inappropriate setting pressure, solder defects will occur. For instance, if there is low pressure, solder defect of excessive solder will be occurred, since solder will not be swept out from squeegee. While high pressure will generate non-wetting defect due to a few solder left at the PCB.

Finally, speed in screen printing machine. Slow speed will result in insufficient solder which is leading to non-wetting defect. This is because solder paste will be entirely swept out from PCB. Whereas higher speed will generate solder defect of excessive solder because of too much solder paste left on PCB.

It can be concluded that all four process inputs have potential to be significant factors affecting non-wetting defective rate. Therefore, in order to find optimal process settings to prevent the issue of non-wetting, Design of Experiment (DOE) is an appropriate tool to test whether these factors have significant effect on non-wetting defective rate. Then, the optimal setting of significant factors will be determined.

## 4.4 Summary of Measure phase chapter

In the measure phase, four tools were applied to use which are Attribute Agreement Analysis, cause and effect diagram, cause and effect matrix, and Pareto chart. Beginning with Attribute Agreement Analysis which is used to appraise the accuracy and the precision of the inspection of non-wetting defect by using three experienced inspectors. Secondly, the cause and effect diagram has been created to find potential causes of non-wetting defect by brainstorming between team members. Then, the cause and effect matrix was used to analyse the possible causes so as to identify the most likely causes. Finally, graph was made from C&E matrix in order to find the most possible causes that have significant impact to the manufacturing process of PCBA which can lead to non-wetting defect. Four potential causes are pressure, speed, temperature, and time during SMT processes. Therefore, the team concluded that these four factors need to be specially focused on and need to be improved in the next phase.

# Chapter 5

# Analyse Phase

In the analyse phase, the selected four factors will be tested whether they are statistically significantly affect the non-wetting defective rate. Using the aid of Design of Experiment technique. The relationship equation of significant terms and the non-wetting defective rate will be determined and used to find out the optimal setting of the significant factors.

## 5.1 Design of Experiment

For the purpose of finding an optimal setting of factors, $2^k$ full-factorial design with centre points are used since each factor is tested at least 3 levels, which enable the ability to test for curvature.

### 5.1.1 Factors to be tested

1. Pressure of squeegee

   Using too high squeegee pressure in screen printing process will result in insufficient solder paste printed on PCB, since it will not entirely sweep solder paste onto PCB pad. There will have low solder volume and solder will not enough and lead to non-wetting defect. In contrast, using too low squeegee pressure will result in high amount of solder paste volume left on PCB pad which finally causes excessive solder paste.

2. Speed of squeegee

Apart from the pressure, squeegee speed is one of the causes that have high impact on product quality. If speed of squeegee is too low, the squeegee will sweep all solder paste out of PCB pad and result in low solder volume at the PCB pad which finally bring about insufficient solder after reflow soldering process. Then, non-wetting will be occurred. However, using high squeegee speed will cause high amount of solder paste left on PCB pad which generates excessive solder.

3. Preheat time

Long preheat time can cause flux in solder paste has been evaporated before wetting process is completed. Flux is one of a component that is combined in solder paste in order to help solder wetting to be completed. If flux is evaporated before wetting process is completed, it will cause non-wetting defect. In contrary, if using short preheat time, a reaction between solder paste and flux to component terminal will still not complete, which finally result in incomplete wetting or it is known as de-wetting defect.

4. Preheat temperature

If preheat temperature in reflow soldering machine is too low, it will generate non-wetting because solder paste has not completely melt at the contact area between component terminal and PCB pads. However, if preheat temperature is high, components will be damaged.

### 5.1.2 Controlled factors

In order to remove an effect on the result of the experiment, variables that are not tested needed to be controlled and must be kept at a constant condition during the experiment.

There are four controlled variables in the experiment which are:

(1) Using the same screen SMT machines such as screen printing, solder paste inspection machine, SMD mounting machine, reflow soldering machines, microscope, and Auto inspection machine

(2) Using the same operators throughout the experiment

(3) Using the same batch lot of raw material such as solder paste and all components used for producing PCBA

(4) Using the same inspection operators throughout the experiment

### 5.1.3 Response

This research will use defective rate of non-wetting defect as the response of the experiment.

### 5.1.4 Design selection

Due to time limitation of the research, this research considered using a $2^k$ full-factorial design with centre points design since it provides the opportunity for testing curvature. If curvature is not statistically significant, then it is assumed to be linear relation; thus, $2^k$ full-factorial design with centre points design is sufficient for this experimentation. However, if curvature is statistically significant, the axial runs will be added and combined to Face-centred design (CCF) and uses the experimental results from CCF to find second order model and then find optimal setting.

$2^k$ full-factorial design with centre points design consists of $2^k$ factorial runs and $n_c$ centre runs (depend on k, factor). Factorial points are at ±1 coded unit from centre run.

In this research, 4 factors were tested and full factorial with centre points requires total of 23 runs, which affordable to be run. In addition, $2^k$ full-factorial with centre points gives good prediction overall design space.

### 5.1.5 Factor levels selection

Referring to previous section, there are four factors to be tested. These factors are pressure, speed, temperature, and time. For $2^k$ full-factorial design with centre points design, each factor is required to be tested for 3 coded unit levels, which are low level (-1), centre point (0), and high level (+1). Next, the uncoded units for each factor were determined by the reason mentioned in Table 11.

**Table 11:** Factor Level Selection

| **Factor** | **Level** | | | **Unit** | **Remark** |
|---|---|---|---|---|---|
| | **Low (-1)** | **Centre (0)** | **High (+1)** | | |
| **Pressure** | 8 | 12 | 16 | kg | Refer to the historical manufacturing data and team discussion, pressure of screen printing machine has been used at 12 kg, but it can be set the parameter at different levels from 8 to 16 kg; thus, for this design pressure was tested at 8, 12, and 16 kg. Pressure level under 8 kg can result in solder defects, as it provides high amount of solder paste volume, while higher pressure than 16 kg can give lower amount of solder paste volume and leads to high non-wetting defect. |

| Factor | Level | | | Unit | Remark |
|---|---|---|---|---|---|
| | Low (-1) | Centre (0) | High (+1) | | |
| **Speed** | 20 | 40 | 60 | mm/s | Refer to the historical manufacturing data and team discussion, normally speed was set at 40 mm/s. However, it can be set at different levels from 20 to 60 mm/s; hence, for this experiment speed was tested at 20, 40, and 60 mm/s. Speed level lower than 20 mm/s can provide solder defects due to insufficient solder, which finally leads to non-wetting defect, while higher speed than 60 mm/s can provide a large amount of solder paste on PCB pad which lead to excessive solder. |
| **Temperature** | 175 | 205 | 235 | °C | Refer to the historical manufacturing data and team discussion, temperature is set at 205°C, but it can be set up at different levels from 175 to 235°C. For this design temperature was set at 175, 205, and 235°C. Temperature under 175°C will lead to unmelt solder paste which finally generate non-wetting defect, while temperature over 235°C will cause the component to burn. |
| **Time** | 45 | 75 | 105 | sec | Refer to the historical manufacturing data and team discussion, time has been set up at 75 sec. However, it can be set at different levels at 45, 75, and 105 sec. Time less than 45 sec. will result in unmelt solder paste, whereas longer time than 105 sec. will cause solder defect of non-wetting. |

### 5.1.6 Sample size design

In order to save cost in PCBA manufacturing process in the company, this research project has to find an appropriate sample size for each experimental run to control cost of raw material, production cost and also utilities cost. Moreover, time consumed of producing PCBA for each work order will be considered because this PCBA will share the same SMT production line with other products. Therefore, the calculation of sample size will be performed prior to the start of the experiment and it can be calculated as follows:

Sample size for each experimental run with $2^k$ full-factorial with centre points design where response is proportion can be calculated from equation (6) and (7) below:

$$n = \left(z_{1-\propto/2} + z_{1-\beta}\right)^2 / (N\delta^2) \qquad (6)$$

where $n = Sample\ size$

$N = \ Number\ of\ factorial\ experimental\ runs = 23$

$\delta = \ A\ function\ of\ proportion\ or\ defective\ rate\ before\ improvement\ and\ after\ improvement$

$\alpha = \ Significance\ level\ at\ 0.05$

$\beta = Propability\ of\ type\ II\ error$

$$\delta = \arcsin\left(\sqrt{p_0 + \Delta/2}\right) - \arcsin\left(\sqrt{p_0 - \Delta/2}\right) \qquad (7)$$

where $p_0 = Defective\ rate\ before\ improvement = 0.0285$

$\Delta\ = The\ change\ in\ defective\ rate\ between\ before\ and\ after\ improvement = 0.0185$

The calculation based on equation (6) yields the sample size (n) = 107 pieces per each experimental run.

It can be concluded that at the power of test equal to 0.9 and significance level at 95%, there will be used at least 107 pieces of PCBAs for one experimental run. For all 23 experimental runs by using $2^k$ full-factorial with centre points design with four factors; 2,461 pieces of PCBAs are needed.

## 5.2 Design matrix and results

The design matrix is shown in Table 12. The experimental runs are randomized so as to reduce the effects of uncontrollable factors. The response value for each run is also shown in Table 12.

**Table 12:** Design Matrix for $2^k$ full-factorial with centre points design and results

| StdOrder | RunOrder | Pressure (kg) | Speed (mm/s) | Temperature (°C) | Time (sec) | Defective rate |
|---|---|---|---|---|---|---|
| 1 | 5 | 8 | 20 | 175 | 45 | 0.0654 |
| 2 | 4 | 16 | 20 | 175 | 45 | 0.0935 |
| 3 | 3 | 8 | 60 | 175 | 45 | 0.1121 |
| 4 | 23 | 16 | 60 | 175 | 45 | 0.1215 |
| 5 | 18 | 8 | 20 | 235 | 45 | 0.0467 |
| 6 | 19 | 16 | 20 | 235 | 45 | 0.0935 |
| 7 | 17 | 8 | 60 | 235 | 45 | 0.0935 |
| 8 | 9 | 16 | 60 | 235 | 45 | 0.0748 |
| 9 | 20 | 8 | 20 | 175 | 105 | 0.1028 |
| 10 | 1 | 16 | 20 | 175 | 105 | 0.1028 |
| 11 | 15 | 8 | 60 | 175 | 105 | 0.1121 |
| 12 | 2 | 16 | 60 | 175 | 105 | 0.1402 |
| 13 | 14 | 8 | 20 | 235 | 105 | 0.0935 |
| 14 | 8 | 16 | 20 | 235 | 105 | 0.1028 |
| 15 | 10 | 8 | 60 | 235 | 105 | 0.0935 |
| 16 | 12 | 16 | 60 | 235 | 105 | 0.1121 |
| 17 | 13 | 8 | 40 | 205 | 75 | 0.0841 |
| 18 | 6 | 16 | 40 | 205 | 75 | 0.1121 |
| 19 | 22 | 12 | 20 | 205 | 75 | 0.1028 |
| 20 | 11 | 12 | 60 | 205 | 75 | 0.1121 |
| 21 | 21 | 12 | 40 | 175 | 75 | 0.1215 |
| 22 | 7 | 12 | 40 | 235 | 75 | 0.1028 |
| 23 | 16 | 12 | 40 | 205 | 45 | 0.1028 |

### 5.2.1 Model Adequacy Checking

Before analyzing the experimental data, model assumptions need to be validated so as to guarantee that regression analysis fits with the data. There are three essential assumptions that need to be validated referring to εij ~NID $(0,\sigma^2)$ principle. Those assumptions are normal distribution of residuals, independence of residuals, and constant variance of residuals.

5.2.1.1 The normality of residuals

The normal probability plot of the residual was used for checking whether the residuals are normally distributed. Regarding to Figure 31, it can be seen that the residuals form a straight line and P-value of Anderson-Daring normality test of 0.05 indicates that residuals are normally distributed which is exact to the standard of the P-value. Hence, the residuals of this experiment are normally distributed.

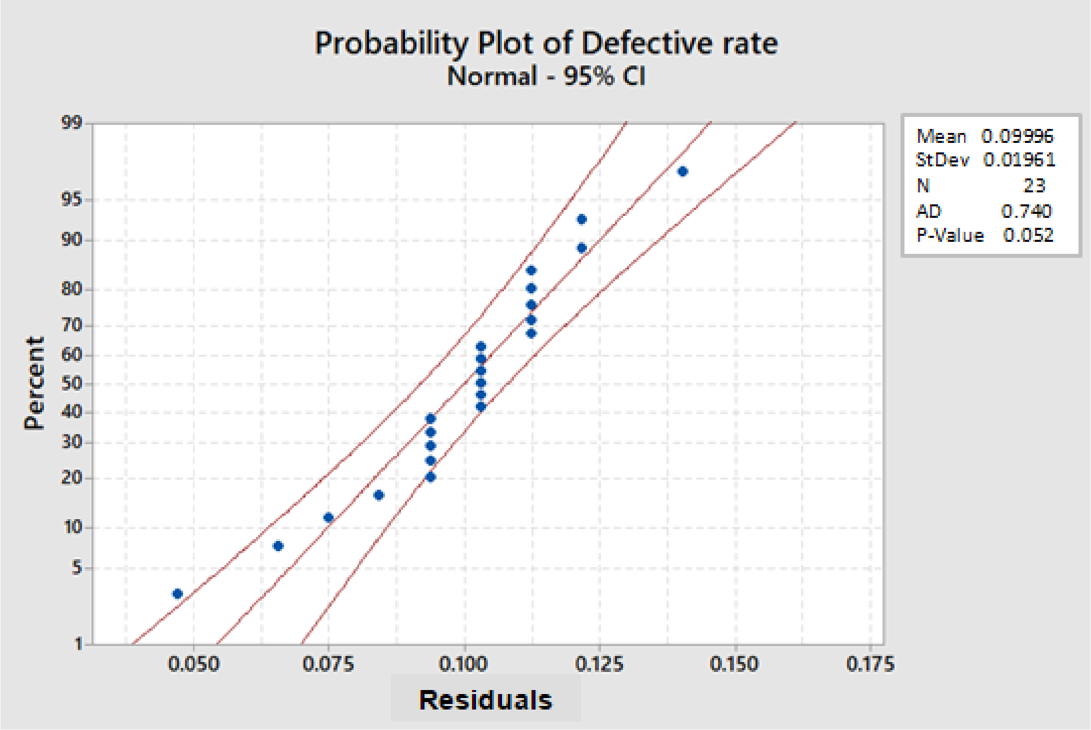


**Figure 31:** Probability Plot of Residuals

### 5.2.1.2 The independence of the residuals

The assumption of the independence of the residuals can be tested using the plot of residuals versus observation order. If the plot indicates the randomly scattered points along the centre line with no pattern in the plot, it can be assumed that residuals are independent. Figure 32 illustrates the randomly residual points around the centre line with no trends. Hence, the residuals are independent.

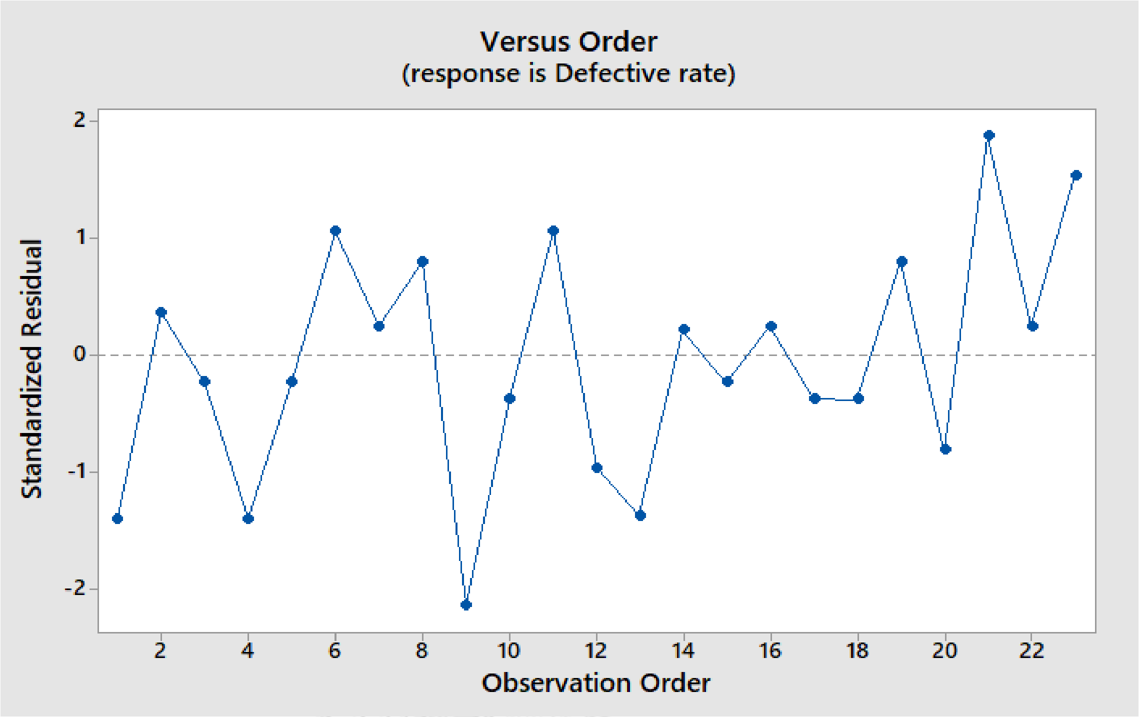


**Figure 32:** The plot of Residuals versus Observation Order

5.2.1.3 The constant variance of the residuals

From the constant variance of the residuals, assumption was tested using the plot of residuals versus fitted values. The plot should display a random pattern of the residuals with the variance constant over all fitted values. Figure 33 indicates the residual points vary constantly over fitted values with no specific pattern. Hence, the residuals have constant variance.

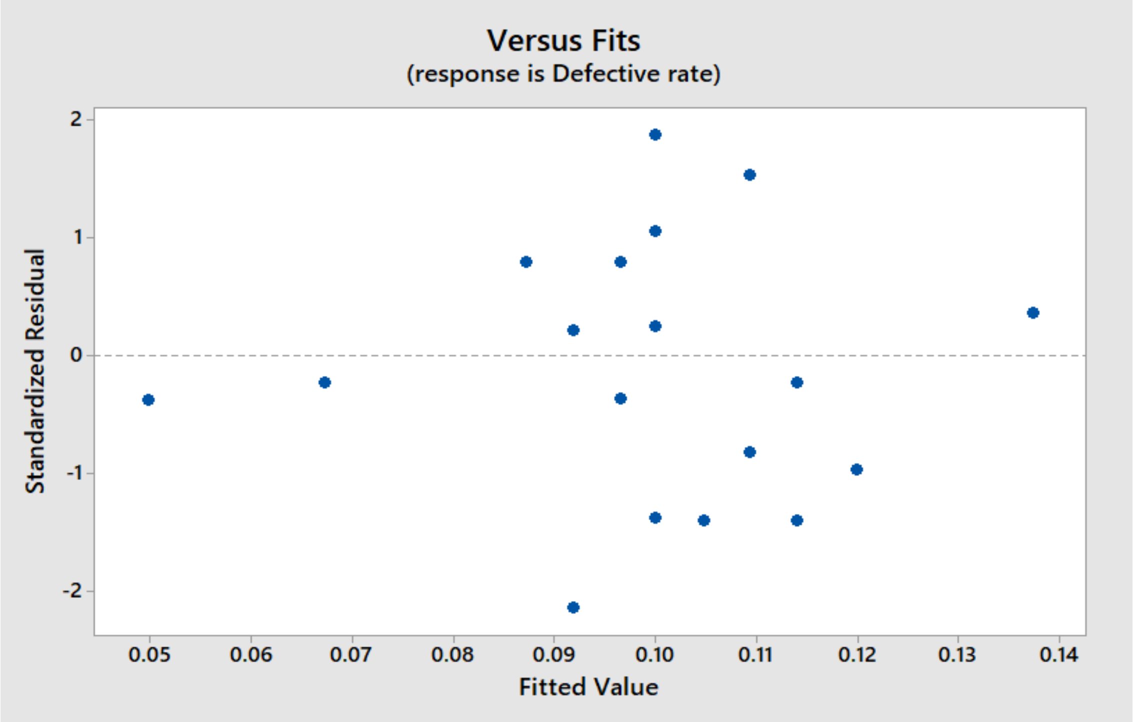
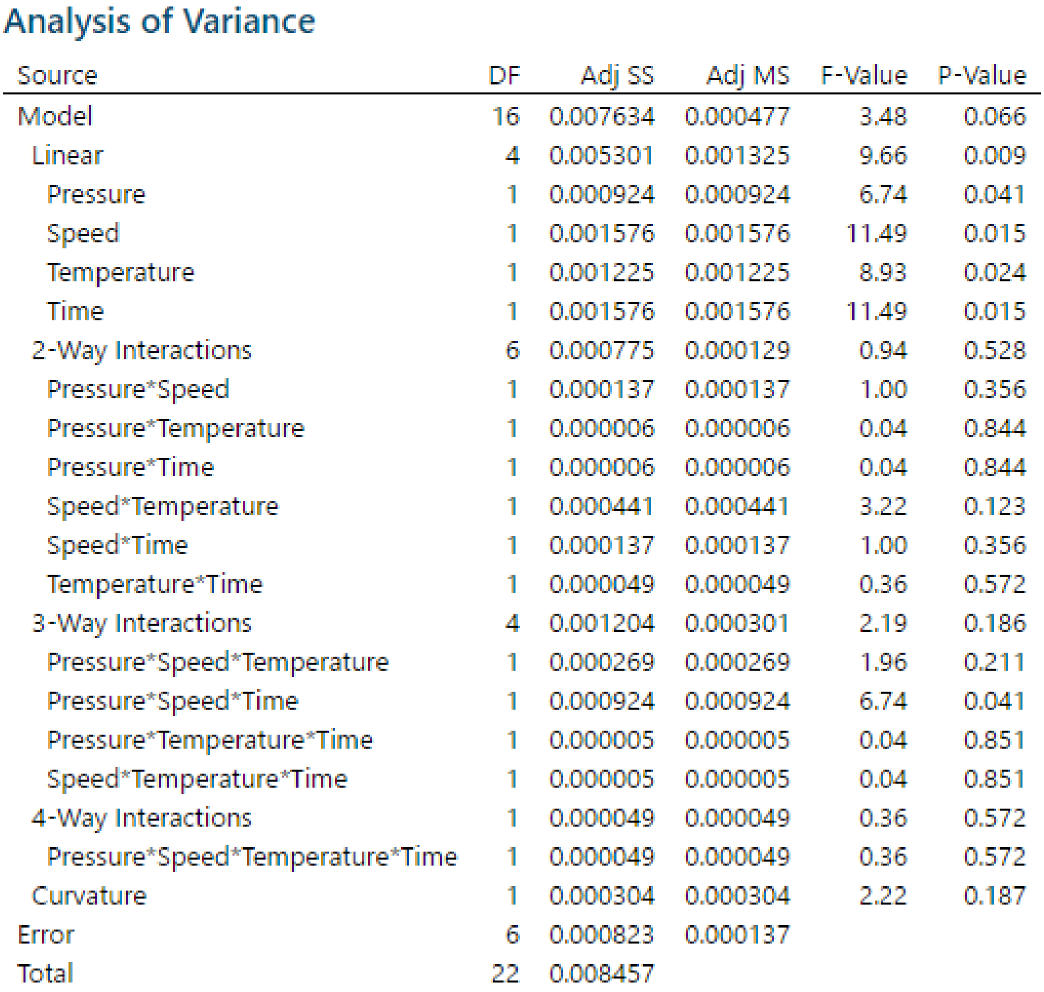


**Figure 33:** The plot of Residuals versus Fitted Values

According to Figure 31, 32 and 33, it can be concluded that all data meet the key assumptions of linear regression model, which can be assumed that the experimental data is valid and can be interpreted further using regression model.

## 5.3 Analysis of Experimental Data

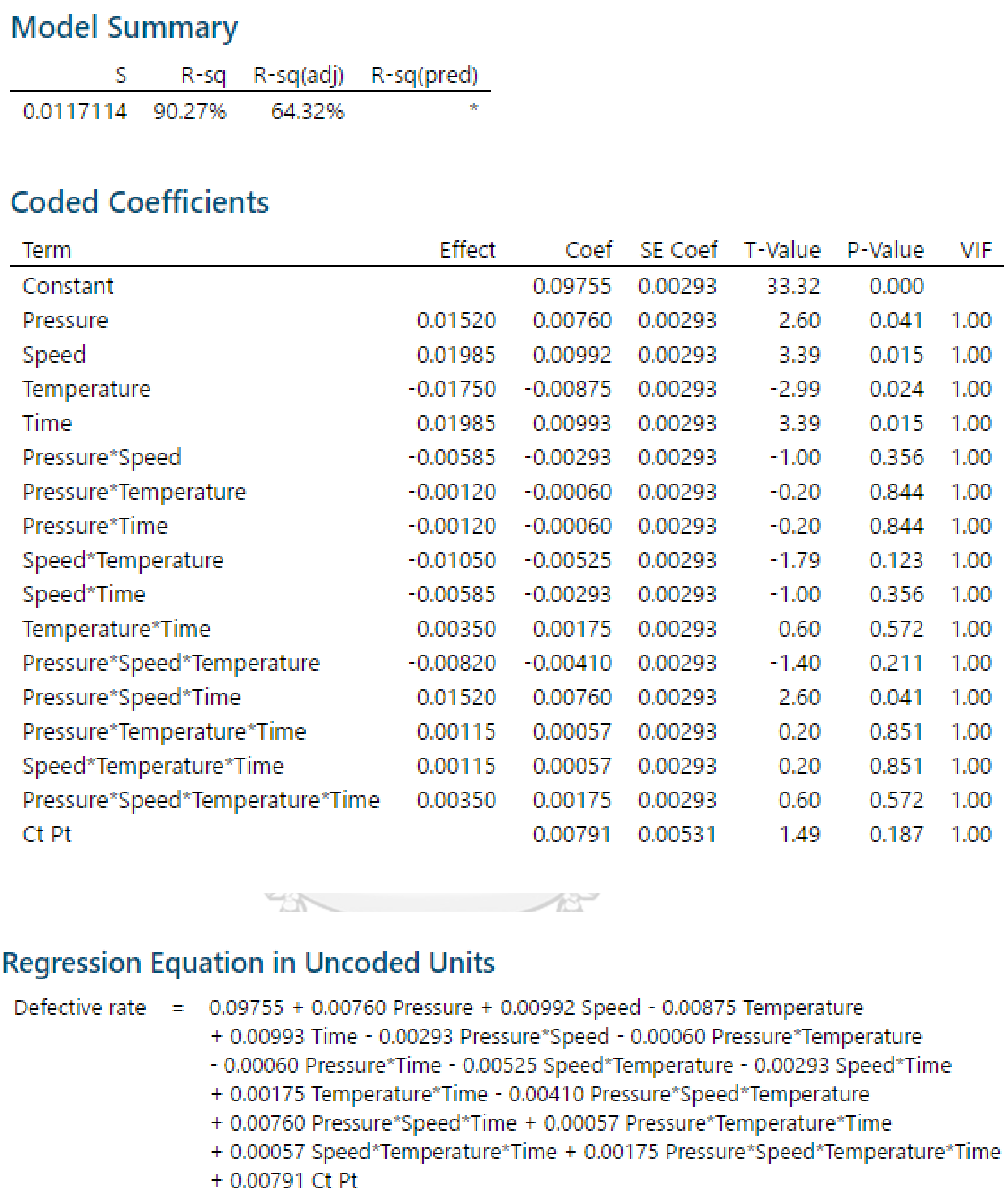
In order to analyse the experimental result, an analysis of variance (ANOVA) technique followed with the stepwise regression were used to determine the terms that significantly affect the defective rate. The result was shown in Figure 34 using MINITAB programme.



Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 16 | 0.007634 | 0.000477 | 3.48 | 0.066 |
| Linear | 4 | 0.005301 | 0.001325 | 9.66 | 0.009 |
| Pressure | 1 | 0.000924 | 0.000924 | 6.74 | 0.041 |
| Speed | 1 | 0.001576 | 0.001576 | 11.49 | 0.015 |
| Temperature | 1 | 0.001225 | 0.001225 | 8.93 | 0.024 |
| Time | 1 | 0.001576 | 0.001576 | 11.49 | 0.015 |
| 2-Way Interactions | 6 | 0.000775 | 0.000129 | 0.94 | 0.528 |
| Pressure*Speed | 1 | 0.000137 | 0.000137 | 1.00 | 0.356 |
| Pressure*Temperature | 1 | 0.000006 | 0.000006 | 0.04 | 0.844 |
| Pressure*Time | 1 | 0.000006 | 0.000006 | 0.04 | 0.844 |
| Speed*Temperature | 1 | 0.000441 | 0.000441 | 3.22 | 0.123 |
| Speed*Time | 1 | 0.000137 | 0.000137 | 1.00 | 0.356 |
| Temperature*Time | 1 | 0.000049 | 0.000049 | 0.36 | 0.572 |
| 3-Way Interactions | 4 | 0.001204 | 0.000301 | 2.19 | 0.186 |
| Pressure*Speed*Temperature | 1 | 0.000269 | 0.000269 | 1.96 | 0.211 |
| Pressure*Speed*Time | 1 | 0.000924 | 0.000924 | 6.74 | 0.041 |
| Pressure*Temperature*Time | 1 | 0.000005 | 0.000005 | 0.04 | 0.851 |
| Speed*Temperature*Time | 1 | 0.000005 | 0.000005 | 0.04 | 0.851 |
| 4-Way Interactions | 1 | 0.000049 | 0.000049 | 0.36 | 0.572 |
| Pressure*Speed*Temperature*Time | 1 | 0.000049 | 0.000049 | 0.36 | 0.572 |
| Curvature | 1 | 0.000304 | 0.000304 | 2.22 | 0.187 |
| Error | 6 | 0.000823 | 0.000137 | | |
| Total | 22 | 0.008457 | | | |

**Figure 34:** ANOVA Table



### Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 0.0117114 | 90.27% | 64.32% | * |

### Coded Coefficients

| Term | Effect | Coef | SE Coef | T-Value | P-Value | VIF |
|---|---|---|---|---|---|---|
| Constant | | 0.09755 | 0.00293 | 33.32 | 0.000 | |
| Pressure | 0.01520 | 0.00760 | 0.00293 | 2.60 | 0.041 | 1.00 |
| Speed | 0.01985 | 0.00992 | 0.00293 | 3.39 | 0.015 | 1.00 |
| Temperature | -0.01750 | -0.00875 | 0.00293 | -2.99 | 0.024 | 1.00 |
| Time | 0.01985 | 0.00993 | 0.00293 | 3.39 | 0.015 | 1.00 |
| Pressure*Speed | -0.00585 | -0.00293 | 0.00293 | -1.00 | 0.356 | 1.00 |
| Pressure*Temperature | -0.00120 | -0.00060 | 0.00293 | -0.20 | 0.844 | 1.00 |
| Pressure*Time | -0.00120 | -0.00060 | 0.00293 | -0.20 | 0.844 | 1.00 |
| Speed*Temperature | -0.01050 | -0.00525 | 0.00293 | -1.79 | 0.123 | 1.00 |
| Speed*Time | -0.00585 | -0.00293 | 0.00293 | -1.00 | 0.356 | 1.00 |
| Temperature*Time | 0.00350 | 0.00175 | 0.00293 | 0.60 | 0.572 | 1.00 |
| Pressure*Speed*Temperature | -0.00820 | -0.00410 | 0.00293 | -1.40 | 0.211 | 1.00 |
| Pressure*Speed*Time | 0.01520 | 0.00760 | 0.00293 | 2.60 | 0.041 | 1.00 |
| Pressure*Temperature*Time | 0.00115 | 0.00057 | 0.00293 | 0.20 | 0.851 | 1.00 |
| Speed*Temperature*Time | 0.00115 | 0.00057 | 0.00293 | 0.20 | 0.851 | 1.00 |
| Pressure*Speed*Temperature*Time | 0.00350 | 0.00175 | 0.00293 | 0.60 | 0.572 | 1.00 |
| Ct Pt | | 0.00791 | 0.00531 | 1.49 | 0.187 | 1.00 |

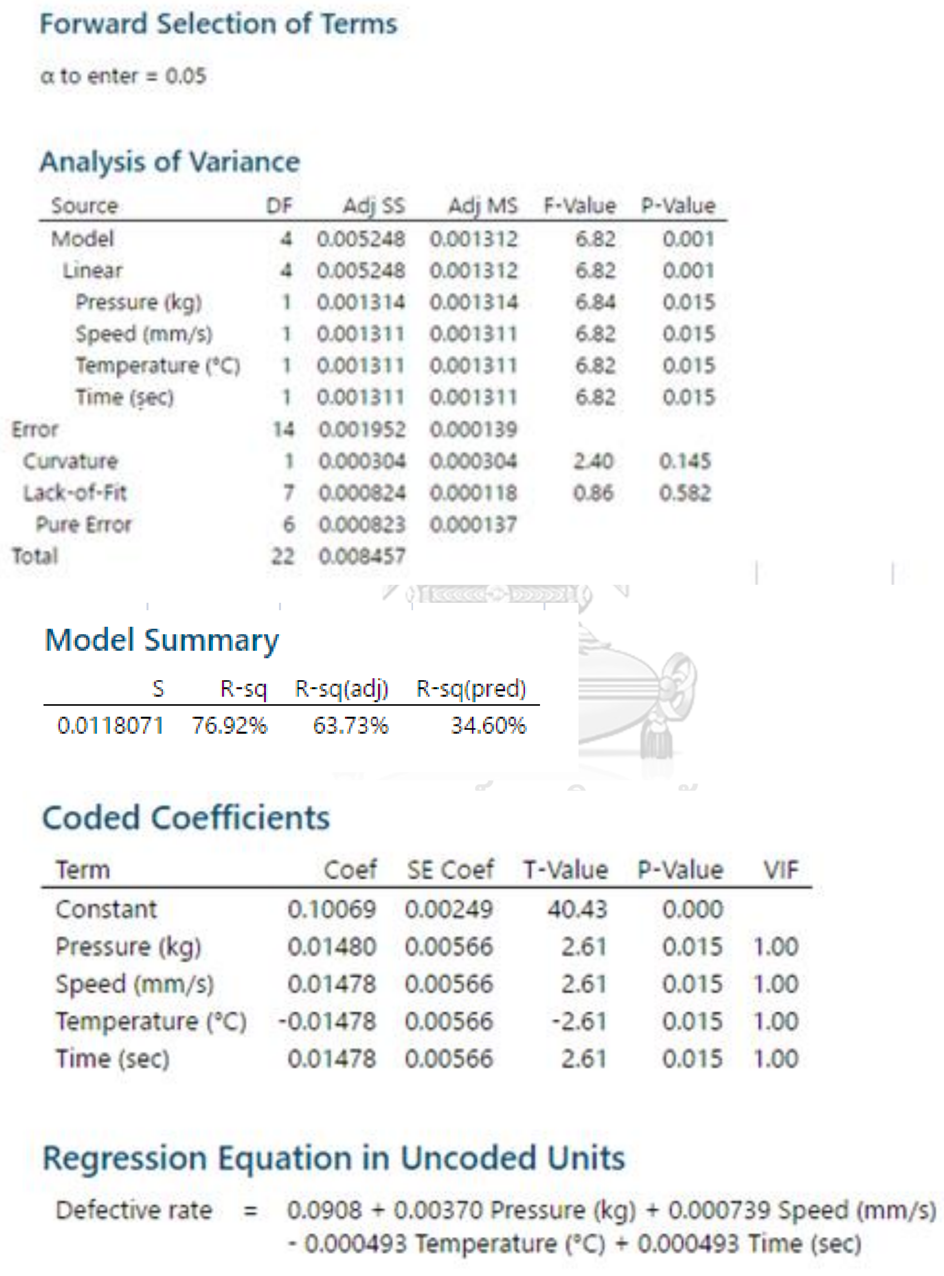
### Regression Equation in Uncoded Units

```
Defective rate  =  0.09755 + 0.00760 Pressure + 0.00992 Speed - 0.00875 Temperature
                   + 0.00993 Time - 0.00293 Pressure*Speed - 0.00060 Pressure*Temperature
                   - 0.00060 Pressure*Time - 0.00525 Speed*Temperature - 0.00293 Speed*Time
                   + 0.00175 Temperature*Time - 0.00410 Pressure*Speed*Temperature
                   + 0.00760 Pressure*Speed*Time + 0.00057 Pressure*Temperature*Time
                   + 0.00057 Speed*Temperature*Time + 0.00175 Pressure*Speed*Temperature*Time
                   + 0.00791 Ct Pt
```

**Figure 34:** ANOVA Table (Cont.)

It can be seen from the ANOVA table in Figure 34 that only main effects of the four factors are significant. The quadratic terms and the interaction terms are not significant. The four main factors which have critical influence on the defective rate are pressure, speed, temperature, and time.

Next, stepwise regression has been performed to obtain a reduced model with only significant terms at the significant level of 0.05. The results are shown in Figure 35.



```
Forward Selection of Terms

α to enter = 0.05

Analysis of Variance

Source              DF    Adj SS     Adj MS   F-Value  P-Value
Model                4  0.005248   0.001312     6.82     0.001
  Linear             4  0.005248   0.001312     6.82     0.001
    Pressure (kg)    1  0.001314   0.001314     6.84     0.015
    Speed (mm/s)     1  0.001311   0.001311     6.82     0.015
    Temperature (°C) 1  0.001311   0.001311     6.82     0.015
    Time (sec)       1  0.001311   0.001311     6.82     0.015
Error               14  0.001952   0.000139
  Curvature          1  0.000304   0.000304     2.40     0.145
  Lack-of-Fit        7  0.000824   0.000118     0.86     0.582
    Pure Error       6  0.000823   0.000137
Total               22  0.008457

Model Summary

        S     R-sq   R-sq(adj)   R-sq(pred)
0.0118071   76.92%      63.73%       34.60%

Coded Coefficients

Term                 Coef    SE Coef  T-Value  P-Value   VIF
Constant           0.10069   0.00249    40.43    0.000
Pressure (kg)      0.01480   0.00566     2.61    0.015  1.00
Speed (mm/s)       0.01478   0.00566     2.61    0.015  1.00
Temperature (°C)  -0.01478   0.00566    -2.61    0.015  1.00
Time (sec)         0.01478   0.00566     2.61    0.015  1.00

Regression Equation in Uncoded Units

Defective rate  =  0.0908 + 0.00370 Pressure (kg) + 0.000739 Speed (mm/s)
                   - 0.000493 Temperature (°C) + 0.000493 Time (sec)
```

**Figure 35:** Stepwise Regression Result

## 5.4 Discussion of results

Figure 36 illustrates the main effect plot of each factor on non-wetting defective rate. Regarding pressure, when pressure increases, the defective rate increases. Similarly to speed, when speed increases, the defective rate increases. However, when temperature increases, the defective rate decreases. Finally, when time increases, the defective rate increases.

This can be explained that using low squeegee speed together with low squeegee pressure can provide enough solder paste volume on PCB pad and when it comes out of reflow soldering machine, solder wetting between PCB pad and component terminal will be in a good condition, which means there is no non-wetting defect. Moreover, using high preheat temperature and taking short preheat time can provide good solder wetting because flux in solder paste will not be evaporated prior to wetting process completion. Therefore, using optimal conditions of each factor is able to provide good solder wetting over the entire component terminal of L7 location.

**Figure 36:** Main Effects Plot for Defect

## 5.5 Summary of Analyse phase chapter

In conclusion, this chapter begins with considering factors to be tested which are pressure, speed, temperature, and time. The response of this experiment is defective rate of non-wetting defect. Next, design selection has been chosen $2^k$ full-factorial with centre points design, since it provides an opportunity for testing curvature and also provides good prediction over the entire range of design space. After that, selection of factor levels has been performed and each factor was tested at 3 different levels following the design. Then, sample size has been evaluated for $2^k$ full-factorial with centre points design and the sample size for each of 23 runs is 107 pieces. Next, design matrix for $2^k$ full-factorial with centre points design was created by using MINITAB programme. The results from stepwise regression show that main effects of pressure, speed, temperature, and time are significant. There is no interaction effect between factors. In addition, there is no curvature effect within the tested range of factor levels.

.

# Chapter 6

# Improve Phase

## 6.1 Optimal setting parameters

Based on stepwise regression model, the optimal setting for pressure, speed, temperature and time of the PCBA is indicated in Table 13.

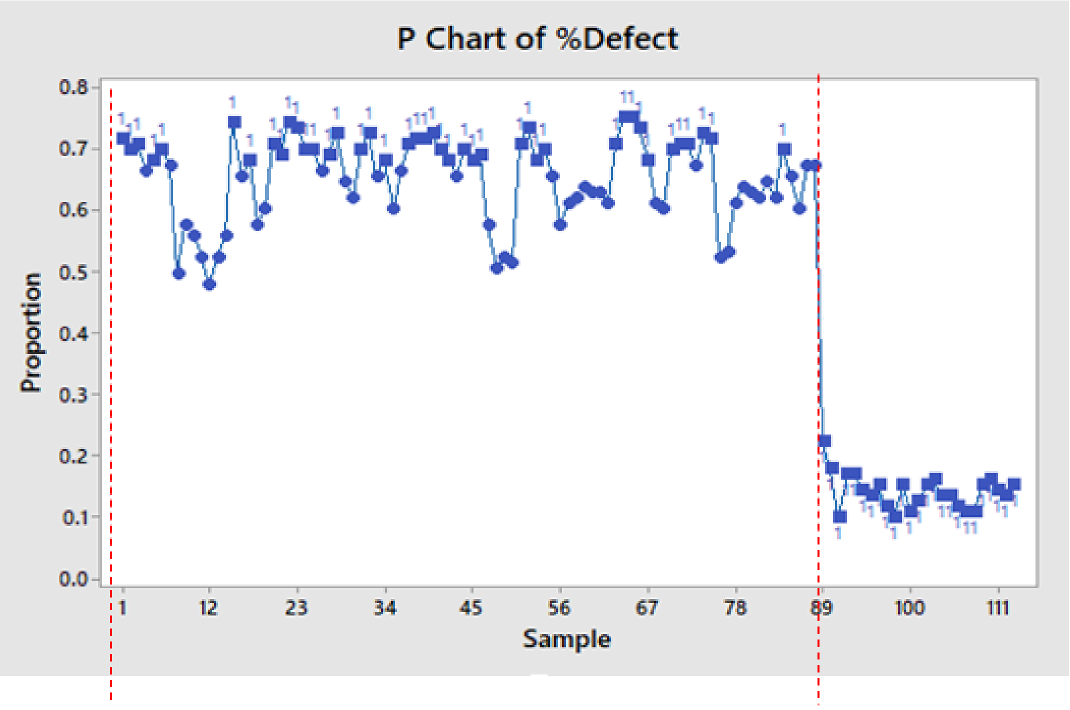
**Table 13:** The optimal conditions of factors

| Factor | Condition | Unit |
|---|---|---|
| A = Pressure | 8 | kg |
| B = Speed | 20 | mm/s |
| C = Temperature | 235 | (°C) |
| D = Time | 45 | sec |

It can be concluded that the lowest defective rate due to non-wetting defect can be obtained by using a squeegee pressure at 8 kg, squeegee speed at 20 mm/s, preheat temperature at 235°C, and preheat time of 45 second.

## 6.2 Confirmation of Improvement Results

According to the plot in Figure 37, it is able to explain that before improvement the defective rate from non-wetting defect was extremely high around 65.36% on average. This historical data was collected three months before improvement. However, after improvement the defective rate from non-wetting defect was dramatically reduced to 15.04% on average, which was collected from one month. The defective rate was reduced by 50.32% from before improvement. The defective rate after improvement met the goal as stated in the change of defective rate between before and after improvement, as the goal is defined that the change will be 1.85%, but after improvement, the change of defective rate was 50.32% which is much higher than the target.

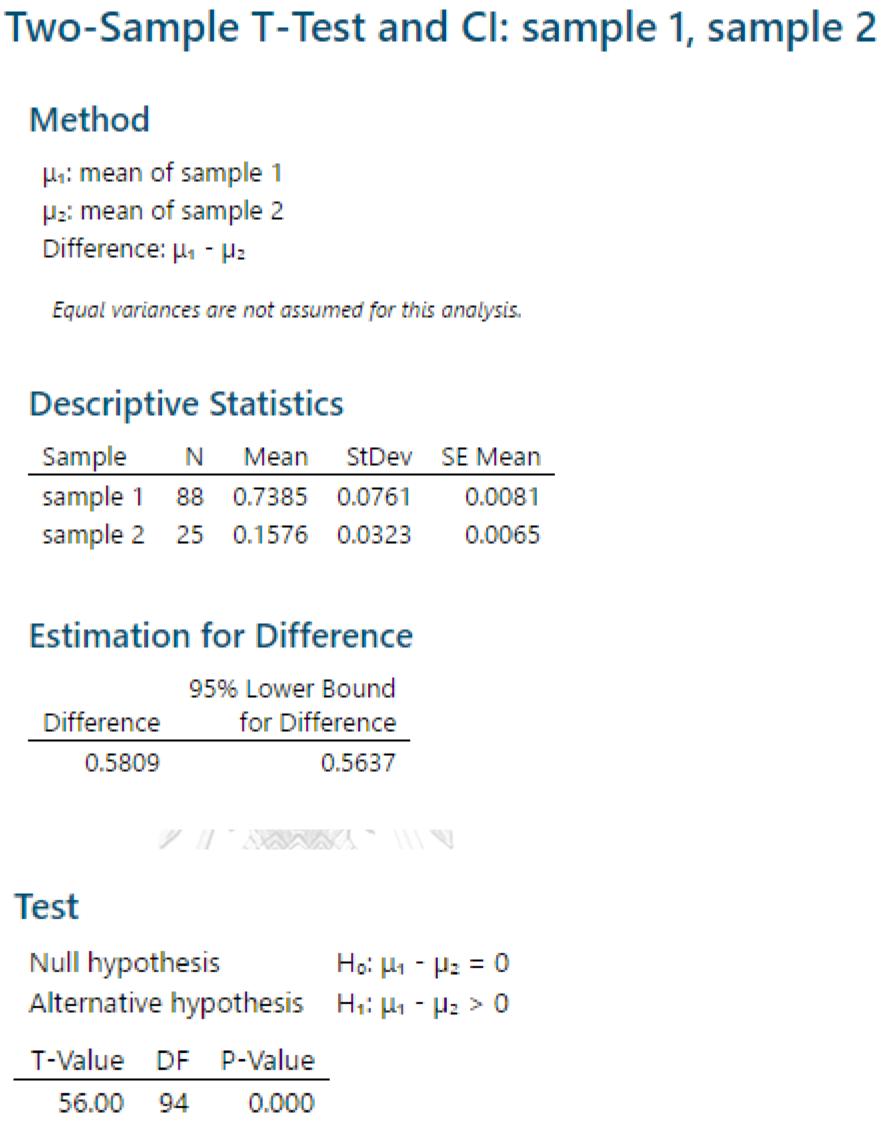


Before improvement

After improvement

**Figure 37:** P-Chart of % Non-wetting defect

In order to ensure that the defective rate from non-wetting defect has been dramatically decreased, Two-Sample T-Test has been applied to compare between defective rate before improvement and after improvement as indicated below:



```
Two-Sample T-Test and CI: sample 1, sample 2

Method

 μ₁: mean of sample 1
 μ₂: mean of sample 2
 Difference: μ₁ - μ₂

  Equal variances are not assumed for this analysis.

Descriptive Statistics

 Sample     N    Mean     StDev   SE Mean
 sample 1  88   0.7385   0.0761    0.0081
 sample 2  25   0.1576   0.0323    0.0065

Estimation for Difference

              95% Lower Bound
 Difference    for Difference
    0.5809             0.5637

Test

Null hypothesis          H₀: μ₁ - μ₂ = 0
Alternative hypothesis   H₁: μ₁ - μ₂ > 0

T-Value   DF   P-Value
  56.00   94     0.000
```

**Figure 38:** Two-Sample T-Test

It can be seen from Figure 38 that the result of P-Value is less than 0.0005 which is less than $\alpha$ (0.05); thus, the null hypothesis has been rejected. Therefore, the alternative hypothesis has been accepted, which means that $\mu_1 > \mu_2$ is correct. Hence, it is able to summarise that the defective rate from non-wetting defect after improvement has been statistically significant reduced from the defective rate of before improvement.

The results of improvement setting and defective rate can be displayed in Table 14.

**Table 14:** Results of improvement setting and defective rate

| Factors | Before improvement | After improvement |
|---|---|---|
| Pressure (kg) | 12 | 8 |
| Speed (mm/sec) | 40 | 20 |
| Temperature (°C) | 205 | 235 |
| Time (sec) | 75 | 45 |
| Defective rate | 0.6536 | 0.1504 |
| Scrapped cost (Baht per month) | 578,937 | 116,096 |
| Scrapped cost (Baht per year) | 6,947,244 | 1,393,152 |

## 6.3 Discussion of optimal setting

It can be seen from Table 14 that new optimal setting after improvement of pressure, speed, temperature, and time are out of range of before improvement. The reason behind is because the parameters setting before improvement were determined from the results of each process, but did not determine from the defects occurred during the manufacturing PCBA. For example, the parameter setting of speed and pressure are determined from screen printing machine and the results of solder %volume from screen printing machine are specified by solder paste inspection machine, which is set specification of solder paste %volume at 50-180%. Moreover, preheat temperature and preheat time are set up at reflow soldering machine. The parameters setting from these two parameters can be considered from specification of solder paste used, which do not concern about the end result of any defects that probably occur to PCBA. Therefore, it can be concluded that the optimal setting from this research are valid and able to apply in the normal production.

In addition, when considered other factors that have related to the manufacturing process and also concerned to optimal setting, it is able to conclude that other factors have not been impacted from the new optimal setting, as other defects have not been statistically increased from before improvement.

Even though the new setting of speed slightly decreased from 40 mm/sec to 20 mm/sec, it does not impact to productivity because the speed of squeegee in screen printing machine is not a bottle neck of the overall process of both before and after improvement. Therefore, the new setting of speed does not impact to productivity. Furthermore, the productivity of one month manufacturing process after improvement has been extremely increased when compared to before improvement due to the fact that non-wetting defective rate has been decreased leading to higher yield and productivity.

## 6.4 Summary of Improve phase chapter

In summary, the new setting parameters have been created based on stepwise regression model. It can be displayed that by using a squeegee pressure at 8 kg, squeegee speed at 20 mm/s, preheat temperature at 235°C, and preheat time of 45 sec, the SMT process was able to generate the least defective rate of non-wetting defect in the PCBA manufacturing line. After improvement, non-wetting defective rate was decreased from 0.6536 to 0.1504 correspond to the percentage reduction of 50.32%. Therefore, it can be summarized that when using the optimal setting in normal production, it will generate significantly lower non-wetting defective rate when compared to the production before improvement.

# Chapter 7

# Control Phase

In the control phase, control activities were set up to maintain the results after improvement. Action plan was developed through a brain storming session among the team members as indicated in Table 15.

**Table 15:** Action plan for maintaining improvement results of non-wetting defective rate in PCBA manufacturing line

| **No.** | **Activity** | **Responsible person** | **Apr-19** | | | | **May-19** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| 1 | Creating new work instruction for PCBA manufacturing process | Process engineer | ■ | | | | | | | |
| 2 | Creating a control plan | Process improvement team | | ■ | ■ | | | | | |
| 3 | Creating a control chart | Researcher | | | | ■ | ■ | ■ | ■ | |
| 4 | Training operators who are working in the manufacturing line | Process engineer | | | | | | | | ■ |

## 7.1 Creating new work instruction for PCBA manufacturing process

Since there is a new setting of parameters in SMT processes which are related to screen printing machine and reflow soldering machine; thus, the setting parameters of squeegee pressure, squeegee speed, preheat temperature and preheat time must be updated and recorded new values in the form. However, there is no change affected the SMT production line except changing these four influenced parameters. Related work instructions and parameter setting can be shown in Appendices section.

## 7.2 Control Plan Setup

Table 16 shows a control plan for two related processes, which are screen printing and reflow soldering processes. Four significant factors have been specified and control methods have been created.

**Table 16:** Control Plan

| **Process** | **Factors** | **Specification** | **Control method** | **Frequency** | **Action** | **Refer** |
|---|---|---|---|---|---|---|
| Screen printing | Pressure (kg) | 8 | Check sheet | Start production order | Inform supervisor and process engineer | Screen printing record |
| | Speed (mm/sec) | 20 | | | | |
| Reflow soldering | Temperature (°C) | 235 | | | | Reflow soldering record |
| | Time (sec) | 45 | | | | |

According to Table 16, the first factor is squeegee pressure in screen printing machine in which specified value at 8 kg. Control method is using check sheet to record pressure when starting new production order by referring to screen printing record. This prevents pressure out of specification, but if it is out of specification, action will be taken immediately by informing supervisor and process engineer. The second factor is squeegee speed in screen printing machine which has a specification of 20 mm/sec. Check sheet is used to control and record the speed value when starting new production order by referring screen printing record. The third is temperature in reflow soldering machine which is set at 235°C and there is a check sheet for recording value when starting new production order. Finally, time in reflow soldering machine is set at 45 second and it can be detected by using check sheet to record preheat time every start new production order.

As seen from control plan, frequency of checking each parameter is when staring new production order. This is because each four factor has been set up when there is produced the PCBA and the actual setting of each four parameters will not be changed throughout the manufacturing process. Thus, it is enough for checking the setting for only starting production run.

## 7.3 Creating the control chart

The control chart is created to monitor the defective rate after improvement. A control limit of P-chart was calculated using one-month data after improvement. The set up P-chart with its control limits is shown in Figure 39. It can be seen that after improvement the defective rate due to non-wetting defect is stable around 15.04%.

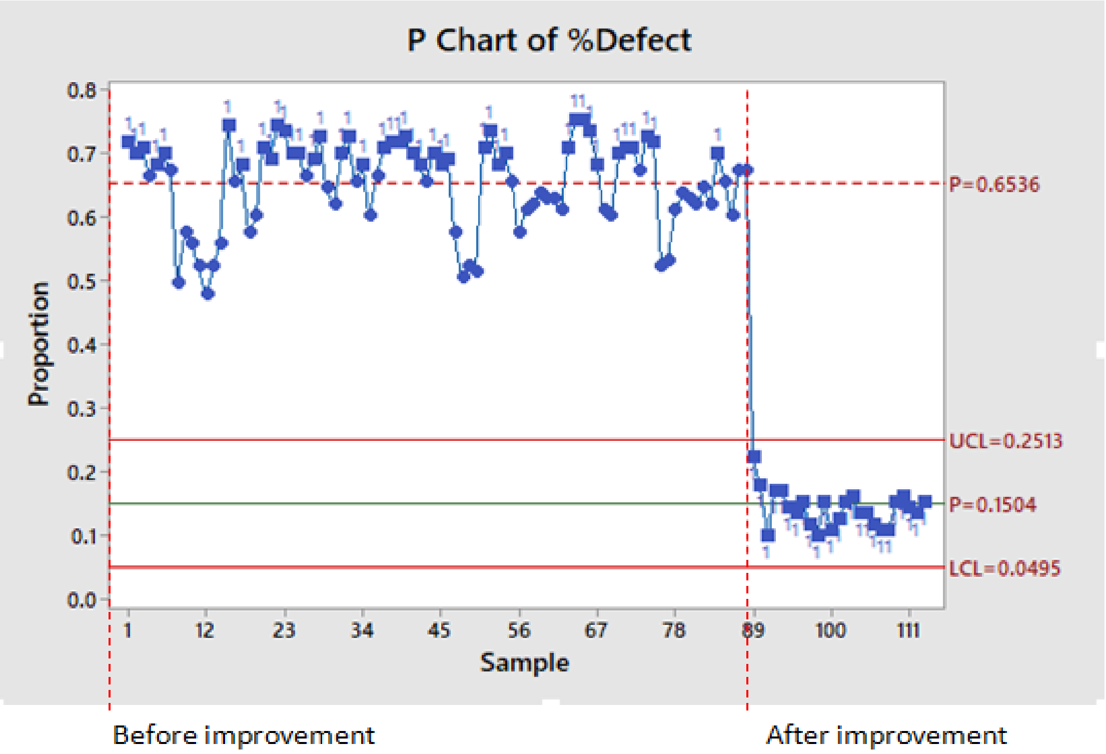


Figure 39: P-Chart of Defective rate from Non-wetting defect

## 7.4 Training operators who are working for the manufacturing line

After new optimal setting of the four factors have been updated, process engineer needs to train new work instruction to supervisor and SMT operators to ensure that they follow the updated work instruction correctly. All related SMT operators who are assigned to work for this PCBA must be trained before producing the PCBA. In addition, inform operators that if they encounter with any problems during manufacturing, they need to inform supervisor and process engineer so as to solve the problem.

## 7.5 Summary of Control phase chapter

In the control phase, beginning with action plan for solving non-wetting defect. It consists of creating work instruction for PCBA manufacturing process, training operators who are working for this PCBA, creating control chart, and performance evaluation. Referring to P chart, it is indicated that by implementing suitable parameters for significant factors for one month, the defective rate from non-wetting defect was dramatically reduced from 0.6536 to only 0.1504 and resulting in the scrapped cost to be decreased from 6,947,244 baht per year to only 1,393,152 baht per year for non-wetting defect of L7 on PCBAs. In addition, control plan has been created to help monitor and control each of the factors with specific value. There are control methods and specify frequency of every check point. Thereby, it can be summarised that the results are very satisfactory by the team members and this improvement has been completed and success for not only the team members, but also for the company.

# Chapter 8

# Conclusion and Recommendation

This research follows Six Sigma DMAIC methodology in order to improve production process of printed circuit board assembly industry. Potential causes affected non-wetting defect were found by using cause-and-effect diagram together with cause-and-effect matrix to prioritise the potential factors. Then, performing experimental design through $2^k$ full-factorial with centre points design in order to find optimal setting parameters of each significant factor. After getting new optimal setting, then apply the optimal setting to normal production for one month and create control chart to see the differences between before and after improvement. The result from control chart shows that non-wetting defective rate has been statistically reduced from before improvement, as the defective rate from non-wetting defect was dramatically reduced from 65.36% to only 15.04% and resulting in the scrapped cost to be decreased from 6,947,244 baht per year to only 1,393,152 baht per year for non-wetting defect of L7 on PCBAs.

The Six Sigma methodology consists of 5 phases which are define phase, measure phase, analyse phase, improve phase, and control phase. The summary of each phase are concluded as the following.

## 8.1 Define Phase

Referred to the current situation of case study company, there is a large number of defect rate from non-wetting defect on L7 location in PCBA product. This defect impacted the company due to high production volumes and it results in high defective parts. Therefore, it is necessary to eliminate the non-wetting defects so as to improve manufacturing process which focused only on SMT production process.

## 8.2 Measure Phase

Based on the problem determined in define phase, the measure phase begins with Attribute Agreement Analysis (AAA) to evaluate the accuracy and the precision of the inspection system. The result showed that 3 operators can inspect non-wetting defect accurately, precisely and they can differentiate between good and bad product of non-wetting defect. Then, cause and effect diagram was performed in order to find possible root causes through brainstorming session from the team members. Moreover, cause and effect matrix has been applied to find the most possible root causes in a depth analysis and it revealed that there are 4 potentials causes of non-wetting which are pressure of squeegee in screen printing machine, speed of squeegee in screen printing machine, preheat temperature in reflow soldering machine, and preheat time in reflow soldering machine.

## 8.3 Analyse Phase

This phase starts with the design selection and $2^k$ full-factorial design with centre points design has been applied because it is able to provide good prediction over the entire range of design space and provide an opportunity for testing curvature. The $2^k$ full-factorial design with centre points design has tested for 3 different levels of each of the four factors and it requires 23 runs. Then, sample size of experimental design has been calculated. There are totally 107 pieces of PCBAs for each run. The results from stepwise regression show that main effects of pressure, speed, temperature, and time are significant. There is no interaction effect between factors. In addition, there is no curvature effect within the tested range of factor levels.

## 8.4 Improve Phase

In improve phase, bases on stepwise regression result, the optimal setting of the four factors are indicated as the following; using squeegee pressure at 8 kg, squeegee speed at 20 mm/s, preheat temperature at 235℃, and preheat time at 45 second. With this setting, defective rate from non-wetting was decreased from 0.6536 to 0.1504, which equivalent to the percentage reduction of 50.32%.

## 8.5 Control Phase

In this chapter, action plan was created to prepare the readiness for future production. Work instruction for PCBA manufacturing process has been updated and following by creating control plan. Then, creating control chart to monitor process variation. Finally, training operators who are working for the PCBA manufacturing line especially inspectors who is responsible for inspect non-wetting defect.

The result of non-wetting defect was plotted as P-chart and it was shown that non-wetting defect was critically reduced from 65.36% to only 15.04%, leading to improved scrapped cost at approximately decreased from 6,947,244 baht per year to only 1,393,152 baht per year.

## 8.6 The limitation of the research

(1) Optimal setting parameters from this research can only be used for specific product which has the same PCB pads, same component types and same size of PCBA.

(2) In case of other products, which this optimal setting cannot be applied, the Six Sigma methodology can still be used to find out the optimal setting for these products.

(3) Factors to be tested come from cause and effect matrix which were weighted from different operators.

## 8.7 Problems in the research

The problems shown in the research as the following;

(1) One of the difficulty of doing the experiment is about there is only one SMT production line that produced this PCBA, so it would impact to normal production while doing the experiment. The experiment took almost 20 days with only day time from 8.00 a.m. – 5.00 p.m. However, normal production was able to run in the night shift with low output.

(2) Since the time limitation, it is necessary that operators who are working for this product have to understand this experiment and strictly follow the work instructions. If they do not follow the work instructions, there will have a big problem.

(3) The limitation of time for the experiment is one of the key parameter that impacted to the experimental design. This is because in the SMT production line, there is only SMT 11 that is used to produce this PCBA for the mass production. Hence, in order to have the experiment, it needs to control time usage for each run.

## 8.8 Recommendations and suggestions for further research

(1) In order to use the result of this research to apply for other products, users must consider the differences between products such as types of product, types of solder paste used, and types of material. If it does not the same types, the result will not be the same.

(2) The knowledge and skills of Six Sigma DMAIC methodology is necessary for the employees in order to apply this methodology to the organization. Corporate management should consider this step and announce to their employees in each level prior to apply this methodology. If employees understand to the principle and objectives, they will support and make it successful.

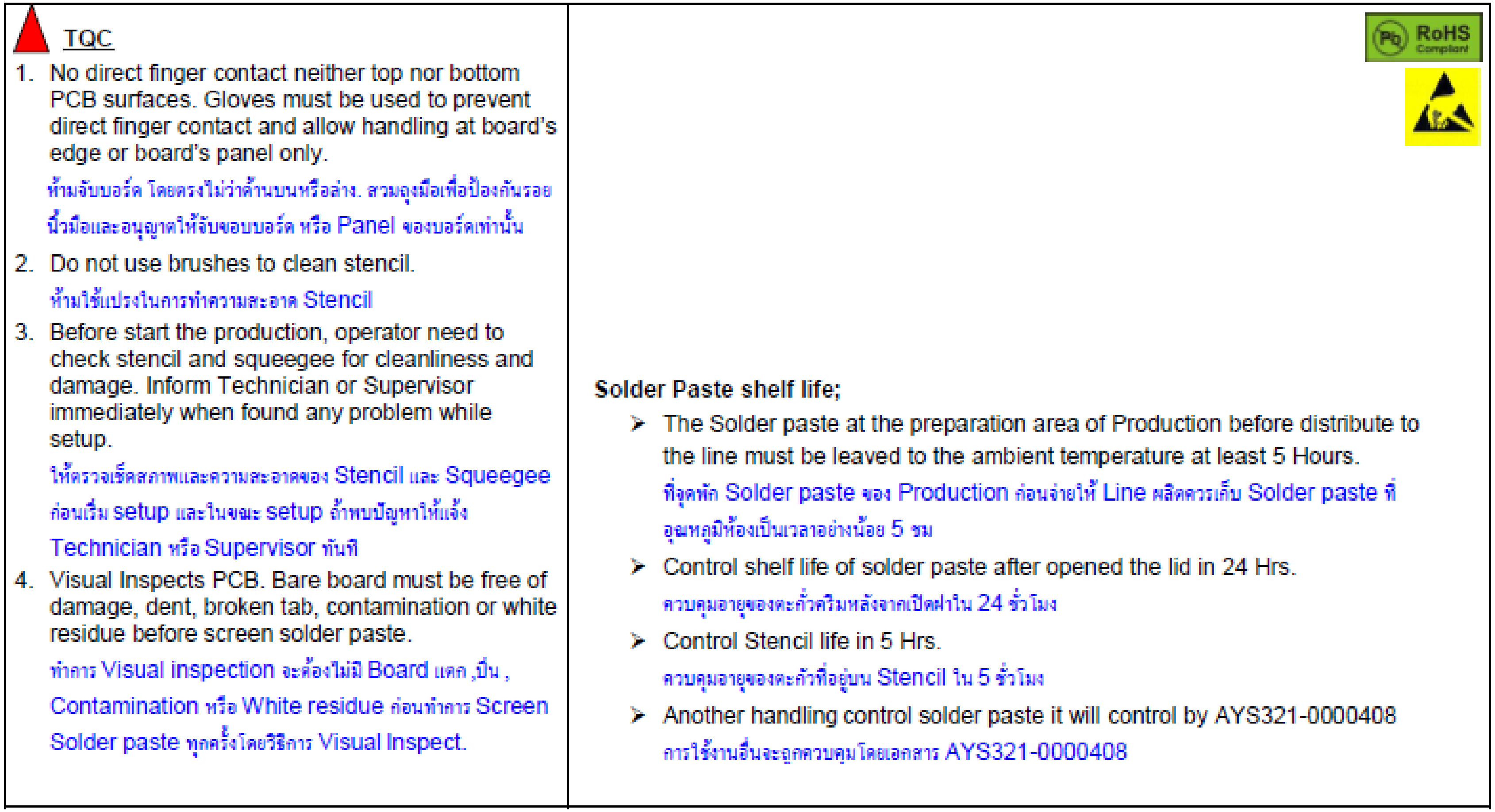
(3) The case study company should apply the Experimental Design to the others types of PCBA so as to find the optimal setting parameters for other PCBAs to help reduce defects.

(4) The case study company should start consider an importance of raw material and select the best quality raw material in order to use in the manufacturing process of PCBA, since a better product quality will come from a higher raw material quality.

# Appendices

## 1. Work Instructions: SMT Processes

### 1.1 Solder paste screen printing



**TQC**

1. No direct finger contact neither top nor bottom PCB surfaces. Gloves must be used to prevent direct finger contact and allow handling at board's edge or board's panel only.

   ห้ามจับบอร์ด โดยตรงไม่ว่าด้านบนหรือล่าง. สวมถุงมือเพื่อป้องกันรอยนิ้วมือและอนุญาตให้จับขอบบอร์ด หรือ Panel ของบอร์ดเท่านั้น

2. Do not use brushes to clean stencil.

   ห้ามใช้แปรงในการทำความสะอาด Stencil

3. Before start the production, operator need to check stencil and squeegee for cleanliness and damage. Inform Technician or Supervisor immediately when found any problem while setup.

   ให้ตรวจเช็คสภาพและความสะอาดของ Stencil และ Squeegee ก่อนเริ่ม setup และในขณะ setup ถ้าพบปัญหาให้แจ้ง Technician หรือ Supervisor ทันที

4. Visual Inspects PCB. Bare board must be free of damage, dent, broken tab, contamination or white residue before screen solder paste.

   ทำการ Visual inspection จะต้องไม่มี Board แตก ,บิ่น , Contamination หรือ White residue ก่อนทำการ Screen Solder paste ทุกครั้งโดยวิธีการ Visual Inspect.

**Solder Paste shelf life;**

- The Solder paste at the preparation area of Production before distribute to the line must be leaved to the ambient temperature at least 5 Hours.

  ที่จุดพัก Solder paste ของ Production ก่อนจ่ายให้ Line ผลิตควรเก็บ Solder paste ที่อุณหภูมิห้องเป็นเวลาอย่างน้อย 5 ชม

- Control shelf life of solder paste after opened the lid in 24 Hrs.

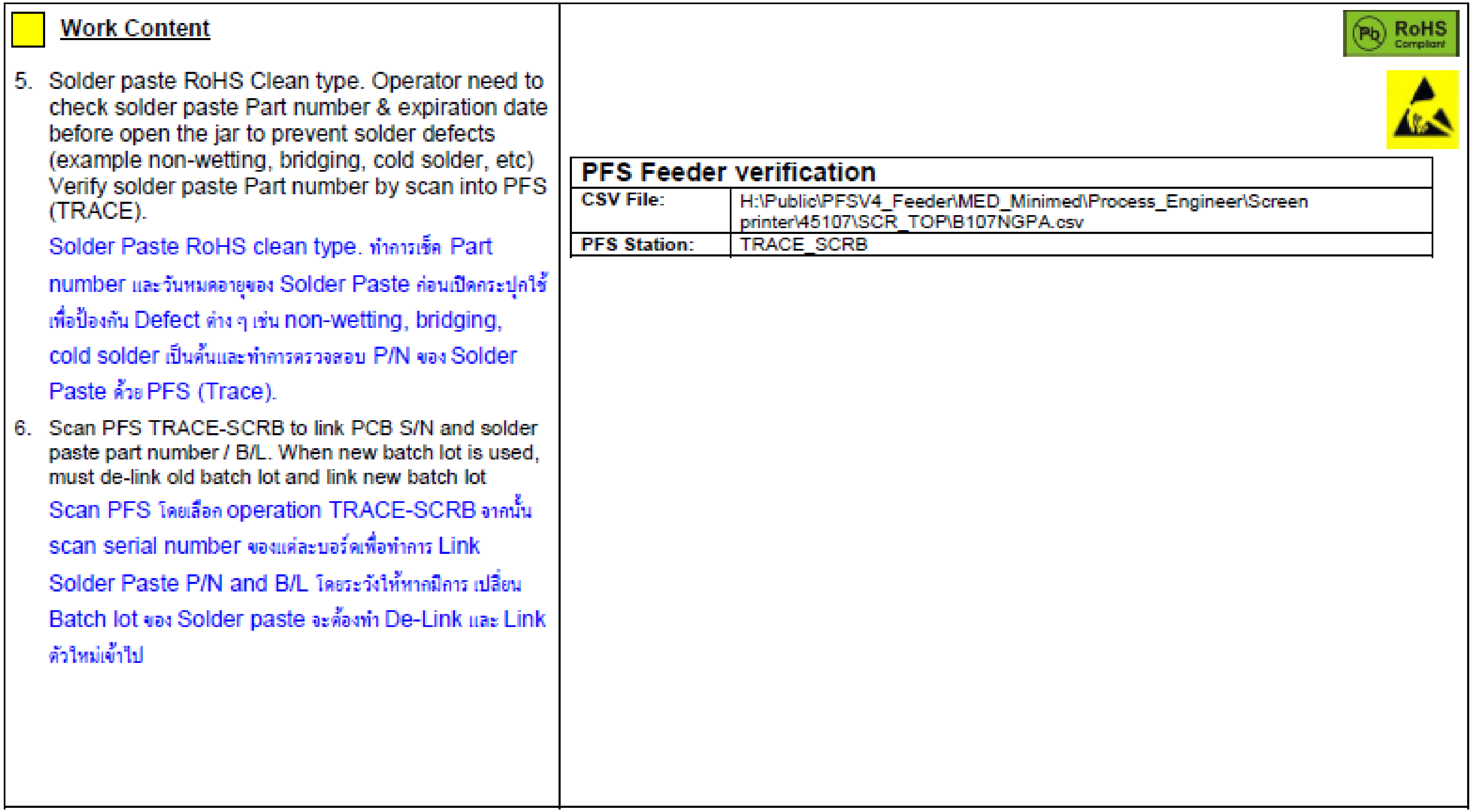
  ควบคุมอายุของตะกั่วครีมหลังจากเปิดฝาใน 24 ชั่วโมง

- Control Stencil life in 5 Hrs.

  ควบคุมอายุของตะกั่วที่อยู่บน Stencil ใน 5 ชั่วโมง

- Another handling control solder paste it will control by AYS321-0000408

  การใช้งานอื่นจะถูกควบคุมโดยเอกสาร AYS321-0000408



**Work Content**

5. Solder paste RoHS Clean type. Operator need to check solder paste Part number & expiration date before open the jar to prevent solder defects (example non-wetting, bridging, cold solder, etc) Verify solder paste Part number by scan into PFS (TRACE).
   Solder Paste RoHS clean type. ทำการเช็ค Part number และวันหมดอายุของ Solder Paste ก่อนเปิดกระปุกใช้ เพื่อป้องกัน Defect ต่าง ๆ เช่น non-wetting, bridging, cold solder เป็นต้นและทำการตรวจสอบ P/N ของ Solder Paste ด้วย PFS (Trace).
6. Scan PFS TRACE-SCRB to link PCB S/N and solder paste part number / B/L. When new batch lot is used, must de-link old batch lot and link new batch lot
   Scan PFS โดยเลือก operation TRACE-SCRB จากนั้น scan serial number ของแต่ละบอร์ดเพื่อทำการ Link Solder Paste P/N and B/L โดยระวังให้หากมีการ เปลี่ยน Batch lot ของ Solder paste จะต้องทำ De-Link และ Link ตัวใหม่เข้าไป

**PFS Feeder verification**

| | |
|---|---|
| **CSV File:** | H:\Public\PFSV4_Feeder\MED_Minimed\Process_Engineer\Screen printer\45107\SCR_TOP\B107NGPA.csv |
| **PFS Station:** | TRACE_SCRB |

7. Program name: **B407NGPA**

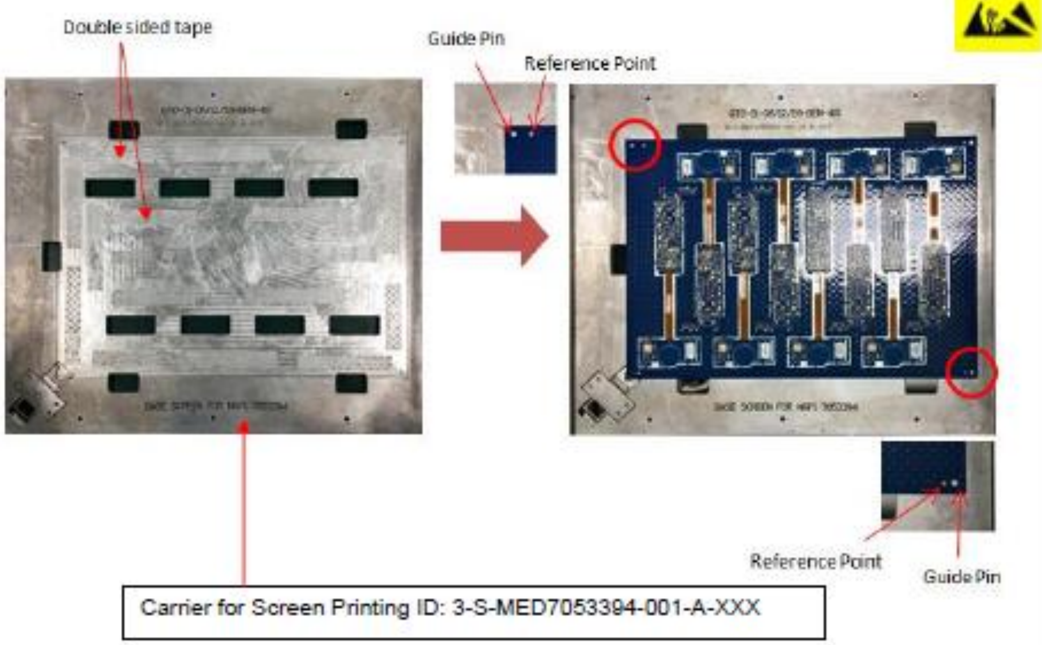
**7.1** Attach double sided tape P/N: BEI0005193 onto Carrier for Screen Printing ID: 3-S-MED7053394-001-LF-A-XXX (XXX is running number) per photo and then load PCB into the carrier. Ensure all 4 corners of PCB have to be fitted into guide pin.

ติดเทปกาวสองหน้า P/N: BEI0005193 ลงบน Carrier for Screen Printing ID: 3-S-MED7053394-001-LF-A-XXX ตามรูป จากนั้นทำการใส่ PCB ลงบน Carrier โดยให้ PCB ทั้ง 4 มุมลงล็อคในตำแหน่ง Guide pin

**7.2** Technician will setup screen printing by refer AYS321-0000410, *Solder Paste Printing*. After technician setup, check the result of %Volume by SPI with spec 50 – 180% and record result in AYFMED-0013307, *SCREEN PRINTING PARAMETER LOG RECORD (7053394-001)*

Technician ทำการ setup เครื่อง screen printing โดยอ้างอิง AYS321-0000410, *Solder Paste Printing* หลังจาก setup เรียบร้อยแล้วให้ทำการตรวจสอบผลโดยใช้ SPI ที่ spec 50 – 180 % Volume จากนั้นทำการบันทึกลงใน AYFMED-0013307, *SCREEN PRINTING PARAMETER LOG RECORD (7053394-001)*

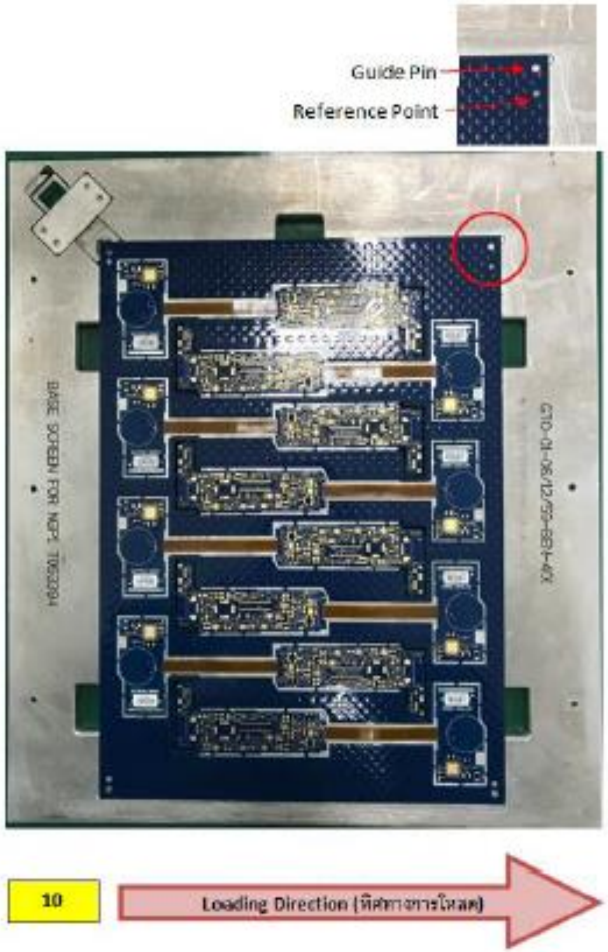
**7.1**



7.3 If found %volume out spec at SPI, call Sustaining to find tune screen printing parameter till %volume meet to SPI spec (50 – 180%)

ถ้าหากพบว่า %Volume หลุดออกจาก SPI spec ให้ทำการเรียก sustaining ทำการปรับค่า screen printing parameter จนกว่าค่า %Volume จะกลับไปอยู่ใน SPI spec

8. Stencil no.: 3-ST-MED7053394-001-LF-B-XXX (XXX is running number)
9. Carrier for Screen Printing: 3-S-MED7053394-001-LF-A-XXX (XXX is running number)
10. Loading Direction as shown.ทิศทางการโหลดบอร์ดดังภาพ
11. Record the time of solder paste usage on Form No AYF321-0000413, *Solder Paste Usage Control Sheet-Clean*. And every time the machine is idle.
    จดบันทึกเวลาที่เริ่มใช้ Solder Paste ลงใน Form No. AYF321-0000413, *Solder Paste Usage Control Sheet-Clean* และทุกครั้งที่เครื่อง Idle
12. Operators need to verify the solder paste screen printing appearance quality when they come back from break. Solder paste must be screened onto PCB Pad properly without any criteria ก่อนเริ่มทำงานหลังจากที่ Operator ไปพัก ให้ทำการ Screen solder paste ลงบน Boards Setup ทุกครั้งเพื่อตรวจสอบ Solder ตาม Criteria



| | |
|---|---|
| 13. In case of machine idle more than 20 min and solder paste still in machine. Need to screen on setup board 20 times before starting production again.<br>ในกรณีที่เครื่องไม่มีการทำงานเกิน 20 นาทีและยังมี Solder paste อยู่ในเครื่องให้ทำการนวด solder paste ลงบน setup panel 20 รอบก่อนที่จะเริ่มทำงานต่อ | Pb RoHS Compliant |

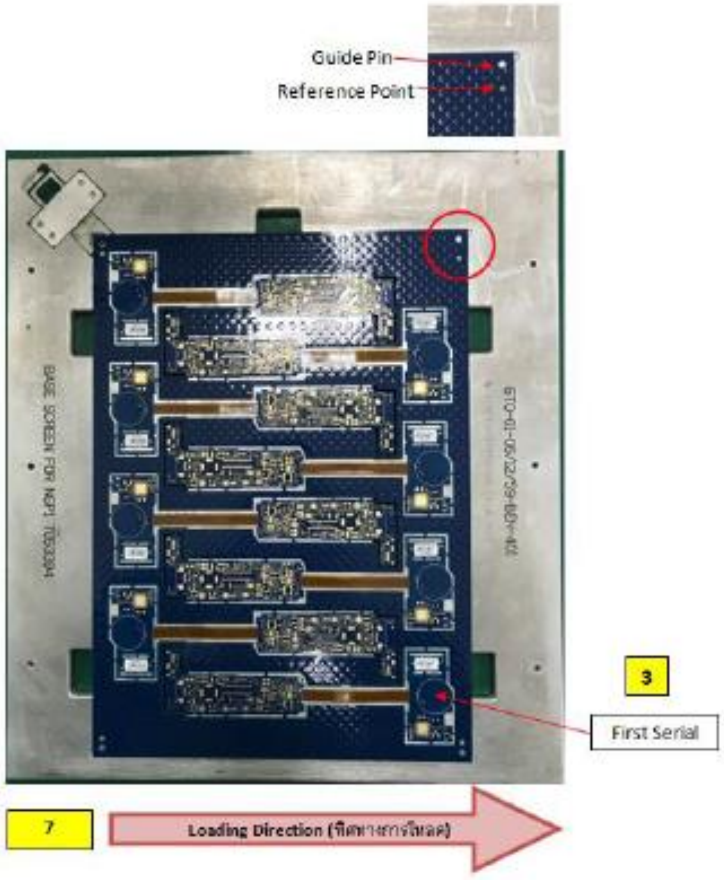
## 1.2 Solder paste inspection

**TQC**

1. No direct finger contact neither top nor bottom PCB surfaces. Gloves must be used to prevent direct finger contact and allow handling at board's edge or board's panel only.
   ห้ามจับบอร์ด โดยตรงไม่ว่าด้านบนหรือล่าง สวมถุงมือเพื่อป้องกันรอยนิ้วมือและอนุญาติให้จับขอบบอร์ด หรือ Panel ของบอร์ดเท่านั้น
2. Handle board to cleaning process by or tray only.
   เคลื่อนย้ายงานไปล้างโดยใส่งานใน Tray เท่านั้น

**Work Content**

3. Before screen solder paste, scan 1st Serial number of each panel at this station.
   ก่อนที่จะเริ่ม Screen solder paste ให้ Scan serial number ของ PCBA แรกที่ station นี้ก่อน
4. Program name: **B407NGPA**
5. Machine Name: KOH YOUNG SPI- KY8030.
6. Refer SPI machine instruction per doc. AYS320-0003309, *Koh Young SPI Machine*
7. Load into SPI machine direction as picture.
   load เข้าเครื่อง SPI ทิศทางดังรูป



8. Handling Rejected board per doc. AYS321-0000410, *Solder Paste Printing*.

   Handling บอร์ดที่ reject ตาม doc. AYS321-0000410, *Solder Paste Printing*

9. If SPI shown warning, this PCB is not rejected and can continue to next operation. If found warning continue 3 times, call technician to fine tune screen printing parameter.

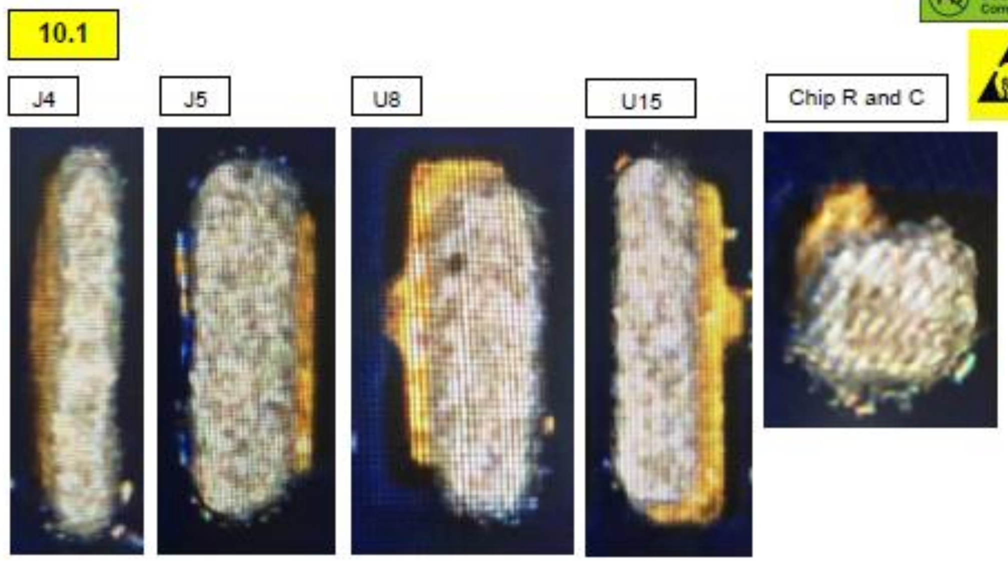
   ถ้าหากผลของ SPI เป็น Warning พนักงานสามารถทำงานต่อไปได้ และงานไม่ Reject แต่ถ้า Warning 3 ครั้งติดต่อให้หยุด Screen และทำการตาม Technician มาทำการปรับเครื่อง Screen printing

10. If SPI shown "NG", operator must verify all defect and refer criteria of acceptable as below per doc. AYS321-0000410.

    ถ้า SPI แสดง "NG" พนักงานจะต้องทำการตรวจสอบตำแหน่งที่เครื่อง SPI แสดงทุกจุด โดยอ้างอิงการ acceptable ตามข้อข้างล่าง

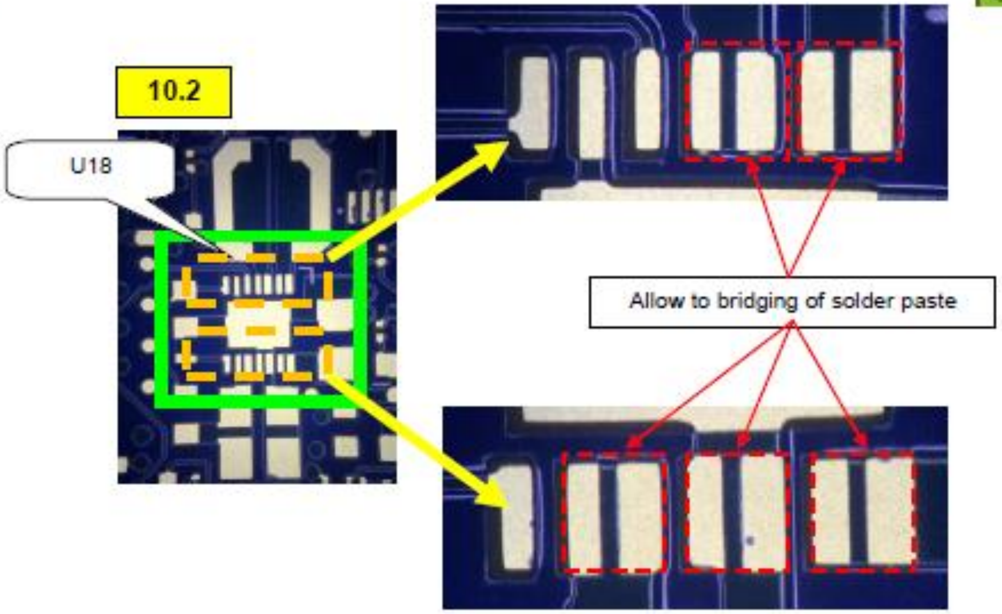
    10.1 Position error: If solder paste was defect side overhang out of pad more than shows in picture allow to acceptable.

    Position error สามารถอนุญาติให้ผ่านได้ถ้าไม่ side ออกนอก pad มากกเกินกว่าในรูป



10.2 U18 bridging: Allow to bridging in Red frame (see direction before verify)

U18 bridging: อนุญาติให้มี solder bridging ได้ ในพื้นที่กรอบสีแดง (ดูทิศทางก่อนทำการตรวจสอบ)



| | |
|---|---|
| 11. Handling Rejected board per doc. AYS321-0000410, *Solder Paste Printing*.<br>Handling บอร์ดที่ reject ตาม doc. AYS321-0000410, *Solder Paste Printing*<br>12. If SPI shown warning, this PCB is not reject and can continue to next operation. If found warning continue 3 times, call technician to fine tune screen printing parameter<br>ถ้าหากผลของ SPI เป็น Warning พนักงานสามารถทำงานต่อไปได้ และงานไม่ Reject แต่ถ้า Warning 3 ครั้งติดต่อให้หยุด Screen และทำการตาม Technician มาทำการปรับเครื่อง Screen printing<br>13. If SPI shown “NG”, this PCB is reject and PCB need to sent to wash per doc. AYS321-0000410, *Solder Paste Printing*. Operator should call technician to fine tune screen printing parameter.<br>ถ้าหากผลของ SPI เป็น “NG” ให้หยุด Screen และทำการตาม Technician มาทำการปรับเครื่อง Screen printing ส่วนงานที่ Reject ให้ทำการล้างตาม doc. AYS321-0000410, *Solder Paste Printing* | Pb RoHS Compliant |

14. Record result into PFS per AYS235-0000226, *PFS Of Regulated Devices*

    ทำการบันทึกผลลง PFS โดยอ้างอิง AYS235-0000226, *PFS Of Regulated Devices*
15. Select PFS operation “SPI-2”.

    เลือก PFS operation ที่ SPI-2
16. If there is no defect, scan result “PASS” into PFS and  PFS operation “TRACE-BOT” to scan serial number.

    หากไม่พบ Defect ให้ Scan “PASS” และให้เลือก PFS operation “TRACE-BOT” เพื่อทำการ แสกน Serial number
17. If found defect, scan defect code and scan repair code by refer Appendix A and sent board to wash.

    หากมี Defect จะต้องทำการใส่ defect code และ Repair code โดยอ้างอิง Appendix A ลงใน PFS และส่งไปล้างที่ aqueous cleaning
18. Rejected PCB from SPI, Handle board to cleaning process by conductive rack or tray only then clean board.

    งานที่ Reject SPI ให้เคลื่อนย้ายงานไปล้างโดยใส่งานใน Conductive rack หรือ Tray เท่านั้น และส่งไปล้างที่ Saponifier cleaning

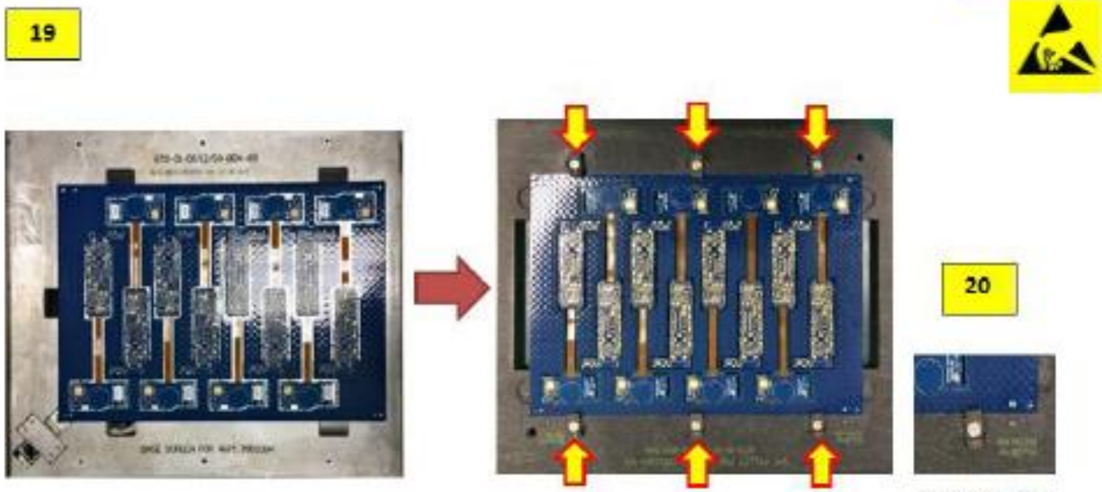
Pb RoHS Compliant

19. Before move accept board to next station, move PCB from Carrier ID: 3-S-MED7053394-001-LF-A-XXX and load into Carrier ID: 3-S-MED7053394-001-LF-B-XXX with care and lock 4 locations, then move to next station.

    หลังจากที่งานผ่านแล้วก่อนที่งานจะส่งต่อไปยัง Station ถัดไป ให้นำงานออกจาก Carrier ID: 3-S-MED7053394-001-LF-A-XXX อย่างระมัดระวังและนำงานไปใส่ที่ Carrier ID: 3-S-MED7053394-001-LF-B-XXX และทำการล็อคก่อนที่จะทำการส่งไปยัง station ถัดไป

20. To inspect all 6 lock tab shall be lock PCB properly.

    ทำการตรวจสอบตัวล็อคทั้ง 6 ตัวจะต้อง ล็อค PCB อย่างถูกต้อง



3-S-MED7053394-001-LF-A-XXX

3-S-MED7053394-001-LF-B-XXX

6 lock tabs shall be locked over PCB

ตัวล็อคทั้ง6 ตัว จะต้องล็อคบน PCB

## 1.3 SMD mounting

| Assy line: SMT Line | Task center #: 1424 | Assy No.: Follow item 1.1 |
|---|---|---|

**TQC**

1. PCB which passed screen solder must have solder appeared on definite designed area.

**Work Content**

1. Fixture Tooling ID : 3-S-MED7053394-001-LF-B-XXX
2. Arrange component feeders and machine program per "Reference Documents and Form" in AYNMED-7053394-002-1424, *SMD MOUNTING (BOTTOM SIDE)*
3. Load PCB in to the machine by refer to arrows of PCB load direction.

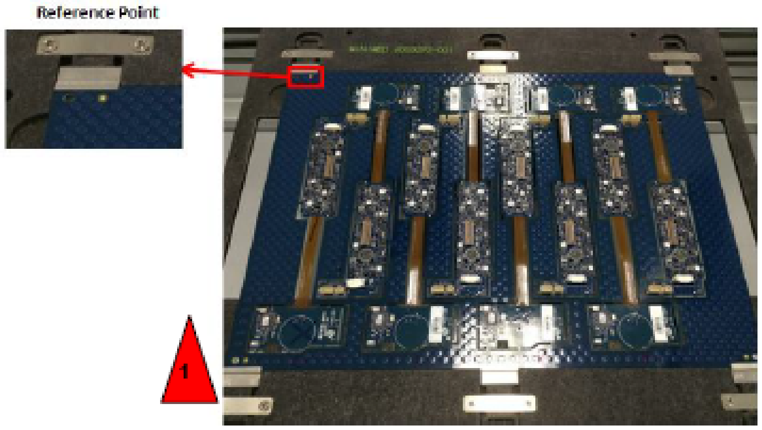
**Verify**

1. N/A

RoHS Compliant

Refer to "Reference Documents and Form" in item 3.1

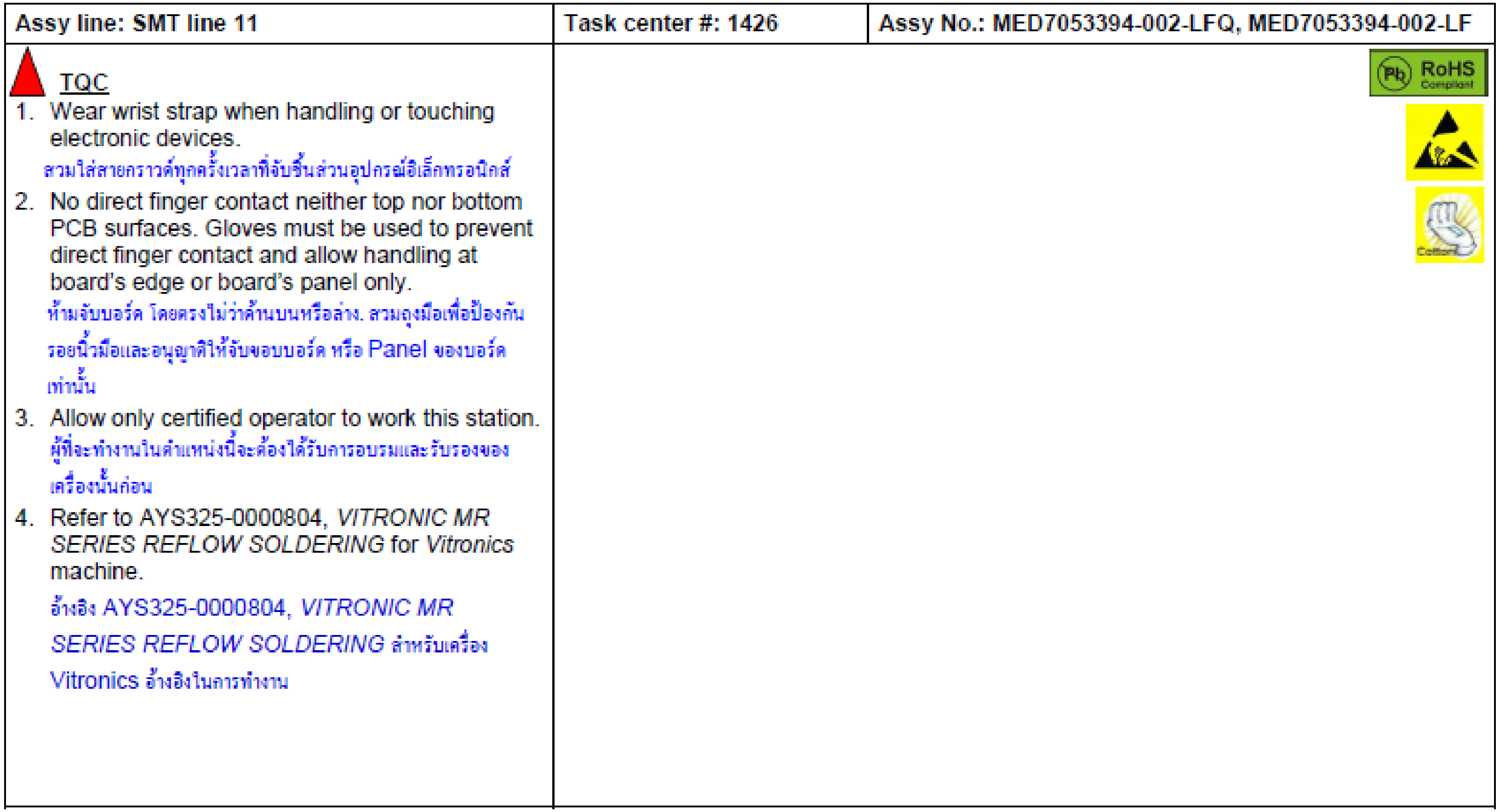
2



PCB Dimension:
X (mm) = 330.000
Y (mm) = 293.000

3 LOADING DIRECTION FOR SMT MACHINE

## 1.4 Reflow soldering



| Assy line: SMT line 11 | Task center #: 1426 | Assy No.: MED7053394-002-LFQ, MED7053394-002-LF |
|---|---|---|

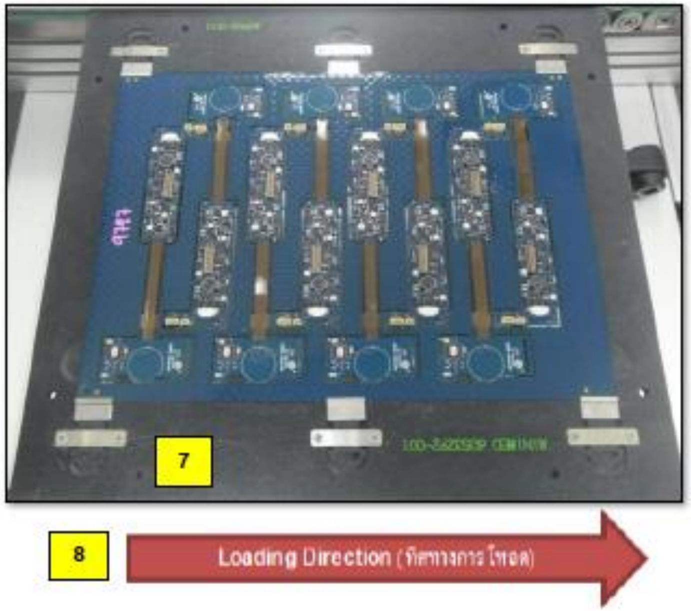
TQC

1. Wear wrist strap when handling or touching electronic devices.
   สวมใส่สายกราวด์ทุกครั้งเวลาที่จับชิ้นส่วนอุปกรณ์อิเล็กทรอนิกส์
2. No direct finger contact neither top nor bottom PCB surfaces. Gloves must be used to prevent direct finger contact and allow handling at board's edge or board's panel only.
   ห้ามจับบอร์ด โดยตรงไม่ว่าด้านบนหรือล่าง. สวมถุงมือเพื่อป้องกันรอยนิ้วมือและอนุญาติให้จับขอบบอร์ด หรือ Panel ของบอร์ดเท่านั้น
3. Allow only certified operator to work this station.
   ผู้ที่จะทำงานในตำแหน่งนี้จะต้องได้รับการอบรมและรับรองของเครื่องนั้นก่อน
4. Refer to AYS325-0000804, *VITRONIC MR SERIES REFLOW SOLDERING* for *Vitronics* machine.
   อ้างอิง AYS325-0000804, *VITRONIC MR SERIES REFLOW SOLDERING* สำหรับเครื่อง Vitronics อ้างอิงในการทำงาน

| Assy line: **SMT line 11** | Task center #: 1426 | Assy No.: MED7053394-002-LFQ, MED7053394-002-LF |
|---|---|---|

**Work Content**

5. Before starting shift (day/night) or each P/O, must check Reflow Profile name and Parameters and record in AYFMED-0013308, *REFLOW SOLDERING PARAMETER LOG RECORD (7053394-001)*. Must stop line and inform Supervisor and SE/PE immediately if any differences found.
   ต้องตรวจสอบชื่อของ Reflow Profile และ Parameter ตาม AYFMED-0013308, *REFLOW SOLDERING PARAMETER LOG RECORD (7053394-001)* และบันทึกผล ทุกครั้งที่เริ่มกะ ให้แจ้งวิศวกรผู้ที่รับผิดชอบทันที หรือ Start P/O ถ้าพบว่ามีอะไรไม่ตรงกันให้ทำการหยุด Line ทันที แล้วแจ้งผู้ที่เกี่ยวข้องเพื่อทำการแก้ไขต่อไป
6. Profile name: **B407NGPA**
7. Carrier ID: 3-S-MED7053394-001-LF-B-XXX
8. Load direction/ ดูจากภาพ
9. Verify the conveyor width by put the fixture into reflow. It should match to fixture size with no loose or tight
   ตรวจเช็คความกว้างของ Conveyor จะต้องพอดีกับชิ้นงาน ไม่หลวมหรือคับเกินไป โดยการทดลองปล่อย fixture วิ่งผ่าน Reflow 1 ครั้งเพื่อทดสอบ



| **Assy line: SMT line 11** | **Task center #: 1426** | **Assy No.: MED7053394-002-LFQ, MED7053394-002-LF** |
|---|---|---|
| 10. Lot can be started when the buy off result pass only. Inform supervisor /PE/SE immediately if the result is fail<br>ทำปล่อยบอร์ดที่จะนำส่ง QA ตรวจเข้าเครื่อง Reflow และนำบอร์ดที่ออกจาก Reflow ส่ง QA เพื่อ Buyoff และรอผลการ Buyoff ก่อนทำการปล่อยงานเข้าเครื่อง Reflow | |  |

## 1.5 Visual inspection after reflow

▲ TQC

1. No direct finger contact neither top nor bottom PCB surfaces. Gloves must be used to prevent direct finger contact and allow handling at board's edge or board's panel only.

   ห้ามจับบอร์ด โดยตรงไม่ว่าด้านบนหรือล่าง. สวมถุงมือเพื่อป้องกันรอยนิ้วมือ และอนุญาติให้จับขอบบอร์ด หรือ Panel ของบอร์ดเท่านั้น.

2. Perform line clearance before startup production. Any Chemicals including IPA and Additional flux are not allowed to clean PCBA. Clean it by Saponifier cleaning only.

   ทำ Line Clearance ก่อนเริ่มงาน ไม่อนุญาตให้ใช้ IPA, Flux หรือ สารเคมีใด ๆ ทำความสะอาดบอร์ด ส่งงานไปล้างที่ Saponifier cleaning

3. Check ground wire of work station and all equipment, no loose or missing connect before start production.

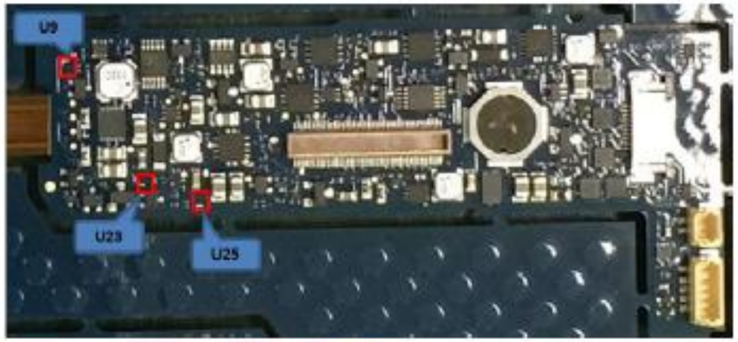
   ตรวจสอบ Ground โต๊ะและอุปกรณ์ก่อนเริ่มงานโดย ต้องไม่หลวมหรือไม่ต่อ ground

Pb RoHS Compliant

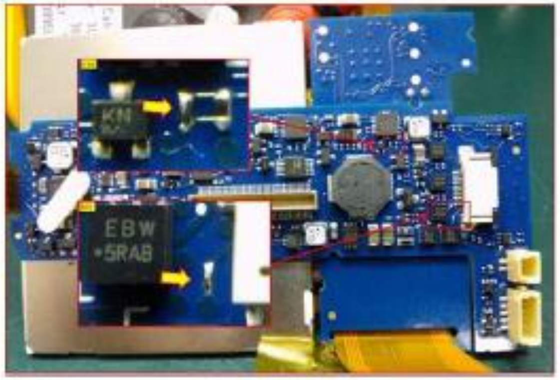
| | |
|---|---|
| 4. Refer to IPC-A-610 (Current Revision), Acceptability of Electronic Assemblies, Class 3 for solder defects.<br>ใช้ IPC-A-610 (Current Revision), Acceptability of electronic assemblies Class 3 ในการตรวจสอบ solder joint ต่าง ๆ<br>5. Send board to cleaning operation within 30 min after board comes out from reflow oven.<br>นำงานไปล้างภายใน 30 นาทีหลังจากบอร์ดออกมาจาก Reflow<br>6. Do not mark anything on the board or parts.<br>ห้ามใช้ปากกาทุกชนิด Mark ลงบนบอร์ดหรือตัวอุปกรณ์<br>7. Contamination or residue is not allowed on parts or board.<br>การตรวจให้เน้นเรื่องความสะอาด โดยจะต้องไม่มีคราบสนิม, contamination หรือสิ่งสกปรกอื่น ๆ ติดอยู่บน Parts หรือบอร์ด | Pb RoHS Compliant |

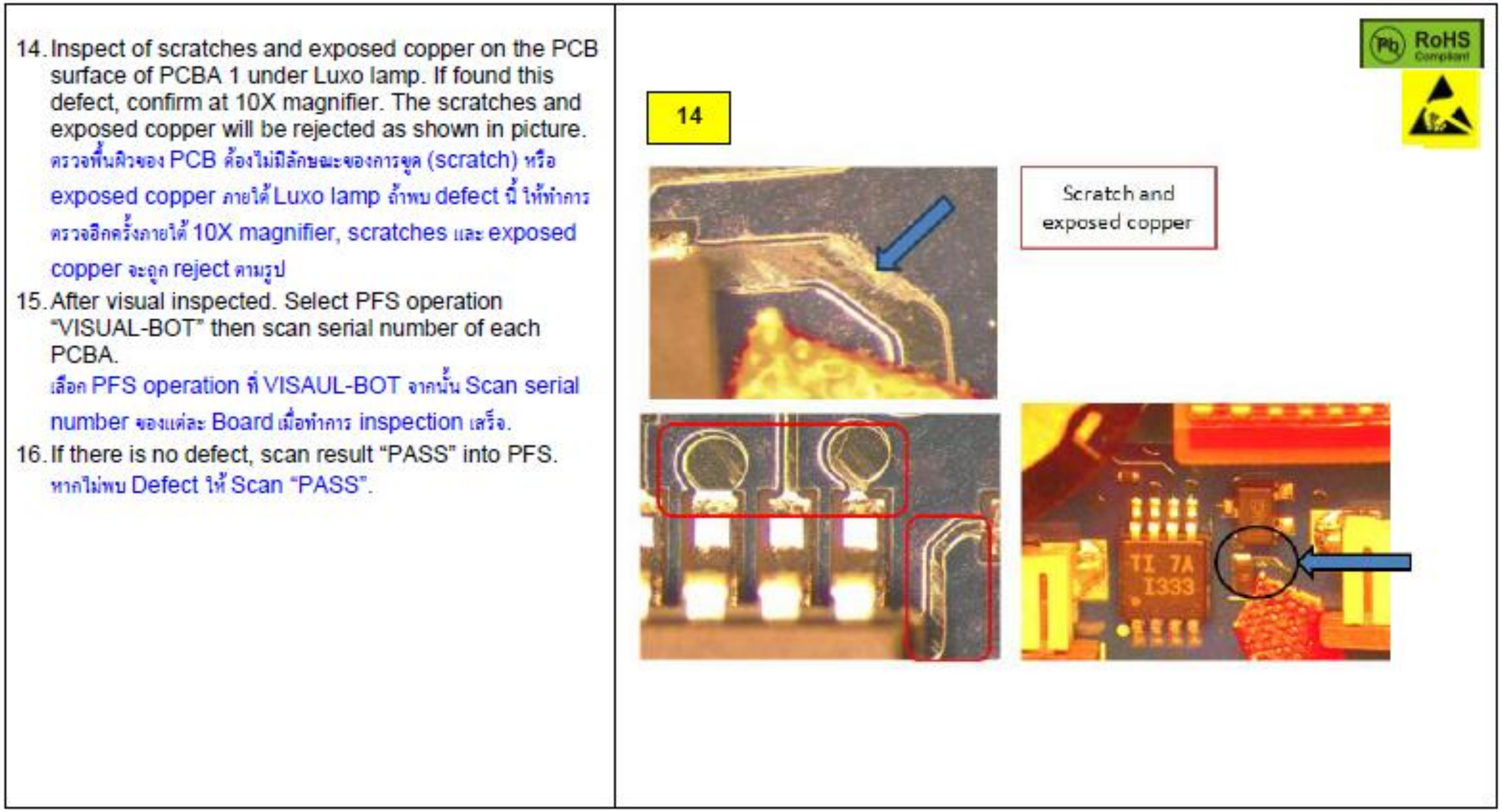
8. Verify the polarity of parts follow the photo as shown in Appendix A.
   ตรวจสอบขั้วของอุปกรณ์ที่มีขั้วตามรูปที่แสดงใน Appendix A
9. Inspection per criteria as below (Solder quality will be inspected by inline AOI, AXI)
   ทำการตรวจสอบตามข้อกำหนดด้านล่างนี้ (คุณภาพของ solder จะถูกตรวจด้วย AOI inline และ AXI)
   - 9.1 Missing Component
   - 9.2 Reverse orientation
   - 9.3 Misalignment
   - 9.4 Damage Component
10. If found defect of Hidden joint component, put board into NCMR.
    ถ้าหากพบเจองานเสียที่เป็นตัวที่มองไม่เห็น Solder joint ให้นำบอร์ดเข้า NCMR
11. Verify U9, U23 and U25 are not damaged
    ตรวจสอบตำแหน่ง U9, U23 และ U25 ต้องไม่ชำรุดเสียหาย
12. Verify C24, C33, C40, R71 and J3 not installed
    ทำการตตรวจ C24, C33, C40, R71 และ J3 ต้องไม่ใส่มา
13. Verify on the non populated area must no bridging solder
    ทำการตรวจสอบตำแหน่งที่ไม่วางอุปกรณ์ จะต้องไม่มีตะกั่ว Bridging

**11**

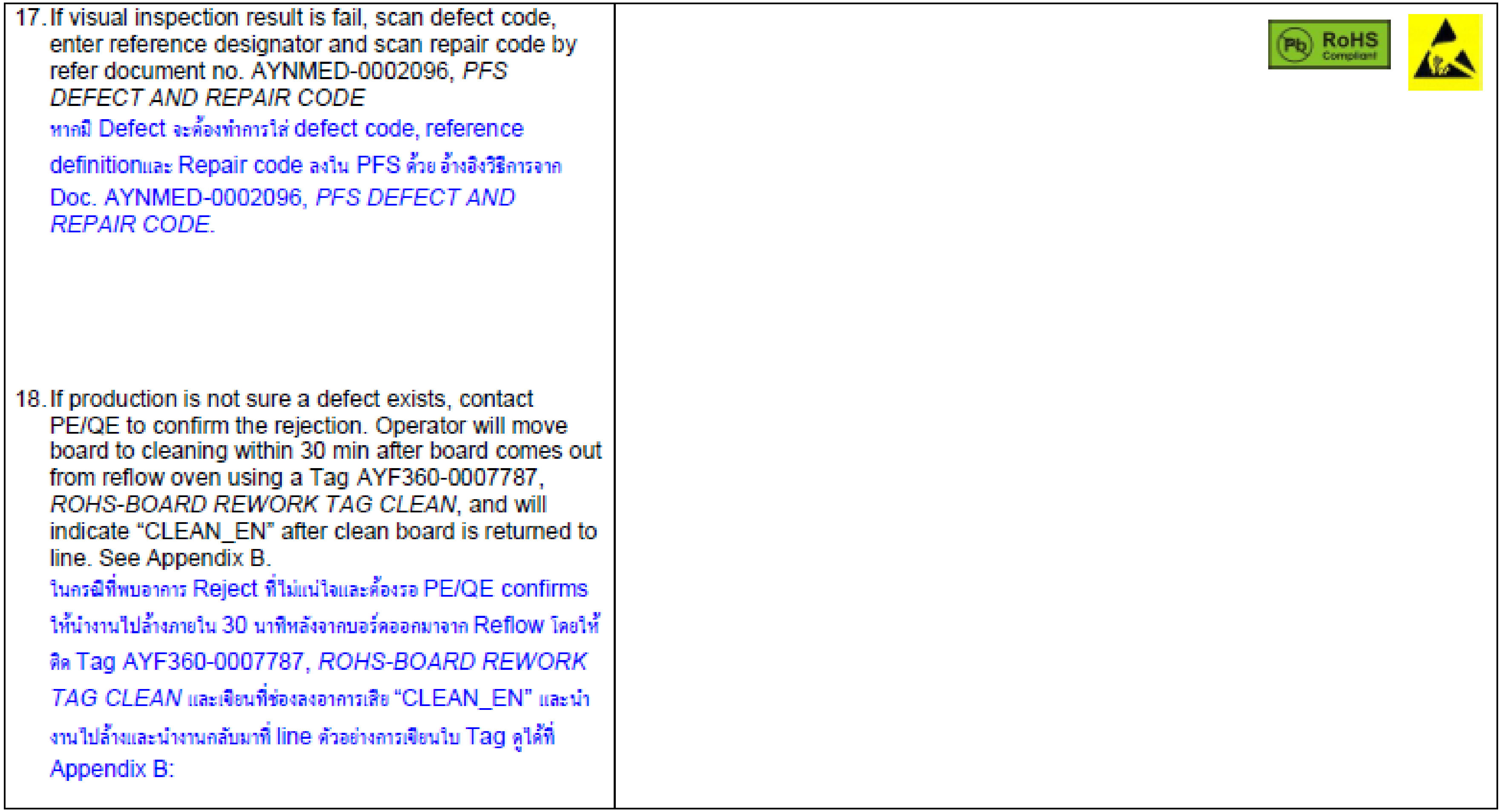


**12**





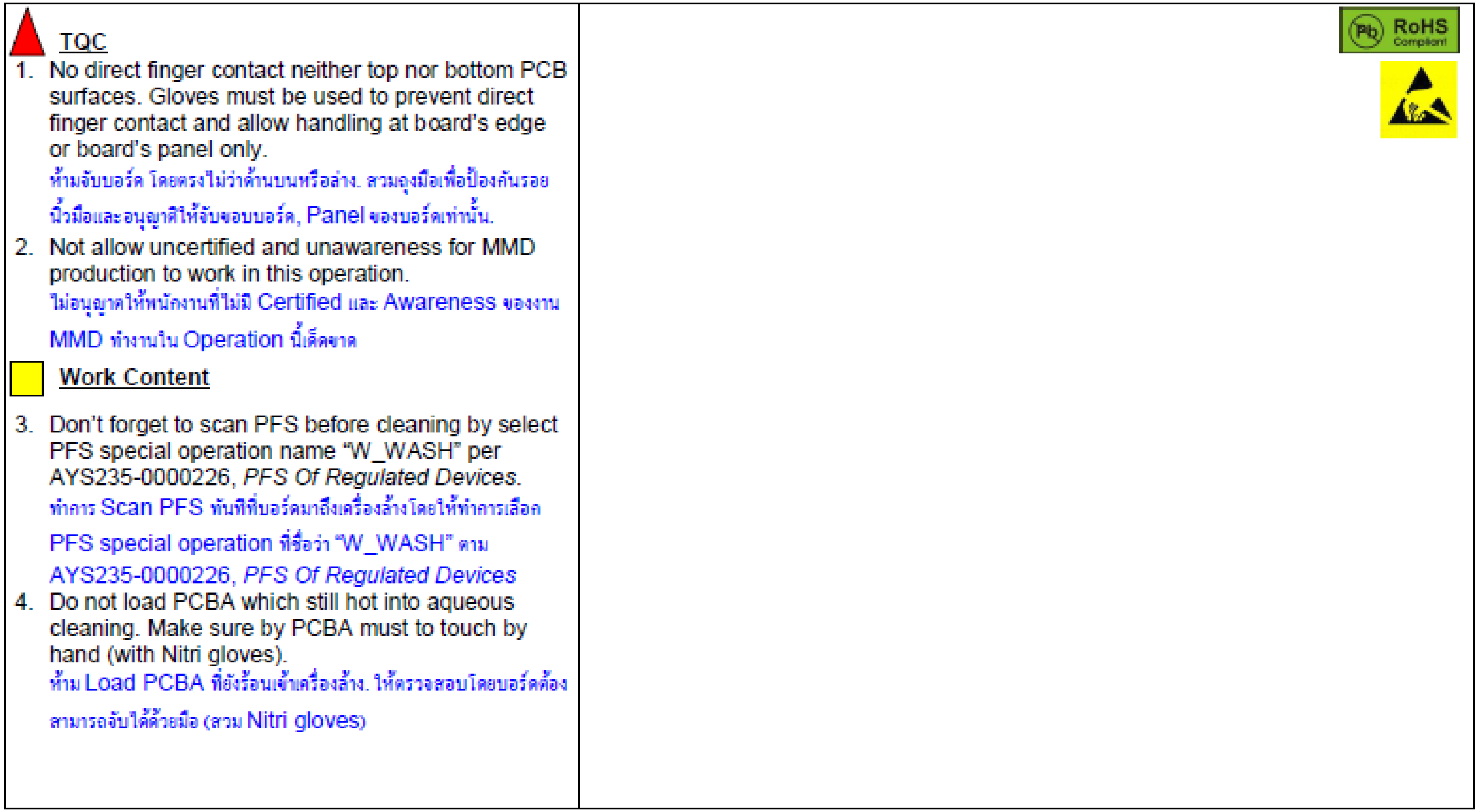
14. Inspect of scratches and exposed copper on the PCB surface of PCBA 1 under Luxo lamp. If found this defect, confirm at 10X magnifier. The scratches and exposed copper will be rejected as shown in picture.
    ตรวจพื้นผิวของ PCB ต้องไม่มีลักษณะของการขูด (scratch) หรือ exposed copper ภายใต้ Luxo lamp ถ้าพบ defect นี้ ให้ทำการตรวจอีกครั้งภายใต้ 10X magnifier, scratches และ exposed copper จะถูก reject ตามรูป
15. After visual inspected. Select PFS operation "VISUAL-BOT" then scan serial number of each PCBA.
    เลือก PFS operation ที่ VISAUL-BOT จากนั้น Scan serial number ของแต่ละ Board เมื่อทำการ inspection เสร็จ.
16. If there is no defect, scan result "PASS" into PFS.
    หากไม่พบ Defect ให้ Scan "PASS".



17. If visual inspection result is fail, scan defect code, enter reference designator and scan repair code by refer document no. AYNMED-0002096, *PFS DEFECT AND REPAIR CODE*
    หากมี Defect จะต้องทำการใส่ defect code, reference definitionและ Repair code ลงใน PFS ด้วย อ้างอิงวิธีการจาก Doc. AYNMED-0002096, *PFS DEFECT AND REPAIR CODE.*

18. If production is not sure a defect exists, contact PE/QE to confirm the rejection. Operator will move board to cleaning within 30 min after board comes out from reflow oven using a Tag AYF360-0007787, *ROHS-BOARD REWORK TAG CLEAN*, and will indicate "CLEAN_EN" after clean board is returned to line. See Appendix B.
    ในกรณีที่พบอาการ Reject ที่ไม่แน่ใจและต้องรอ PE/QE confirms ให้นำงานไปล้างภายใน 30 นาทีหลังจากบอร์ดออกมาจาก Reflow โดยให้ติด Tag AYF360-0007787, *ROHS-BOARD REWORK TAG CLEAN* และเขียนที่ช่องลงอาการเสีย "CLEAN_EN" และนำงานไปล้างและนำงานกลับมาที่ line ตัวอย่างการเขียนใบ Tag ดูได้ที่ Appendix B:

## 1.6 Cleaning



**TQC**

1. No direct finger contact neither top nor bottom PCB surfaces. Gloves must be used to prevent direct finger contact and allow handling at board's edge or board's panel only.
   ห้ามจับบอร์ด โดยตรงไม่ว่าด้านบนหรือล่าง. สวมถุงมือเพื่อป้องกันรอยนิ้วมือและอนุญาติให้จับขอบบอร์ด, Panel ของบอร์ดเท่านั้น.
2. Not allow uncertified and unawareness for MMD production to work in this operation.
   ไม่อนุญาตให้พนักงานที่ไม่มี Certified และ Awareness ของงาน MMD ทำงานใน Operation นี้เด็ดขาด

**Work Content**

3. Don't forget to scan PFS before cleaning by select PFS special operation name "W_WASH" per AYS235-0000226, *PFS Of Regulated Devices.*
   ทำการ Scan PFS ทันทีที่บอร์ดมาถึงเครื่องล้างโดยให้ทำการเลือก PFS special operation ที่ชื่อว่า "W_WASH" ตาม AYS235-0000226, *PFS Of Regulated Devices*
4. Do not load PCBA which still hot into aqueous cleaning. Make sure by PCBA must to touch by hand (with Nitri gloves).
   ห้าม Load PCBA ที่ยังร้อนเข้าเครื่องล้าง. ให้ตรวจสอบโดยบอร์ดต้องสามารถจับได้ด้วยมือ (สวม Nitri gloves)

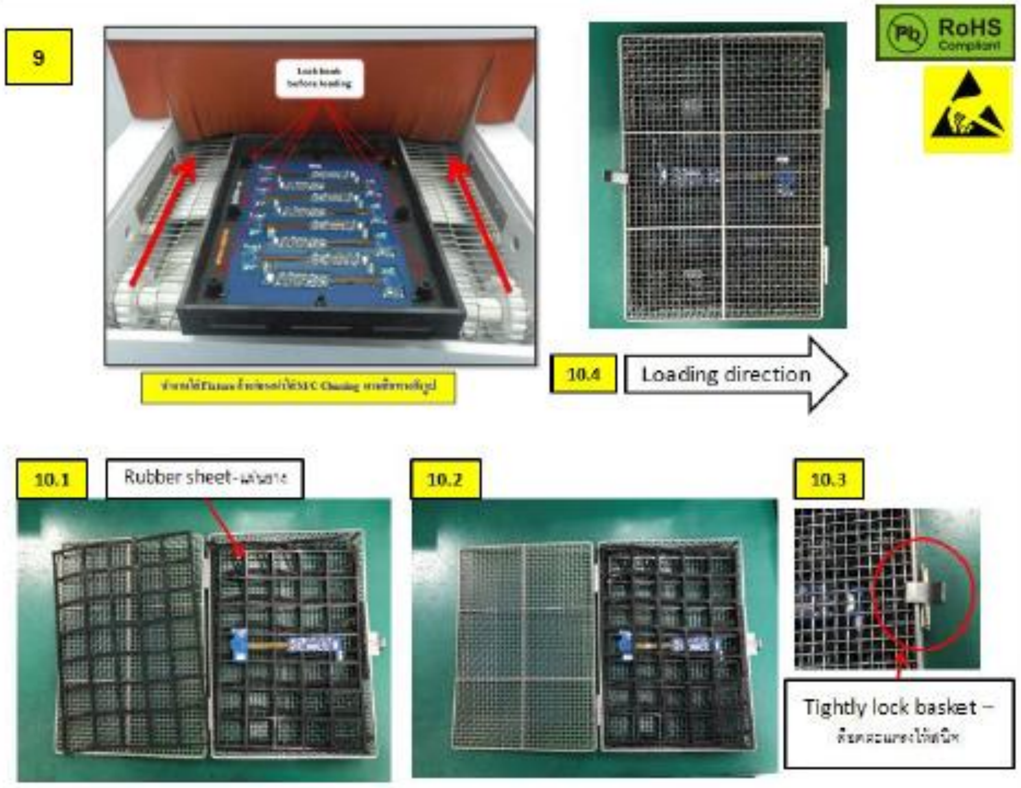
| | |
|---|---|
| 5. Before start to run operator must be check Parameters of Saponifier cleaning and record in log record if found parameter out of control, operator must inform supervisor immediately and do not load PCBA into machine.<br>ให้พนักงานตรวจเช็คค่า Parameters ของเครื่องล้างและลง Log Record ก่อน Start Run หากพบเจอค่าที่ไม่อยู่ใน spec ให้รีบตาม Supervisor ทันทีและห้ามนำงานเข้าเครื่องล้าง<br>6. Refer to AYS334-0010731, *Electrovert Aquastorm AS200C* for operation instructions.<br>อ้างอิง AYS334-0010731, *Electrovert Aquastorm AS200C* ในการใช้งานเครื่องล้าง<br>7. Fixture Cleaning: Tool ID: 3-AQ-MED7053394-001-LF-Q-001 to 3-AQ-MED7053394-001-LF-Q-014 and 3-AQ-MED7053394-001-LF-Q-017 to 3-AQ-MED7053394-001-LF-Q-020<br>8. Use Form No.: AYFMED-0014786, *Electrovert AS200C with Saponifier Parameter Log* for recording observed parameter before startup and every 4 hours, if parameter is out of spec, do not load PCBA into machine then stop production and inform Supervisor immediately. Refer Saponifier Concentration Measurement per doc. AYS340-0010890, *Saponifier Concentration Measurement*<br>Clean process ให้ใช้ Form No.: AYFMED-0014786, *Electrovert AS200C with Saponifier Parameter Log* ในการลง Log Record ของเครื่องโดย | Pb RoHS Compliant |

ตรวจสอบก่อน Startup และทุกๆ 4 ชม. หากมี Parameter หลุดออกจาก spec ให้หยุดไม่ให้นำงานเข้าไปล้างและให้แจ้ง Supervisor ทันที. อ้างอิงวิธีการวัด Saponifier Concentration ตาม Doc. AYS340-0010890, Saponifier *Concentration Measurement*

9. Loading Direction: ดูจากภาพ
10. In case there is single board from Rework, use generic cleaning basket and be aware of putting boards into basket.
    - **10.1** Put rubber sheet onto basket
    - **10.2** Put board and cover by another rubber sheet.
    - **10.3** Tightly lock basket as shown in pictures.
    - **10.4** Loading direction as picture

ในกรณีที่บอร์ดมาจาก Rework ซึ่งเป็นบอร์ดที่ถูก De-panel แล้ว (single board)

- 10.1 ให้นำบอร์ดใส่ตะแกรงโดยต้องวางแผ่นยางก่อน
- 10.2 วางบอร์ดลงไป จากนั้นให้นำแผ่นยางอีกแผ่นมาวางทับลง
- 10.3 ปิดฝาตะแกรงและล็อคให้สนิท ตามรูป
- 10.4 ทิศทางการโหลด ตามรูป



**Verify**

11. Visual inspects PCBA for damage component and PCB prior to scan result into PFS.

    ตรวจสอบ PCBA ใน Criteria damage component และ PCB ก่อน scan PFS.

12. Select operation of PFS special operation name "W_WASH" and work center select "WASH

    ให้พนักงานทำการเลือก PFS special operation ที่ชื่อ "W_WASH" และ Work center ให้เลือก "WASH"

13. Before sent board to Aqueous Cleaning, select Wash Input and scan S/N of board into Basket Number field.

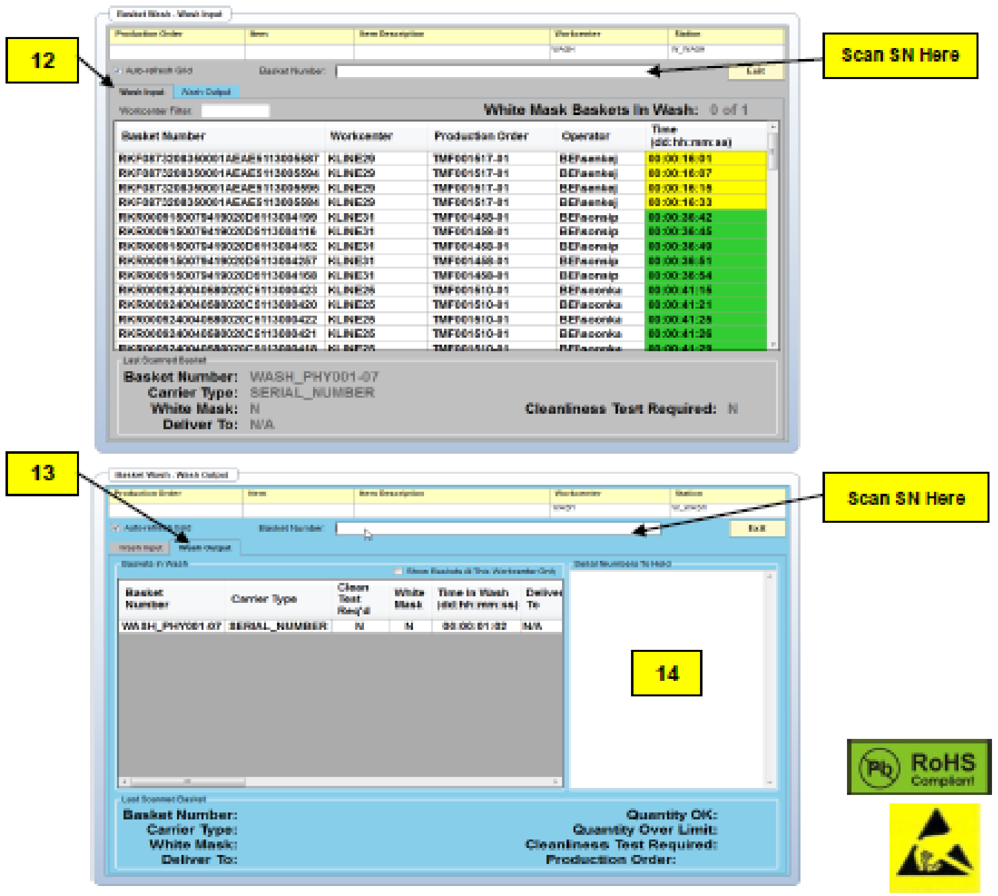
    ก่อนนำงานเข้าเครื่องล้างให้เลือก PFS หน้าต่าง Wash Input และให้ scan SN ของงานเข้าไปในช่อง Basket Number

14. After wash, select Wash output and scan S/N of board into Basket Number field.

    หลังจากที่งานออกมาจากเครื่องล้างแล้วให้เลือกหน้า Wash Output และให้ scan SN ของงานเข้าไปในช่อง Basket Number

15. If S/N shown on the "Serial Numbers To Hold", operator must put that S/N to NCMR and call QE/PE to make disposition.

    ถ้าหากว่า S/N ไปแสดงที่หน้าต่าง "Serial Numbers To Hold" พนักงานจะต้องนำงานเข้า NCMR และทำการเรียก QE/PE มาทำการตัดสินใจ

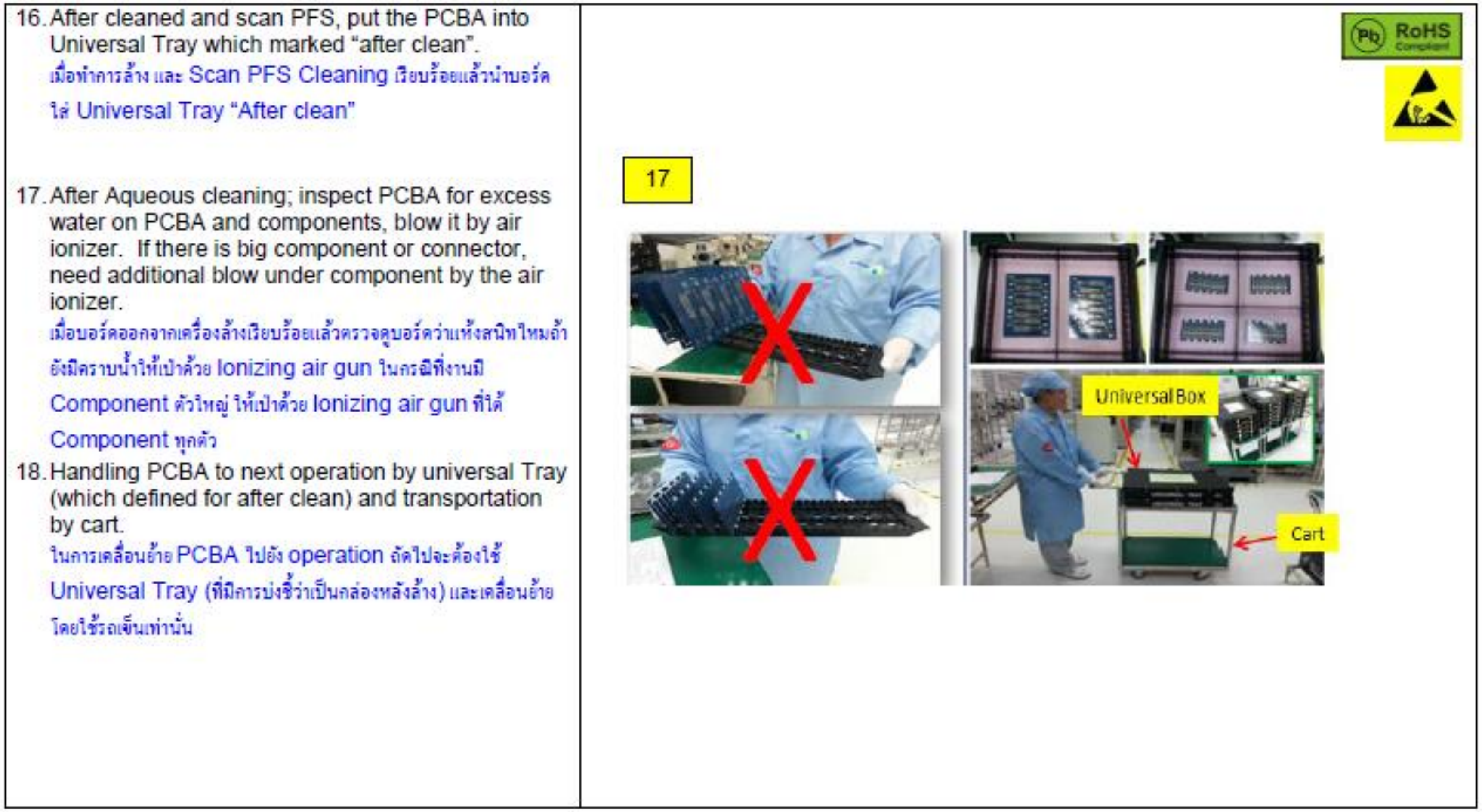


White Mask Baskets In Wash: 0 of 1

Last Scanned Basket
Basket Number: WASH_PHY001-07
Carrier Type: SERIAL_NUMBER
White Mask: N
Deliver To: N/A
Cleanliness Test Required: N

| Basket Number | Carrier Type | Clean Test Req'd | White Mask | Time In Wash (dd:hh:mm:ss) | Deliver To |
|---|---|---|---|---|---|
| WASH_PHY001-07 | SERIAL_NUMBER | N | N | 00:00:01:02 | N/A |

Last Scanned Basket
Basket Number:
Carrier Type:
White Mask:
Deliver To:
Quantity OK:
Quantity Over Limit:
Cleanliness Test Required:
Production Order:

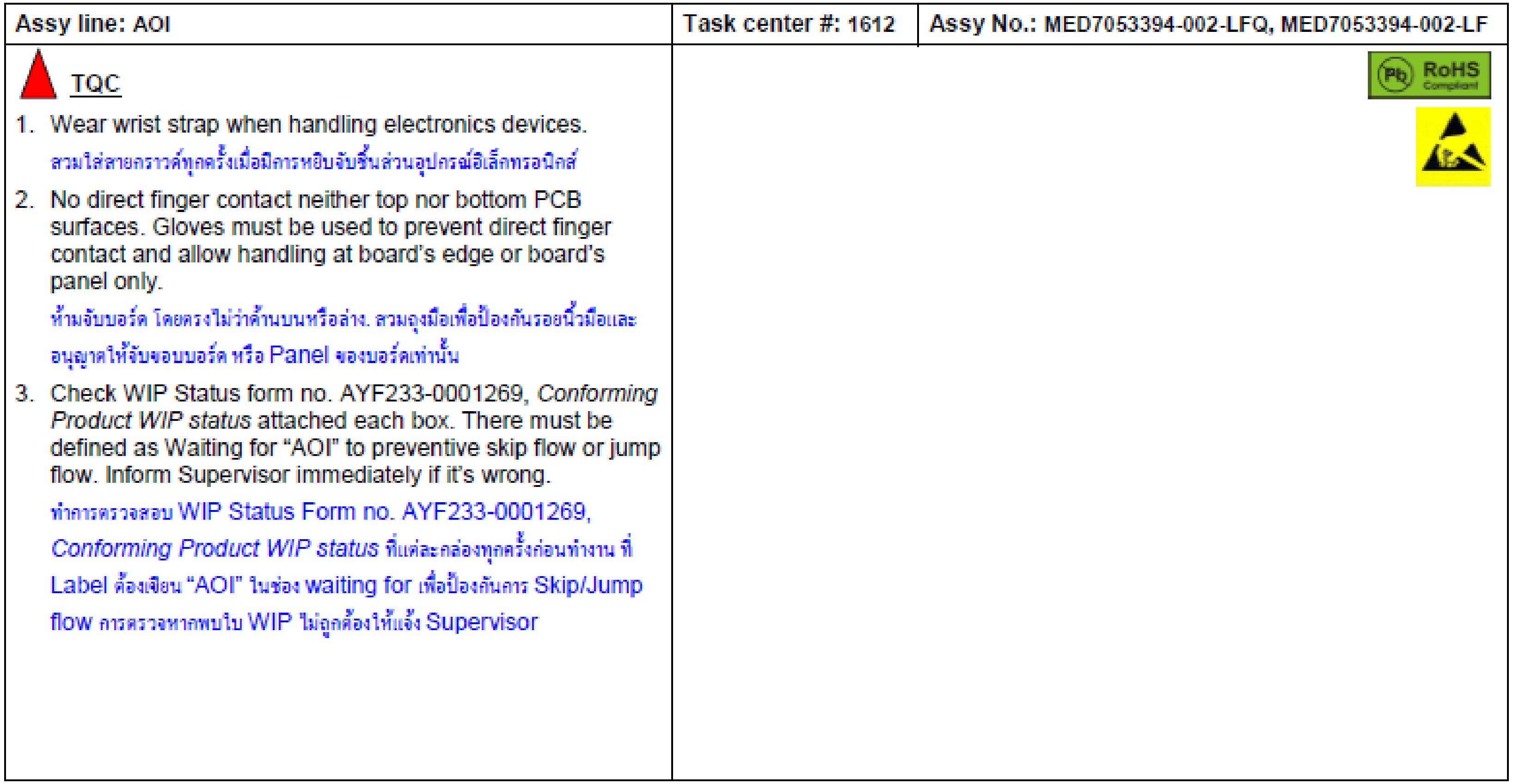


16. After cleaned and scan PFS, put the PCBA into Universal Tray which marked “after clean”.
    เมื่อทำการล้าง และ Scan PFS Cleaning เรียบร้อยแล้วนำบอร์ดใส่ Universal Tray “After clean”

17. After Aqueous cleaning; inspect PCBA for excess water on PCBA and components, blow it by air ionizer. If there is big component or connector, need additional blow under component by the air ionizer.
    เมื่อบอร์ดออกจากเครื่องล้างเรียบร้อยแล้วตรวจดูบอร์ดว่าแห้งสนิทไหมถ้ายังมีคราบน้ำให้เป่าด้วย Ionizing air gun ในกรณีที่งานมี Component ตัวใหญ่ ให้เป่าด้วย Ionizing air gun ที่ใต้ Component ทุกตัว

18. Handling PCBA to next operation by universal Tray (which defined for after clean) and transportation by cart.
    ในการเคลื่อนย้าย PCBA ไปยัง operation ถัดไปจะต้องใช้ Universal Tray (ที่มีการบ่งชี้ว่าเป็นกล่องหลังล้าง) และเคลื่อนย้ายโดยใช้รถเข็นเท่านั้น

## 1.7 AOI



**Assy line:** AOI

**Task center #:** 1612

**Assy No.:** MED7053394-002-LFQ, MED7053394-002-LF

TQC

1. Wear wrist strap when handling electronics devices.

   สวมใส่สายกราวด์ทุกครั้งเมื่อมีการหยิบจับชิ้นส่วนอุปกรณ์อิเล็กทรอนิกส์
2. No direct finger contact neither top nor bottom PCB surfaces. Gloves must be used to prevent direct finger contact and allow handling at board's edge or board's panel only.

   ห้ามจับบอร์ด โดยตรงไม่ว่าด้านบนหรือล่าง. สวมถุงมือเพื่อป้องกันรอยนิ้วมือและอนุญาตให้จับขอบบอร์ด หรือ Panel ของบอร์ดเท่านั้น
3. Check WIP Status form no. AYF233-0001269, *Conforming Product WIP status* attached each box. There must be defined as Waiting for “AOI” to preventive skip flow or jump flow. Inform Supervisor immediately if it's wrong.

   ทำการตรวจสอบ WIP Status Form no. AYF233-0001269, *Conforming Product WIP status* ที่แต่ละกล่องทุกครั้งก่อนทำงาน ที่ Label ต้องเขียน “AOI” ในช่อง waiting for เพื่อป้องกันการ Skip/Jump flow การตรวจหากพบใบ WIP ไม่ถูกต้องให้แจ้ง Supervisor

| **Assy line:** AOI | **Task center #:** 1612 | **Assy No.:** MED7053394-002-LFQ, MED7053394-002-LF |
|---|---|---|
| 🟨 **Work Content**<br>4. Program name: **B407NGPA**<br>5. Machine Name/ Document: **Yestech-YTVFX**<br>6. Tooling ID: 3-A-MED7053394-001-LF-A-XXX<br>7. Loading Direct refer to graphic on machine<br>8. Reference IPC-A-610 (Current Revision), *Acceptability of electronic assemblies Class 3* for acceptance criteria and to confirm rejected units.<br>ใช้มาตรฐาน IPC-A-610 (Current Revision), *Acceptability of electronic assemblies Class 3* ในการตรวจงาน และ Confirm งาน<br>9. Refer to Appendix B for component location.<br>อ้างอิงไปที่ Appendix B สำหรับ ตำแหน่งของ Component<br>10. Scan S/N barcode of each PCBA after visual inspected.<br>ทำการ Scan S/N barcode ทุกบอร์ดหลังจากทำการ inspection<br>11. Select PFS operation "AOI-BOT" after verified or inspection, record the result in PFS.<br>ให้เข้า PFS เลือก operation "AOI-BOT" หลังจากทำการ ตรวจสอบเรียบร้อยแล้วทำการลงผลที่ PFS<br>12. If there is no defect, scan result "PASS" into PFS.<br>หากไม่พบ Defect ให้ Scan "PASS".<br>13. If defect found used AYNMED-0002096, *PFS Defect Code and Repair Code* found reject and need to be rework using defect code clean and apply green tag AYF360-0007787, *Board Rework Tag Clean* to handle. If operator not sure about defect criteria please inform supervisor, PE/QE to | Pb RoHS Compliant<br>⚠ | |

| **Assy line:** AOI | **Task center #:** 1612 | **Assy No.:** MED7053394-002-LFQ, MED7053394-002-LF |
|---|---|---|
| verify before scan rejected to PFS<br>ถ้าพบ Defect ใช้ AYNMED-0002096, *PFS Defect Code and Repair Code* ในการลง Defect code หากมีพบ Defect ให้ทำการติด Tag สีเขียว AYF360-0007787, *Board Rework Tag Clean* และระบุ Location กับ Defect code เพื่อนำไปซ่อมใน Rework Station Clean ในกรณีที่ Operator ไม่แน่ใจใน Defect ที่พบให้แจ้ง Supervisor หรือ PE/QE เพื่อทำการ confirm<br>14. Attached Tag no. AYF233-0001269, *Conforming Product WIP status* when handling it to the rework station.<br>ในกรณีที่ Handling งานที่ถูก Reject ไปยัง Rework Station จะใช้ใบ Tag no.AYF233-0001269, *Conforming Product WIP status*<br>15. Each rejected board shall be attached the failure tag no. AYF360-0007787, *Board Rework Tag Clean*, if board is required to rework by clean process and define “CLEAN_RW” in tag per sample in Appendix A. After passed the rework/touch up, send to cleaning within 30 min.<br>โดยที่แต่ละบอร์ดที่ Reject จะต้องผูก Tag no.: AYF360-0007787, *Board Rework Tag Clean* และบอร์ดนั้นจะต้องทำการ Rework ด้วยกระบวนการ clean และทำการเขียนที่ใบ Tag ต่อการอาการ Reject ด้วยว่า “CLEAN_RW” ดูตัวอย่างได้ที่ Appendix A และหลังจากที่ทำการ Rework/Touch up เรียบร้อยแล้วให้ส่งไปล้างภายใน 30 นาที | | Pb RoHS Compliant<br>⚠ |

<table>
<tr><th>Assy line: AOI</th><th>Task center #: 1612</th><th>Assy No.: MED7053394-002-LFQ, MED7053394-002-LF</th></tr>
<tr><td>16. When put board on work station, use AIR BUBBLE SHEET supporting or put it in the Universal Tray only.<br>ในการวางงานบน Work Station จะต้องวางบน AIR BUBBLE หรือ ใส่ลงใน Universal Tray เท่านั้นห้ามวางบน Work Station โดยตรง<br>17. Handling PCBA to next operation by universal Tray (which defined for after clean) and transportation by cart.<br>ในการเคลื่อนย้าย PCBA ไปยัง operation ถัดไปจะต้องใช้ Universal Tray (ที่มีการบ่งชี้ว่าเป็นกล่องหลังล้าง) และเคลื่อนย้ายโดยใช้รถเข็นเท่านั้น</td><td colspan="2">17<br><br> </td></tr>
</table>

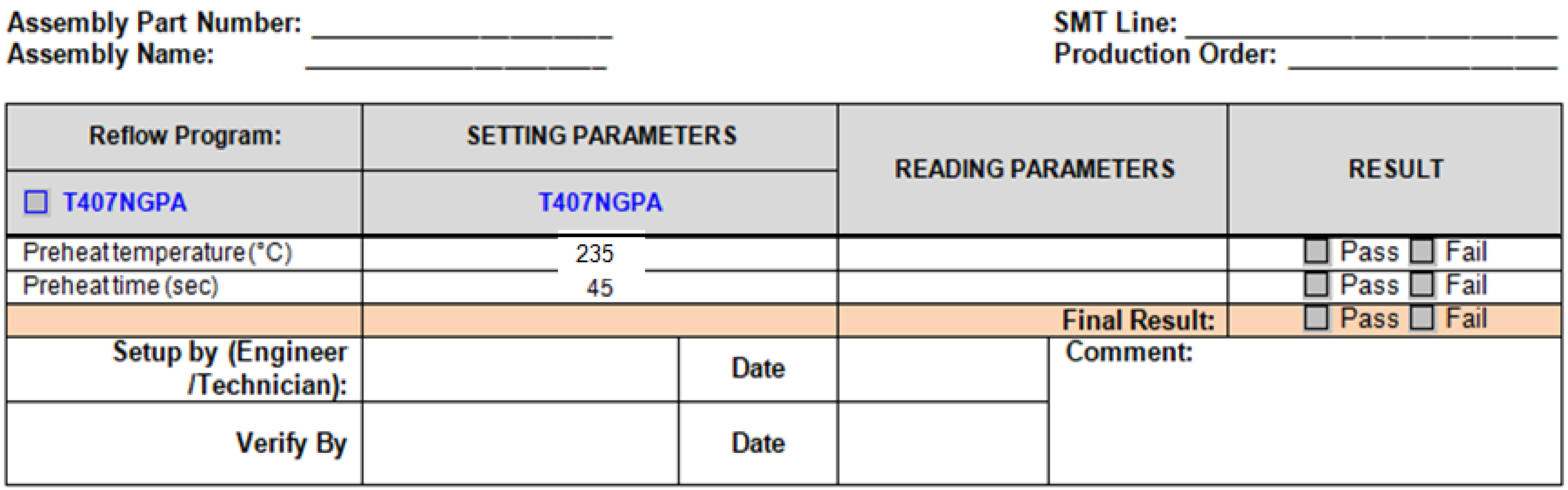
## 2. Screen printing record form

**Assembly Part Number:** ____________________ **SMT Line:** ____________________

**Assembly Name:** ____________________ **Production Order:** ____________________

| Screen Printing Parameter Settings | | | | |
|---|---|---|---|---|
| **Parameters** | **Guide line Setting** | | **Actual Setting** | **Reason for change** |
| Screen Printing Speed (mm/sec) | 20 | | | |
| Pressure (Kg) | 8 | | | |
| Program name: | T407NGPA | | | |
| **SPI Result** | **Min:** | **Max:** | ☐ PASS ☐ NG | |
| **SPI %volume** | | | | |
| | | **Setup/ Change by:** | | |
| | | **Date:** | | |

## 3. Reflow soldering record form



Assembly Part Number: ____________________ SMT Line: ____________________
Assembly Name: ____________________ Production Order: ____________________

| Reflow Program: | SETTING PARAMETERS | | READING PARAMETERS | RESULT |
|---|---|---|---|---|
| ☐ T407NGPA | T407NGPA | | | |
| Preheat temperature (°C) | 235 | | | ☐ Pass ☐ Fail |
| Preheat time (sec) | 45 | | | ☐ Pass ☐ Fail |
| | | | Final Result: | ☐ Pass ☐ Fail |
| Setup by (Engineer /Technician): | | Date | | Comment: |
| Verify By | | Date | | |

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