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Application of Six Sigma Methodology to Reduce Defective Products in Temperature Control Device Manufacturing

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Abstract

This study aims to demonstrate the application of the DMAIC-based Six Sigma methodology to reduce defective products in the manufacturing of temperature control device Model A. This research was begun with the Define Phase to define the scope of the project. A process flow chart was constructed, followed by a Pareto analysis that identified excessive solder and solder short as the key defect types. This then proceeded to the Measure phase to determine current status of the process and analyze the measurement system. One year of data (January to December 2024) showed defective products accounted for 17.8% of total production volumes. Attribute Gage Repeatability and Reproducibility results showed the measurement system was reliable. In the Analyze phase, the objective was to identify defect causes using Fishbone diagrams and prioritize them by Risk Priority Number (RPN) based on expert operator evaluation. The project then moved into the Improve phase, aiming to reduce defects by applying ECRS principles such as flux concentration control, solder paste inspection, conveyor speed standardization, stencil pressure control using jig, and the auto optical inspection machine. In the final Control phase, aimed to sustain improvements, a Control Plan was formulated to train the workforce. Monitoring for 3 months after these improvements found that the ratio of defective products fell from 17.8 to 10%, demonstrating that the application of Six Sigma methodology significantly contributed to defect reduction and increase the efficiency of manufacturing processes for electronic devices.

Keywords
Six Sigma, Defective Products, DMAIC, Process Improvement, Electronic.

1. Introduction
The electronics sector has a key role in powering the Thai economy, especially with regard to exports and investment, and high-tech skills development. This industry is highly competitive, in terms of quality, costs and rapid delivery of products. Despite facing challenges of raw material shortages and increased manufacturing costs, the electronics sector is still on a trend of continuous growth, causing companies to prioritize quality improvement and enhance the efficiency of manufacturing processes (Office of Industrial Economics 2023).

The case study company, located in the northern region of Thailand, has an integrated manufacturing process for electronic devices. The core business unit is the manufacture and assembly of Printed Circuit Board Assembly (PCBA), Integrated Circuits (IC), and Micro-displays. The core revenue structure of the case study company is derived from PCBA.

The temperature control device is an item of electronic equipment used to measure, control and maintain temperature levels required for various processes or systems, such as industrial machinery, thermal systems, refrigeration systems and electronic components requiring stable temperatures. PCBAs are key components in the device's operation and rely on precise, accurate assembly and soldering. Defects arising in manufacturing may result in errors of temperature control that may lead to damaging systems or interruptions to users' manufacturing processes.

In the manufacturing process for the temperature control device in the case study company, and specifically the process of PCBA, defects were found in the process of soldering electronic components, such as excessive solder on joints and solder short circuits. These were the cause of increased rework, caused waste in the manufacturing process, while increasing operating costs. Faulty products also impacted the product's trustworthiness and customer satisfaction. This caused the control and reduction of defects to become a key issue requiring systematic remedy. Therefore, the case study company has a need to systematically and sustainably improve its processes in order to reduce defects.

1.1 Objectives

This research is therefore focused on applying Six Sigma techniques to systematically improve manufacturing processes of a temperature control device in a case study company. This research proposes clear outcomes of reducing defective products and increasing the efficiency of the manufacturing process, as well as practical knowledge which can be applied as a methodology to upgrade the capabilities of manufacturing processes in other industries with similar characteristics.

2. Literature Review

Six Sigma is a concept and methodology for quality improvement focused on reducing variability and waste in the manufacturing process by applying statistical principles, with a data-driven approach. From a statistical perspective, Six Sigma represents a level of process capability with no more than 3.4 defects per million opportunities (DPMO), achieved by controlling process variation within appropriate quality specification limits (Montgomery 2019; Harry and Schroeder 2000). In operational terms, Six Sigma has been employed as a tool to improve quality, reduce waste, reduce costs and enhance organizational competitiveness, particularly in industries that require high precision, such as the electronics industry (Pyzdek and Keller 2018).

Six Sigma approaches commonly employ the DMAIC framework of Define, Measure, Analyze, Improve and Control to define problems, measure the current process and analyze measurement system, analyze causes and improve the process, while controlling outcomes so that problems do not reoccur. This framework improves processes systematically with retroactive verification, and is appropriate for addressing complex quality improvement issues in electronics manufacturing processes (Antony 2014). Antony et al. (2005) report that the application of Six Sigma to manufacturing reduces waste and manufacturing costs, and enables concrete improvements to the company's competitive capabilities. Meanwhile, Snee (2010) indicates that the DMAIC framework has a key role in remedying complex quality improvement issues, while supporting continuous and sustainable improvements to the process.

Other tools may be employed in combination with Six Sigma, such as the principles of ECRS (Eliminate, Combine, Rearrange, Simplify). This tool reduces losses and improves process efficiency. It is focused on eliminating activities not adding value, combining and rearranging procedures, and simplifying processes to have greater clarity. ECRS principles have been applied in tandem with Six Sigma to support outcomes of concrete and sustainable improvements in manufacturing processes (Niebel and Freivalds 2009; Zandin 2001).

A review of current research shows that Six Sigma has been integrated with Lean principles, forming what is known as "Lean Six Sigma". Lean primarily focuses on eliminating waste and improving process flow to increase speed and efficiency, while Six Sigma emphasizes reducing process variation and defects. By combining these two approaches, organizations can simultaneously enhance efficiency and improve quality in a systematic and sustainable manner. Previous studies have further reinforced the effectiveness of Lean Six Sigma and DMAIC-based methodologies in manufacturing environments. For example, Tampubolon and Purba (2021) highlighted that Lean Six Sigma significantly improves process capability and defect reduction across various manufacturing sectors. Condé et al. (2023) demonstrated that the integration of DMAIC with Lean tools can effectively reduce defect rates and enhance operational performance in manufacturing systems. In addition, Pongboonchai-Empl et al. (2024) emphasized the growing trend of integrating Industry 4.0 technologies with Lean Six Sigma to strengthen data-driven decision making and sustain quality improvement initiatives in complex manufacturing environments.

A review of the research literature finds that Six Sigma has been widely applied in manufacturing processes, and electronics and electrical appliance sectors in particular. These are industries requiring high precision and are sensitive to variables in the manufacturing process. Khan and Tonoy (2024) compiled and analyzed research on the application of Lean Six Sigma to the electrical and electronics industries, and found that it was possible to reduce waste, increase rates of production and significantly reduce manufacturing costs, most particularly in processes concerned with the assembly and quality improvement of electronic components.

At the level of the manufacturing process, the research of Tong et al. (2004) has applied the DMAIC framework to improve the quality of processes manufacturing Printed Circuit Boards (PCB). This was focused on reducing variability in printing and soldering, which are critical procedures of Surface Mount Technology (SMT). This study found that it was possible to upgrade process capabilities and effectively reduce defects from soldering. This illustrates that Six Sigma is appropriate for addressing quality issues in the electronics sector. As well as this, research by Mapong (2014) has applied Six Sigma under the DMAIC framework to improve manufacturing processes for electronics circuit boards at the soldering stage. This study found that it was possible to reduce waste and increase production rates (% Yield) in excess of the stipulated standards. This research confirmed that Six Sigma is an effective methodology to reduce defects in soldering processes of the electronics industry. Although Six Sigma has been widely applied in manufacturing environments, the integration of structured problem-solving tools such as DMAIC with practical process improvement approaches remains an important research area. This study contributes to the literature by demonstrating how DMAIC-based Six Sigma can be systematically implemented in electronic device manufacturing to reduce solder-related defects and improve process performance.

3. Research Methods and Results

Six Sigma was selected in this research because it provides a structured data-driven framework capable of identifying root causes of defects and guiding systematic process improvement in complex manufacturing systems. The researchers conducted research according to the DMAIC-based Six Sigma methodology in 5 Phases with the following details:

3.1 Define Phase

The phase of defining the scope of the project (Define Phase) has the objective of studying and compiling relevant data to determine the scope of the problem, and bring clarity to the objectives and goals of the research, with the following details:

Creating Process flow chart

The Model A temperature control device was selected for this study for its high production volumes and relatively high defect rate compared to other models. The case study company therefore prioritized it as the first product to improve the manufacturing process. On top of this, Model A is a product with a structured integrated manufacturing process incorporating the processes of Surface Mount Device (SMD), Pin Through Hole (PTH) and Final Assembly, which are core processes in which issues with soldering are frequently encountered.

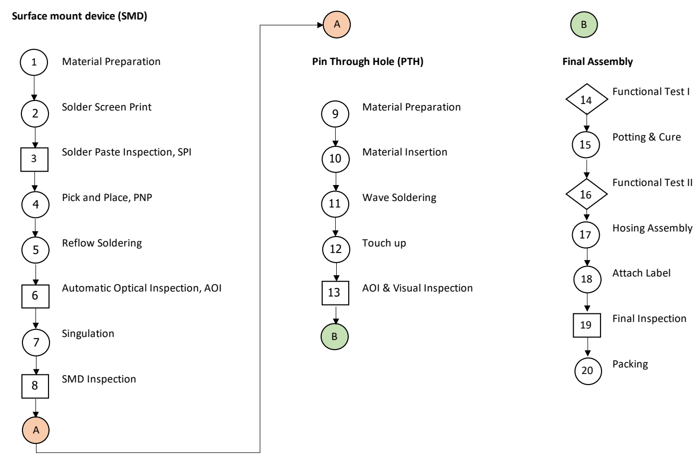


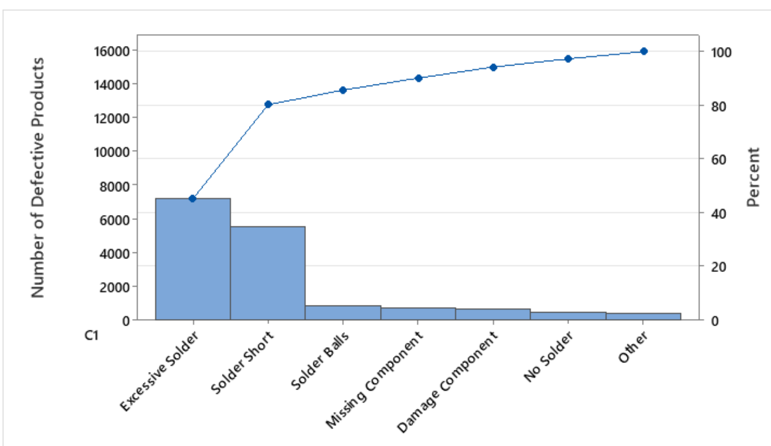
Figure 1. Process flow chart of Model A temperature control device.

To better understand the manufacturing processes of the Model A temperature control device systematically, the researchers created a Process flow chart from raw material preparation to final inspection and packaging, as shown in Figure 1. This Process flow chart made visible the procedural steps and connections between processes, to clearly identify points which may be causing problems or wastes in the production process.

From Figure 1, it is possible to divide core manufacturing processes into three parts SMD, PTH, and the Final Assembly process. SMD involves installing electronic components to PCB; PTH involves inserting component lead wires into holes on the PCB. Both of these processes are key steps concerned with soldering and the attachment of components to the PCB, which are points in the process with a high opportunity for causing defective products.

Prioritizing defect types with a Pareto diagram

The researchers compiled one year (January to December 2024) of historical data of defective products from the manufacturing process for the Model A temperature control device, to analyze categories of defect and to prioritize issues. This data analysis found that the top three types of defective products were Excessive Solder, accounting for 45.3 percent, Solder Short at 34.9 percent, and Solder Balls at a rate of 5.4 percent.



C2	7214	5562	867	711	655	485	428
Percent	45.3	34.9	5.4	4.5	4.1	3.0	2.7
Cum %	45.3	80.2	85.7	90.2	94.3	97.3	100.0

Figure 2. Pareto diagram showing number of defective products by category in the manufacture of Model A temperature control device during 2024.

After creating the Pareto diagram as shown in Figure 2, it was found that products with excessive solder and solder short made up approximately 80 percent of all defects. The research therefore focused on remedying these issues causing defects. According to the Pareto principle, 20% of causes produce 80% of effects. Each type of defect had the following characteristics:

1) Excessive Solder – means solder overflowing the copper traces of the PCB and not having a pyramidal shape, as shown in Figure 3.

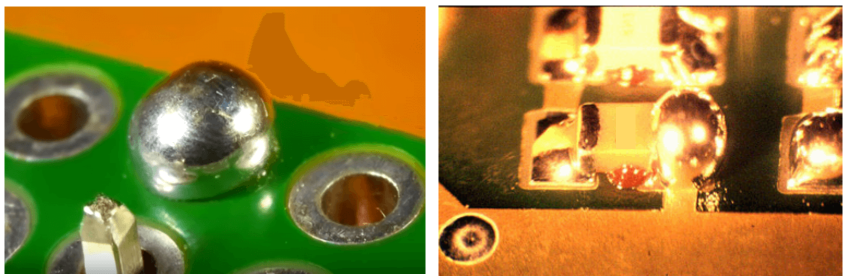


Figure 3. Excessive Solder

2) Solder Short – this is the case of solder causing connections between components in two or more places resulting in short circuits on the PCB, as shown in Figure 4.

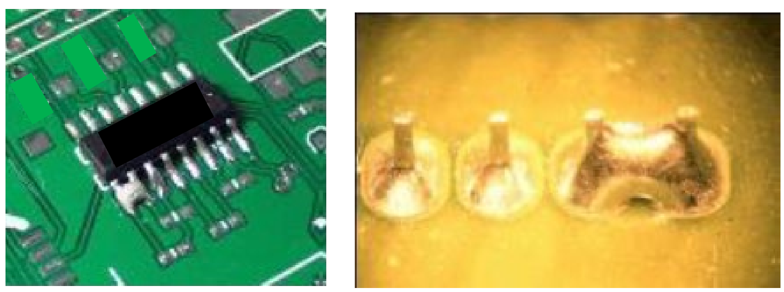


Figure 4. Solder Short

3.2 Measure Phase

The Measure Phase consists of two main parts: measuring the current status of the process and analyzing the measurement system. This step has the objective of evaluating the current status of the issue, and to ensure the reliability of the measurement system, with the following details:

Measuring current status of the process

The researchers compiled data of products with defects from the manufacturing processes of the Model A temperature control device for a period of one year from January to December 2024, considering %Yield and proportion of defective products. It was found that products had an average rate of 17.8% of defects, with a resulting percent yield of 82.2%, with the two most common defects being excessive solder, at a rate of 8.06%, and solder short, at a rate of 6.21%.

Measurement System Analysis

This research performed analysis of the measurement system using Attribute Gage Repeatability and Reproducibility (Gage R&R) Analysis to evaluate capabilities to inspect quality in the inspection processes for PCBA, which is the last stage of the PTH process before proceeding to the next assembly stage. This quality inspection is carried out with the Auto Optical Inspection Machine (AOI Machine). This compares products with defects to a master which engineers have programmed into the machine. After the AOI Machine has made an inspection, the operator must make a repeated inspection, whenever the machine has discovered defective products.

This study selected 3 operators from the inspection team tasked with inspection on the production line. Twenty sample pieces were used, divided into 5 good samples and 15 defective samples. Each member of the team conducted 3 rounds of inspection. From there, the inspection results were evaluated by using the Kappa coefficient (K, equation 1) together with the Effectiveness (O_E, equation 2), False Alarm Rate (I_{FA}, equation 3) and the Miss Rate (I_{MISS}, equation 4), with reference to criteria of acceptability following the AIAG (2010) standard. An attribute measurement system is considered acceptable when it demonstrates an overall effectiveness of at least 90 percent. In this case, the system correctly classifies parts at a very high rate, while maintaining a miss rate of no more than 2 percent and a false alarm rate of no more than 5 percent. This level indicates strong decision reliability and minimal risk to customers or production (AIAG 2010).

$$K = \frac{P_o - P_e}{1 - P_e} \tag{1}$$

where P_o is observed agreement and
P_e is expected agreement

$$O_E = \frac{\text{Number of Correct Decisions}}{\text{Total Number of Samples}} \times 100\% \tag{2}$$

$$I_{FA} = \frac{\text{Number of Good Parts Rejected}}{\text{Total Number of Good Parts}} \times 100\% \tag{3}$$

$$I_{MISS} = \frac{\text{Number of Bad Parts Accepted}}{\text{Total Number of Bad Parts}} \times 100\% \tag{4}$$

Table 1 and Table 2 shown that the value of the Kappa coefficient between each pair of the inspection team, including between the operator and standard samples, has a value of more than or equal to 0.75, which is within the stipulated acceptable criteria.

Table 1. Kappa coefficient (vs Operator)

Operator	**1**	**2**	**3**
1	-	1.00	1.00
2	1.00	-	1.00
3	1.00	1.00	-

In addition, as shown in Table 2, every member of the inspection team had O_E equal to 100 percent, and no erroneous inspections, whether in the I_{FA} or I_{MISS}. Therefore, the measurement system was stable, reliable, and suitable for use in subsequent process analysis and improvement.

Table 2. Kappa coefficient (vs Standard), O_E, I_{FA} and I_{MISS}

Operator	**Kappa coefficient (vs Standard)**	**%O_E**	**%I_{FA}**	**% I_{MISS}**
1	1	100	0	0
2	1	100	0	0
3	1	100	0	0

3.3 Analysis Phase

The Analysis Phase has the objective of analyzing the root causes of each type of defect and selecting the important causes for use in improving the manufacturing process in subsequent phases, with details as follows:

Analysis of each type of defect

The researchers arranged brainstorming sessions for staff involved, being 4 individuals from Engineering, Technical, Production and Quality Control. This was to identify probable causes of each category of defect, and then building a

Fishbone diagram to make visible the connections between the causes of each issue systematically. Figure 5 is the Fishbone diagram showing the causes concerned with defects of excessive soldering, with each cause arranged according to 6 factors of Man, Material, Method, Machine, Measurement and Environment. The Fishbone diagram showing the causes of the solder short defects is not shown here, but can be analyzed with the same methodology.

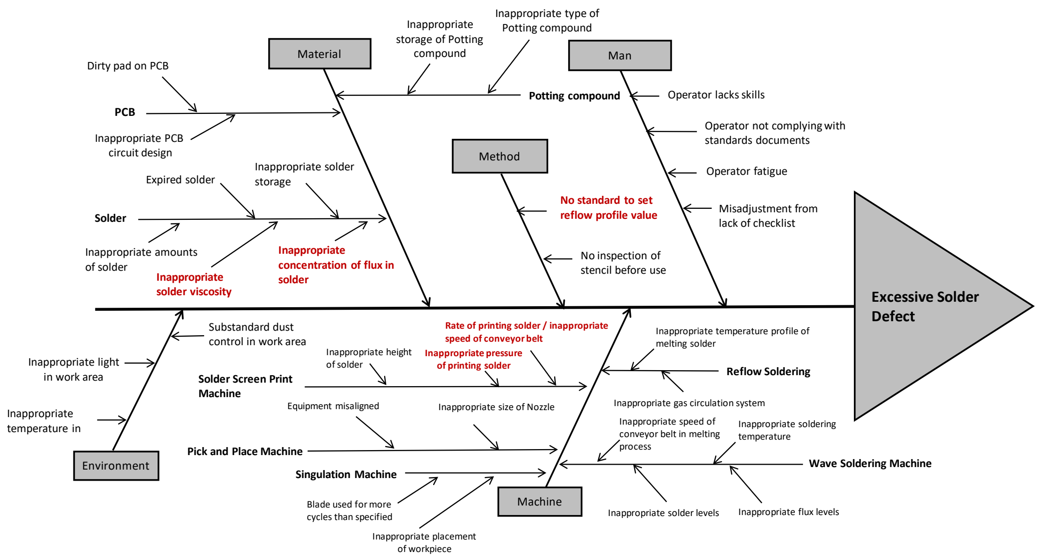


Figure 5. Fishbone diagram showing causes of the excessive solder defect

Ranking the importance of causes of each type of defect

To select the causes which are important and appropriate to use in remedying the issues causing defects, the researchers got experts from each department to evaluate each cause obtained from the Fishbone diagram by using evaluation criteria awarding points in three aspects as shown in Table 3:

Table 3. Criteria of evaluation points

Points	1	2	3	4	5
Severity (S)	Minor impact, no impact on function/standards	Partial impact, still usable	Medium impact requiring rework/ reinspection	High impact with the chance of not passing testing/delivery	Critical impact, risk of short circuit/ damage/customer complaint
Occurrence (O)	Rare occurrence	Small occurrence	Occasional occurrence	Frequent occurrence	Very frequent/ repeated occurrence continuously
Detection (D)	Very easy to detect/control, immediate	Easy to detect	Medium to detect, requiring adjustment to conditions	Difficult to detect, requiring coordination with many departments/ adjustments of machinery	Very difficult to detect, requiring time/high cost/having technical limitations.

From there, points in all three aspects were calculated to find the product or RPN, for use in ranking the importance of each cause according to (5).

$$RPN = \text{Severity} \times \text{Occurrence} \times \text{Detection} \quad (5)$$

Table 4 shows the results of evaluating points for each cause of the excessive solder defect and selecting the top five causes with the highest RPN for application in the Improve Phase. Analysis of root causes for the solder short defect are not shown here, but can be analyzed with the same methodology.

Table 4. Results of evaluation points of the root causes of the excessive solder defect.

Cause	S	O	D	RPN
Man				
Misadjustment from lack of checklist parameter	3	2	3	18
Operator fatigue	2	2	3	12
Operator not complying with standards documents	2	2	3	12
Operator lacks skills	2	2	3	12
Machine				
Rate of printing solder/inappropriate speed of conveyor belt	3	3	3	27*
Inappropriate pressure of printing solder	3	4	2	24*
Inappropriate height of solder	3	2	3	18
Inappropriate size of nozzle	3	2	3	18
Equipment misaligned	3	2	3	18
Blade used for more cycles than specified	3	2	3	18
Inappropriate placement of work piece	3	2	3	18
Inappropriate speed of conveyor belt in melting process	3	2	3	18
Inappropriate soldering temperature	3	2	3	18
Inappropriate solder levels	3	2	3	18
Inappropriate flux levels	3	2	3	18
Inappropriate temperature profile of melting solder	3	3	2	18
Inappropriate gas circulation system	3	2	3	18
Method				
No standard to set reflow profile value	4	3	2	24*
No inspection of stencil before use	3	2	3	18
Material				
Inappropriate concentration of flux in solder	4	4	2	32*
Inappropriate solder viscosity	3	3	3	27*
Inappropriate amounts of solder	3	2	3	18
Expired solder	3	2	3	18
Inappropriate solder storage	3	2	3	18
Inappropriate PCB circuit design	3	2	3	18
Dirty pad on PCB	3	3	2	18
Inappropriate storage of Potting compound	3	2	3	18
Inappropriate type of Potting compound	3	2	3	18
Environment				
Inappropriate light in work area	2	2	3	12
Inappropriate temperature in work area	2	2	3	12
Substandard dust control in work area	2	2	3	12

3.4 Improve Phase

This phase has the objective of proposing methodologies for improvement and reducing each type of defect, with the following details:

Process improvement on the principles of ECRS

This research applied the principles of ECRS to improve processes, with the details shown in Table 5. Details of improving manufacturing processes for each category of defect by applying the principles of ECRS with the following methodology:

Excessive Solder

Eliminate: Eliminated the use of solder close to expiry, or which has failed incoming inspection, to reduce the risk of inappropriate materials

Combine: Combined inspection of temperature profile with pre-run audit to reduce chances of using inappropriate thermal values

Rearrange: Rearranged inspection and control of conveyor speed, and stipulating inspection according to standard checklist, every time before restarting production.

Simplify: Used jigs to control pressure of the stencil and arrange training for operators to set parameters according to standard checklist, for greater consistency in printing solder.

Solder Short

Eliminate: Eliminated dirt and oxidation on the pad of the PCB before entering the soldering process for surfaces to be ready for attachment of the solder.

Combine: Combined procedure of cleaning pad with pre-inspection as a part of process standards.

Rearrange: Rearranged inspection of flux volumes before the soldering stage to prevent solder bridges from excessive flux.

Simplify: Adjusted AOI system to improve picture and resolution and light, as well as conducting preventive maintenance on the nozzle head on the machine placing equipment to reduce misalignment in placing the components.

Table 5. Methods of improvement under the principles of ECRS to reduce each type of defect

Category	Cause	ECRS Action	Expected Result
Excessive Solder			
Material	Inappropriate concentration of flux in solder	**Simplify** → Create standard of mixing flux and inspect batch before use	Reduce flux with wrong concentration, reduce defects ~ 30%
Material	Inappropriate solder viscosity	**Eliminate** → Stop using paste close to expiry **Rearrange** → Do incoming check	Reduce chance of spoiled paste, reduce rework
Machine	Inappropriate rate of printing solder/conveyor speed	**Rearrange** → Standardize speed setting using checklist	Reduce solder overflow
Machine	Inappropriate printing pressure	**Simplify** → Use jig to control pressure and training operator	Increase printing consistency
Method	Inappropriate reflow profile	**Combine** → Combine inspection of temperature profile with pre-run audit	Reduce defects from overheating
Solder Short			
Measure ment	Low sensitivity of AOI system	**Simplify** → Calibrate AOI to increase resolution and lighting	Increase chance of detecting solder short
Material	Dirty pad on PCB	**Eliminate** → Cleaning pad before process **Combine** → Incorporate cleaning into pre inspection	Reduce abnormal joints
Material	Excessive flux causing solder bridge	**Rearrange** → Inspect flux volumes before soldering **Simplify** → Use dispenser control	Reduce solder bridge
Machine	Misaligned equipment Nozzle placement misalignment	**Simplify** → Preventive maintenance and alignment check	Reduce misplacement defect

Method	Inappropriate Reflow profile	**Rearrange** → Standardize profile for each product type	Reduce bridging from excess flow

Comparing processes before and after improvement
When improvements were carried out according to the methodologies proposed, this caused changes to steps of the manufacturing process. These were, before improvements, procedures concerned with soldering lacked control of key parameters according to standards, such as properties of the solder, amounts of flux, setting temperature values for the reflow process, and quality inspection at some points. This resulted in defects of excessive solder and solder short at rather high rates requiring increased rework. After improving the manufacturing process by increasing incoming inspections of raw materials, controlling the pressure of printing solder by using a jig, specifying a standard temperature profile in the reflow process and calibrating the AOI system resulted in the process being more consistent, reducing defective products and reducing the necessity for rework. Figure 6 shows the Process flow chart of the manufacturing process for the Model A temperature control device before and after improvements, to clearly compare changes to the manufacturing process.

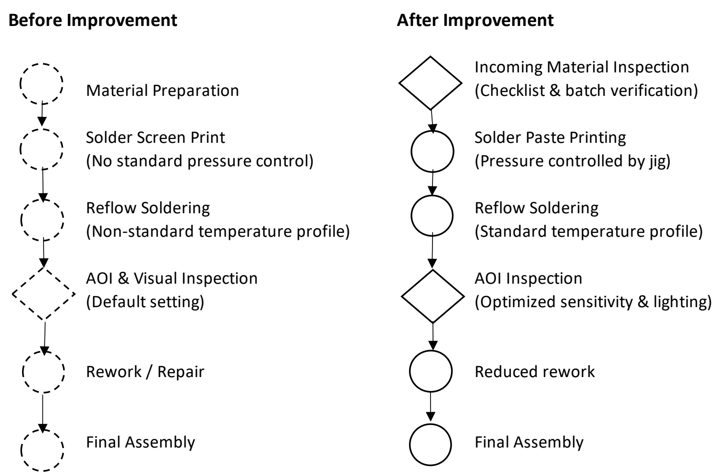


Figure 6. Process flow chart (before vs after improvements)

Results of improvements
After implementing process improvements and monitoring production results from May to July 2025 (a three-month period), total production volume amounted to 22,385 pieces. It was found that defective products in the category of excessive solder were reduced from 8.06 percent to 4.43 percent, while defective products in the category of solder short were reduced from 6.21 percent to 3.42 percent, with the result of total defective products being reduced from 17.8 percent to 10 percent.

Besides this, improvements to these processes also had a positive impact on other operations, such as reducing volumes of rework and reducing time spent on inspections and adjusting machinery settings before starting a production run, stemming from the use of clearer checklists and work standards. This boosted continuity of production and reduced losses from the processes overall. The results of these improvements illustrate that the application of ECRS principles in combination with Six Sigma techniques was able to concretely reduce defects and enhance manufacturing process efficiency. This study is limited to a single production line and a specific product model. Therefore, the generalizability of the results may vary when applied to different manufacturing environments or product types.

3.5 Control Phase
The Control Phase had the objective of designing and implementing a system of quality control for the manufacturing process to maintain results of the improvement and prevent problems of defective products reoccurring in the future. This research specified methodologies of control with a focus on creating systematic standards for working and inspection with continuous monitoring. A control plan was developed by determining clear methods to control the frequency of inspections, criteria of acceptability and the persons responsible for each stage of the process. On top of this, checklists were created to inspect key parameters before production startup, and to record data which was the

result of inspections. This could be used in monitoring trends of the process and prevent deviation from the stipulated standards. Responsibility for controlling these processes was clearly assigned to a team of Operator, QC Engineer, Technician and Production Supervisor. There was also stipulated an inspection regime on a daily, weekly and monthly basis, for confidence that the improvements carried out would be maintained and continued in the long term.

4. Conclusion and Discussion

This study demonstrates the role of Six Sigma methodology as a systematic process improvement framework through its application in the manufacturing of temperature control devices. It can be seen that by applying the Six Sigma DMAIC framework to Model A reduced the overall defect rate from 17.8% to 10% in three months and significantly decreased excessive solder and solder short defects. This research provides empirical insights into defect reduction and manufacturing process efficiency enhancement, contributing both practical and academic value.

The proposed improvement strategies in this study can be applied as a standard quality control and improvement approach for similar electronic soldering processes, particularly precision PCBA production. As well as this, the formulation of a Control Plan and checklists from this research enable continuous quality control, reduce reliance on the specific experience of individuals and reduce rework in the long term.

Besides this, although this research focused on Model A, the DMAIC framework and tools can also be applied to other electronics factories with similar processes and quality issues. There may be adjustments in detail of parameters or procedures and tools to be appropriate to the context of each factory.

For future research recommendations, first, when applying the Six Sigma DMAIC framework to other temperature control products or other production lines, appropriate and effectiveness of the proposed approach should be evaluated across diverse contexts, including assessing the extent to which the process improvement strategies can be transferred and scaled to the broader electronics industry. Future studies should also evaluate the sustainability of process improvements, especially the Control phase. For example, process capability indices (Cp, Cpk) and statistical control plans can be used to confirm the sustainability of the results.

Furthermore, an economic and quality cost analysis should be conducted. That is, there should be studies of the impacts of process improvements in the dimension of costs, such as the Cost of Quality and Returns on Investment (ROI), to better illustrate the economic value of applying Six Sigma techniques to the industrial sector.

In addition, other quality improvement tools should be integrated. Future research may incorporate Six Sigma techniques with other productivity tools such as Lean Six Sigma Manufacturing, to combine the methodologies of Lean which emphasize the reduction of waste, and Six Sigma which is focused on defects. The core objective is to maximize the efficiency of processes, improve product quality, reduce costs, operate more quickly and generate maximum customer satisfaction. Moreover, other tools such as Design of Experiments (DOE) should be used to study the relationship between process or machine parameters and defective products in detail. In addition, Failure Mode and Effects Analysis (FMEA) can be used improve waste reduction and proactively prevent defects. Besides this, future research may apply digital technology such as real time process monitoring systems, Big Data Analytics, or the use of Artificial Intelligence to predict defects and shift from reactive to preventive quality control.

The final recommendation is to ensure that Six Sigma improvements are sustained by company personnel and systematically expanded to other projects. Also in the future, there may be studies of the role of human and corporate factors such as workforce training, a culture of quality and the participation of work teams to gain understanding of the success factors in implementing Six Sigma programs more systematically.

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Biographies

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Fareeda Waree received the Bachelor of Science degree in Industrial Chemistry and is currently pursuing the Master of Engineering degree in Industrial Engineering at Chiang Mai University, Thailand. Her research focuses on defective products reduction in temperature control device manufacturing using Six Sigma techniques. She is a Sales Engineer at a manufacturing company specializing in industrial materials, responsible for export markets across Asia. Previously, she worked in the electronics manufacturing industry, with experience in quality management systems, process optimization, and continuous improvement. Her interests include Six Sigma, DMAIC, quality engineering, and manufacturing process improvement.

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