An Application of DMADV Methodology for Increasing the Yield Rate of CMOS Camera

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\textbf{ABSTRACT}
Some of Taiwan genuine products are the first position of market share around the world, and there are also many competitors show their capability in challenging the position of Taiwan manufacture. The strategy for products in the stage of maturity under steep competition is to increase their quality and yield rate which will prevent unnecessary waste. There are some researches about adopting Six Sigma for improving the yield rate of products, and the results had approved the remarkable outcomes. In this research, the DMADV methodology will be implemented for improving quality of CMOS camera, and diminishing its excess cost occurred in process.

\textbf{Key word:} Six Sigma, DMADV, Soldering defects,

\section{Introduction}
Motorola implemented Six Sigma companywide in 1987–1997, and this practice has caused its stock price grown more 21% every year, and it also records as high as 17 billion in saving. There are many researches about Six Sigma, Ham et al. (2002) had proposed MAIC methodology for process improvement, Michael (2002) described the process of DMAIC, and Motorola University developed frame work DMADV within DFSS. There are also researches and cases about Six Sigma practice in Taiwan, Chen et al. (2005) adopted DMAIC to TFT-LCD Panel Quality Improvement, Cheng (2005) implemented DMADV to improve assembly efficiency of military product.

The population of elders in Taiwan has caught up the rate of developed countries around the world. There are many kinds of social problems, like social welfare, medical care and social security issues had drawn forth more attention from government. Since more and more elders need proper full attendance, medical care service provider can remotely monitor seniors daily activities with surveillance camera which is equipped with internet or wireless telecommunication technology, video signal could be recorded properly for necessary review.

Two of seven basic tools of quality improvement, Pareto chart and Cause & Effect Diagram will be used in this research for finding primary causes, and a quality performance index would be proposed to measure soldering defective rate. As soon as the primary causes been identified, redesign the key components or process improvement need to be carried out. Thru repeatedly test and verification, the purpose of this research is following Six Sigma systematic practice to efficiently reduce defective rate and improve the level of quality.

Soldering defects will occur in manual soldiering process and process of automatic surface mounting (SMT), machine setup, negligence of operator, improper soldering time and improper soldering temperature all possible cause the defects. Types of soldering defects could be short circuit, missing item, wrong item, cold soldering, insufficient soldering, wrong polarity, inaccurate positioning, circuit board distortion and so on. Some of these causes will make the components not working properly, and the complete CMOS camera will be identified as poor quality product.

A brief description of manufacturing process for surveillance camera shown in Figure 1, we find there are some quality issues being validated, which includes surface mounted process and manual soldering process. Bad quality of assembly process will cause high scale of variability happened in post process, like no video, or video unstable etc. To find out the possible causes in assembly process, and redesign new layout, then Six Sigma DMADV methodology will be implemented for process improvement to
upgrade the quality of surveillance cameras. The implementation procedures are:

Define: The goal of this research is to upgrade the quality of surveillance camera, reduce defectives rate and relieve cost of quality

Measure: Measure, and identify the CTQs(Critical to Quality) for surveillance camera quality. Develop an index of soldering process failure rate as an assessment model, and then quality level of soldering process would be estimated by statistical hypothesis test.

Analyze: Pareto chart and Cause & Effect diagram are adopted for analyzing possible causes

Design: To improve or delete the causes found by analysis step, redesign key components or process

Verify: Verify the new design of new component, to prove the improvement thru hypothesis test and efficiently reduce failure rate of surveillance camera

**Fig. 1 The flow diagram of SMT process for surveillance camera printed circuit board**

### 2.0 Methodology

#### 2.1 Define

In the step of Define, quality of surveillance camera was concerned by the manufacturer, the rework data showed high percentage of defective units happened in process, and the rework records show that most of rework is caused by bad soldering joint. Therefore, this research will focus about quality level of soldering process. The bad soldering joint may be caused by manual or SMT automatic soldering process, machine setup, manual negligence, and improper solder temperature setup will cause bad soldering process. Bad soldering joint will cause the complete set of camera to unstable or no picture response.

#### 2.2 A Measurement Model defined for bad soldering process

The soldering failure rate will be defined as following:
\[ p = \frac{N}{m} \]  

(1)

Where soldering defect rate \( p \) is defined as bad soldering counts \( N \) divided by total soldering joint counts of each printed circuit board \( m \). \( p_0 \) is the upper acceptable limit of soldering defect rate, the manufacturer could define \( p_0 \) by itself, and it should be equal or smaller than customer’s limit. \( U \) is the acceptable soldering joint defect counts limit with upper acceptable limit \( p_0 \). Therefore, the soldering quality index \( I_D \) is defined:

\[ I_D = \frac{p}{p_0} = \frac{mp}{mp_0} = \frac{N}{U}, \]  

(2)

A soldering quality index \( I_D \) would be defined as: when \( I_D < 1 \), it means that defective rate of soldering not reach limit yet; when \( I_D = 1 \), it means that defective rate of soldering just reach limit; when \( I_D > 1 \) it means that defective rate of soldering had exceed the maximum limit. Therefore, the value of \( I_D \) is smaller, it means that soldering process is carried out more correctly, and the level of soldering process quality will be better. If there is an upper limit \( \nu \) (where \( 0 < \nu < 1 \)) for \( I_D \), then the hypothesis test would be defined as:

- \( H_0 : \nu \leq I_D \) (Quality for soldering process is good)
- \( H_1 : \nu > I_D \) (Quality for soldering process is poor)

If the test approves the null hypothesis, then the quality level of soldering process meets the requirement, otherwise the quality level of soldering process did not meet the requirement. Since every PCB has the same soldering joints, we define as \( m \). Then bad soldering rate for \( j \) th sampling is defined as \( p_j \), and its estimator is:

\[ \hat{p}_j = \frac{N_j}{m}, \]  

(3)

Which \( N_j \sim B(m, p) \), let \( j = 1, 2, \ldots k \) represent \( k \) samplings have been collected, the average bad soldering rate:

\[ \bar{p} = \frac{\sum_{j=1}^{k} \hat{p}_j}{k}, \]  

(4)

The estimator of \( j \)th sampling:

\[ \hat{I}_{D_j} = \frac{\hat{p}_j}{p_0} = \frac{m\hat{p}_j}{mp_0} = \frac{N_j}{U}, \]  

(5)

And average soldering quality index \( I_D \) for \( k \) samplings:

\[ \bar{I}_D = \frac{\sum_{j=1}^{k} \hat{I}_{D_j}}{k} = \frac{\sum_{j=1}^{k} N_j}{Uk}, \]  

(6)

Then expected value and variance of \( \bar{I}_D \) would be:

\[ E(\bar{I}_D) = \frac{\sum_{j=1}^{k} E(\hat{I}_{D_j})}{k} = \frac{\sum_{j=1}^{k} E(N_j)}{Uk} = \frac{kN}{Uk} = \frac{N}{U} = I_D, \]

(7)

\[ V(\bar{I}_D) = \frac{\sum_{j=1}^{k} V(\hat{I}_{D_j})}{k^2} = \frac{\sum_{j=1}^{k} V(N_j)}{k^2U^2} = \frac{N(1-N/m)k}{k^2U^2} = \frac{N(1-N/m)}{kU^2} = \frac{I_D(1-N/m)}{kU}, \]

(8)

Apparently, \( \bar{I}_D \) is the best Uniformly Minimum Variance Unbiased Estimator (UMVUE) of \( I_D \)
Let \( Z = \frac{\bar{I}_D - I_D}{\sqrt{I_D(1 - \frac{N}{m})/kU}}, \quad (9) \)

When sample size is large enough, then Central Limit Theorem shows that random variable \( Z \) would be approximate to a standardized normal distribution. For \( k \) sampling, and each value \( \hat{I}_{Dj} \) for each sampling \( j=1,2,\ldots k \), and \( \bar{I}_D \) is the average value of \( k \) samplings.

\[
\bar{I}_D = \frac{1}{k} \sum_{j=1}^{k} \hat{I}_{Dj} = w. \quad (10)
\]

According to \( \bar{I}_D = w \) then \( p\text{-value} = 1 - P(Z \leq \frac{w - v}{\sqrt{v(1 - \frac{N}{m})/kU}}) = 1 - \Phi(z) \)

\( \Phi \) is the Normal standardized cumulative distribution function. The rules for measurement will be defined as following:

1. \( p\text{-value} < 0.01 \) : it means that CMOS camera manufacturer has very significant not capable of soldering process, it should address on improving its previous process, find out the causes, and possible solution project for eliminating this dilemma should be proposed.
2. \( 0.01 \leq p\text{-value} < 0.05 \) : it means that CMOS camera manufacturer has significant not capable of soldering process, there is room for improving, it should revised its quality level to ideal target value.
3. \( p\text{-value} \geq 0.05 \) : it means that CMOS camera manufacturer has capable of soldering process, it is unnecessary to improve the process immediately, continuous monitor the process and keep the quality level of CMOS camera for its competition.

2.3 Analyze

In the step of analyze, Pareto chart and Cause & Effect Diagram are adopted to find out all possible causes. There is a summarized for test record of video response shown in Fig 2. Apparently, the vital portion of unacceptable quality performance comes into 68.7% (no response) of total defective units, and the second large portion comes into 27.2% (video unstable) of total defective units. The reasons for no video response are solder bridging between two joints, or insufficient solder. The defective crystal quartz or crack found on the CMOS unit also causes no video response in quality test. Poor manual touch up solder for power/ signal line, and poor connector work will cause video unstable.

Therefore, in order to improve the quality of camera, causes must be found out, this research had checked and reviewed 268 defective units from lots, and categorized four major rework types: 1.Manual touch up solder; 2.Replace power/video line 3.Replace quartz; 4.Replaces CMOS. And, 239 units (89.2%) belonged to type 1, Replacement material (power line and signal line, quartz, CMOS), occupies 29 units (10.8%), a rework record shown in Figure 3.
As a result, we find that bad soldering quality is the major cause of video response unstable, oscillation, and power intermittent. To explore all the potential causes that result in the bad soldering, and propose a possible solution to improve the quality level of CMOS cameras. A cause & effect Diagram shown in Fig.4 is adopted to find the potential causes, the size of printed circuit board is restricted according its design constrain which cause the soldering joints of components too close. The joints are too close to each other will be very complicated for operator; improper soldering process will come with short circuit, misalignment, pin hole, cold soldering, and uneven soldering. The project team spent time in elaborative brainstorm, the major reason of causing bad soldering process is manual touch up joints are too close to each other, then redesign or re-layout for the circuit board need to be carried out.

Fig 2 Test record of Video response  \hspace{1cm} Fig 3 Rework record for defective unit

**2.4 Design**

The size of complete circuit diagram shown in Fig.5 is limited, and it has to fit in a small space, and increase the size of board is not possible; therefore, a redesign for printed circuit board joints is performed shown in Fig 6. The manual touch up soldering joints designed for power and video signal purpose are replaced by a new connector shown in Fig. 7, the soldering joints will be soldered by automatic SMT machine.
2.5 Verify

30pcs of redesign units has been sampling for hypothesis test, the operator records each critical quality performance. Table 1 shows that only one unit is identified no video response caused by crack CMOS, and none of these is identified as video unstable or bad wire connection.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Types of Causes</th>
<th>Video response Test</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No response</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Video unstable</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Bad wire connection</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Since the original design research, we find most defective units are caused by bad soldering, then a hypothesis test is carried out for testing if defective rate is lower than the previous. Let \( p \) is the fraction about manual soldering joint rework counts to the total defect counts, then \( p_1 \) is defined as the rate for before redesign process, and it is 0.89 which is found in step of analyze; and \( p_2 \) is defined as the rate for after redesign process, and it is 0 which is found Table 1. Therefore, a hypothesis test is defined as:

\[
H_0 : p_1 \leq p_2 \quad \text{(Bad soldering rate not improve)}
\]

\[
H_1 : p_1 > p_2 \quad \text{(Bad soldering rate improve)}
\]

If \( z^* > z_{0.01} \), then reject \( H_0 \); and if \( z^* \leq z_{0.01} \), then do not reject \( H_0 \) where the critical value \( z_{0.01} = 2.326 \)

\[
z^* = \frac{(\hat{p}_1 - \hat{p}_2) - (p_1 - p_2)}{\sqrt{\frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2}}} = 4872.727
\]

The evidence shows there is significant improvement of bad soldering rate, the redesigning process which was proposed by the analysis result of practicing DMADV has improved the bad soldering rate, and reduced the cost of failure rate; efficiently enhance the quality of surveillance camera.

3.0 Conclusion

The research result shows soldering quality of printed circuit board is the key cause of unacceptable quality of surveillance camera quality, therefore, this research applies DMADV methodology of Six Sigma practice to improve quality of manual soldering process. To help the camera manufacturer to assess if soldering quality fall in between tolerance limits, this research proposed an index as soldering process quality evaluation model. Pareto chart, and Cause & Effect Diagram are adopted to find the major causes of poor quality, then process of redesigning the key component, and process will be conducted. The final verification and test had showed that DMADV methodology had reduced the bad soldering rate. This research may provide a solution of practicing DMADV, and then camera manufacturer could improve its product quality.

Reference


Authors’ Background

Mr. Tsang-Chuan Chang currently enrolled his second year of graduate school of Industrial Engineering and Management. His major interests are Statistics, Six Sigma management and Quality management.

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