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An application of DMADV methodology for increasing the yield rate of surveillance cameras

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ABSTRACT

Taiwan has officially been an "Aging society" since 1993, and a growing number of elderly people there cannot receive proper care from family members. Therefore, Taiwan's "long-distance home care services" have been classified as an emerging service industry. This industry rests mainly on information and telecommunications technology to overcome the barriers of distance and, thereby, to deliver health services. Surveillance cameras constitute important transmission equipment whose function is to provide real-time monitoring services; therefore, the quality and the efficiency of the camera adopted in the long-distance home care industry are important.

Some of Taiwan's domestic products occupy dominant positions in their respective global markets, and there are also many foreign competitors that have exhibited a formidable challenge to the prominent position of these Taiwan manufacturers. The production strategy for mature manufacturers under steep competition is to increase their quality and yield rate, steps that can prevent unnecessary waste. Some research has adopted Six Sigma to improve products' yield rates, and the results have been remarkable. In this research, the DMADV methodology will be implemented for improving the quality of surveillance cameras and for diminishing related excess costs.

1. Introduction

Motorola implemented Six Sigma companywide between 1987 and 1997, and this practice has helped the company's stock price to grow by more than 21% every year, and the company has also recorded savings as high as US$17 billion. Snee and Roger [1] provided a step-by-step approach to the management of the overall Six Sigma process, not just of individual projects. This approach provides more detailed and more specific advice on how to actually deploy Six Sigma than is available anywhere else in the market. The approach focuses on practical managerial advice. Antony et al. [2] found that linking Six Sigma to customers and linking Six Sigma to business strategy are the most critical factors for the successful deployment of Six Sigma in UK SMEs. Linderman et al. [3] pointed out that Six Sigma can apply to the processes of making goods, executive management, business trade, and service. The dual characteristic of combining statistics and management explains why Six Sigma is more than quality control. Pyzdek [4] provides dozens of project management tools for each step of the DMAIC process, and the corresponding step-by-step guidelines help in project management. Ham and Lee [5] proposed MAIC methodology for process improvement, Michael [6] described the process of DMAIC, and Motorola University developed a DMADV framework within DFSS.

There are also case studies and other research about Six Sigma practices in Taiwan. Chen et al. [7] adopted DMAIC, integrating it into TFT-LCD Panel Quality Improvement. Chang et al. [8] implemented DMADV to improve quality of product; Cheng [9] implemented DMADV to improve the assembly efficiency of military products. Chen et al. [10] applied Six Sigma methodology in constructing the quick response of 911 case-reporting systems. It is also noteworthy that the DMAIC process has served to improve response-time intervals, case-solving times, and case-solving rates,

The population of seniors in Taiwan has caught up with the corresponding population levels characteristic of developed countries around the world. These levels are associated with many kinds of social problems that concern, for example, social welfare, medical care, and social security issues and that have attracted considerable attention from governments. Since more and more seniors need proper full-time attendance, medical-care service providers remotely monitor seniors' daily activities with surveillance cameras that are equipped with internet or wireless telecommunication technology; furthermore, the proper recording of video signals can allow for necessary review.

This research will use two of seven basic quality-improvement tools, a Pareto chart and a cause and effect diagram, to identify primary causes, and proposes a quality-performance index to measure soldering-defect rates. As soon as the primary causes have

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been identified, this research shall redesign key components or shall undertake process improvements therein. Through repeated testing and verification, this research follows Six Sigma systematic practices in order to efficiently reduce defect rates and to improve quality levels.

Soldering defects will occur in manual-soldering processes and in automatic surface mounting (SMT), machine setup, operator negligence, improper soldering time, and improper soldering temperature. Types of soldering defects include short circuits, missing items, wrong items, cold soldering, insufficient soldering, wrong polarity, inaccurate positioning, and circuit-board distortion. Some of these defects can undermine the proper operation of other components. In the context of surveillance cameras, the entire product featuring such defects will be identified as a poor-quality product.

Fig. 1 presents a brief description of the surveillance-camera manufacturing process. In the description, we find that quality issues arise in the surface-mounting process and the manual-soldering process. A poor-quality assembly process will cause a high scale of variability in the post-assembly process, resulting in such problems as an absence of video or the presence of video instability. To identify the possible assembly-process causes of these problems, and to redesign a new layout, the current study has implemented the Six Sigma DMADV methodology for process improvement in upgrading surveillance-camera quality. The implementation procedures are as follows:

Define: The goal of this research is to upgrade the quality of surveillance cameras, to reduce defect rates, and to minimize the cost of quality insurance.

Measure: This research will measure and identify any relevant CTQ (Critical to Quality) factors for surveillance-camera quality, will develop an index of soldering-process

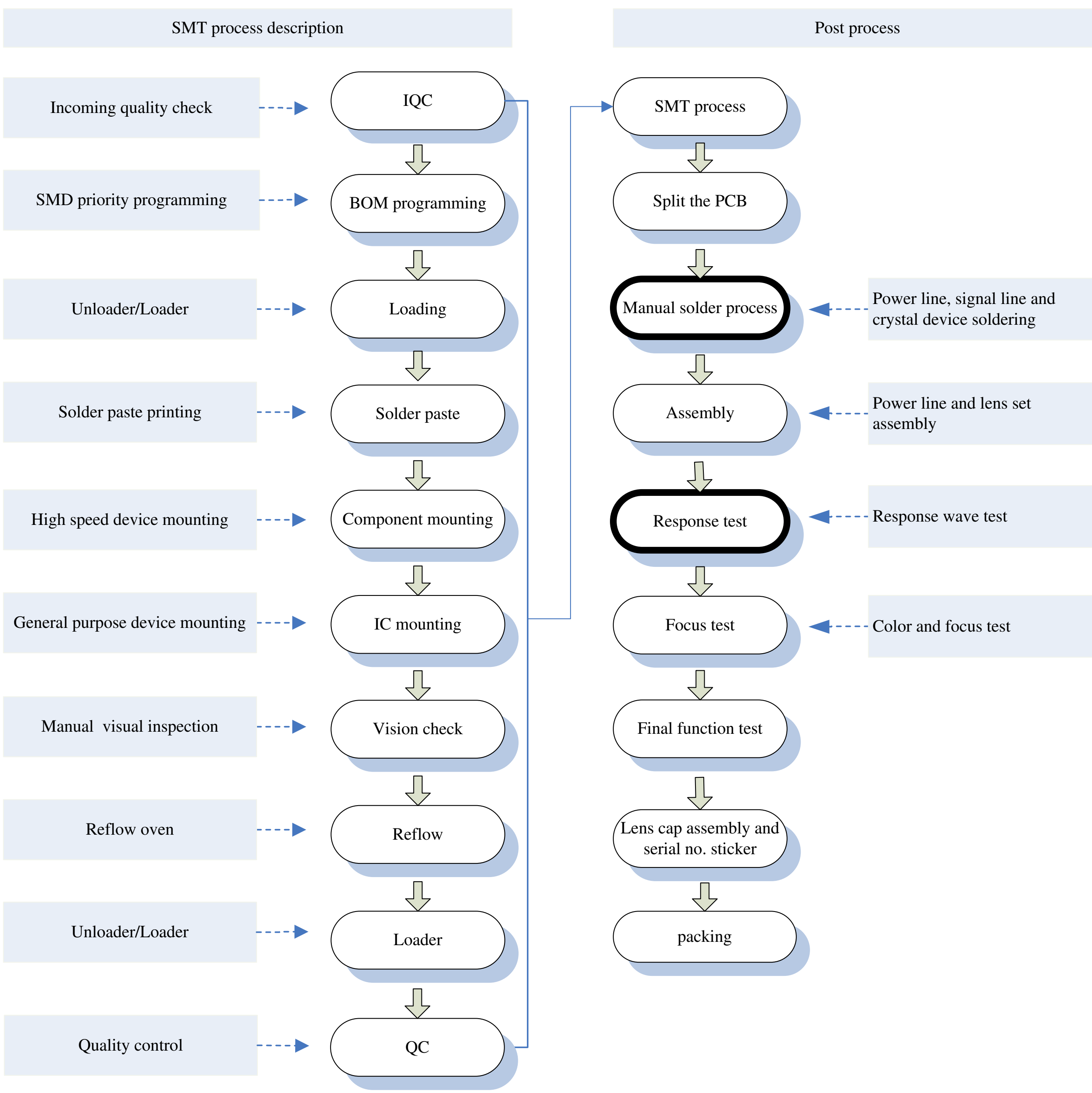

Fig. 1. The flow diagram of the SMT process for surveillance cameras.

failure rates as an assessment model, and will then estimate quality levels of the soldering process according to a statistical hypothesis test.

Analyze: This research uses the Pareto chart and a Cause and Effect diagram to analyze possible causes of problems

Design: This research is an attempt to rectify or to eliminate causes of problems by analyzing and redesigning key components or processes.

Verify: This research serves to verify the new design of new components, to prove the presence of improvements according to a hypothesis test, and to efficiently reduce failure rates of surveillance cameras.

2. Methodology

2.1. Define

The define step revealed that surveillance-camera quality was a concern to the manufacturer, that the rework data showed a high percentage of defective units coming from the assembly process, and that the rework records attributed most of the rework to poor soldering of joints. Therefore, this research will focus on the quality levels of the soldering process. The poorly soldered joints may be caused by manual or SMT automatic soldering processes, machine setup, manual negligence, or improper solder temperature setup. Poorly soldered joints can compromise the entire camera by creating an unstable picture or no picture at all.

2.2. A measurement model defined for poor-soldering processes

There are m pieces of identical and small printed circuit boards forming a complete printed circuit board. The soldering failure rate will be defined as follows:

$$p = \frac{N}{m}, \tag{1}$$

where N is the number of small printed circuit boards, and each of these has at least one identified poorly soldered joint. The value of p_0 is the upper acceptable limit of the soldering-defect rate: the manufacturer could define p_0 by itself, and it should be equal to or smaller than the customers' limit. The value of U is the acceptable "soldered-joint defect" count limit with the upper acceptable limit of p_0. Therefore, the soldering quality index I_D is defined:

$$I_D = \frac{p}{p_0} = \frac{mp}{mp_0} = \frac{N}{U}, \tag{2}$$

A soldering quality index I_D would be defined accordingly: when $I_D < 1$, the soldering-defect rate has not reached its limit; when $I_D = 1$, soldering-defect rate is at its limit; when $I_D > 1$ the soldering-defect rate has exceeded the maximum limit. Therefore, the value of I_D is smaller than 1, the soldering process has been carried out correctly, and the quality level of the soldering process will be relatively good. If there is an upper limit v (where $0 < v < 1$) for I_D, then the hypothesis test would be defined thus:

H_0: $I_D \leqslant v$ (Quality for soldering process is good).
H_1: $I_D > v$ (Quality for soldering process is poor).

If the test approves the null hypothesis, then the quality level of the soldering process meets the requirements; otherwise, the quality level of the soldering process has failed to meet the requirement. A poor-soldering rate for jth sampling is defined as p_j, and its estimator is

$$\hat{p}_j = \frac{N_j}{m} \tag{3}$$

where $N_j \sim B(m,p)$, so let $j = 1, 2, \ldots, k$ represent k samplings that have been collected, the average poor-soldering rate is

$$\bar{p} = \frac{\sum_{j=1}^{k} \hat{p}_j}{k} \tag{4}$$

The estimator of jth sampling is

$$\hat{I}_{D_j} = \frac{\hat{p}_j}{p_0} = \frac{m\hat{p}_j}{mp_0} = \frac{N_j}{U} \tag{5}$$

And the average soldering quality index I_D for k samplings is

$$\bar{\hat{I}}_D = \frac{\sum_{j=1}^{k} \hat{I}_{D_j}}{k} = \frac{\sum_{j=1}^{k} N_j}{Uk} \tag{6}$$

Then, the expected value and variance of $\bar{\hat{I}}_D$ would be

$$E(\bar{\hat{I}}_D) = \frac{\sum_{j=1}^{k} E(\hat{I}_{D_j})}{k} = \frac{N}{U} = I_D, \tag{7}$$

$$V(\bar{\hat{I}}_D) = \frac{\sum_{j=1}^{k} V(\hat{I}_{D_j})}{k^2} = \frac{I_D(1-\frac{N}{m})}{kU}. \tag{8}$$

Apparently, $\bar{\hat{I}}_D$ is the best Uniformly Minimum Variance Unbiased Estimator (UMVUE) of I_D

Let

$$Z = \frac{\bar{\hat{I}}_D - I_D}{\sqrt{\frac{I_D\left(1-\frac{N}{m}\right)}{kU}}}. \tag{9}$$

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

Suppose

$$\bar{\hat{I}}_D = \frac{\sum_{j=1}^{k} \hat{I}_{D_j}}{k} = w. \tag{10}$$

According to $\bar{\hat{I}}_D = w$, then $p\text{-}value = P(\bar{\hat{I}}_D \geqslant w | I_D = v)$

$$= 1 - P\left(Z^* \leqslant \frac{w - v}{\sqrt{\frac{v(1-\frac{N}{m})}{kU}}}\right) = 1 - \Phi(z) \tag{11}$$

where $\Phi(z)$ is the cumulative distribution function of the standard normal distribution. A table of the p-value is given in Appendix. The flowchart shown in Fig. 2 is designated for the measurement process.

The rules for measurement will be defined as follows:

1. *p-Value* < 0.01: This inequality means that the surveillance-camera manufacturer has very significant soldering-process problems and that the manufacturer should address them by identifying the causes, and by proposing a possible solution.
2. $0.01 \leqslant$ *p-Value* < 0.05: These inequalities mean that the surveillance-camera manufacturer has significant soldering-process problems, that there is room for improvement, and that the manufacturer should revise its quality level up toward an ideal target value.
3. *p-Value* $\geqslant 0.05$: This inequality means that the surveillance-camera manufacturer has a capable soldering process, that there is no need to improve the process immediately, and that

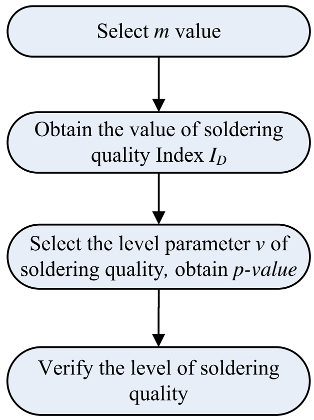

Fig. 2. Flowchart for measurement.

the manufacturer should continuously monitor the process and should preserve the high surveillance-camera quality levels for competition purposes.

Table 1 presents the $\hat{p}_j$ and poor-soldering counts N_j of the previous 100 pieces of complete printed circuit boards. With these data sets, we would like to validate the quality of the soldered joints within the following parameters: $m = 28$, $p_0 = 0.02$, and $v = 0.5$.

Table 1 presents the following information: $\bar{p} = 0.085357$, $\bar{\hat{I}}_D = 8.535714$, and $z = 62.87$ can be obtained from Eq. (9). Since $z = 62.87$, we can find that the p-value < 0.001. This finding shows that the surveillance-camera manufacturer has very significant soldering-process problems, and that the manufacturer should address them by identifying the causes and by proposing a possible solution.

Table 1
$\hat{p}_j$ and poor-soldering counts N_j of 100 units of complete PCBs.

PCB no.	N_j	$\hat{p}_j$	$\hat{I}_{D_j}$	PCB no.	N_j	p_j	$\hat{I}_{D_j}$
1	2	0.071429	7.142857	51	0	0	0
2	0	0	0	52	3	0.107143	10.71429
3	3	0.107143	10.71429	53	4	0.142857	14.28571
4	2	0.071429	7.142857	54	4	0.142857	14.28571
5	4	0.142857	14.28571	55	2	0.071429	7.142857
6	1	0.035714	3.571429	56	2	0.071429	7.142857
7	5	0.178571	17.85714	57	4	0.142857	14.28571
8	2	0.071429	7.142857	58	2	0.071429	7.142857
9	1	0.035714	3.571429	59	5	0.178571	17.85714
10	4	0.142857	14.28571	60	0	0	0
11	4	0.142857	14.28571	61	5	0.178571	17.85714
12	2	0.071429	7.142857	62	2	0.071429	7.142857
13	4	0.142857	14.28571	63	2	0.071429	7.142857
14	3	0.107143	10.71429	64	1	0.035714	3.571429
15	2	0.071429	7.142857	65	0	0	0
16	3	0.107143	10.71429	66	4	0.142857	14.28571
17	3	0.107143	10.71429	67	2	0.071429	7.142857
18	3	0.107143	10.71429	68	3	0.107143	10.71429
19	3	0.107143	10.71429	69	5	0.178571	17.85714
20	4	0.142857	14.28571	70	5	0.178571	17.85714
21	3	0.107143	10.71429	71	1	0.035714	3.571429
22	1	0.035714	3.571429	72	2	0.071429	7.142857
23	4	0.142857	14.28571	73	5	0.178571	17.85714
24	0	0	0	74	1	0.035714	3.571429
25	4	0.142857	14.28571	75	3	0.107143	10.71429
26	2	0.071429	7.142857	76	4	0.142857	14.28571
27	5	0.178571	17.85714	77	2	0.071429	7.142857
28	2	0.071429	7.142857	78	1	0.035714	3.571429
29	0	0	0	79	5	0.178571	17.85714
30	3	0.107143	10.71429	80	0	0	0
31	0	0	0	81	3	0.107143	10.71429
32	4	0.142857	14.28571	82	4	0.142857	14.28571
33	0	0	0	83	1	0.035714	3.571429
34	2	0.071429	7.142857	84	2	0.071429	7.142857
35	2	0.071429	7.142857	85	3	0.107143	10.71429
36	2	0.071429	7.142857	86	2	0.071429	7.142857
37	5	0.178571	17.85714	87	1	0.035714	3.571429
38	1	0.035714	3.571429	88	1	0.035714	3.571429
39	1	0.035714	3.571429	89	2	0.071429	7.142857
40	2	0.071429	7.142857	90	0	0	0
41	0	0	0	91	3	0.107143	10.71429
42	2	0.071429	7.142857	92	3	0.107143	10.71429
43	3	0.107143	10.71429	93	2	0.071429	7.142857
44	1	0.035714	3.571429	94	5	0.178571	17.85714
45	4	0.142857	14.28571	95	0	0	0
46	0	0	0	96	1	0.035714	3.571429
47	1	0.035714	3.571429	97	0	0	0
48	2	0.071429	7.142857	98	5	0.178571	17.85714
49	4	0.142857	14.28571	99	2	0.071429	7.142857
50	4	0.142857	14.28571	100	1	0.035714	3.571429

2.3. Analyze

In the analysis step, we used the Pareto chart and a cause and effect diagram to identify all possible causes of the problems. Fig. 3 summarizes the test records of the video responses. Apparently, the "no response" problem accounts for 68.7% of the defective units, and the "unstable video" problem accounts for 27.2% of the defective units. The reasons for the absence of a video response are solder bridging between two joints, insufficient soldering, and defective crystal quartz or cracks found on the surveillance units. Poor manual touch-up soldering for power/signal lines, and poor connector work will cause video instability.

Therefore, in order to improve the quality of these cameras, we checked and reviewed 268 defective units, and we categorized four major rework types: manual touch-up soldering, replacement of power/video line, replacement of crystal quartz, and "other." And we noted that 239 units (89.2%) needed to undergo manual touch-up soldering rework, specifically regarding components of the balance (29 units, 10.8%). These components include power lines, signal lines, quartz, and lens sets, which typically needed to be replaced.

We found that poor soldering quality was the major cause of unstable video response, oscillation, and intermittent power. To explore all the potential causes of the poor soldering, and to propose a possible solution to the unacceptable quality levels of the surveillance cameras, we had to take specific steps. First, we adopted a cause and effect diagram (shown in Fig. 4) to undertake this task, and we found that the size of the printed circuit board was restricted according to design constraints, which caused the components' soldered joints to be too close to one another. This

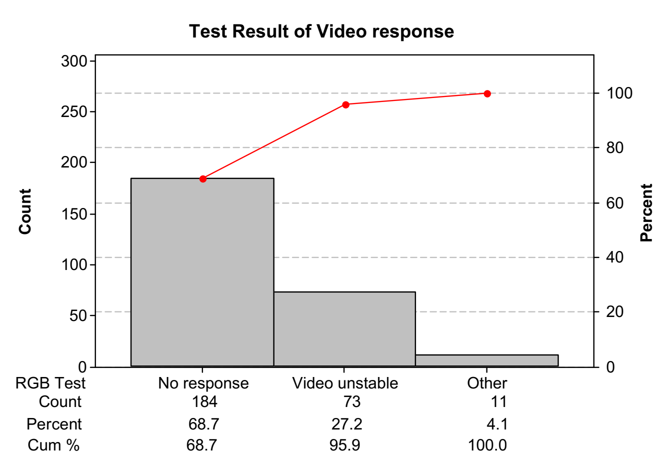

Fig. 3. Test record of video response.

closeness, in turn, severely complicated operations insofar as the improper soldering process could trigger short circuits, misalignment, pin holes, cold soldering, and uneven soldering. The project team, thus, brainstormed, identified the major reason for the poor soldering (i.e., the reason being the close proximity of manually touched up joints), and then re-designed or created a new layout for the circuit board.

2.4. Design

The result of the analysis shows that poor soldering quality was the main cause of poor signal response, and the study also found that both the poor design of the manually soldered pads and the poor circuit layout in the printed circuit board led to poor soldering quality. The signal response, which is the most vital characteristic of a surveillance camera, therefore needed to undergo a redesign regarding the locations of both the soldering pads and the circuits. These were the two main necessary improvements. The previous design of the electronic circuits was stabilized, and the size of the printed circuit board was reduced according to the shape of the complete product and of all components; therefore, it was hardly necessary to increase the size of the printed circuit board. After holding a cross-department meeting, the printed circuit board itself needed to be re-designed with a smaller size.

Another major design-process task was the re-layout or rearrangement of the manually soldered pads located in the printed circuit board. With the help of Surface Mount Technology, the manually soldered pads for power cords and for signal lines would be re-designed; moreover, an L-shaped connector (shown in Fig. 5) would replace the manually soldered pads. By avoiding the manually soldered pads, we eliminated the improper manual-soldering process and the quality of the soldering improved.

The re-designed flow chart is shown in Fig. 6, The size of printed circuit board is limited by customers which lead to difficulty in the manufacturing process and, eventually, to unstable signal responses. Therefore, this design process proposed a redesign of the printed circuit board: the redesign emphasized that printed circuit board should have a limited size.

The size of the circuit diagram is limited, the printed circuit board (PCB) has to fit in a small space, and increasing the size of the board is not possible; therefore, a redesign for the printed circuit board was performed (shown in Fig. 7).

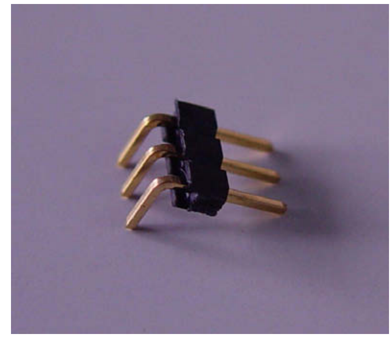

Fig. 5. New L-shaped connector.

A new connector replaced the manually soldered pads designed for power and video-signal purposes. One end of the new connector would fit into the newly designed circuit board; the other end would couple with the secured signal-power connector. The poor soldering quality caused by manually soldered pads was corrected by the new connector, and the error caused by the wiring mismatch was eliminated too.

2.5. Verify

There were 616 re-designed units in the sample for this study's hypothesis test, and the operator recorded each critical-quality performance. Table 2 shows that only one unit exhibited no video response (caused by a cracked CMOS unit) and that no unit exhibited either unstable video or mismatched wires. Therefore, the improvement of the printed circuit board with a new L-shaped connector effectively reduced the occurrence of poor soldering. Table 3 presents the poor-soldering counts for the previous layout and the redesign.

We found that poor soldering caused most of the defective units, which need "manual touch-up soldering" rework to be performed. We then tested a hypothesis to determine whether the defect rate of re-designed PCB would be lower than the defect rate of previous PCB. Let p be the ratio of "manual touch-up soldering" rework count to the total defect count, and then let p_1 be the ratio for previous PCB, p_2 as the ratio for re-designed PCB. From Table 3, we can obtain the defective ratio (p_1) of manually soldered joint for

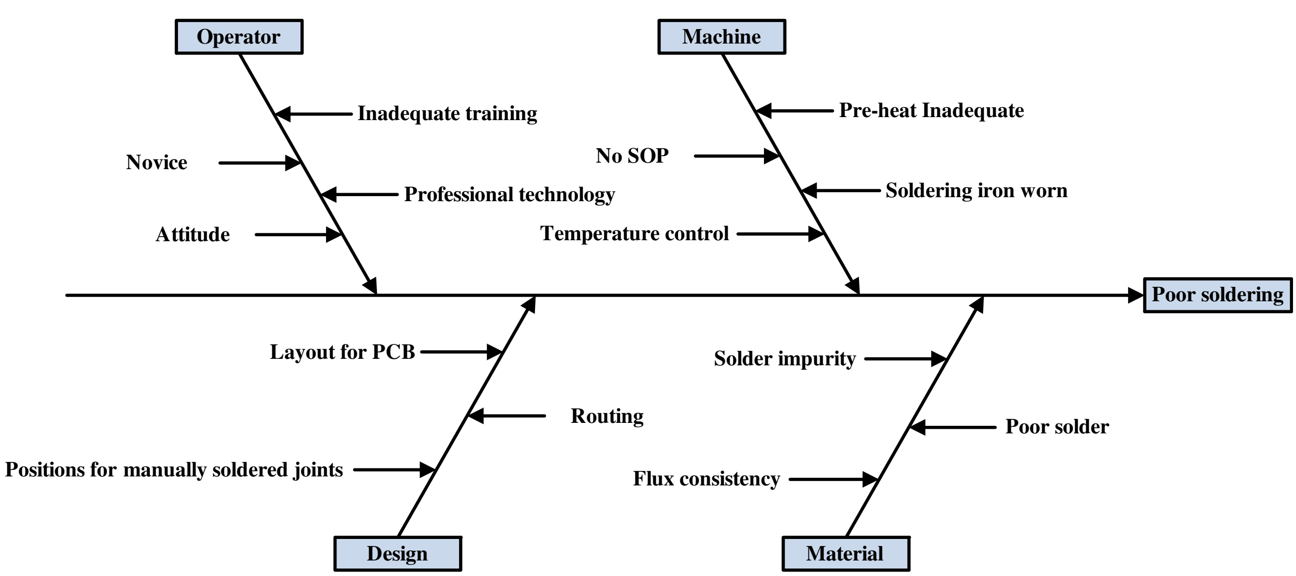

Fig. 4. Cause and effect diagram for poor soldering.

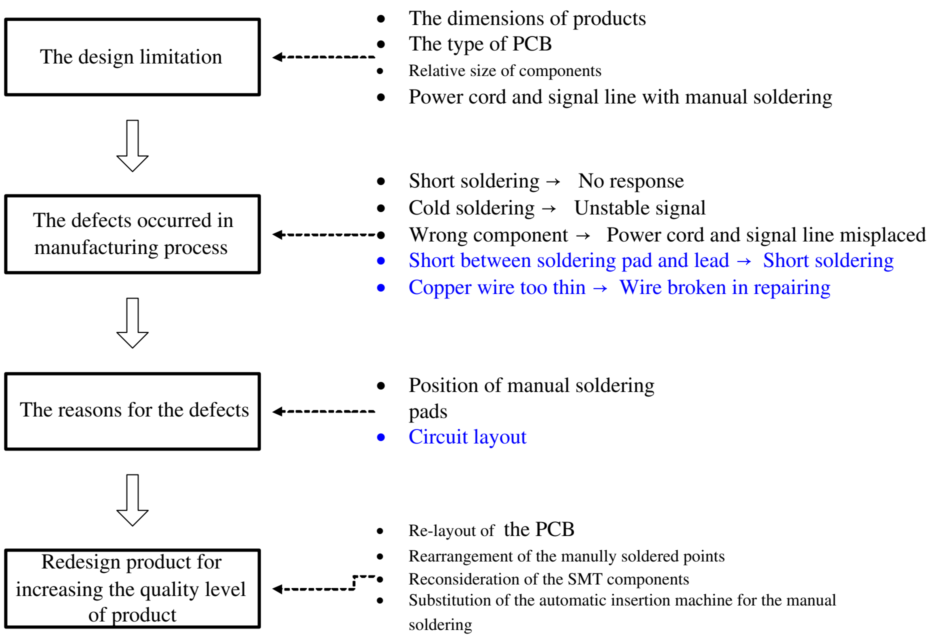

Fig. 6. Design process.

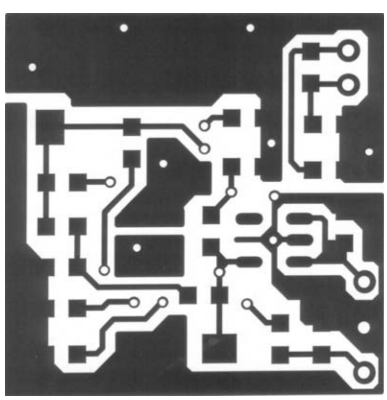

Fig. 7. Redesigned printed circuit board layout.

Table 2
Video-response test results with re-designed PCB.

Types of causes	Operation: Video-response test	Count
1	No response	21
2	Video unstable	5
3	Bad wire connection	6
Total		32

Table 3
Poor-soldering counts for the previous PCB layout and the re-designed PCB layout.

Rework type	Previous PCB layout		Re-designed PCB layout	
	Count	Percentage	Count	Percentage
Manual touch-up soldering	239	89.2	0	0
CMOS IC change	12	4.5	23	71.9
Quartz change	9	3.4	3	9.4
Lens set change	8	3	6	18.7
Total	268	100	32	100

previous PCB design is 0.89, and the defective ratio (p_2) of manually soldered joint for re-designed PCB design is 0. Therefore, we defined our hypothesis test as follows:

H_0: $p_1 \leqslant p_2$ (no improvement in poor-soldering rates).
H_1: $p_1 > p_2$ (improvements in poor-soldering rates).

if $Z^* > Z_{0.01}$, then reject H_0; and if $Z^* < Z_{0.01}$, then do not reject H_0 where the critical value $z_{0.01} = 2.326$. We can obtain Z^* from Table 3:

$$Z^* = \frac{\hat{p}_1 - \hat{p}_2}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} = 11.82.$$

Because $Z^* > Z_{0.01}$, then we conclude that H_1 is accepted.

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. Conclusion

The research findings show that the soldering quality of printed circuit boards was the key cause of unacceptable surveillance-camera quality; therefore, this research has used DMADV methodology of Six Sigma practices to improve the manual-soldering process. To help the camera manufacturer to assess whether or not the soldering quality fell within tolerance limits, this research proposed an index as a model for "soldering-process quality" evaluations. We adopted the Pareto chart and a cause and effect diagram to identify the major causes of poor quality, and we then re-designed the key components. The final verification and test shows that DMADV methodology reduced the poor-soldering rate. This research should provide insights into practicing DMADV so that surveillance-camera manufacturers can improve the quality of their products.

Acknowledgement

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