Research on Increasing the Production Yield Rate by Six Sigma Method : A Case of SMT Process of Main Board

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Abstract

Face the process yield rate improvements of motherboard, although general enterprises finish deployment goal of each functions by overall quality managements, through quality improvement methods, industry engineering methods, plan-do-check-act (PDCA) methods and other improvement solutions, but it is only can be improved partially and unable to enhance the yield rate of product to the target. It only can takes one step ahead to enhance the process yield rate of motherboard with six sigma (6 σ) overall DMAIC process and tactics. This research aimed to use six sigma quality improvement tactics by DMAIC systematic procedure and tactics, and find the key factors that effect to the process yield rate of surface mount technology. It also identified the keys input and process and output index to satisfy customer requirements and internal process index. The results showed that the major effective factors by fishbone and process failure modes and effects analysis (PFMEA). If the index of input and output that can be quantified, the optimum parameter can be found through design of experiment to ensure that the process is stable. If the factor of input and output that cannot be quantified, we found out the effective countermeasure by Mind_Mapping, make sure whole processes can be controlled stably, to reach the high product quality and enhance the customer satisfaction.

Key Words: Six Sigma (6 σ), Surface Mount, Yield Rate, Process Failure Modes and Effects Analysis

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1. Introduction

In the highly competitive environment of information industry for reserving the competitive advantage, each major industry separates the brand and manufacture independently, so that the operation of brand and channel is more flexible and has more advantages. Professional Original Equipment Manufacturer (OEM) can have a mutual optimum effect through operating with large quantity and low-cost products. Laptop is the hardware product with most growth potential in the field of Information technology (IT). With the improvement of functions and the decline in prices, it replaces of desktop rapidly. Except that Japanese manufacturers still insist on manufacturing partial laptops by themselves, other manufacturers commission Taiwan's OEM to manufacture laptops. In 2006, the shipment of laptop manufactured in Taiwan accounted for about 80% that of the world, Taiwan's enterprises basically monopolized the laptop OEM. In the face of cost pressures, Taiwan's enterprises relocate their laptop OEM operations to the east of China mainland. The production facilities of Quanta and Inventec are located in Shanghai and those of Compal and Wistron are set in Kunshan, and ASUS in Suzhou. In this fiercely competitive environment, only through the enhancement of production capacity and yield rate to reduce costs, the comprehensive competitiveness of enterprises can be enhanced. In order to resolve this problem, enterprises must start from the design of front-end product first, and then rely on the good manufacturing technology of back-end products, to play a competitive role. The solutions to solve problems related to production and upgrade manufacturing technology are a lot, such as Quality Control Circle (QCC), Total Quality Management (TQM), design of experiments, Process Failure Modes and Effects Analysis (PFMEA) and Six Sigma (6 Sigma, 6 σ) method, among them, the Six Sigma can effectively enhance the overall capacity of the process with a systemic and comprehensive approach, so it is the most effective method of improvement.

In order to fight for the orders from famous international factories, Laptop OEM enterprises use low-price strategy one after another, resulting in the gradual decline in operating gross profit. In this competitive environment, OEM can only advance the product quality and reliability, meet the needs of customers and enhance the competitiveness of enterprises through improving internal flows and processes. In the face of customers' requirement for product quality, as well as the requirements from cost decline in competitive environment, the project management team is committed to improve the existing production process, although there are significantly improvements, it has reached a bottleneck, which can not achieve the best overall process capability. As to the product quality improvement, despite the functions are targeted in total quality management through quality control practices, IE tactics, Plan-Do-Check-Act (PDCA) tactics and various improvement measures, the yield rate of product still cannot be increased to the goal. Of course, design of experiments is also considered to find ways to improve, based on the relationship of quality characteristics and factors; it can only find the best parameter combination to get the best quality properties through the experimental method. Only 6 Sigma can improve product quality comprehensively with a systematic DMAIC process and tactic. It starts from key customer needs and internal process needs, set the key quality index and key process index, and clarify the definitions of key input, process and output index, then identify the important factors through Cause and Effect Diagram and PFMEA. For the quantifiable input, output index, find the best process parameter to achieve stable process through experimental design; for the other affecting factors can not be quantified, find the effective countermeasure through Mind_Mapping to control the whole process stably, reaching a high level of product quality to enhance customer satisfaction.

With regard to the purpose of this study, under the premise of meeting customer requirements and internal process index, it used quality improvement method of 6 σ to identify the key factors for yield rate in SMT process of main board, as well as the best parameter combination with the systematic approach, so as to enhance process yield rate and customer satisfaction.

2. Literature Review

2.1 Total Quality Management (TQM)

Dr. Feigenbau (Armand V. Feigenbau), U.S. world-class quality control master, in the book of "Total Quality Control", divided the development of TQC into six stages: (1) the first stage: before 1900, the times of quality control belong to the operators, from the selection of raw materials, manufacture, the ultimate test of product were all completed by the workers, the quality relied on inspection. (2) The second stage: from early 1900 to 1920, it belonged to the times of quality control by foreman. He managed the production and monitored the workers' working; the quality relied on the inspection under the foreman's supervision. (3) The third stage: from 1920 to 1940, as the production system became complex and output was relatively raised, there began to have a full-time QC to inspect all the products, the quality still relied on the inspection. In 1924, WA Shewhart developed a set of statistical control chart for product qualitative variability. At this stage, Dodge and Roming (1986) also developed a set of acceptance standard for sampling inspection replace of fully inspection. (4) The fourth stage: from 1940 to 1960, the quality control gradually broke away from the manufacturing units to become an independent department. W.A. Shewhart's control chart and the sample inspection of Dodge and Roming have been widely used in the production industry. As statistical quality control, online sample tests and monitoring with control chart were used to correct abnormity, the quality at this stage depended on manufacture.

American Society for Control was established in 1946; W. Edwards Deming arrived in Japan to lecture statistical methods in 1950; in 1960, Japan promoted the Quality Control Circle for the purpose of improving quality, and seven tactics of QC were also implemented. (5) The fifth stage: from 1960 to 1980, in the early stages of this 10 years, the product quality could not be improved completely relying on the quality inspection system, so the quality assurance system was set to strengthen the inspection of finished product at the last of process, so as to ensure that the unqualified products were detected in the factory and not be in the hands of customers. In addition, the Incoming Quality Control was extended to quality management during product design, emphasized that quality relied on design. In the late decade of this stage, Dr. Feigenbau promoted the theory of Total Quality Control (TQC), the scope of statistical process control was expanded to design quality management, supplier quality management, product reliability control. (6) The sixth stage: after 1980, TQC concept was rampant. In the United States, Malcolm Baldrige National Quality Award was established to become the standard to judge the effectiveness of TQM implementation. Additionally, Dr. Genichi Taguchi's experimental design method was affirmed to be an effective tool for improving the quality. In the 1990s, as a result of implementing TQM, the U.S. automobile industry emphasized the idea of improving the quality endlessly, so the customer satisfaction was improved continuously. In 1984, ISO introduced ISO 9000 quality management and quality assurance systems in Europe. In 1990, ISO 9000 became the standard of international quality assurance system; the requirements of this standard were come from the ideas in total management.

Deming (1982, 1986) summed up his philosophy of quality improvement, proposing 14 pieces of management theory to improve the quality and productivity, which are recognized as one of the important philosophies of TQM. TQM applies statistical methods and human resources to establish a continuous improving organization, so as to obtain a comprehensive competitive advantage, improve each resource, process in the organization and meet customer demands. TQM has a complete set of guiding principle and philosophy as a base to improve organization continuously. It uses measurement methods and human resources to improve all activity processes in the enterprise organizations, so as to go beyond the present and future demands from customers. TQM is aimed at providing the products with customer satisfaction, based on this to achieve high productivity, reduce costs and improve product quality, and then remain unbeaten in the highly competitive market.

2.2 Six Sigma

Motorola Company was founded in 1928. From the 1970s, it met with the quality and price competitive threats from Japanese manufacturers; its market share was lost gradually. Till the mid-1980s, in order to reduce customers' complaints about unqualified products, the

QC department put forward the process quality control strategy of Six Sigma. In this strategy, each employee is called for understanding his own process, using various statistical tools to continuously pursue improvement. The success in Motorola made the process quality control strategy of Six Sigma become the best method of process improvement in manufacturing industry. In 1994, Larry Bossidy (former vice chairman of General Electric), board chairman of Allied Signal, promoted and implemented the 6σ plan in the company. In 1995, Jack Welch, board chairman in General Electric Company (GE), accepted Bossidy's view and also decided to implement 6σ plan, determined to pay full attention to quality. Till 1998, fund saved by implementing Six Sigma project was more than 750 million USD, which was over the investment costs of GE. Because of the brilliant achievements from Six Sigma in GE Company, it thus draws the attention of the world's leading enterprises to follow.

2.2.1 Definition of Six Sigma

6σ in English is read “Six Sigma”; σ is a symbol of Statistics, it symbolizes the process observed or variation degree of product. When σ value is greater, the degree of variation is greater. σ can measure the level of quality, the higher the level is, the lower the probability of shortcoming generated is. 6σ symbolizes the long-term process capacity less than 3.4 defects per million. Eckes (2002) thought that Six Sigma was a management philosophy; its goal was to improve customer satisfaction by improving the culture of process, to reach a higher level of customer satisfaction. Mast (2003) considered that Six Sigma was a customer-oriented method, which emphasized on the basis for decision-making with quantitative methods and priority for saving money. Blakeslee (1999) explained the Six Sigma's definition from the statistics, business operation and operating process. Hahn *et al.* (1999) figured the concept of Six Sigma Quality in short, that was under the quality level with Six Sigma, the shortcomings or failure should not exceed 3.4ppm. Pande *et al.* (2001) defined “Six Sigma” in three aspects: (1) statistical measurement to the process, service or product performance: Six Sigma was taken as the first step to measure the standard, which was to identify customers' real expectations, it also was the Critical to Quality (CTQ), and then measure the process according to the key demands; (2) Near-perfect performance index: Six Sigma is committed to reducing the possibility of failure, there were only 3 or 4 failures per million operations, and the performance close to zero-failure was regarded as the objective of the enterprise; (3) Performance management system for sustainable business: in the spirit of Six Sigma, the quality doesn't rely on inspection, but the design and manufacture. The real purpose is to eliminate potential costs, create customer value and enhance enterprise competitiveness through the improvement activities of Six Sigma and together with the company strategy and guideline. Snee and Hoerl (2003) proposed the implementation steps of Six Sigma include: (1) Carry out project activities of Six Sigma; (2) Manage the project effectiveness of Six Sigma; (3) Maintain and measure the effectiveness of Six Sigma; (4)

Make the Six Sigma become the corporate culture. Lynch *et al.* (2003) pointed out the five major steps to achieve Six Sigma: the Define, Measure, Analyze, Improve and Control. Slater (2000) revised the General Electric's steps of implementing Six Sigma: (1) Measurement: measure each operational procedure and process; (2) Analysis: analyze each operational procedure and process; (3) Improvement: make efforts to improve each operational procedure and process; (4) Control: Once these operational procedure and process have been improved, strictly control them to maintain. Mach and Guagueta (2001) proposed the DMAIC problem-solving mode of well-known enterprise Motorola implementing Six Sigma: (1) Define: confirm the core processes and customer demands to set goals; (2) Measure: validate problem and process to measure the key steps and inputs; (3) Analyze: develop the assumptions of cause and effect to confirm the root of some key issues and validate assumptions; (4) Improve: trying to eradicate the problem; test the solutions, standardize the solutions and measure the results; (5) Control: establish the measurement standards to maintain the effectiveness and correct the problem if necessary. In this study, the five major steps of implementing Six Five proposed by Lynch *et al.* (2003) were used: Define, Measure, Analyze, Improve, Control, so as to improve the company's process.

2.2.2 Strategy of Six Sigma

1. The critical success factors of Taiwan enterprises promoting Six Sigma: According to 21 business cases of implementing Six Sigma in Taiwan interviewed by Chen (2002), nine critical success factors of promoting Six Sigma were proposed in this study: (1) the actual participant of high-level executives; (2) Project Review System; (3) appropriate pressure on the project contractors; (4) Necessary support and promise to the contractor from the Project Review System; (5) Regular meetings between Master Black Belt and Black Belt or Belt Green; (6) All staff in the organization should understand what is Six Sigma; (7) Regularly track the cumulative results of the project; (8) The importance of the project is determined by the figure; (9) Regularly bring the award activities into the open.
2. The critical success factors of General Electric implementing the Six Sigma: According to Slater's The GE Way Field Book: Jack Welch's Battle Plan for Corporate Revolution (2000), there were ten critical success factors of General Electric implementing Six Sigma: (1) develop the plan; (2) Active participation of high-level executives; (3) Selection of special case; (4) Project Review Mechanism; (5) Track of project; (6) Set fighter class and support each other; (7) Actively involved in training; (8) Promotions and communications; (9) Incentive Measures; (10) Develop supplier program.

2.2.3 Improving steps of Six Sigma

During the implementation of Six Sigma in enterprises, the most common set is the one with five steps of improvement orderly, also known as DMAIC, which contains Define, Measure, Analyze, Improve and Control. The description of the steps is below: (1) Define: define the necessary conditions for high-quality, the necessary conditions which make the customers satisfy with a product or transaction process. That is, stand in the customers' position to find out the projects with significant economization or profits, as well as to raise customer satisfaction. (2) Measure: understand the current situation and the gap between customers; identify the failures caused by key processes. Take the data as the Benchmark during measurement, so the employees must receive training in basic statistics and probability, including the courses of measurement and analysis etc. At the beginning, the work is led by Black Belt or experienced people with the actual implementation of Six Sigma. (3) Analyze: find out why the failure happens in the process. In this stage, the brainstorming and many statistical tools should be used to research the key few reasons, which cause the gap between the present situation and demands, so as to identify and measure the potential variables affecting the outcome, and then take them as a basis for improvement. (4) Improve: confirm the key variables, and then quantify their influence on high-quality necessary conditions. Find out the maximum tolerance range of key variables, so as to confirm the measurement system can measure the variability of the key variables. Finally, correct the process and keep it within acceptable limits. (5) Control: maintain the effectiveness improved; ensure the key variables are maintained within the max tolerance range through statistical process control or a simple test table and other tools.

2.2.4 Relevant literatures of Six Sigma

Cheng (2004) used quality improving methods of Six Sigma together with Yate's experimental design to find out the key factors impacting the output increase of mirror SS plate production line. With the process steps -- DMAIC of Six Sigma management, Yeh (2004) carried out the printing process improvement for light guide plate to find the best parameter combination of process, so as to validate the best parameter process capability, and list the standardization of best parameter in the control items, so that the quality and process capabilities are improved and more stable. Through the methods of in-depth interviews and questionnaire, Chen (2002) aimed at some Taiwan enterprises implementing 6σ to discuss their introduction motives, implementing manner, effectiveness, achievements and obstacles of the implementation etc, providing an implementing structure for 6σ. Tzeng (2003) used the case of a Taiwan aerospace science and technology company, which applied Six Sigma methods to implement the maintenance of aircraft components. Based on the formulation of business strategy, planning of corporate goals and the deploy of departmental performance index, to study how to use define, measure, analyze, improve and control of Six Sigma quality improvement method to improve circulation.

Based on literature review, Huang (2003) collected the critical success factors of 6σ from

Taiwan and foreign scholars to revise and conclude the 6σ key factor. Through the experts' suggestions, the measurement variables for 6σ key factors were gathered. Wang (2004) studied the three major activities of quality, total quality operation, ISO 9000 quality management system, as well as Six Sigma theory and practices, mainly took the Field Study. from the angle of actors to observe the phenomenon to be studied, also according to the experts and scholars' suggestions, literatures at home and abroad, as well as the analysis, comparison, summary and extraction of related activities in international leading enterprises, from the evolution development of TQM to explore the unique relationship between the purposes, level, measurement etc of TQM and ISO 9000, TQM and Six Sigma, so as to study how did ISO 9000 and Six Sigma support and integrate TQM. Hsu (2004) took the companies, which successfully promoted the Six Sigma activities, and their improving items as the empirical study subjects, to study and explore their modes of Six Sigma activities, and thus to evaluate performance with financial index. Through data envelopment analysis and statistical methods to assess and identify their improving achievements, analyze their differences, clarify the reasons and establish standards for project improvement.

With the concept of Six Sigma DMAIC steps, Chiou (2004) understood the real demands from customers and achieved customer satisfaction actually. The previous prevention is done properly in advance; through necessary trainings, human resources are made the most use to save unnecessary waste of human and financial resources. Cheng (2002) carried out the study on 6σ system and the business strategy literature, he advanced the study structure for business strategic integration mode of 6σ system, including two variables: strategy operation and promoting operation; one dependent variable: quality performance index; eight variable topics: organize corporate culture, organize environmental assessment, positioning of strategic formation, improve the structure and methods, promote the organizational structure, quality improving technology, improve the performance measurement and improve the integral orientation; four indexes for the dependent variable: stimulate employees, enhance customer satisfaction, increase corporate profits and decrease business costs. Through the study and analysis of the single case, the business strategic process for enterprise integrating 6σ systems is known.

2.3 Design of Experiments (DOE)

Based on the understanding of 0201 passive component size and material properties, combined with yield rate analysis and testing during process, Su (2004) determined the ideal design of end plate component, material characteristics and process parameters. During the research, Taguchi method and experimental design and analysis were used to obtain the most messages of 0201 passive component through the least times of experiments. First of all, decide experimental factors and level to configure the orthogonal array. Secondly, through the chi-square test to determine whether the experimental data is in normal distribution. Get the significant factor of the experiment through the signal-noise ratio and analysis of variance. Taguchi's cumulative analysis was used also to expect a significant factor. Experiment verified whether the best process parameter combination had reproducibility. Finally, implement the thrust force test to ensure the best parameter combination for 0201 passive component process. Yang (2003) found the best parameter combination and achieved the best quality performance with the least times of experiments. The integrated center cutting machine experiment was studied, the round processing track and path were taken the quality control of roundness, Taguchi experimental design was used to explore the impact of two major parts on processing, one is the control system factor, such as time constant of acceleration and deceleration, load inertia, the pre-control factor, the pre-control time constant; the other is the cutting system factor, such as the feed of each cutting-edge, cutting depth, cutting speed and so on. With different level of value, through the orthogonal array configuration to analyze average of each level and the responding array, so as to find the best parameter blocks of numerical control equipment in the control system and machining and reach the best quality, and thus stabilize the demand for product quality and enhance the effectiveness of the cutting.

Fan (2004) discussed the performance and phenomenon of mass transfer when packed bed absorber absorbed volatile organic compounds (VOCs). Firstly, organic triethylene glycol solution was used to absorb VOC like toluene, methanol, ether and butanone etc, and then the impact of various operating conditions on mass transfer coefficient. Secondly, the 2-level full factorial designs were used to plan each experimental factor of response value (mass transfer coefficients), the purpose was to get a reasonable and accurate analysis result with less experimental combination. In addition, the statistical ANOVA was also used to explain the impact of experimental factor on response value as well as the interaction between the factors. Also, the interfacial disturbance phenomenon, which is caused by the difference in surface tension between absorbent and volatile organic compounds, was also another subject of study; it proved that the interfacial disturbance phenomenon in the mass transfer process was helpful to upgrade the performance of mass transfer during absorption.

2.4 Process Failure Mode and Effects Analysis (PFMEA)

Ho (2004) used the Case Based Reasoning (CBR) in expert system, the simple definition is: assist to solve the current problems through the past solutions and experiences. With the assistance of IT, a set of FMEA expert system for auxiliary implementation was established t play o the real role of FMEA. Chen (2004) studied the process improvement of printed circuit board assembly developed in plant test side and the establishment of FMEA. Take Design FMEA and Process FMEA as the Structure; emphasize the feasible human-machine interface and quickly data and information, the difficulties in establishing and maintaining

FMEA data are improved. The disorder way in the past is corrected. Test equipment is essential in the main board assembly industry, how to use the most efficient testing method with the maximum coverage to inspect the product quality is the goal of all test engineers. Therefore, on the premise of the project with the same pace, it is necessary to rethink the process of testing and developing equipment as well as dealing with the abnormities in the past. Coupled with the FMEA system, which is developed to detect PCBA, the whole process is made to be more efficient. Chang (2003) used quality function deployment to assess the key quality factor between the needs of customers and technical requirements. The analysis which is supported by the questionnaire and cluster analysis techniques, through the quality function deployment to deduce the key quality factor to find the best quality combination of factor and level, so as to reduce the noise variation and stabilize the reference for the process.

3. Case Study

The DMAIC process and tactics were used in this case study to improve the process of main board comprehensively, covering the definitions of the key input, process and output index, through the Cause and Effect Diagram and PFEMA to identify important impact factors, also through experimental design and Mind_Mapping tactics to find the best process parameters and improve measures, so as to achieve stable process and product of good quality.

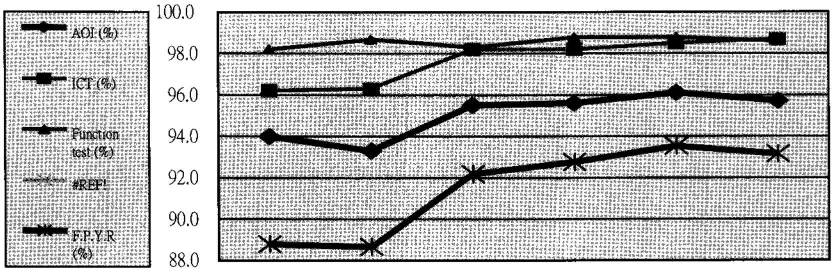
3.1 About main board process

The process of main board begins with the load circuit board, solder paste is printed on the welding mat of circuit board through the printing press, a high-speed chip shooter places the small parts on welding mat, a multi-function placer places the big parts on the circuit board, then heated by a vapor oven to fix the parts on the circuit board, do a circuit testing and functional testing, and then inspect the appearance and packaging. The factors influencing the yield rate of main board process are very complicated, in this case, through the 6 σ tactics, in such a complex system, mutual relations between the factors of input, process and output were considered comprehensively, layered find out the advanced problems affecting the yield rate of main board process, and then seek improvement measures with different tactics to comprehensively enhance the yield rate of main board process.

3.2 Define

In the face of fierce competition in OEM industry, in order to enhance the competitive advantage, first is to understand customers' voice, demand and consideration, which are the key indexes of quality. On the other hand, consider from the internal process to find the key process issue and key process index, so as to find the best opportunities for improvement, thus decide the subject of Six Sigma as the yield rate upgrading main board process. Through the collection of yield rate for A product which is the key machine type by system, the data collection period from October 2006 to March 2007, the calculation method of yield rate for main board SMT process and trends are shown in Figure 1. Yield rate is from 88.8% in October 2006 to 93.1% in March 2007, from the trends we can see that when the yield rate is up to 93%, the bottleneck is encountered with and can not enhance forward.

$$\frac{\textbf{AOI BOT pass qty}}{\textbf{AOI BOT input qty}} * \frac{\textbf{AOI TOP pass qty}}{\textbf{AOI TOP input qty}} * \frac{\textbf{ICT pass qty}}{\textbf{ICT input qty}} * \frac{\textbf{F/T pass qty}}{\textbf{F/T input qty}}$$



	Oct'05	Nov'05	Dec'05	Jan'06	Feb'06	Mar'06
AOI (%)	94.0	93.3	95.5	95.6	96.1	95.7
ICT (%)	96.2	96.3	98.2	98.2	98.5	98.7
Function test (%)	98.2	98.7	98.3	98.8	98.8	98.6
F.P.Y.R (%)	88.8	88.7	92.2	92.8	93.5	93.1

Figure 1. Trend diagram for yield rate of current main board process

Select the members in the improvement team for Six Sigma based on the scope of the project. The functions include Black Belt, Green Belt, industrial engineering, SMT processes, supplier quality management, production management, quality control and other staffs. The duty of each member is also formulated to ensure that the overall improvement can be carried out smoothly. The duties of the team and members are as shown in Table 1.

As to the collection of process failure analysis from January 2007 to March 2007 of the data, based on the data analysis and revise shown in the figure, the first five reasons are empty solder parts, offset parts, tin short circuit, missing pieces and bad material, which account for 83% of the total failures. Further analyze the reason of empty solder parts to find a potential opportunities to win quickly, aim at the position and reason for empty solder parts (DM1/DM2/X7/CN7/IDE1), in accordance with easy, cheap and rapid implementation, as well as within the range of team control to assess the feasibility of its implementation, and to formulate a measure to replace PP material, amend the hole size of steel plate X7, requiring manufacturers to improve the board quality, change IDE1 plate openings, and decide who will be responsible for and completion date.

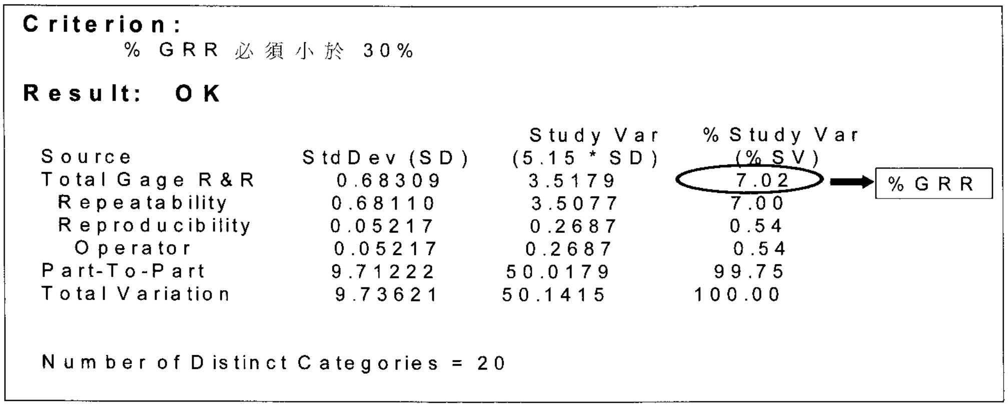
Table 1. Team members and their duties

Project Title	Name	Tel/Ext	Job Description
Champion	David Chang	3571	1. Plan the project subjects.
			2. Support and allocate resources.
BB	Eagle Lin	3325	1. Allocate team members' work. 2. Hold the meeting and follow up the schedule. 3. Collect VOC
GB	Paul Wang	2950	1. Integrate the report. 2. Calculate ROI and Financial data. 3. SIPOC process analysis
	Tom Lee	1452	
IE	Thomas Lin	1543	1. Data collection
PSE	Jack Lee	1760	1. Data collection
SQM	Tony Kao	2251	1. Vendor quality improvement
PD(PCBA)	Jeff Lee	2532	1. Data collection 2. DL manpower management
QA	Andrew Chen	2740	1. Collect VOC. 2. Audit the action status

3.3 Measure

The analysis aimed at measurement system of main board process, including the repetition and regeneration analysis, as well as the current assessment of process capacity to ensure the system has a statistical stability. Measurement capability analysis was based on solder paste thickness inspection and Automatic Optical Inspection (AOI), first of all, Gauge R and R implementation plan was formulated. The item to be measured was the output index, the form of data can be divided into continuous and discrete two broad categories, such as height, length and time are continuous data, qualified and unqualified products are discrete data. Number of samples is determined by the accuracy of the data, conduct methods details data collection method and different data types have different methods to determine. The data collection is done in accordance with measurement implementation plan, the GRR percent of solder paste inspection thickness is 7.02% < 30%, as shown in Table 2, which means this measurement system without problems. The Kappa value of AOI is 0.97 > 0.9, as shown in Table 3, it means that the measurement system without problems.

Table 2. Analysis on measurement system of solder paste thickness inspection



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Criterion:
     % GRR 必須小於 30%

Result:  OK

                                          Study Var     %Study Var
 Source                StdDev (SD)     (5.15 * SD)       (%SV)
 Total Gage R&R          0.68309          3.5179           7.02     → %GRR
   Repeatability         0.68110          3.5077           7.00
   Reproducibility       0.05217          0.2687           0.54
     Operator            0.05217          0.2687           0.54
 Part-To-Part            9.71222         50.0179          99.75
 Total Variation         9.73621         50.1415         100.00

 Number of Distinct Categories = 20
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Table 3. Analysis on measurement system of AOI

Appraoser	Response	Kappa	SE Kappa	Z	P (vs > 0)
1	NG	1	0.0962250	10.3923	0.0000
	OK	1	0.0962250	10.3923	0.0000
2	NG	1	0.0962250	10.3923	0.0000
	OK	1	0.0962250	10.3923	0.0000
3	NG	0.97957	0.0962250	10.3923	0.0000
	OK	0.97957	0.0962250	10.3923	0.0000

At the same time, as the analysis of existing process capability, the data period was from January 2007 to March 2007, the process capacity of each inspection is as shown in Table 4.

Table 4. Analysis of existing process capacity

Stage	AOI	ICT	Function test	Current FPYR	Target FPYR
Yield rate	95.8%	98.7%	98.7%	93.1%	96.0%
DPPM	42,000	13,000	13,000	69,000	40,000
Sigma level	3.2	3.7	3.7	3	3.3

3.4 Analyze

The reasons for bad SMT process is analyzed according to types of machine and parts, summarized as shown in Figure 2, left is the name of the machine, the top is the main reason affecting product yield rate, including empty solder, shift, solder short, missing pieces and bad materials. from the diagram it can be found the failures of empty solder and solder short are concentrated in parts of multi-function placer, and the type of spare parts is connector; the failures of shift and missing pieces are gathered in parts of high-speed chip shooter, and the type of part is 1005 RP3 type resistance and 1005 CP5 capacitance.

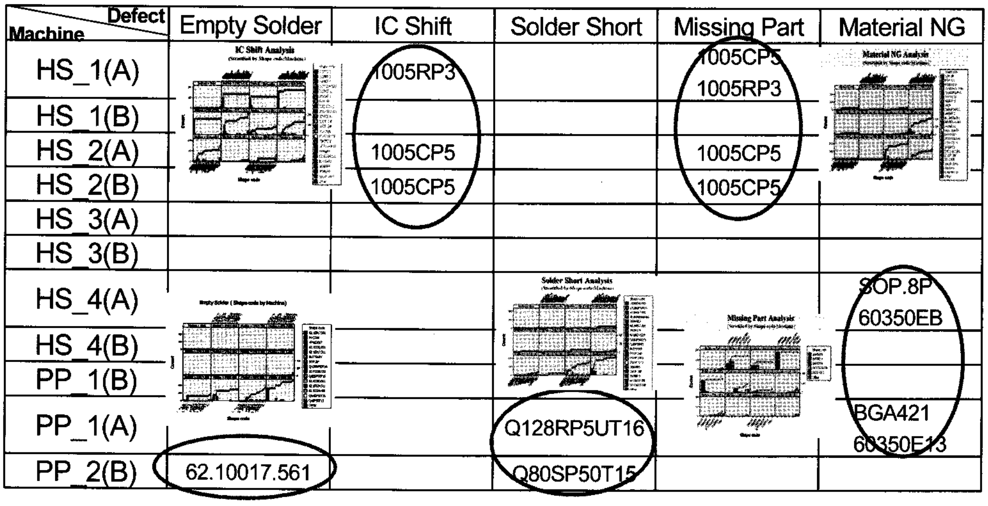


Figure 2. Analysis on reason for bad SMT process

According to layer data, further analysis is done on the possible reason for impacting bad yield rate of main board process. Find out the reason with Fishbone Diagram from empty solder, shift, solder short, the missing pieces and bad material. In addition, according to main process steps and sub-step process for the spindle, set out the input and process index with impact; and then based on the weight factor which affects the degree of yield rate, to score the empty solder, shift, solder short, the missing pieces and bad material, analyze the factors impacting the yield rate of main board process with a cause-effect matrix to identify the possible reasons. To find out the important factor impacting the process, for solder paste printer, the rate of release, the pressure on the blade, blade speed and the distance from release are important impact factors. For high-speed chip shooter, suction speed, location of the suction, suction height, the speed of placement and placement height are important impact factors. Based on the analysis of fishbone diagram and cause-effect matrix, the factors impacting process yield rate are got; at last, the failure phenomenon (small y) and possible factors are listed in the data collection table. Output index is the data impacting yield data (Y1~Y5), input index is the key process parameters (X1~X10) impacting yield rate, the operation is defined as the method of collecting data; also, the sources of data, the sample amount of data collection, data collector, data collecting period and method are defined to ensure the data collection is in line with the direction of analysis.

As for the possible impact factors of data collection table, collect actual production data and test them through assumed test method to further screen whether they are the impact factors. Take the thickness of solder paste as a example, when the thickness is 0.11~0.14 mm, the qualified products are 4189pcs and the unqualified products are 97pcs; when the thickness is 0.15~0.18mm, the qualified products are 15,055 pcs and the unqualified products are 52pcs; when the thickness is 0.19~0.22mm, the qualified products are 1,449 pcs and the unqualified products are 456pcs; Shows that the thickness of solder paste is the high-impact factor, at the same time, in accordance with its chi-square test, the P-value is $0 < 0.05$, it can be determine the thickness of solder paste is the important impact factor.

3.5 Improve

Based on the factors got in the stage of analyze to think of ideas to solve the problem. As to the solder paste printing machine, it is considered to use the experimental design method to find out the best parameter combination with blade speed, the speed of release, the release distance and blade pressure as experimental factors, so as to reach a stable printing process. As for the high-speed chip shooter, the experimental design method is also considered to use to find out the best parameter combination with suction speed, location of the suction, suction height, the speed of placement and placement height as experimental factors, so as to enhance the placement yield rate of 1005RP3 resistance and 1005CP5 capacitance. The other factors are considered to use brainstorming solutions. First of all, collect existing products with high yield rate like the thickness of solder paste, analyze the differences in qualified product, solder short and empty solder, each small cell on the map symbolizes the location of parts with high yield rate, when welding parts have empty solder, qualified prod-

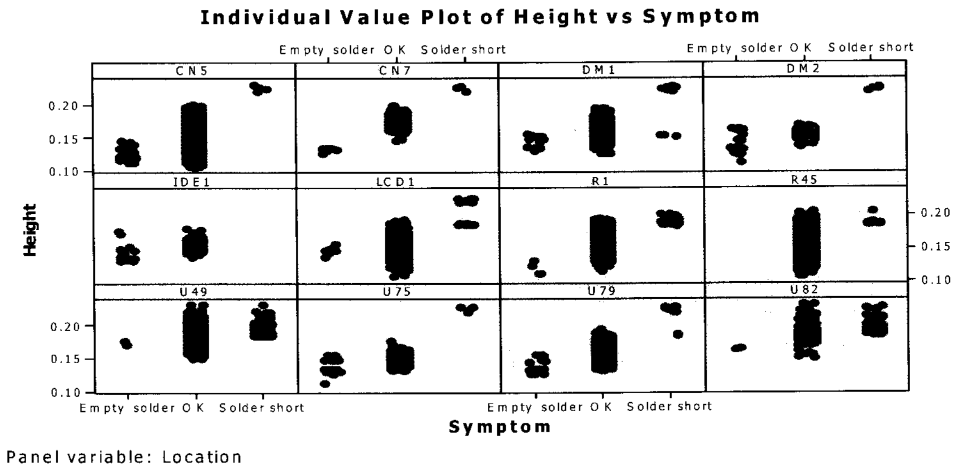


Figure 3. Analysis chart for the thickness of solder paste and soldering of parts

uct and solder short, from the diagram for the thickness of solder paste, according to the data, it can see that if solder paste thickness is greater than 0.20 mm, the parts are easy to have solder short; If thickness is less than the 0.14 mm, the parts are easy to have empty solder, such as the data shown in Figure 3.

Then blade speed, release speed, release distance and the blade pressure are aimed at to do the experimental design for the thickness of solder paste, and the up and down limits of the machine are listed, taking into account of the current settings for each factor to set the settings of the experimental level for each factor, the up and down limits blade speed are

Table 5. Table for experimental data of printing machine

Std Order	Run Order	Center Pt	Blocks	A	B	C	D	S	Mean
19	1	1	1	20	0.8	1	7	0.019056	0.153101
24	2	1	1	50	0.8	5	7	0.017221	0.152968
1	3	1	1	20	0.2	1	5	0.018987	0.159492
10	4	1	1	50	0.2	1	7	0.012085	0.148233
7	5	1	1	20	0.8	5	5	0.015506	0.151906
5	6	1	1	20	0.2	5	7	0.018821	0.149605
13	7	1	1	20	0.2	5	7	0.016177	0.146999
20	8	1	1	50	0.8	1	5	0.023603	0.163974
12	9	1	1	50	0.8	1	5	0.027754	0.172966
28	10	0	1	35	0.5	3	6	0.01439	0.158615
23	11	1	1	20	0.8	5	5	0.01429	0.159482
2	12	1	1	50	0.2	1	7	0.019428	0.182104
8	13	1	1	50	0.8	5	7	0.015852	0.150491
14	14	1	1	50	0.2	5	5	0.027433	0.168163
6	15	1	1	50	0.2	5	5	0.033836	0.165766
25	16	0	1	35	0.5	3	6	0.014433	0.155439
15	17	1	1	20	0.8	5	5	0.018577	0.160694
16	18	1	1	50	0.8	5	7	0.017175	0.151095
26	19	1	1	35	0.5	3	6	0.019126	0.154672
3	20	1	1	20	0.8	1	7	0.015153	0.153633
21	21	1	1	20	0.2	5	7	0.012017	0.147391
27	22	0	1	35	0.5	3	6	0.013524	0.153491
18	23	1	1	50	0.2	1	7	0.019279	0.157231
11	24	1	1	20	0.8	1	7	0.013741	0.146178
4	25	1	1	50	0.8	1	5	0.024223	0.164958
9	26	1	1	20	0.2	1	5	0.017022	0.147686
22	27	1	1	50	0.2	5	5	0.027581	0.1715
17	28	1	1	20	0.2	1	5	0.015981	0.156164

50mm/s and 20mm/s, the up and down limits of the release speed are 0.8mm/s and 0.2mm/s, the up and down limits of the release distance is 5.0mm and 1.0mm, the up and down limits of the blade pressure is 7kg and 5kg, the thickness of solder paste is the experimental response value. The part location with bad yield rate is selected as the measuring point for the thickness of solder paste. There are four factors in the experiment: blade speed (factor A), release speed (factor B), release distance (factor C) and blade pressure (factor D), the resolution is IV, a total of eight level combination, each level combination copies three experiments and the focal point has four experiments, a total of 28 experiments. The order of the experiments is in accordance with random Run Order, and the experimental data collection is as shown in Table 5. S is the standard deviation of the thickness of solder paste in the location selected as measuring point; Mean is the average thickness of solder paste in the location selected as measuring point.

Analyze the experimental data on average; from the main effect map it can see the blade pressure (factor D) and blade speed (factor A) are the impact factors. Additionally, from the interaction map it can be seen the blade pressure and speed exist interaction. Then, through the regression analysis to get an average thickness of solder paste, the return-forecast is shown in the following formula.

$$\text{Avg} = 0.147314 + 0.00118679 \times \text{blade speed} + 0.00154333 \times \text{blade pressure} + 0.000007083 \times \text{release distance} - 0.00006042 \times \text{release speed} - 0.00015746 \times \text{blade pressure} \times \text{blade speed};$$

$$\text{R - Sq} = 79.57\%; \quad \text{R - Sq (adj)} = 74.93\%$$

Then do the optimize analysis, the average thickness of the solder paste is set at 0.165 mm to do the best mode analysis, when the blade speed is set at 40, the release speed is 0.8, the release distance is 5 and blade pressure is 5, it can get the best y Value of 0.1643, as shown in Figure 4.

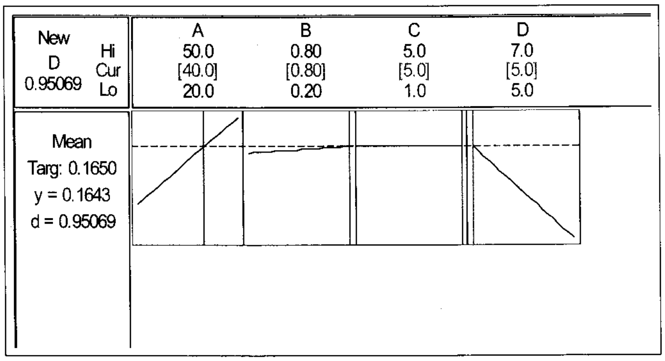


Figure 4. Optimization analysis on factors of printing machine

The best parameter for solder paste printing machine is confirmed by 10 times of experiment and the average is 0.1635 mm, which is close to the average 0.1643 mm from the re-

Table 6. Experimental design data for high-speed chip shooter

Std Order	Run Order	Center Pt	Blocks	A	B	C	D	E	S	Mean
9	1	1	1	0.6	-0.2	-0.2	1	0.2	0.032	0.036
13	2	1	1	0.6	-0.2	0.2	1	0.4	0.075	0.082
17	3	1	1	0.6	-0.2	-0.2	0.6	0.4	0.073	0.077
2	4	1	1	1	-0.2	-0.2	0.6	0.2	0.037	0.036
29	5	1	1	0.6	-0.2	0.2	1	0.4	0.08	0.093
7	6	1	1	0.6	0.2	0.2	0.6	0.4	0.098	0.101
11	7	1	1	0.6	0.2	-0.2	1	0.4	0.075	0.07
25	8	1	1	0.6	0.2	-0.2	1	0.2	0.033	0.036
18	9	1	1	1	-0.2	-0.2	0.6	0.2	0.038	0.04
5	10	1	1	0.6	-0.2	0.2	0.6	0.2	0.07	0.068
3	11	1	1	0.6	0.2	-0.2	0.6	0.2	0.04	0.038
10	12	1	1	1	-0.2	-0.2	1	0.4	0.083	0.072
19	13	1	1	0.6	0.2	-0.2	0.6	0.2	0.04	0.038
36	14	0	1	0.8	0	0	0.8	0.3	0.037	0.05
32	15	1	1	1	0.2	0.2	1	0.4	0.095	0.092
8	16	1	1	1	0.2	0.2	0.6	0.2	0.073	0.071
22	17	1	1	1	-0.2	0.2	0.6	0.4	0.095	0.093
31	18	1	1	0.6	0.2	0.2	1	0.2	0.067	0.085
27	19	1	1	0.6	0.2	-0.2	1	0.4	0.074	0.082
33	20	0	1	0.8	0	0	0.8	0.3	0.045	0.048
14	21	1	1	1	-0.2	0.2	1	0.2	0.075	0.076
24	22	1	1	1	0.2	0.2	0.6	0.2	0.078	0.08
34	23	0	1	0.8	0	0	0.8	0.3	0.047	0.045
21	24	1	1	0.6	0.2	0.2	0.6	0.2	0.05	0.055
15	25	1	1	0.6	0.2	0.2	1	0.2	0.072	0.072
1	26	1	1	0.6	-0.2	-0.2	0.6	0.4	0.07	0.066
12	27	1	1	1	-0.2	-0.2	1	0.2	0.035	0.032
20	28	1	1	1	-0.2	-0.2	0.6	0.4	0.053	0.055
4	29	1	1	1	-0.2	-0.2	0.6	0.4	0.075	0.082
35	30	0	1	0.8	0	0	0.8	0.3	0.045	0.05
30	31	1	1	1	-0.2	0.2	1	0.2	0.07	0.069
16	32	1	1	1	0.2	0.2	1	0.4	0.138	0.158
28	33	1	1	1	0.2	-0.2	1	0.2	0.028	0.031
26	34	1	1	1	-0.2	-0.2	1	0.4	0.099	0.093
6	35	1	1	1	-0.2	0.2	0.6	0.4	0.14	0.133
23	36	1	1	0.6	0.2	0.2	0.6	0.4	0.102	0.098

gression, the credibility of the experiment is showed. Suction speed, suction position, suction height, placement speed and height are used to do the experimental design for the placement precision of high-speed chip shooter, also the up and down limits of the machine are listed, taking into account the current settings of each factor, set the experimental settings for each factor, the up and down limits of suction speed are 100% and 60%, the up and down limits of suction position are 0.2mm and -0.2mm, the up and down limits of suction height are 0.2mm and -0.2mm respectively, the up and down limits of placement speed are 100% and 60%, and the up and down limits of placement height are 0.4mm and 0.2mm, the response value y is the average shift of offset pieces. There are four factors: suction speed (factor A), suction position (factor B), suction height (factor C), placement speed (factor D) and height (factor E) in the experiment, the resolution is V, a total of 16 level combinations, each level combination copies two experiments, and the focal point is done four times of experiments, a total of 36 experiments, the order of the experiments is in accordance with random Run Order, and the experimental data collection is shown in Table 6, X-avg is the average shift degree of Parts X on the coordinates, Y-avg is the average shift degree of Parts Y on the coordinates.

From the analysis on average absolute value of shift in the experimental data, as well as the main effect map, it can see that the factors impacting X coordinate shift are placement height (factor E), suction height (factor C) and suction speed (factor A). And the factors impacting Y coordinates shift are placement height (factor E) and suction height (factor C). The placement precision is got by regression analysis; the return-forecasts for X, Y average are shown in the following formula.

X_Avg = -0.0073368 + 0.0251563 × suction speed + 0.0035937 × suction location + 0.0770313 × suction height - 0.0001563 × placement speed + 0.183438 × placement height;

R-Sq = 71.12%; R-Sq (adj) = 66.30%

Y_Avg = -0.0057222 + 0.0093750 × suction speed + 0.0846875 × suction location + 0.01541 × suction height + 0.0075000 × placement speed + 0.182500 × placement height;

R-Sq = 72.67%; R-Sq (adj) = 68.11%.

The goal of average placement precision is set to 0 to do the best mode analysis, when the suction speed is 60%, suction location is -0.2, suction height is -0.2, placement speed is 100% and placement height is 0.2, the best results can be got: the average of X coordinate shift is 0.0282, the average of Y coordinate shift is 0.0303, as shown in Figure 5.

The best parameters of high-speed chip shooter obtained are confirmed by 10 times of experiments, the average of X coordinate shift is 0.0265, the average of Y coordinate shift is 0.0343, which are close to the value from the regression: 0.0282 and 0.0303, which shows the credibility of the experiment. On the other hand, look for feasible countermeasures to improve with Mind Mapping for the impact factors difficult to quantify. The main reason are the misusing of Feeder washer, poor connection of feeding bond, shift feeder center and dirty feeder, the solution is to use universal-type magnetic pads, as well as cleaning with air gun before feeding.

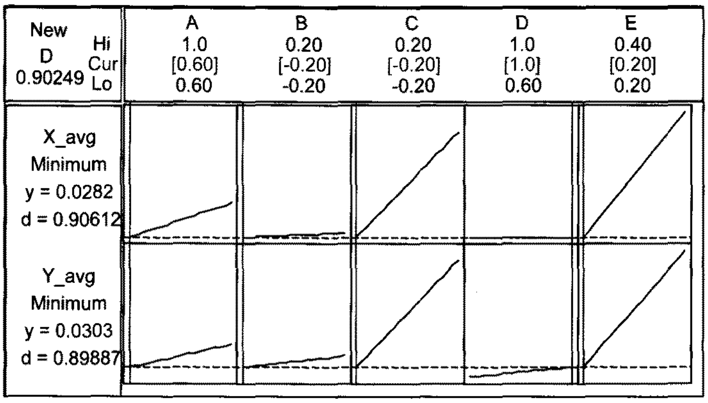
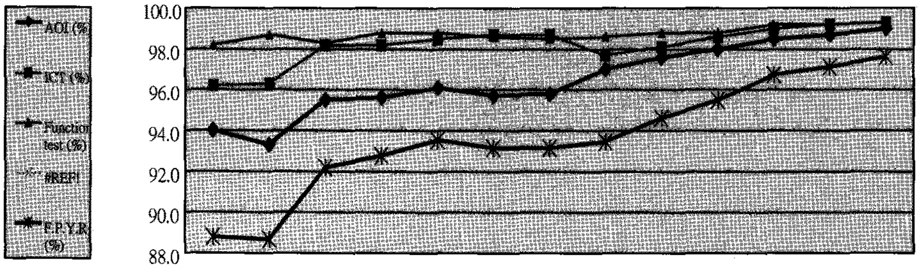


Figure 5. Optimization analysis on factors of high-speed chip shooter

The results of the experimental design on solder paste printing machine and high-speed chip shooter, as well as Feeder NG's Mind Mapping were integrated to analyze possible feasible improving measures. List various options through the revise and assessment of decision-making matrix to. Also the process, customer demands, the cost and time of implementation, and the extension complexity of the measures are considered, according to their impacting degree to give different weight, so as to achieve the weight points of each option. As to the result of selecting the measures, the measure with a total score more than 500 is developed the implementation control table, manager and period. And then trace the effectiveness improved and show it in Figure 6, the yield rate before improving is 93.1%, and after is 97.6%.



	Oct'05	Nov'05	Dec'05	Jan'06	Feb'06	Mar'06	Apr'06	May'06	Jun'06	Jul'06	Aug'06	Sep'06	Oct'06
AOI (%)	94.0	93.3	95.5	95.6	96.1	95.7	95.8	97.0	97.6	98.0	98.5	98.7	99.0
ICT (%)	96.2	96.3	98.2	98.2	98.5	98.7	98.7	97.7	98.1	98.6	99.0	99.2	99.3
Function test (%)	98.2	98.7	98.3	98.8	98.8	98.6	98.5	98.6	98.8	98.8	99.2	99.2	99.3
F.P.Y.R (%)	**88.8**	**88.7**	**92.2**	**92.8**	**93.5**	**93.1**	**93.1**	**93.4**	**94.6**	**95.5**	**96.7**	**97.1**	**97.6**

Figure 6. Trend diagram of yield rate before and after improvement

3.6 Control

In order to ensure the measures are continued and implemented effectively, the measures should added to the Process Control System as the basis for control, QC also take it as the basis for audit. If the thickness of solder paste is too thick, it is easy to have solder short; if the thickness is too thin, it is easy to have empty welding, so how to ensure the thickness of solder paste is very important to the control. Xbar-S chart can be used to monitor the thickness of solder paste. The yield rate data in the process is most easy to get which can also be used as the initial SPC quality control features. The yield rate data can be monitored by P chart in the control diagram. Make use of SFCS information, collect the yield rate data of each Model in production line every two hours, when the sample point exceeds the control limits NG will show, related engineers will solve the problem. Through Web's P chart, the yield rate information can be collected easily and automatically. Noted that, since the data is collected automatically, so the situation of P chart in each production line should be monitored by someone, monitor whether there is a point beyond the control limits.

4. Conclusions

In this study, 6σ quality improvement method was discussed and practically applied to the process improvement of one laptop OEM. A case of SMT process of main board was taken as the subject to optimize process parameters with Six Sigma methods. First of all, the possible factors impacting process quality were analyzed with CED, followed by the use of cause-effect matrix to identify the key important factors, then according to factor experimental design and Mind Mapping to find effective countermeasures, and control with process control system to ensure the continued effective implementation. Through a comprehensive consideration of 6σ system, to find out the key process for main board yield rate, which are the thickness of solder paste printing machine as well as the placement precision of high-speed chip shooter; While the key process parameters impacting solder paste printing thickness are blade pressure and speed, and there is high degree of interaction between two factors. Through the best model analysis after experimental design, when the blade pressure is set to 5kg and blade speed is set to 40mm/s, the best value of solder paste printing thickness $y = 01643$ mm can be got, also the best product quality is got. The key process parameters influencing the placement precision of parts in high-speed chip shooter are placement height, suction height and suction speed. Through the best model analysis after experimental design, when the placement height is set to 0.2mm, suction height is set to -0.2mm, suction speed is 60%, the best placement precision of parts can be got, the average X coordinate shift absolute value is 0.0282, the average Y coordinate shift absolute value is 0.0303. Additionally, for the impact factors difficult to quantify, look for feasible improvement measure with the Mind Mapping to aim at the failure reason of Feeder, a universal magnetic-magnet was discussed to use. The air gun was used to clean before feeding and replace the connecting length to increase process yield rate. With the help of all above-mentioned practices of countermeasures, the yield rate of main board was increase from 93.1% to 96.7%. In the DOE study experiment of printing press, steel plate was set to fixed parameters, which limited the solder quality. The direction of future research will focus on the plate opening of various parts for further research, so as to make the product yield rate and quality meet the target fast.

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