12-2015

Project of productivity improvement and quality control at a smart card company based on six sigma

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Project of Productivity Improvement and Quality Control at a Smart Card Company Based on Six Sigma

by

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A Starred Paper

Submitted to the Graduate Faculty of

St. Cloud State University

in Partial Fulfillment of the Requirements

for the Degree of

Master of Engineering Management

October, 2015

Starred Paper Committee:
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Abstract

The development of smart cards already has a nearly 20-year history in the world. As the improvement of producing techniques and degree of the popularity become more mature, smart card's development is stepping into a high-speed period. The application of smart cards is widely used in various fields such as telecommunication, financials, transportation, social security, medical treatment, etc. This smart card company was undergoing a downturn times due to the competitive pressure and bottleneck process on assembly line. Therefore the objectives of this project were to help the company becoming competitive by increasing the yield and maintaining the decent qualities of smart cards.

The project conducted DMAIC (Define, Measure, Analysis, Improve, Control) process, a very important methodology of Six Sigma, to help this company improving the productivity in the competitive smart cards market without adding any unvalued equipment or additional labor. At the same time maintained the quality of smart cards to satisfy the customers. Nowadays Six Sigma is becoming popular especially in manufacturing fields and industrial sectors as a set of techniques and tools for process improvement. This project eventually presented the desirable results and achievements to illustrate the significance of applying Six Sigma.

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Chapter I: Introduction

Introduction

In this chapter, the author will make a brief statement for the whole project. It includes the problems, significance and objectives of the project. Also, the limitation of this project will be stated. Some necessary terms used frequently in this project are explained for reference.

Problem Statement

The market for smart cards is in a status of demand exceeds supply, thus the company wanted to increase the yield of smart cards by improving the bottleneck process of product based on Six Sigma, meanwhile to get more economic profits. With the help of the quality control team and the author, this project was conducted to achieve the yield goal and decrease the defective rate of production, which results from the low-productivity grooving equipment.

Nature and Significance of the Problem

The bottleneck process reduced efficiency of the whole assembly line of smart cards. Also, it caused the defects of production, which affected the company's profits directly. So finding out the major factors that influenced the bottleneck process by conducting Six Sigma methods helped the company to achieve a higher yield and ensure the good qualities of smart cards. After improving the bottleneck process, the company created a series of documents and files for better control in the future. The quality control department also carried through the results of project, which has critical significance not only to the company but also to the customers. Additionally, as the smart cards with newest techniques became increasingly popular in China, the Chinese government vigorously promoted the new identity cards, which would be more convenient for residents' lives and easy for government to manage. On the other hand, the entire smart card industry will gain a larger Chinese market share since the financial smart card was promoted as a national key development project recently. Generally speaking, becoming competitive in the market is the only way to be alive and profitable for the smart card company.

Objective of the Project

The objectives of the project were to conduct the quality management systematically, increase yield by improving the bottleneck process, decrease defective rate and enhance the productivity and efficiency of production. Eventually benefitting the company to become more competitive in the market.

Project Questions/Hypotheses

1. How to use Six Sigma methods to increase the yield for the company?
2. How to find out the factor that has the most influence on the process?
3. How much will the company save after improvement?
4. How to maintain the outcome of improvement in control phase?

Limitations of the Project

The data collection in the measure phase and improve phase was not sufficient enough due to the time limitation and team cooperation issues, which might cause the unspecific results of the experiments contained in this project. Plus, lacking of the comparative data from other companies made this project not very meaningful for the whole smart card industry.

Definition of Terms

Quality Management. It ensures that an organization, product or service is consistent. It has four main components: quality planning, quality control, quality assurance, and quality improvement.

Quality Control. It is a process by which entities review the quality of all factors involved in production. ISO defines quality control as “A part of quality management focused on fulfilling quality requirements”.

Six Sigma. It is a set of techniques and tools for process improvement. Six Sigma seeks to improve the quality output of process by identifying and removing the causes of defects and minimizing variability in manufacturing and business process.

Figure 1.1: DMAIC Process Figure

DMAIC. It is an abbreviation for define, measure, analyze, improve and control. The process of it is shown in Figure 1.1. It refers to data-driven improvement cycle used for improving, optimizing and stabilizing business processes and designs. The DMAIC improvement cycle is the core tool used to drive Six Sigma projects.

MSA. A measure systems analysis is a specially designed experiment that seeks to identify the components of variation in the measurement. A measurement system analysis evaluates the test method, measuring instruments, and the entire process of obtaining measurements to ensure the integrity of data used for analysis and to understand the implications of measurement error for decisions made about a product or process.

DOE. Design of experiment is the design of any information gathering exercise where variation is present, whether under the full control of the experiment or not.

SIPOC. It stands for suppliers, inputs, process, outputs, and customers. It is a tool that summarizes the inputs and outputs of one or more processes in table form. The SIPOC is often presented at the outset of process improvement efforts or during the define phase of the DMAIC process.

FMEA. Failure mode and effects analysis is one of the systematic techniques for failure analysis. It is also used to identify the contingency plans to eliminate or reduce the probability or severity of the problem. A FMEA is often the first step of a system reliability study. It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects.

SPC. Statistical process control is a method of quality control, which uses statistical methods. SPC is applied in order to monitor and control a process. Monitoring and controlling the process ensures that it operates at its full potential.

Fishbone Diagram. Common uses of the fishbone diagram are product design and quality defect prevention, to identify factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Causes are usually grouped into major categories to identify the sources of variation.

Pareto Chart. It is a type of chart that contains both bars and a line graph, where individual values are represented in descending order by bars, and the cumulative total is represented by the line.

Summary

Above was a brief introduction of the whole project; it contained the problem statement, the significance and objectives of the project. The questions raised up in this chapter by the author will get solved in the following chapters. Next chapter will talk about the background of this project.

Chapter II: Background and Review of Literature

Introduction

In this chapter, the author introduces the background of the smart card company, including what types of products they manufacture and the conditions they are in. In addition, this chapter contains the literature review related to the project problem and methodology.

Background Related to the Problem

The Project was conducted in a smart card company, which located in an industrial city of northern China. This company is a joint venture company of a France smart card giant company with a Chinese central enterprise. It was founded in 1996 but officially put into operation in 1997. They produce and sell UIM card, IC telephone card, IC account number card, SIM card, account cards and other types of smart cards. They also provide software development and related technical consulting services. As the first batch of smart card manufacturers in China, the company was authorized with certificate of IC manufacturer by the national IC card registration center in 2001. The company owns fully automatic equipment for smart card production, with perfect card detection methods, testing equipment, professional graphic design and printing equipment. Moreover, they have actual professional staff engaged in design work, and assist five important telephone operators (China Telecom, China Netcom, China Mobile, China Unicom, China Railcom) to complete the revision work for card patterns.

However, as the competitive trend of the smart card market becomes severe, increasingly small companies and workshops divide up the market share depending on the low price advantage. Obviously, these small factories lack of the advanced techniques to guarantee the quality of smart cards, which is a deadly disadvantage. Thus the company that the author conducted the project in had to increase the yield to fulfill the needs from market under the prerequisite of believable and eligible quality.

The producing flow chart of the smart card is shown below in Figure 2.1.

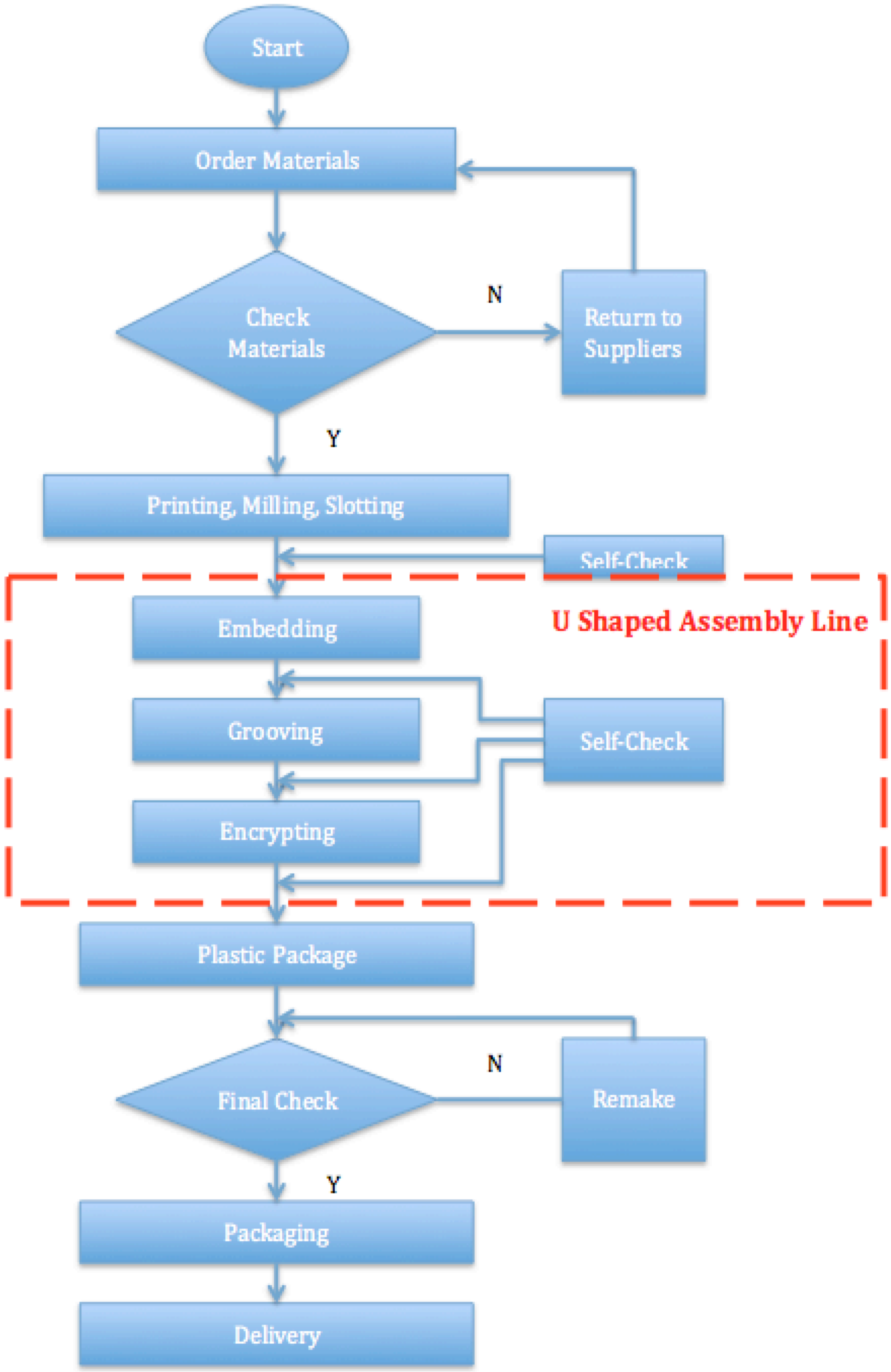

Figure 2.1: Producing Flow Chart of the Smart Card

The main producing procedures of smart cards are shown in Figure 2.2, from printing, milling, slotting card to embedding, grooving and personalization, it contains six main procedures. Accordingly, the equipment used to finish each procedure is also shown below in Figure 2.3.

Figure 2.2: Main Producing Procedures Chart of the Smart Card

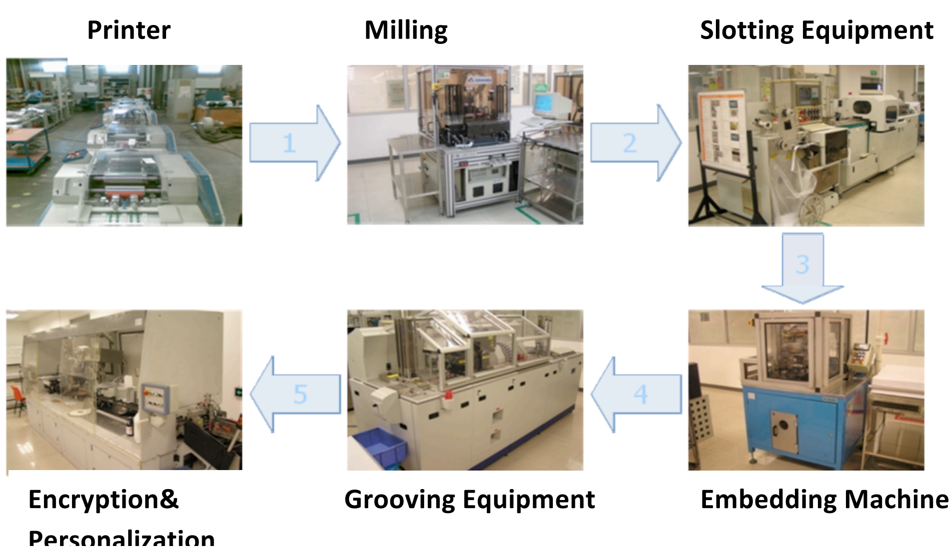

Figure 2.3: Procedures' Equipment Chart

The equipment of embedding, encrypting, grooving are in a U shaped assembly line, their productivities are shown in Table 2.1.

Table 2.1: Equipment Productivity in U Shaped Assembly Line

Equipment Use	Quantity	Productivity (pieces/hour)
Embedding	1	3500
Grooving	2	2800
Encrypting	1	3200

The author, along with the quality control team, found the grooving station was the bottleneck process in the whole assembly line after analyzing the data collected by the team, which caused the lower yield and undesired productivity for the production.

Literature Related to the Problem

Smart cards' history can be traced back to 1968 when using plastic cards as carrier of microchips; it was developed by two German inventors, Helmut Grötrupp and Jürgen Dethloff. Later, the first formal reality of a smart card came with Roland Moreno's smart card patents in France in 1974. He was a French journalist who invented the IC card that could embed the programming circuit into a plastic card, which is the earliest IC card with versatile functions (Ferrari, Mackinnon, & Yatawara, 1998, p. 2). French Postal and Telecommunications Services carried out the fist field trial of telephone cards successfully in 1984. In 1980, ISO (International Organization for Standardization) and IEC (International Electro-technical Commission) developed an international standard related to electronic identification cards with contracts, especially smart card called ISO/IEC 7816, which pushed the quickly development of the smart card industry (Dreifus, 1998, p. 33).

Chinese Smart Card Development Association raised that smart card is becoming smaller than before at present; it requires more sophisticated techniques and quality level. Plus, different requirements from customer incentive the market to provide more novel designs like financial smart card. Thus the smart card company must conduct lean manufacturing techniques and quality management based on Six Sigma, in order to maintain competitiveness in smart card field (China Smart Card Development Association Journal, 2014, p.14). Compared with European countries, the birthplace of the smart card, smart cards' application depth in China is still far less than developed country. However the pace of development and the depth of applications of the smart card are gratifying (Smart card.org.cn, 2013). Chinese smart card market is expending, it attracted a large number of manufacturers to enter, which resulted in the fierce competition. Because of the two forces' interaction, the progress of economy and technology and the diversified needs and personalization demand from customers, the Chinese smart card market is showing the trend of finding ways to reduce production costs to become competitive. At the same time, external pressure of market competition will force companies to invest in R&D gradually, which will increase the production costs and cause rising product price. But with the market development of the smart card industry, the capacity of the entire market will increase rapidly, which will boost to enlarge the scale of production and obtain the large-scale economies (Liu, 2015, p. 45).

Literature Related to the Methodology

People's activities of quality control could be traced back to Industrial revolution times, when production activities became mechanized and large-scaled. Some awareness and concepts of quality control occurred in people's mind, which was the beginning of the contemporary quality management. From the primary stage of examining the quality of products after producing to the total quality management, which already became a kind of advanced protective management, quality management involved many disciplines like statistics and probability theory to forecast the trend of producing process. It not only reduced the inspection costs, but also increased the efficiency of examination. Besides, it was a full participation of every department rather than just the duties of quality control department (Ross, 1995, p. 4).

As the concept of total quality management was promoting gradually, many famous organizations and corporations all over the world regarded it as the core theory to practice on quality management and made some innovation correspondingly. Like Ritz-Carlton, Motorola and Engelhard-Huntsville, the preventative companies who use total quality management to succeed in their fields, became the models that be learnt by other companies (George & Weimerskirch, 1998, p. 62). K. J. Zink also gave out many inside stories from European quality award winners to illustrate how European companies used total quality management to regain or maintain their competiveness around the world in 1990's (Zink, 1997, p. 10).

As time went by, engineers and scientists like William Deming, Joseph Juran and Philip Crosby came up with more mature perspectives and methods. Six Sigma was regarded as a new method that inherited the total quality management. Six Sigma originated from Motorola Company in 1988, when Bob Calvin took over it and started the quality path. In accepting the first ever Macolm Baldrige National Quality Award, he described the company's turnaround as something called Six Sigma. The engineer called Bill Smith who worked for Motorola was known as the father of Six Sigma. Nowadays, Six Sigma is a data driven and profit focused improvement methodology for organizations to increase their customer satisfaction. It is not only a tool for company to reduce process defect, but also a framework for overall organizational cultural change (Summers & Summers, 2007, p. 9).

Summary

In this chapter, the author stated the detailed background of the problems and explained the problems based on the description of smart cards' producing flow chart. According to the productivity contrast chart, it presented the bottleneck process regarding the grooving station. Also, in this chapter the problems and methodology got proved and clarified by the related literature review. Next, the author will explain in detail the methodology used in this project to solve the problems.

Chapter III: Methodology

Introduction

In this chapter, the author states the methodology that used in the project, and the methods used to support methodology. It contains a framework of study and rationale for using every approach. Also, the way of data collection and analysis will be illustrated. Besides, the budget and timeline are given out in table format.

Design of the Study

First of all, the project was totally conducted in this smart card company based on Six Sigma management. Sigma is a Greek letter; in statistics it is called the standard deviation, which is used as an indicator of the dispersion degree of the data. In quality management it is used to describe the level of quality fluctuation. It is also an indicator for perfect improvement specifically associated with statistical modeling of manufacturing processes. The maturity of a process can be described by a sigma rate indicating its yield or the percentage of defect-free products it creates. Six Sigma level statement is shown in Table 3.1. A Six Sigma process is one in which 99.99966% of all opportunities to produce some features of a part are statistically expected to be free of defects (3.4 defective features / million opportunities), although, consider of 1.5 sigma shift, this defect level corresponds to only a 4.5 sigma capability.

Table 3.1: Six Sigma Level Statement Table

Sigma Level	Percentage Yield %	PPM
±1 σ	66.27	317300
±2 σ	94.45	45500
±3 σ	99.73	2700
±4.5 σ	99.99966	3.4
±5 σ	99.999943	0.57
±6 σ	99.99999982	0.0018

Thus the DMAIC process was the mainline and route for this project. Six Sigma is precise technique and principle of implementation to mine the essence of the problem efficiently and to give suggestions for improvement (Han, 2008, p. 15). Therefore, this project followed the DMAIC process to solve the problems without influencing the customer satisfaction as the premise, to identify the significant factors and consolidate the ways to improve in order to get the expected effect. In the process the data was a basis for analysis, the author applied some statistics tools and charts to define, measure, analyze, improve, and control the process, such as process capability analysis, variance analysis, FMEA, DOE, Pareto chart, Fishbone map, etc. Figure 3.1 is the mainline and study framework for this project.

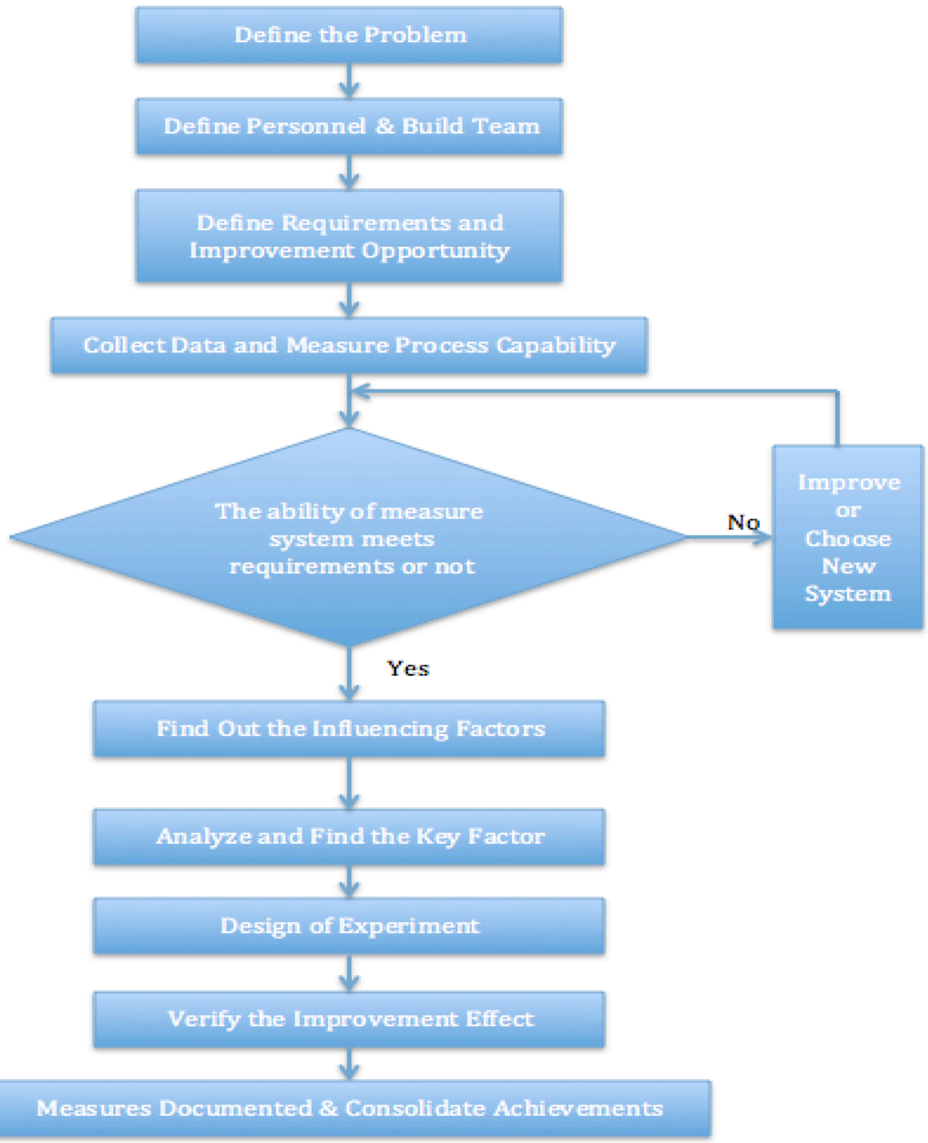

Figure 3.1: Study Framework of the Project

DMAIC process is used to improve the process performance and conduct the future control over the production. It contains different methods to reach the goals in each phase. The methods regarding this project in every phase are illustrated in the following paragraphs.

1. Define phase was to identify and validate the improvement opportunity, along with customer's requirements. In this project, the bottleneck process regarding grooving was the biggest problem that needed to be solved. Therefore the measure of connection force between the metal chip and the plastic part on the smart card needed to be figured out as a standard requirement at first, which was included in the production process analysis. Then the needs and demand from customers got clarified. Next stage was to establish a project charter and build a Six Sigma team. Meanwhile clarifying the roles and responsibilities among the team members. The tool named SIPOC process map was adopted by the author in this phase.
2. The first step in measure phase was to confirm the measured objects. Then collected the data including the producing speed of grooving equipment, the monthly yield of smart cards, and the qualified rate. In order to make sure the consistency and accuracy of measuring system, attribute agreement analysis was used to analyze the conformance degree; then defined the types of defects by using brainstorming methods to organize ideas and generated the potential causes by fishbone diagram. Conducted T-test to ensure the reliability of measuring devices. Lastly, conducted process capability analysis to understand the current system better, also got the sigma capability.
3. In analysis phase, the measured data was analyzed by statistical and non-statistical methods. A complete root cause analysis was performed to

identify the root cause of the problem. To determine the importance and priority level of all the causes, conducted FMEA to get the RPN value. FMEA was also used to identify the contingency plans to eliminate the probability or severity of the problem.

4. Improvement phase was to make some specific changes to counteract the causes after understanding what were the influencing factors in the previous phase. Design of experiments was the lean tool used in this project. Factorial design was adopted in this phase. Here Minitab was a very popular software for conducting DOE to get important analysis graphs such as main effects plot, contour plot, and surface plot etc., which helped to get the response optimizer for the researching objects.
5. The last phase of control was very important to sustain the implemented improvements and achieve the desired results continuously. The communication of the new methods, procedures, and responsibilities should be integrated into a training program for the process personnel. Control charts were used to indicate if the process was in statistical process control.

Data Collection and Analysis

Define phase. In order to meet the changes of market demands, the smart card company needed to make adjustments quickly and properly according to the capacity situation. To increase the overall capacity became an opportunity and inevitability for improvement.

a. **Define the Improvement Opportunity**. As what the author illustrated in above chapter, the equipment of embedding, grooving, encrypting, were in a U shaped assembly line. Their productivities were 3500 p/c, 2800p/c, and 3200 p/c. Grooving equipment contained two sets of machines, which had the lowest productivity of 1400 p/c among three working stations. Therefore the opportunity emerged. If the speed of grooving equipment increased 10% while other equipment's speed stayed constantly, it could make the whole assembly line an increase of 10% and achieved economic profits.

b. **Define the Requirements**. The producers and the customers had different requirements toward smart cards. Their requirements are listed in Table 3.2.

Table 3.2: Internal and External Requirements Table

Group	Requirements
Producers	-The force between the metal chip and the plastic part cannot be too small, in order to avoid being damaged or cracked on the assembly line.
	-Increase the grooving equipment speed to meet the speed requirements of the whole U shaped assembly line.
Customers	-The force between the metal chip and the plastic part cannot be too big, in order to avoid making too much effort to break off the chip and damage the circuitry.
	-No quality problems.

Depend on above requirements, the smart card company manufactured a set of detective device of simulating artificial card-breaking activity. They received an average power value for the connecting force between the metal chip and the plastic part of the smart cards. The smart card company unified the technical specification requirements for connecting force to be controlled within a range of 28 to 40 Newton.

If they could guarantee this condition for the force value, both the internal and external groups' needs were met.

c. **Build Six Sigma Team**. Build a Six Sigma team was very important to the project. The roles and responsibilities had to be clearly defined for the sponsor, champion, Master black belts, Black belts, Green belts and Facilitator. The author just worked as an intern along with the quality control team in the smart card company, who mainly responsible for analysis of the data and the charts.

d. **SIPOC Diagram**. SIPOC diagram helped the stakeholders to understand the scope of the process and agree the boundaries of what everyone should work on. It provided a structured way to discuss and get consensus on every procedure. The SIPOC diagram is shown in Table 3.3.

Table 3.3: SIPOC Diagram

Supplier	Input/Requests	Process	Output/Requests	Customer
Raw Materials Warehouse	The size of cards meets ISO7816 and company requirements; Cards materials meet national environmental requests.	Milling and Slotting	The cards should be flat and all the grooves are flawless, including the size and position of the slot.	Embedding Process
Milling & Slotting Process	Process SOP; The cards and slots are perfect.	Embedding	The cards meet the requests of direction, flatness, and the standards of firmness.	Grooving Process
Embedding Process	Process SOP; The cards meet the requests of direction, flatness, and the standards of firmness.	Grooving	The cards meet the customer needs; the size, position, shape, connecting force meet ISO 7816.	Encrypting Process
Grooving Process	Process SOP; The cards meet the customer needs; the size, position, shape, connecting force meet ISO 7816.	Encrypting	The cards shape and graph is qualified is well done with ink-jet and laser printing; the program.	Plastic Packaging Process
Encrypting Process	Process SOP; The cards shape and graph is qualified with ink-jet and laser printing; the program is well done.	Plastic Packaging	The cards get perfect plastic packaged; the appearance is good.	Packaging Process
	Plastic Packaging Process	Packaging	Meet customers' requirements of packaging.	Finished Product Storage

e. **Define the Benefits**. By conducting this project, the speed of grooving equipment increased, which contribute to the increasing yield of the U shaped line. Undoubtedly the smart card company will get profits from it. Therefore the quality control team and the author made a formula to calculate the direct profits from the project.

$$P = C * (Q - Q_0)$$

P: Direct profits after the improvement.

C: Stand for the fixed cost, which is the part of assembly line, including the cost of labor and equipment; it does not change during improvement.

Q: Annual yield after the improvement.

Q_0: Annual yield before the improvement.

Measure phase. The goal of this phase was to gather the data that described the nature and extent of the problem. First of all, the author chose the measuring objects before collecting the data. They were Y1 and Y2. Y1 stood for the speed of the grooving equipment. Two types of reference data were used to describe this speed. One is the producing cycle time for the single smart card, which could be used to make compare on the changes of speed during improvement. Another one is the monthly yield of the smart cards. Y2 stood for the defect-free rate of smart cards in the grooving process. The expectation was to improve Y1 while not bringing negative effects on Y2.

a. **Data Collection**. In order to analysis the data specifically and make compare with the future improvement, the ways of colleting data during the whole project must be consistent. The data of monthly yield would be downloaded from KPI database in company's ERP system. The data of producing cycle time of single smart card would be copied from the display panel on the equipment. Since all the equipment were the same type and the LED digital panel displayed clearly, this part of data collecting work was finished by the department engineers. Basically, the author used histogram and line graph to analyze the data in this part. The monthly yield and defect-free rate are shown in table 3.4. Histogram of monthly yield is shown in Figure 3.2; Line graph of monthly defect-free rate is shown in Figure 3.3.

Table 3.4: Monthly Yield and Defect-free Table

Item	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Yield (million pieces)	6.60	6.72	6.81	6.67	6.79	6.74
Defect-free Rate %	99.961	99.962	99.963	99.959	99.963	99.960

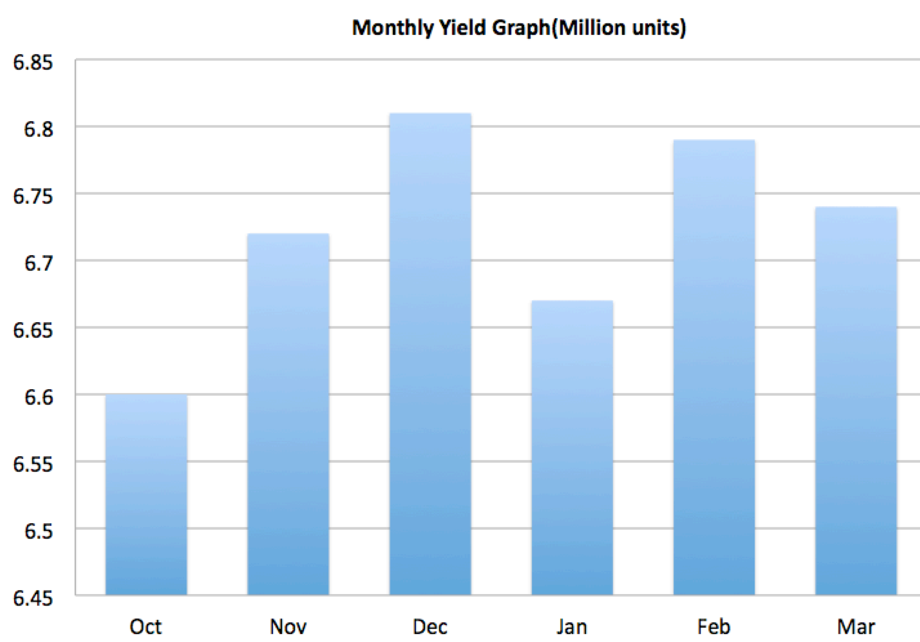

Figure 3.2: Histogram of Monthly Yield

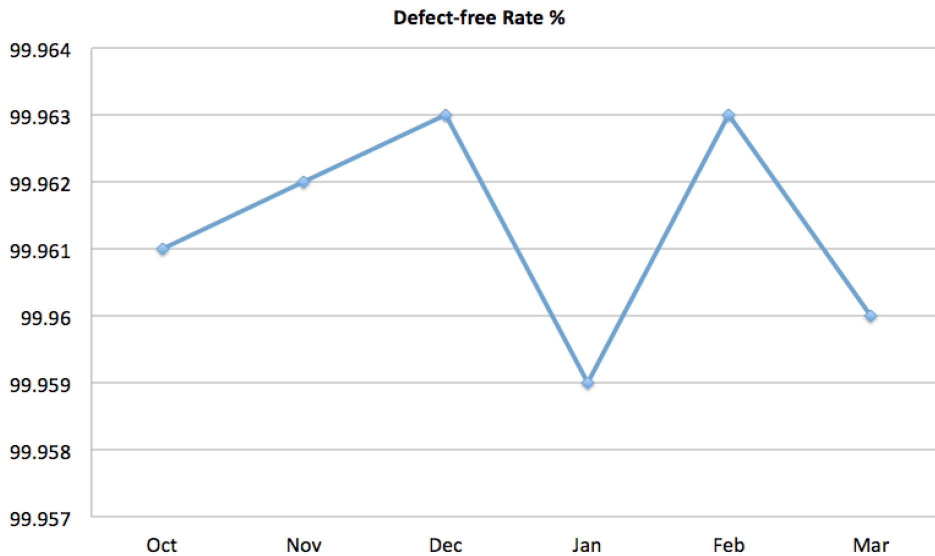

Figure 3.3: Line Graph of Monthly Defect-free Rate

b. **Attribute Agreement Analysis of MSA**. To evaluate the accuracy and precision of subjective ratings made by multiple operators, the author chose to use attribute agreement analysis way, which is a branch of MSA. The defect-free rate belonged to attribute data. It was the data that had quality characteristic of whether the products meet the specification or not. In this company, every process had to conduct self-check before the products going to the next process. That meant every operator worked on the assembly line needed to make a subjective judgment on the quality of the smart cards. The standards and frequency of check based on the requirements from the company. In order to verify the operators' abilities of judging and classifying on the defective products, attribute agreement analysis is an ideal tool to figure out how likely the measurement system was to misclassify a part. There were several types of defective smart cards:

A. Damaged card body; deformation or serious damage on card due to the mechanical drive failure on equipment.

B. Flocks; existed flocks that stick on the card edges during producing.

C. Connecting force beyond requirement range.

D. Punching shift; the size and position of cards changed due to the mechanical location problem.

E. Surface scratches; scratches on smart card body or metal chip.

F. Cross structure cracks; connecting structure failures result from the grooving process troubles.

In this phase the quality control team collected 50 smart cards including all kinds of typical defective cards in. Then they picked up five operators randomly on the assembly line for checking the quality of smart cards, except the most inexperienced and the most sophisticated operators. These five operators made one time classification on the 50 smart cards and collected the judgment results. Finally, the quality control team and the author used Minitab to analyze the data.

From the results, in Figure 3.4, the appraise ability of operator “d” was the best; operator “c” was in the next place. The entire assessment agreement rate was 86% based on 95% confidence interval, which was greater than the usual acceptable rate of 80%. Also, the assessment agreement between appraisers was good. Therefore the judgment abilities and assessment agreement of operators were credible.

Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
a	50	48	96.00	(86.29, 99.51)
b	50	48	96.00	(86.29, 99.51)
c	50	49	98.00	(89.35, 99.95)
d	50	50	100.00	(94.18, 100.00)
e	50	48	96.00	(86.29, 99.51)

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

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
50	43	86.00	(73.26, 94.18)

Matched: All appraisers' assessments agree with each other.

All Appraisers vs Standard

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
50	43	86.00	(73.26, 94.18)

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

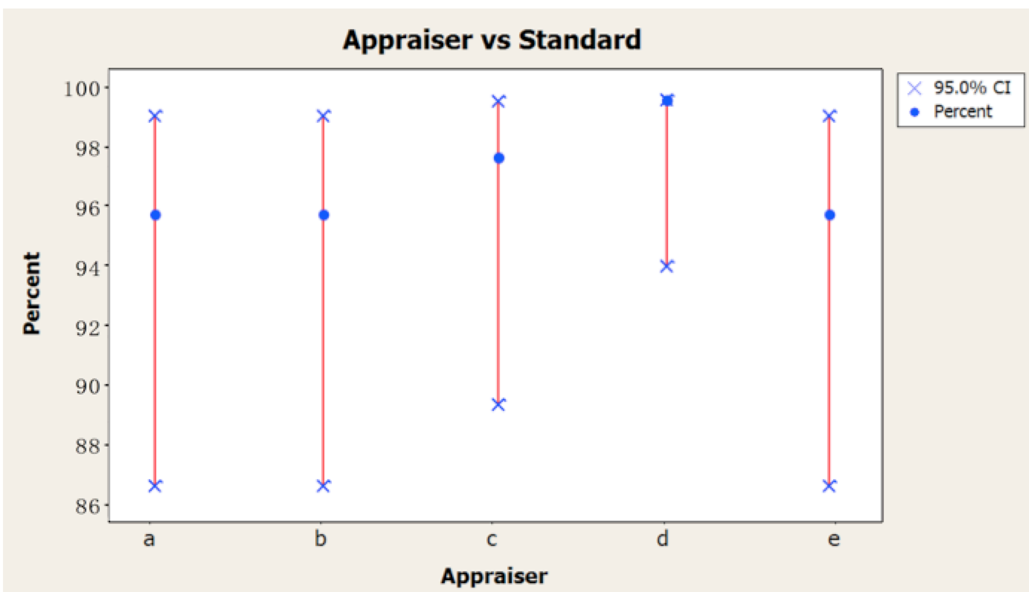

Figure 3.4: Attribute Agreement Analysis Figure

c. **Measure the Potential Factor**. The quality control team brainstormed the reasons that cause the defects on smart cards and the relative low productivity. Then they made fishbone diagram in types of staff, equipment, materials, environment and produce methods. The fishbone diagram also named cause-and-effect diagram, which is shown in Figure 3.5.

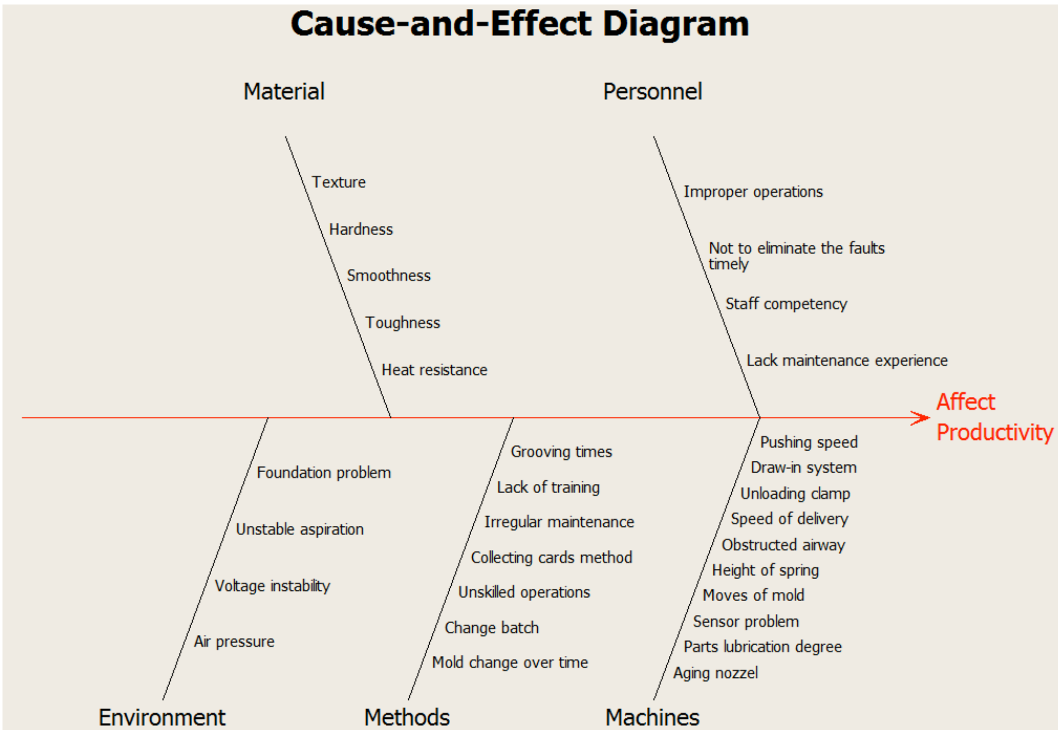

Figure 3.5: Cause-and-Effect Diagram

The quality control team picked out the reason of times of grooving to measure, which was easy to verify and caught the most doubts on. They adjusted the previous two-time grooving to only one-time grooving and found the speed of grooving equipment increased obviously. The cycle time of producing single card was changed from 2.49 seconds to 2.19 seconds. The display panels on equipment are shown in Figure 3.6.

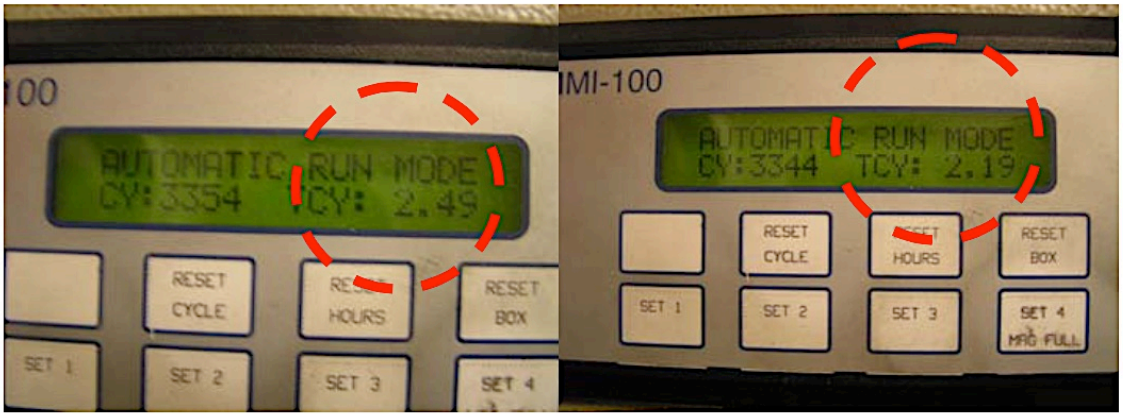

Figure 3.6: Comparison Figure of Display Panels on Equipment

However, the connecting force was out of the required range when changing the grooving times. The quality control team had to ensure the defect-free rate was acceptable although the yield was changing. Thus the next step was to find the way to maintain the required connecting force.

d. **T-test for measuring devices**. Under the premise of one-time grooving, the quality control team had to make sure the connecting force was in the required range. First of all, to ensure there were no differences between the measuring devices and the results of measurement were specific and reliable, the quality control team decided to use T-test method. The first step of conducting two-sample T-test was to raise the null hypothesis and alternative hypothesis. The measuring devices with LED digital display screens were provided by the company. Experiment process was to have one operator grooved one smart card sample from its two edges, then measured the two forces by using device A and device B, in this way could the operator maintain the same experiment conditions and material, only leaving the connecting force as the only variable. The sample size was 20. Result is shown in Table 3.5.

Table 3.5: Data Table of T-test

Card No.	X_i (Device A)	Y_i (Device B)	$D_i = X_i - Y_i$
1	33.09	33.07	0.02
2	33.35	33.43	-0.08
3	33.06	33.11	-0.05
4	33.87	33.98	-0.11
5	33.54	33.54	0
6	35.86	35.85	0.01
7	35.95	35.93	0.02
8	34.12	34.08	0.04
9	33.61	33.64	-0.03
10	34.14	34.10	0.04
11	34.65	34.66	-0.01
12	34.47	34.47	0
13	34.31	34.31	0
14	34.55	34.56	-0.01
15	33.53	33.55	-0.02
16	33.34	33.29	0.05
17	34.23	34.21	0.02
18	34.12	34.10	0.02
19	33.61	33.61	0
20	35.66	35.67	-0.01
Average	34.153	34.158	-0.005
Standard Deviation	0.895	0.851	0.0394

H_0: There is no significant difference between device A and device B; $\mu1 - \mu2 = 0$

H_1: There are differences between device A and device B; $\mu1 - \mu2 \neq 0$

Two-Sample T-Test and CI: Device A, Device B

```
            N    Mean   StDev  SE Mean
Device A   20   34.153  0.859     0.19
Device B   20   34.158  0.851     0.19

Difference = mu (Device A) - mu (Device B)
Estimate for difference:  -0.005
95% CI for difference:  (-0.552, 0.542)
T-Test of difference = 0 (vs not =): T-Value = -0.02  P-Value = 0.985  DF = 38
```

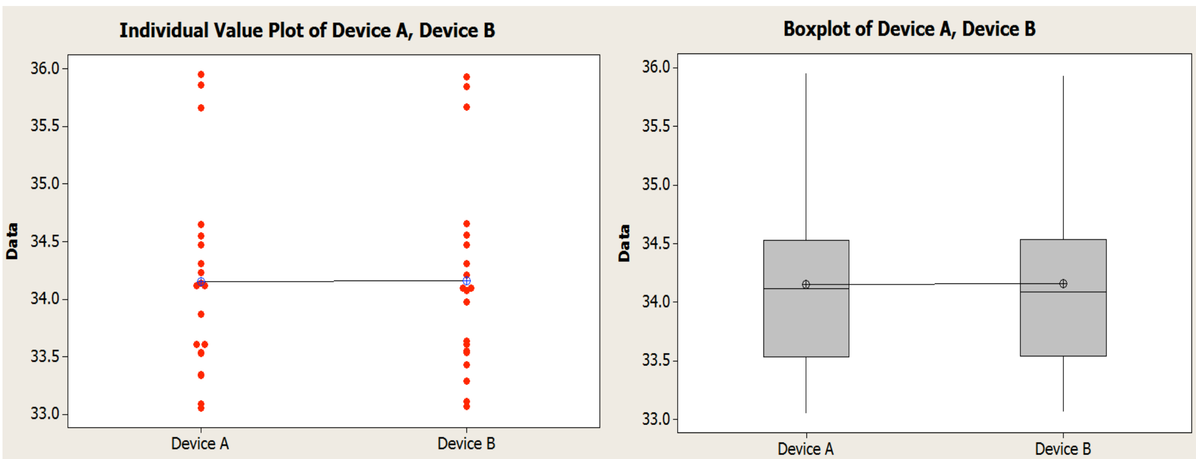

Figure 3.7: T-test Results Figure

In T-test, the T-value measured the size of the difference relative to the variation in the sample data. The greater the magnitude of T-value is, the greater the evidence against the null hypothesis; the closer T-value is to 0, the more likely there is not a significant difference. The results indicated T-value was 0.02, and P-value was 0.985, which stood for the null hypothesis could not be rejected. There was no significant difference between device A and device B, which also proved that the measurement system was reliable.

e. **Capability Analysis (Binomial)**. To understand the current system's capability, the author adopted binomial process capability analysis method. The data used was the ratios of smart cards from October 2014 to March 2015. The result is shown in Figure 3.8.

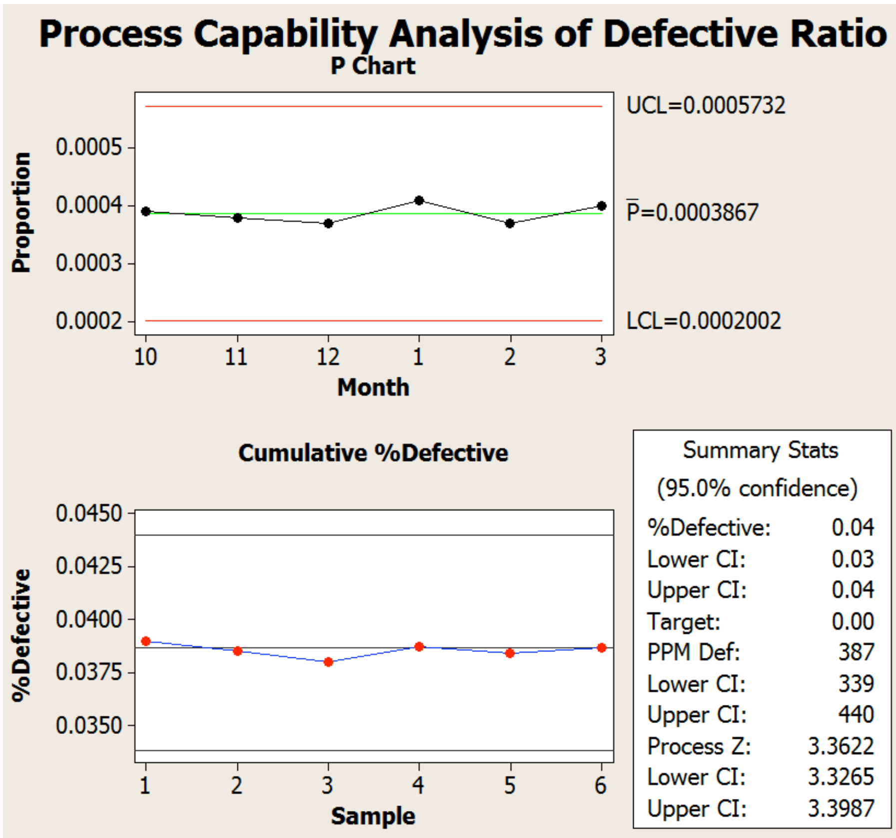

Figure 3.8: Figure of Process Capability Analysis

The P chart and cumulative defective ratio chart indicated the process capability of defective rates of smart cards in the past six months was in the control. Sigma capability was 3.36. PPM was 387.

Analysis phase. In this phase the quality control team wanted to figure out the potential causes that made effects on the connecting force. Then they raised hypothesis on the reason and examined the possibilities, in order to come up with the suggestions for improvement.

a. **FMEA**. Failure modes and effects analysis is a methodical approach for preventing defects by prioritizing the problems. It is also used to identify the contingency plans to eliminate or reduce the probability or severity of the problem. The author defined the function of each procedures of grooving process and identified the failure modes and their effects for each function. Then marked the severity for failure modes, the probability of occurrence and the likelihood of detection. The rating for security, occurrence and detection is shown in Table 3.6. The final FMEA results are shown in Table 3.7.

Table 3.6: Rating Table for FMEA

Scale	Severity	Occurrence		Detection	
			Frequency (1in...)		Certainty
1	No effect	Likelihood is remote	1 000 000	Sure that the potential failure will be found	100%
2	Cannot draw in the card	Low failure rate with proof	20 000	Almost certain that the failure will be found	99%
3	Cards with flocks	Low failure rate without proof	5 000	Low likelihood that the failure will be found	95%
4	Cards deformation and damage	Occasional failures	2 000	The potential failure might be found	90%
5	Cards cracks	Relatively moderate failure rate with proof	500	Moderate likelihood that the failure will be found	85%
6	Severe damage on cards	Moderate failure rate without proof	100	Controls are unlikely to detect or prevent the failure	80%
7	Forcse beyond range	Relatively high failure rate with proof	50	Poor likelihood that the failure will be detected	70%
8	Cards break up	High failure rate without proof	20	Very poor likelihood that the failure will be detected	60%
9	Cards damage equipment	Failure is almost certain based on proof	10	Current controls probably will not detect the failure	50%
10	Equipment break down	Assure of failures	2	Absolutely certainty that the current controls are useless	<50%

Table 3.7: FMEA Table

Process Function	Potential Failure Mode	Potential Effect of Failure	S	Potential Cause of Failure	O	Current Design Controls	D	RPN
Operations	In what ways can process step go wrong	What is the impact on the failure mode	How sever is the effect	What are the causes of the failure mode	How often does the cause occur	What are the existing controls and procedures that prevent the causes	How well can you detect the cause	Calculate rike priority number
Draw in the cards	Draw-in failure	Cards get stuck in; scratches on cards	4	Too much flocks block the vacuum nozzle, or damage the valve of vacuum tube	2	Check and repair	2	16
Delivery	Track delivery failure	Cards get stuck	3	The airway is obstructed	2	Unchoke airway	2	12
Push the cards into mold tracks	Push track failure	Cards get stuck and damaged	4	The airway is obstructed	1	Unchoke airway	2	8
Posit cards to the required point	Inaccurate position	Grooving position shift	3	Position devices are faulty or get stuck by flocks	2	Check and repair	4	24
Grooving	Springs problem	Indentation and cracks on cards	2	Flocks on molds	3	Clean and repair the molds	2	12
	Molds match-up problem	Cards get damaged and crack on the body	5	Aging molds or improper molds	6	Update molds	4	120
	Upper mold problem	Forces beyond required range	7	Defective molds	5	Hard to solve	4	140
	Lower mold problem	Forces beyond required range	7	Defective molds	5	Hard to solve	4	140
	Stocking cutter problem	Forces beyond required range	7	Defective molds	5	Hard to solve	4	140
	Mold operating distance of each move	Cards get deformation or damaged	4	Improper operating move	4	Adjust move	6	96
	Flocks on the edges of cards	Cards with flocks	2	Aging molds or improper molds	2	Check and repair	3	12
Push the cards out of molds	Push-out failure	Cards get stuck and damaged	4	The airway is obstructed	2	Unchoke airway	2	16
Upper draw in the cards	Upper draw-in failure	Cards get stuck in or fall down	4	Too much flocks block the vacuum nozzle, or damage the valve of vacuum tube	3	Check and repair	1	12
Lead screw move	Lead screw move failure, not on position	Cards get stuck	2	Physical damage, lack of engine oil	4	Check and repair	3	24
Put the cards into storage box	Storage boxes are out of position or sent out of time	Cards fall down from equipment	2	The airway is obstructed	2	Check and repair	2	8

The author calculated the RPN (risk priority number) by multiplying the severity, occurrence and detection levels. Figure 3.9 is the Pareto chart of RPN values.

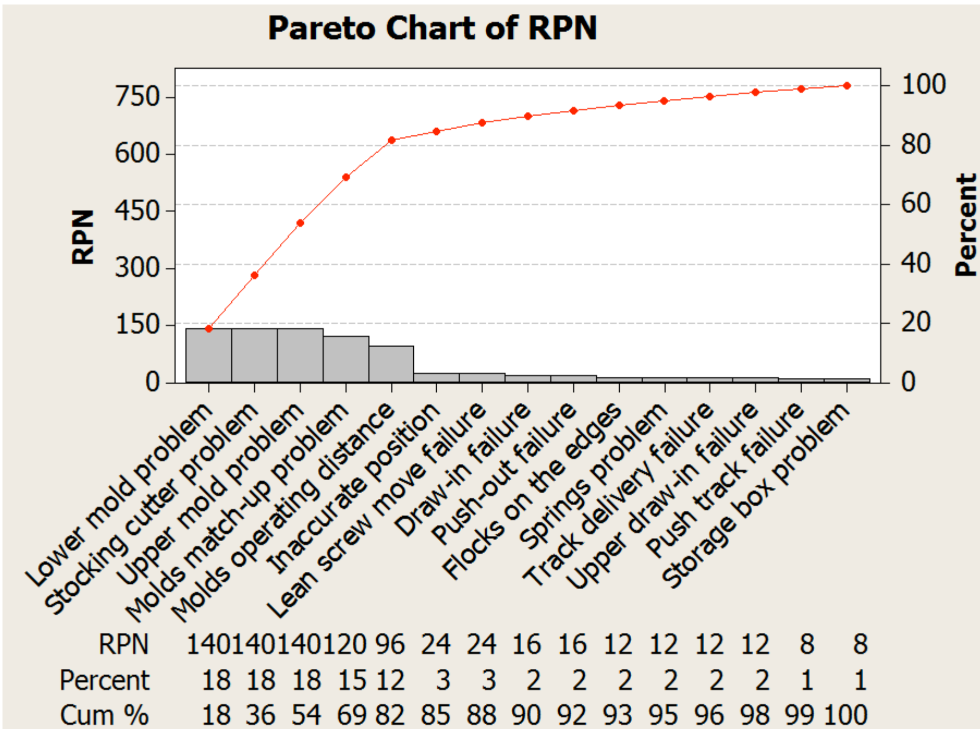

Figure 3.9: Pareto Chart of RPN Values

b. **Find significant factor**. From above analysis, the way to increase the operating speed of grooving equipment was found already. However, how to maintain the connecting force became the problem to be solved next. The first five significant factors that would be influencing the connecting force are shown in Pareto chart of RPN value.

Lower mold: The lower component of the entire mold, a concave part cooperates with the upper mold. The main point for this part is to investigate the sharpness of cutting edge.

Stocking cutter: Two sets of cutters nested in the middle of entire mold, the function is to finish the pre-cut process and make grooving line on the cards. The main point for this part is to examine the cutter size.

Upper mold: The upper component of the entire mold, a convex part consists of three blades. The main point for this part is to investigate the sharpness of cutting edge.

Molds match-up: The mold assembling conditions of all the components. The match-up problems probably exist even if every assemble process is in the same criteria. Some may result from the motions of assembling; some are due to the working habits of different assembling operators.

Molds-operating distance: The motion distance of the molds operating in each complete cycle (He & Dong, 2005, p. 106).

To conduct a further analysis, the quality control team quantized the levels for five factors. The original sizes of stocking cutter were 0.31mm and 0.34mm. The adjusted sizes were 0.55mm and 0.60mm. The new size was not an exact value, it was the relatively large value used to determine whether the factor really has main effect. The new set of stocking cutters were provided by the supplier and the sizes were designed depend on their processing experience. The design drafts are shown in Figure 3.10.

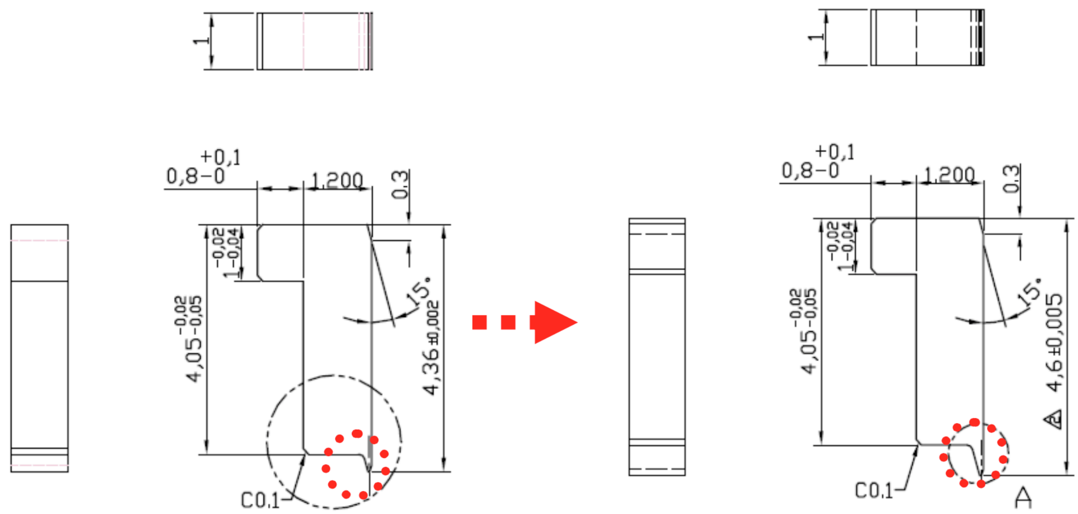

Figure 3.10: Design Drafts of Stocking Cutters

Budget

The smart card company covered all the cost of this project including the software providing and technical consulting.

Timeline

The project started in December 2014, and ended in August 2015. The timeline of this project is shown in Gantt chart in Figure 3.11.

	Task Name	Duration	Start	Finish
1	Define the objective and significance of the project	3 days	Mon 12/1/14	Wed 12/3/14
2	Define the problem	2 days	Thu 12/4/14	Fri 12/5/14
3	Define the personnel and build team	2 days	Mon 12/8/14	Tue 12/9/14
4	Define requirements and improvement opportunity	5 days	Wed 12/10/14	Tue 12/16/14
5	Define phase summary	1 day	Wed 12/17/14	Wed 12/17/14
6	Collect and analyze data	20 days	Thu 12/18/14	Wed 1/14/15
7	Measure process capability	10 days	Thu 1/15/15	Wed 1/28/15
8	Find out the influencing factors	10 days	Thu 1/29/15	Wed 2/11/15
9	Measure and Analysis phase summary	1 day	Thu 2/12/15	Thu 2/12/15
10	Design of experiment	20 days	Thu 2/12/15	Wed 3/11/15
11	Verify the improvement effect	15 days	Thu 3/12/15	Wed 4/1/15
12	Improve phase summary	1 day	Wed 4/1/15	Wed 4/1/15
13	Testing stage	109 days	Wed 4/1/15	Mon 8/31/15
14	Improving results classified and documented	8 days	Thu 8/20/15	Mon 8/31/15
15	Control phase summary	1 day	Tue 9/1/15	Tue 9/1/15
16	Write report and documents	30 days	Mon 8/3/15	Fri 9/11/15

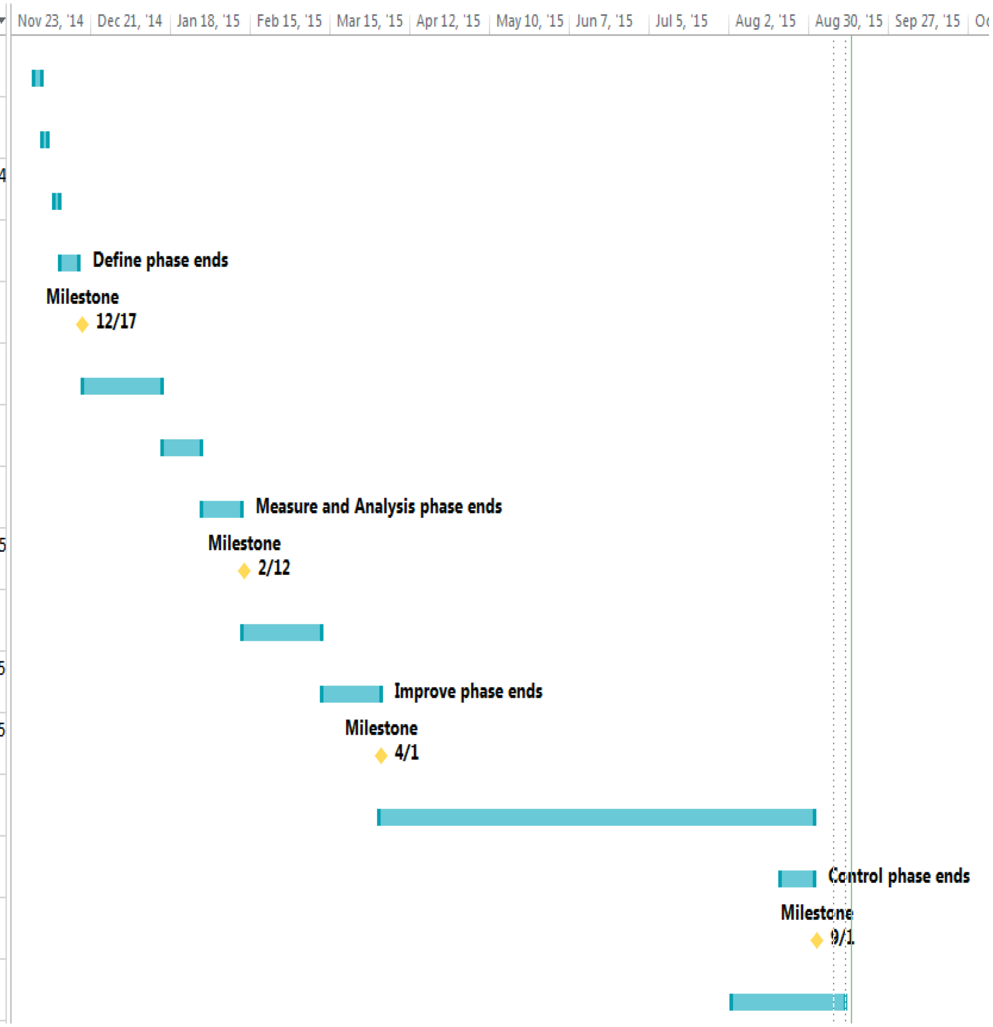

Figure 3.11: Timeline Gantt Chart

Summary

In this chapter, the author presented the study framework of this project. And explained the methodology that used in the every phase, the methods of data collecting and analyzing in DMAIC order. The budget and timeline were presented also. In next chapter, the presentation and detailed analysis of data will be introduced.

Chapter IV: Data Presentation and Analysis

Introduction

In this chapter, the author makes overall data presentation, and a further analysis of data, especially regarding the improve phase and the control phase of this project.

Data Presentation and Analysis

Improve phase. In this phase, the situations were not clear as to what caused the problem. In addition, there were several process parameters need to be considered. Therefore DOE was the best alternative to make a factorial analysis and got the response optimizer of the factor (Hong & Hou, 2007, p. 256). From the last chapter the first five influencing factors that need to be improved were summarized. They were lower mold, stocking cutter, upper mold, molds match-up and molds-operating distance. Because the levels of molds match-up mainly depended on the operators' subjective working methods, which needed to be unitized and standardized, it would not be designed as a factor in this experiment. The levels of the remaining four factors were defined in Table 4.1.

Table 4.1: Four-factor and Two-level Model

Factor	Level 1	Level 2
A: Lower Mold	Old and worn part	New part
B: Stocking Cutter	Size of 0.31 & 0.34mm	Size of 0.55 & 0.60mm
C: Upper Mold	Old and worn part	New part
D: Mold-operating Distance	Low position	High position

This was the 4-factor and 2-level model of DOE. The author conducted 16 sets of experiments and measured the different connecting forces. Then the data were analyzed by using Minitab. The result is shown in Figure 4.1 and Figure 4.2.

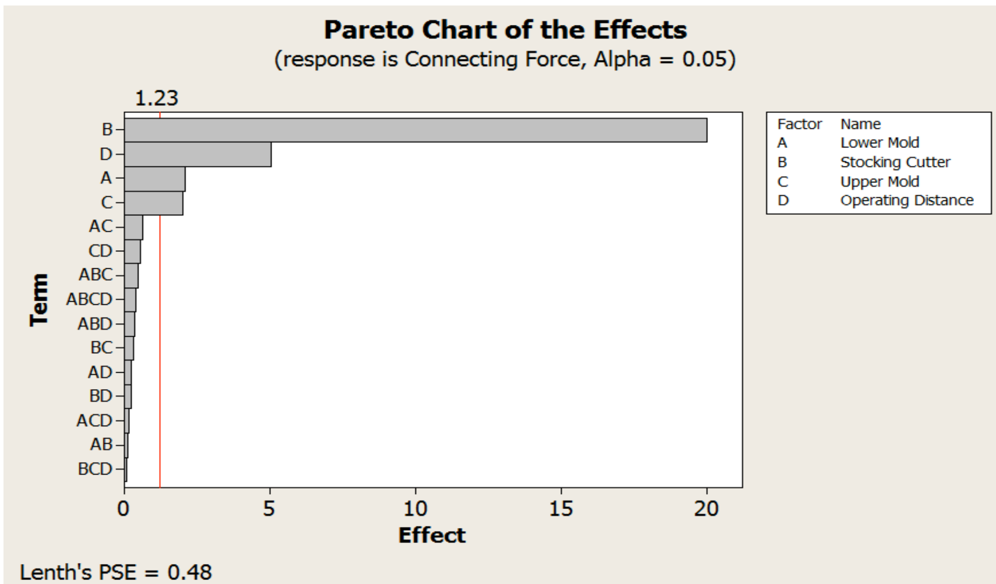

Figure 4.1: Pareto Chart of the Four-factor Effects

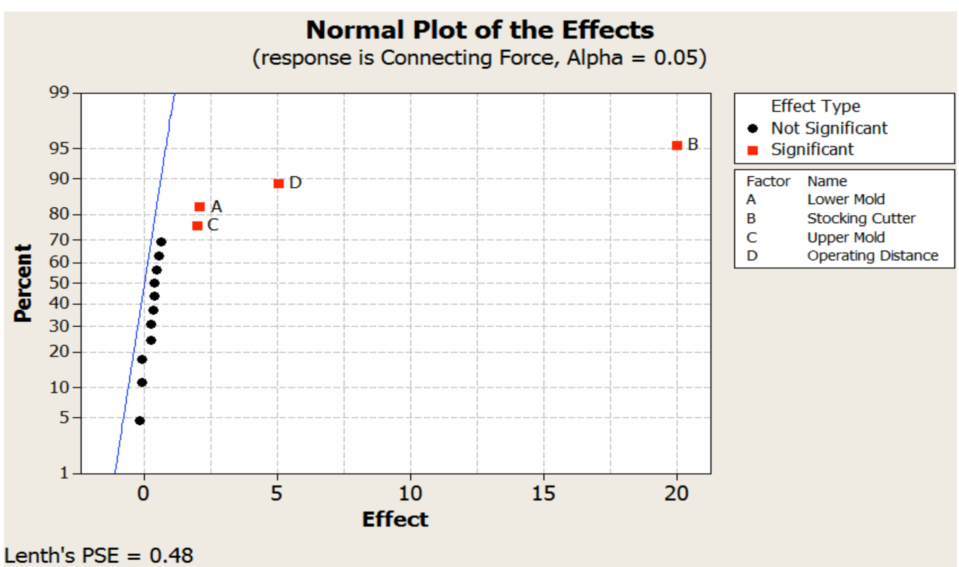

Figure 4.2: Normal Plot of the Four-factor Effects

From the Pareto chart and normal plot of the effects, all the four factors were influencing the connecting force significantly and independently. Especially factor B, stocking cutter, was beyond the red line and far away from other factors.

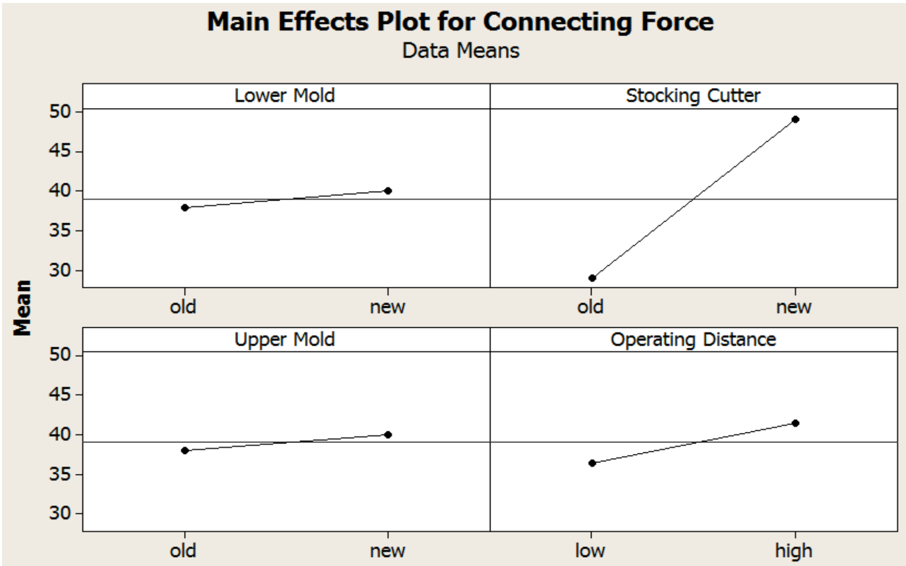

Figure 4.3: Main Effects Plot for Connecting Force

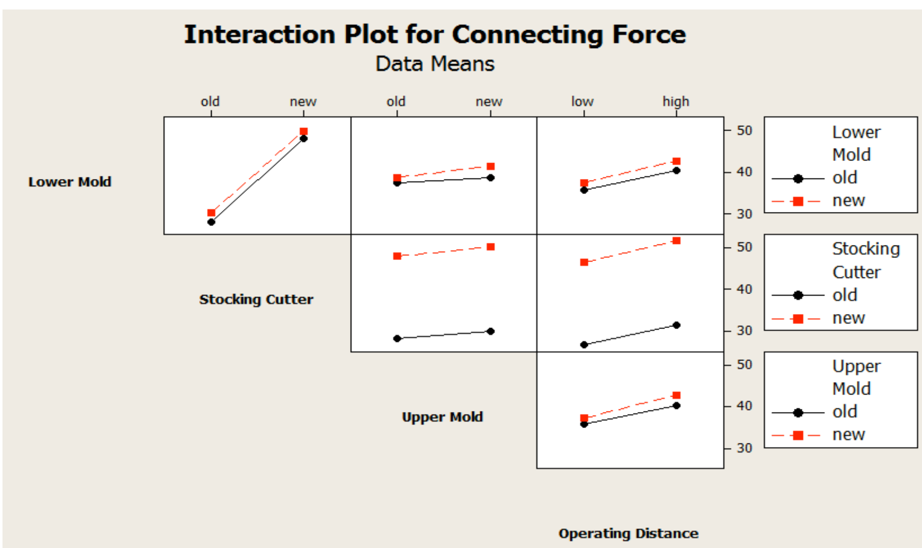

Figure 4.4: Interaction Plot for Connecting Force

In the main effects plot, shown in Figure 4.3, the line of lower mold, upper mold and operating distance tended to flat due to the small slope, which meant they did not have important effects to connecting force no matter the mold was wore or new. While the interaction plot, shown in Figure 4.4, indicated all the four factors did not have interaction with each other.

As far as this stage, there was no doubt the most significant factor, stocking cutter, was needed to be redesigned for the project. The author designed another experiment for stocking cutter in order to determine the best size of cutters. The original size of cutters were 0.31mm and 0.34mm, while the reference size of cutters used in the experiment that provided by supplier were 0.55mm and 0.60mm. The two sets of cutters were defined as cutter A and cutter B. Thus the second experiment was a 2-factor and 2-level model. The experiment data is shown in Table 4.2. The results from Minitab are shown in Figure 4.5.

Table 4.2: Two-factor and Two-level Model

Factor	Level 1	Level 2
Cutter A	0.31mm	0.55mm
Cutter B	0.34mm	0.60mm

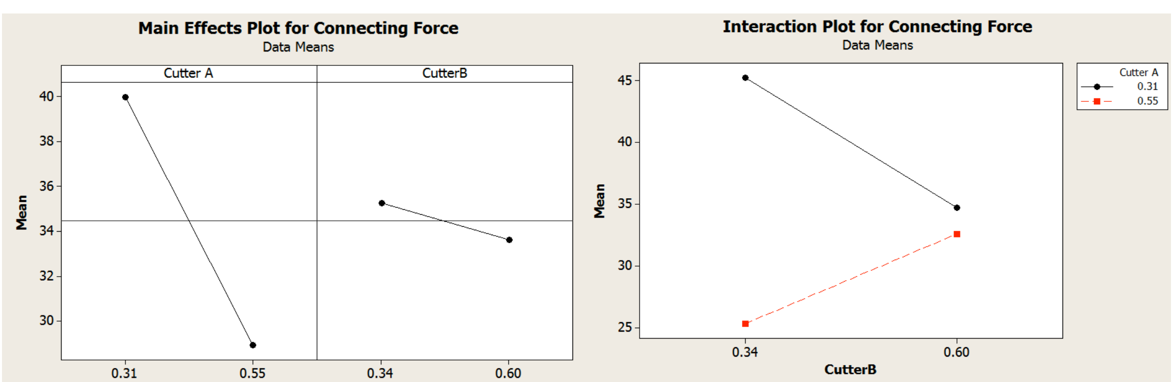

Figure 4.5: Effects Plots for Connecting Force

From the main effects plot and interaction plot for connecting force, both cutter A and cutter B had effects toward connecting force and they had interaction to each other. To find the optimal sizes of cutter A and cutter B became the critical task.

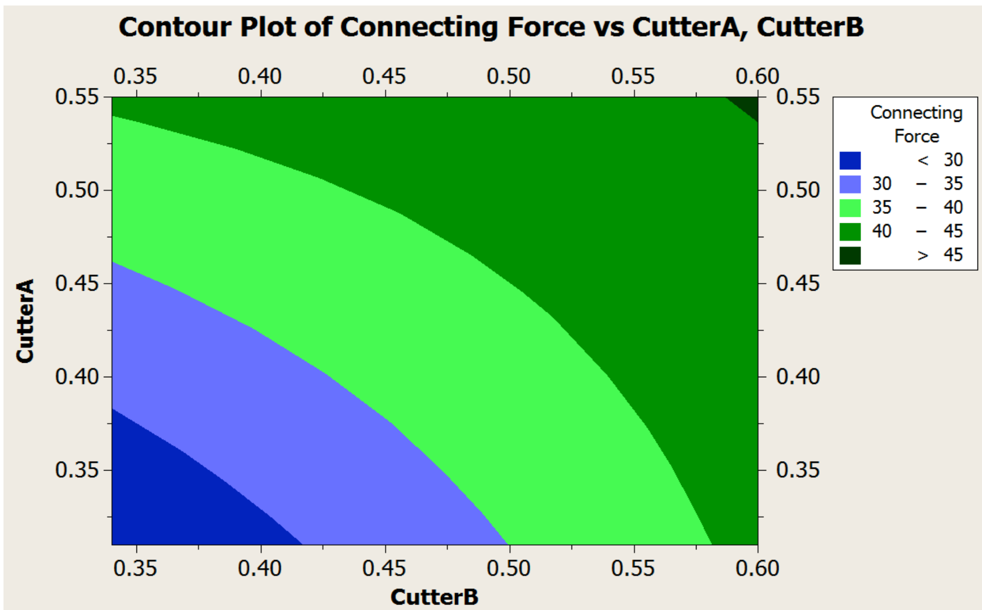

Figure 4.6: Contour Plot of Connecting Force vs. Cutter A, Cutter B

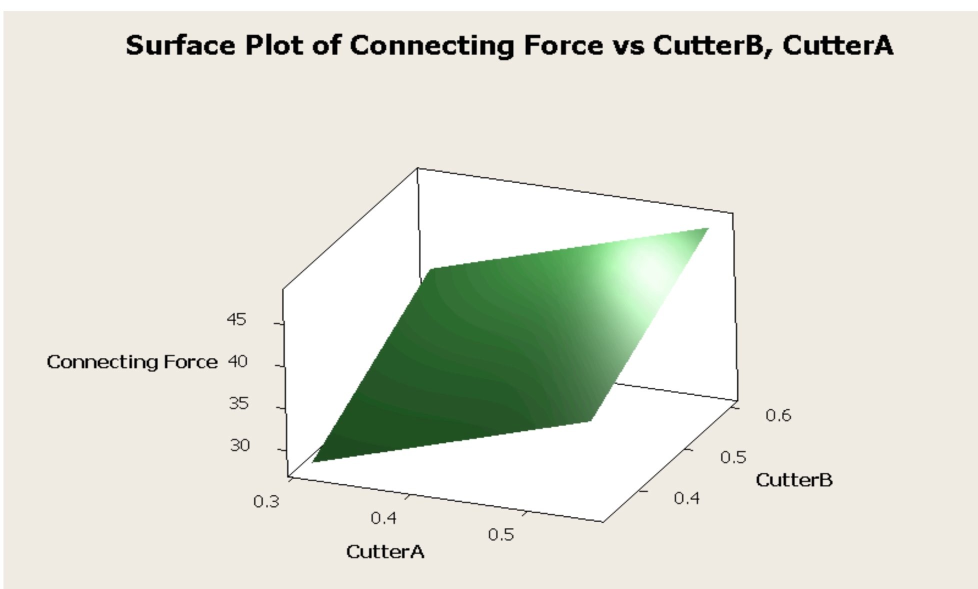

Figure 4.7: Surface Plot of Connecting Force vs. Cutter A, Cutter B

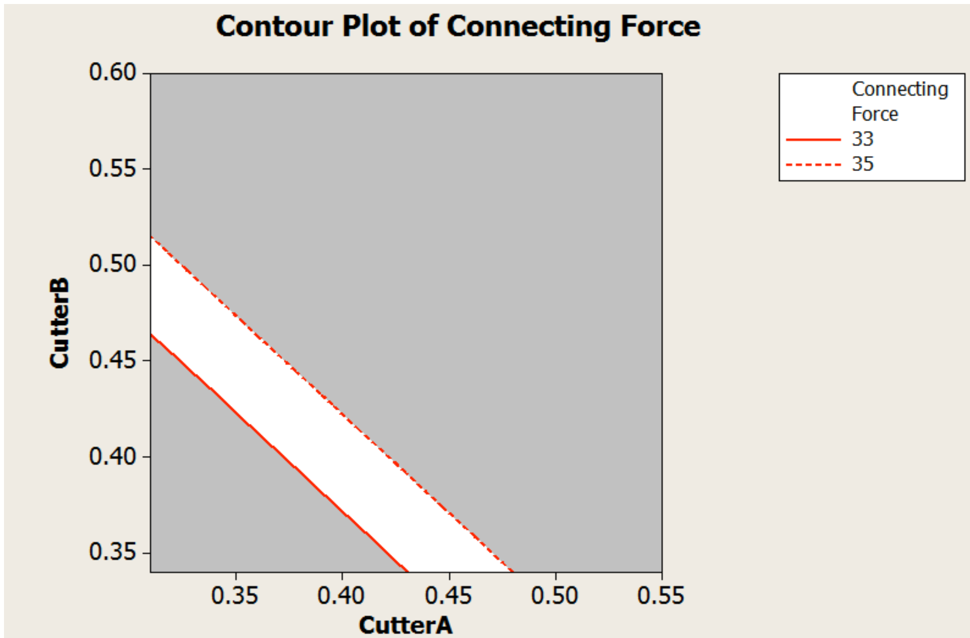

Figure 4.8: Contour Plot of Connecting Force

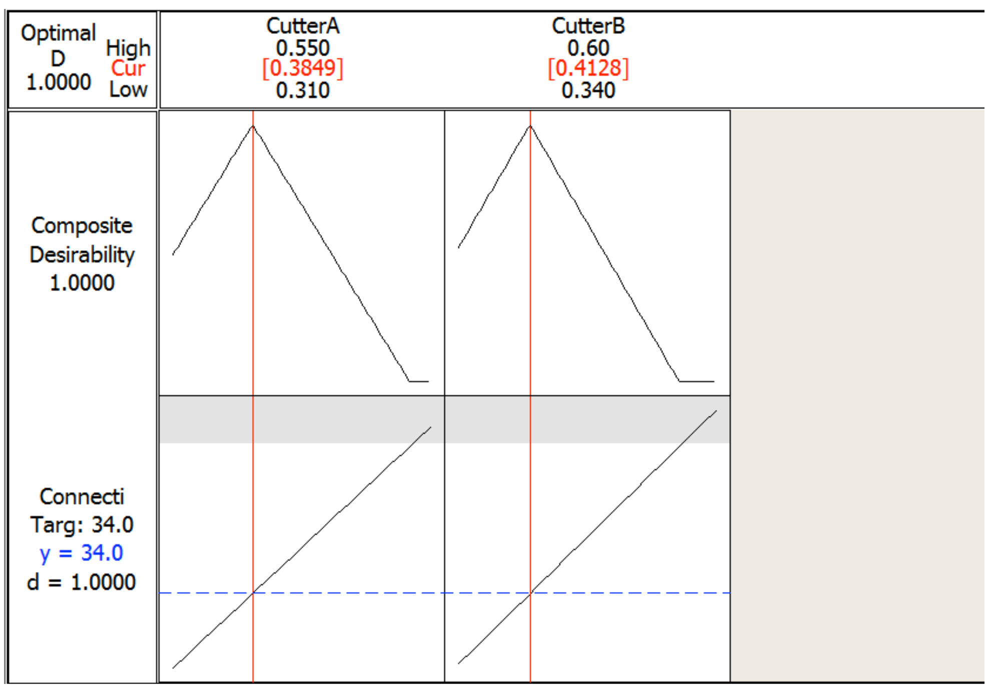

Figure 4.9: Response Optimizer Figure

Above were the contour plot in Figure 4.6 and Figure 4.8, and the surface plot in Figure 4.7, the optimal sizes of cutters for getting an average connecting force within required range could be distinguished. However the specific values for cutters could be read from the Figure 4.9 of the response optimizer. They were 0.39mm for cutter A and 0.41mm for cutter B. The supplier produced the new sets of cutters depend on the feedback, and the new cutters were set up to conduct examination immediately.

Control phase. This phase was very important to sustain the improvements and maintain the desired results continuously. The new sets of cutters were put into use and had a fifteen-day examination. The control team conducted capability analysis for the new connecting force.

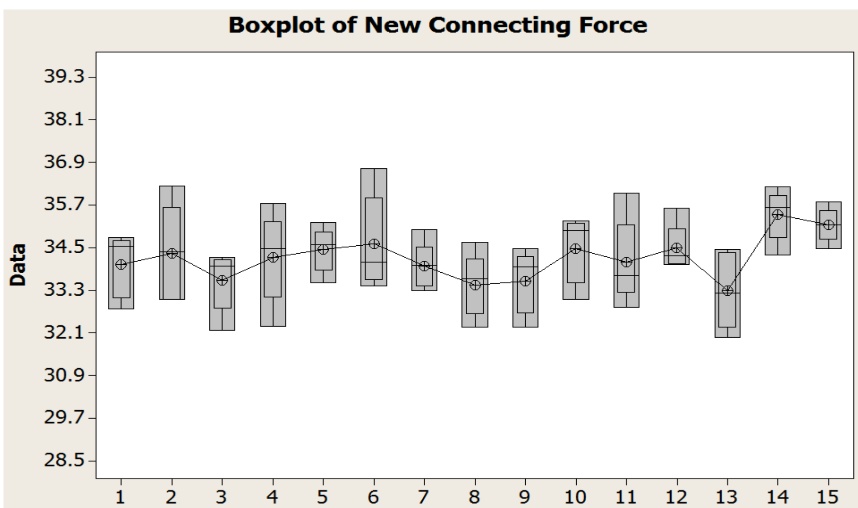

Figure 4.10: Boxplot of New Connecting Force

The boxplot in Figure 4.10 indicated that the new connecting force was in a relatively stable status in the fifteen-day examination. There was no outlier in the plot. The connect line of mean values fluctuated slightly. The upper and lower boundaries were within the range of 32 to 37 Newton, which did not exceed the required range of 28 to 40 Newton.

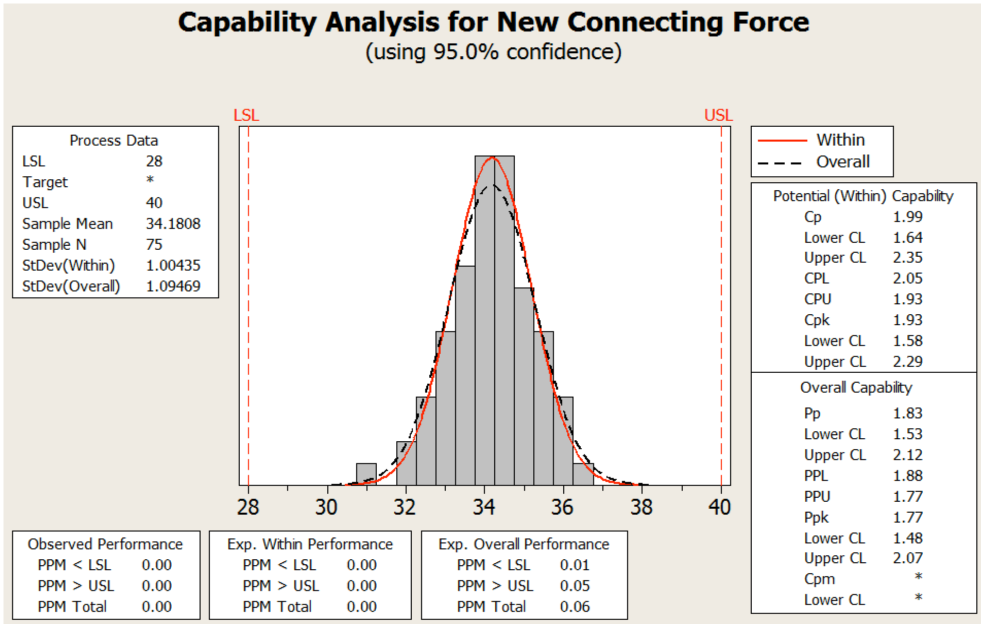

Figure 4.11: Figure of Capability Analysis for New Connecting Force

The capability analysis showed that the new process was normally distributed. The histogram did not exceed the upper specification limit or the lower specification limit. The mean value was 34.18, which was perfectly met standards. Additionally, some statistics that can be used to measure the capability are on the right side of the histogram, which is shown in Figure 4.11.

$$C_p = \frac{USL - LSL}{6 \times \hat{\sigma}}$$

$$C_{pk} = min\left(\frac{USL - \mu}{3 \times \hat{\sigma}}, \frac{\mu - LSL}{3 \times \hat{\sigma}}\right)$$

$$P_p = \frac{USL - LSL}{6 \times s}$$

$$P_{pk} = min\left(\frac{USL - \mu}{3 \times \hat{\sigma}}, \frac{\mu - LSL}{3 \times \hat{\sigma}}\right)$$

Generally, Cp determines the spread of the process while Cpk determines the shift in the process. Both these indexes provide information about how the process is performing with respect to the specification limits. Here Cp was 1.99 and Cpk was 1.93, which stood that the current process capability was perfect and there was no need to adjust anymore. It also meant the new sets of cutters fit the standards perfectly. In addition, the Pp and Ppk proved that the overall capability was also very good.

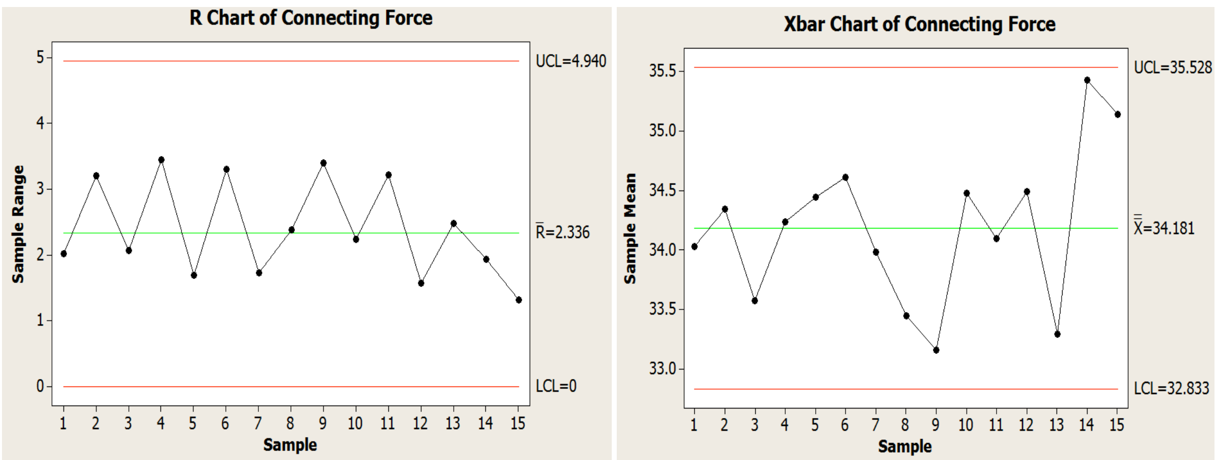

Figure 4.12: R Chart and Xbar Chart of Connecting Force

R chart and Xbar chart are used together to show the sample means and the variations within the poles through their spread. R chart tracks the amount of variability in the pattern of measured valued; Xbar chart tracks the center of the pattern of measured values. From above control charts shown in Figure 4.12, all the plots were within the control limits and the variation exhibited a random pattern around the mean, thus the process was stable and under control.

The quality control team recorded the monthly yield and defect-free rate after improvement for five months. The data is shown in Table 4.3. Here was an overall comparison.

Table 4.3: Monthly Yield and Defect-free Rate Table after Improvement

Item	Apr	May	Jun	Jul	Aug
Yield (million pieces)	8.15	7.64	7.45	7.50	8.20
Defect-free Rate %	99.971	99.970	99.972	99.968	99.970

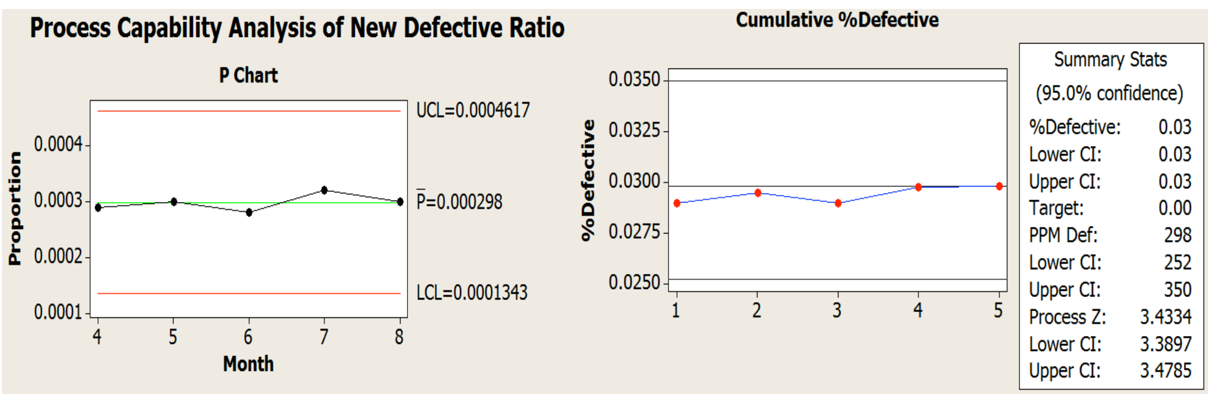

Figure 4.13: Figure of Process Capability Analysis for New Defective Ratio

Compared with the previous six months, both the monthly yield and defect-free rate increased. The new results in Figure 4.13 showed that the process capability of defective rates of smart cards from April to August was in the control. Sigma capability was 3.43, which increased compared with the previous capability 3.36. PPM was 298, which meant the defective parts per million decreased compared with the precious PPM 387.

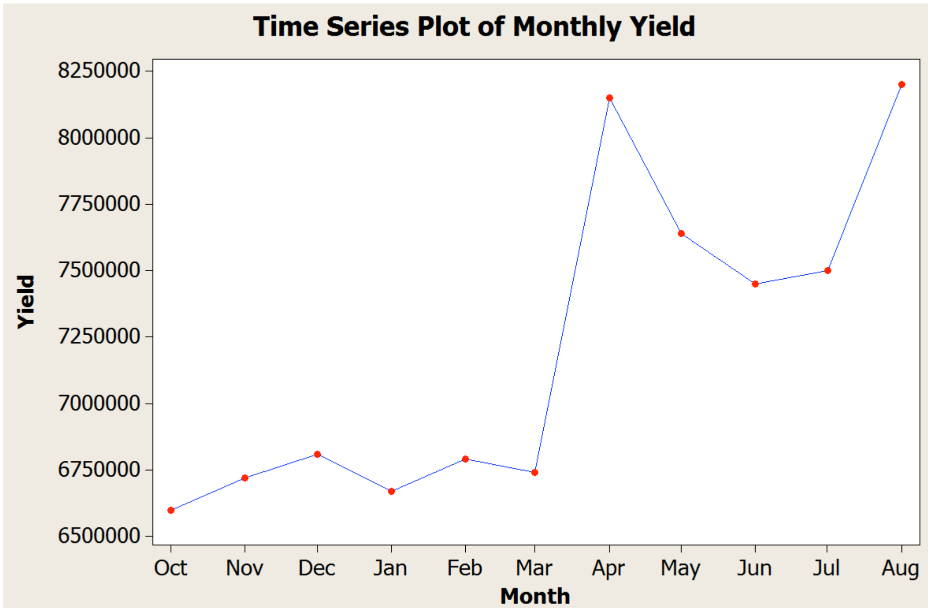

Figure 4.14: Time Series Plot of Monthly Yield

Lastly, the time series plot of monthly yield in Figure 4.14 presented the obvious changes after the improvement. The yield increased dramatically from April and kept in a stable status.

Depend on the formula for direct benefits the author calculated the annual profits after the improvement roughly. Profits = 0.03 RMB *(93456000 pieces – 80660000 pieces) = 383880 RMB.

In order to maintain the desirable results of improvement, the company decided to make the working process standardized and documented the improving methods. They are listed in Table 4.4

Table 4.4: Table of Documentation Lists

Documentations	Requirements
Operation Standards	A. Standardizing the grooving operation procedures and methods. B. Training personnel, and conduct ability assessment for management regularly.
Improving Methods	A. Update the new molds and the changeover methods. B. Share the drawing of new cutters with every department. C. Collect and analyze data from ERP system regularly.
Process Management	A. Measure and record every test indicator regularly especially the connecting force. B. Make regular maintenance plan for equipment. C. Producing department summarizes and reports the yield and defect-free rate every month. D. Quality management department checks the monthly report and submits to upper management department.

Summary

In this chapter, all the data regarding the improve phase and the control phase were presented and analyzed in detail, combined with corresponding charts and figures. The documentations after improvement were offered by the control team and the author at last. The results, conclusion and recommendations for this project will be illustrated in the next chapter.

Chapter V: Results, Conclusion, and Recommendations

Introduction

After conducting five phases of DMAIC in the above chapters, all the processes of this project were explained elaborately, from the design of study to the collection, presentation and analysis of data. In this chapter, the results, conclusion and recommendations for this project will be summarized systematically.

Results

By changing the grooving times and the sizes of stocking cutters, the bottleneck process of the U shaped assembly line was eliminated. The productivity of smart cards was improved as expectation and the quality of smart cards was also in the control. Last but not the least, the smart card company will be gaining 383880 RMB (around 60,000 US dollars) as extra profits every year.

All the results are shown in Table 5.1.

Table 5.1: Results List Table

Results	Before Improvement	After Improvement
Cycle time of producing single card	2.49 s	2.19 s
Productivity of grooving	2800 p/h	3140 p/h (12% increase)
Annual yield	80660000 pieces	93456000 pieces
Defect-free rate	99.961%	99.970%
Profits (60,000 US dollars)	2.4 million RMB	2.8 million RMB
Sigma capability	3.36	3.43
Defective PPM	387	298

The project questions that raised in Chapter I could get answered here.

Q1: How to use Six Sigma methods to increase the yield for the company?

A: Basically, this project conducted Six Sigma based on the process of DMAIC. In the define phase the bottleneck process was referred in the problem statement, so the yield of smarts cards was increasing by eliminating the bottleneck grooving process in the improvement phase.

Q2: How to find out the factor that has the most influence on the process?

A: DOE is a very useful tool in improvement phase to help finding out the significant factors that had main effects on the researching objects. In this project the author did two-stage design of experiment and made factorial analysis on the factors with the highest values of RPN, which provided by FMEA table.

Q3: How much will the company save after improvement?

A: Depend on the formula for direct benefits the author calculated the annual profits roughly. The smart card company will get the profits of 383880 RMB (around 60,000 US dollars) every year after improvement.

Q4: How to maintain the outcome of improvement in control phase?

A: In control phase, several control charts and the process capability analysis both indicated that the improvement results were desirable and the new process was in the control basically. Therefore the smart card company made the working process standardized and the improving methods documented to maintain the results of improvement. The paper work was documented from three aspects: operation standards, improving methods and process management.

Conclusion

This Six Sigma project of productivity improvement and quality control at Smart Card Company took nine months to finish. The DMAIC was carried out in sequence as what showed in the design of study. Obviously, the results were desirable and met the objectives and expectations in this project. The productivity of smart cards increased dramatically, while the defect-free rate of smart cards still maintained well during improvement, which meant the quality of smart cards was perfectly in the control. What is the most important is that the smart card company adopted the improving methods and will be profiting from it. In conclusion, this project was finished successfully and it was worthy of referring for the future control.

Recommendations

Here are some recommendations to the smart card company for the future control. First of all, the smart card company has to update and share information regarding improving methods with every department. Secondly, every department should be more responsible for their duty works, and solves the problems or reports to the upper management department immediately once some abnormal situations were found. Next, the working methods and operation procedures should be standardized and integrated, and the training work for personnel should be developed regularly. Lastly, the ability assessment system and supervision system must be implemented in the smart card company to ensure all the processes will be in the control in the future.

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