Defect Reduction in Ready Rice Packaging by Applying Six Sigma Approach

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Chapter 1

Introduction

Nowadays, Thailand gains more benefits from growing world rice demand and has become the leader of rice exporter in 2015 as shown in Figure 1.1 [www.statista.com, 2016]. It causes business competitiveness of rice products in Thailand become more intensive and interesting. There are a variety of business strategies such as price war, product promotion, distribution channel and new differentiate products introducing to consumers and marketplace. However, increasing trend of health concerns make rice industry more seriously control their product's quality to keep their brand's image and reputation.

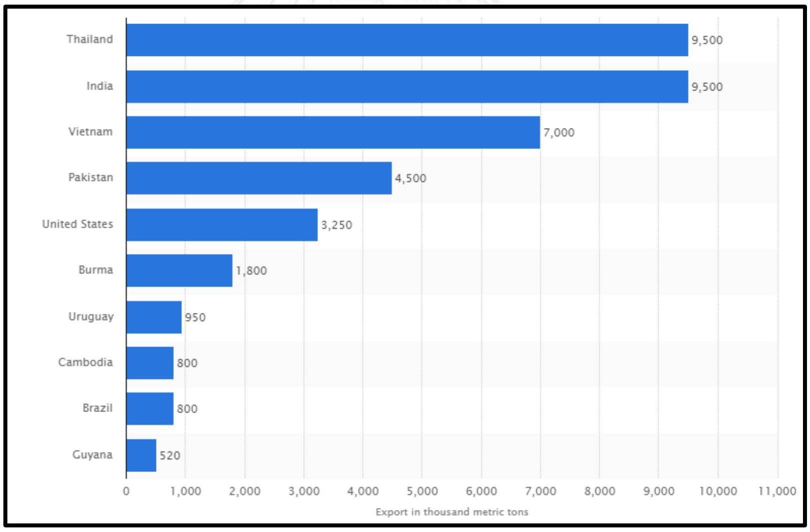


Figure 1.1: Principle rice exporting countries worldwide in 2015/2016

Therefore, production and quality control process at manufacturing site must be rigorously inspected to ensure the defective products not to be passed and released to markets. However, they have to face the problem of high number of waste that impacts the business loss in both production process and also sale opportunities. Reduction of defect in rice product manufacturing is very important to reduce product cost and increase more profit and competitive advantage for the business.

1.1 Background of research

Bangsue Chia Meng (BSCM) Foods Co., Ltd is the subsidiary enterprise of BSCM Groups established in 2010. The key mission of company is to produce the new age of rice products by transforming rice to the processed rice, healthy food and beverage. From 4 years of research and development, BSCM Foods Co., Ltd launched the wide variety of rice products to the marketplace including Ready Rice, Rice Milk and Energy Drink. Because of the subsidiary enterprise of BSCM Groups which is the world class expertise in rice industry, BSCM Foods Co., Ltd has a great advantage to ensure that they can select the standard of raw material, manufacture with the sophisticated process and control the quality in end to end process from rice grains to finished goods until delivery to customers.

Moreover, BSCM Foods Co., Ltd uses the sophisticated automatic machineries which are certified from mandatory manufacturing standard. The size of company's area is around 10,000 square meters which can produce rice products for more than 3,000 tons per year. More than 100 company's well-trained staffs make the company ensure that they can satisfy the high quality of product to the customers. Their major products are shown in Table 1.1

Table 1.1: Products of BSCM Foods Co., Ltd

	• Brand "Golden Phoenix" (Hong Thong)
	• Ready Rice product
	• 2 product pack size
	    o 150 grams
	    o 180 grams
	• Wide variety of rice such as Germinated Brown, Germinated Red and Black Jasmine

	• Brand “Frezfill” • Rice Milk product • 2 flavors of rice milk • Jasmine Rice • Black Jasmine Rice • 180 ml size
	• Brand “Enere” • Beverage product • 180 ml size • Ingredients with vitamin B3, B6, B12, Zinc, Niacin and Potassium

1.2 Statement of problem

In the last few years, BSCM Foods Co., Ltd needs to satisfy the growth of demand in their Ready Rice product by increasing their capability and introducing various sizes of product. However, they have faced the problem because some product defects are found before packing process. The high defective rate is found in Ready Rice product when compared to other products as shown in Table 1.2

Table 1.2: Production volume and percentage of defect in July 2014 – March 2015

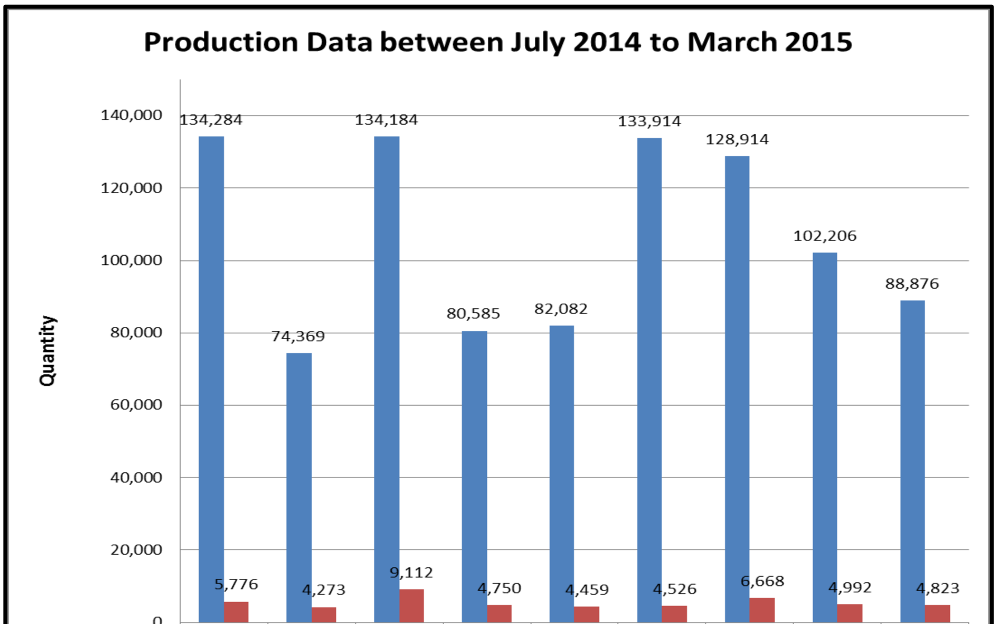
Product	Production Volume (units)	Defect (%)
Ready Rice	959,414	5.14
Rice Milk	92,886	0.42
Beverage	50,105	0.85

The impacts of problems are not only the increase in the production cost but also the opportunities loss to sell the product. Overall, the percentage of defect of Ready Rice product is around 5.14%. The defect grade of Ready Rice product can be segregated as the "Grade B" product that can be sold at the lower price and "Grade C" product that have to be rejected as waste. BSCM Foods Co., Ltd defines the standard defect to segregate these two defect grades based on severity level. For example, the out of shape of cup can be segregated to Grade B if it is minor out of shape and Grade C if cup is obviously deformed. The number of waste unit and waste cost value per unit are calculated and compared between Grade B and Grade C product as shown in Table 1.3

Table 1.3: Total waste cost value between two waste grades in July 2014 – March 2015

Waste grade	Number of waste (units)	Waste cost value	Total waste cost value (THB)
B	40,477	Grade A price – Grade B price = 5 THB/unit	202,385
C	8,902	Cannot be sold (100% loss) = 13 THB/unit	115,726

Table 1.3 shows the waste cost value company lost in nine months. Therefore the total loss is approximated 320,000 THB. The total number of products produced and defects of Ready Rice product found during July 2014 to March 2015 are shown in Figure 1.2 and 1.3.



	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Production Vol	134,284	74,369	134,184	80,585	82,082	133,914	128,914	102,206	88,876
Defect	5,776	4,273	9,112	4,750	4,459	4,526	6,668	4,992	4,823

Figure 1.2: Production volume and defect rate of Ready Rice product in July 2014 - March 2015

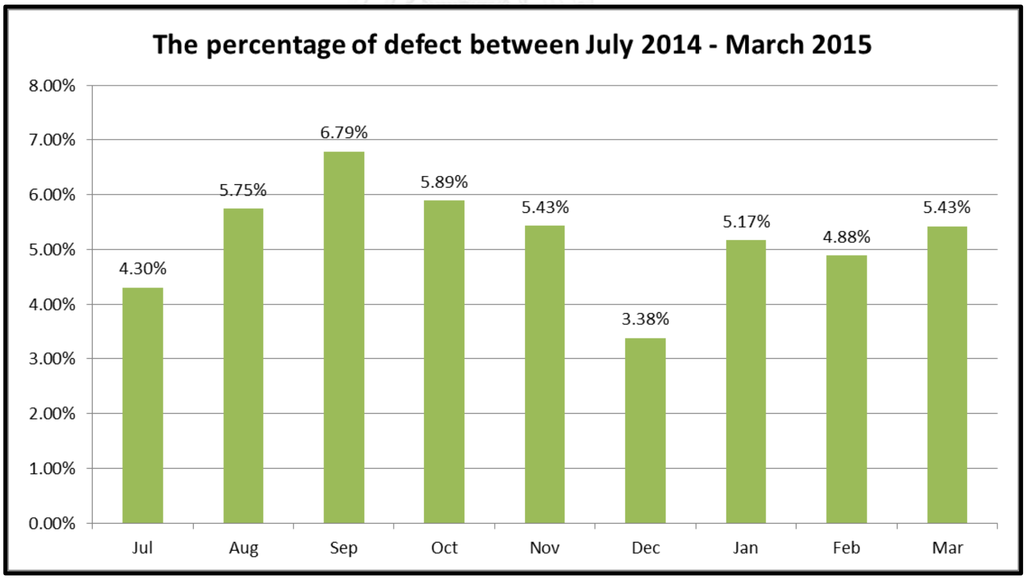


Figure 1.3: The percentage of defect in Ready Rice product in July 2014 - March 2015

Figure 1.2 and 1.3 represent production volume compared to the defect rate found each month in the second half of 2014 and first quarter of 2015. It is observed that production volume was fluctuated because the Ready Rice product is an innovative product for new life style consumer who has no enough time to cook the rice by their own. Moreover, it had just been launched in the market for the last two years and remains in introduction phase of product life cycle. The defective rate was fluctuated as well in the range of 3.38% and 6.79% with average at 5.14% of nine months. Therefore, the high defective rate is affected to production plan since they have to prepare more materials and produce more quantity of product to compensate the waste loss of defective products and caused to higher product cost. There are many types of defect contributed the company loss around 50,000 defective products in nine months period. When considered in waste cost value company lost, there are three defect types majority covered 80% of total loss.

Six Sigma is one of popular techniques based on statistical tools to improve the process capability. The goal of Six Sigma is not only to reduce the defective rate by reducing the process variation but also to produce the quality product according to the customer requirements. (Kumar, et al., 2011) Therefore, Six Sigma is taken into consideration as the appropriate technique to solve the problem in Ready Rice packaging defect.

1.3 Objective of the research

The objective of this research is to reduce the defective rate of the Ready Rice product by applying Six Sigma concept.

1.4 Scope of study

This research is to reduce the defective rate of Ready Rice product in studying company. The following topics will be included:

1. To study in Ready Rice production process.
2. Focus on three major defect types including the out of shape of plastic cup, the wrinkle of seal and the illegibility date code.

1.5 Expected outcomes

1. The reduction in defective rate of Ready Rice product
2. The key factors that impact to the defect rate are identified
3. The appropriate process parameter setting levels are identified in order to minimize the defective rate of each defect type
4. The studying company gains more profitability from the defect reduction
5. The studying company can apply this Six Sigma tool to reduce other defect types of other products

1.6 Proposed methodology

The research procedure follows the concept of Six Sigma framework called "DMAIC" which are Define, Measure, Analyze, Implement and Control phase.

1. Define the problem and area of opportunity for improvement.
2. Review the current process and measure the accuracy of the current data
3. Analyze the root cause of problem
4. Implement and collect data
5. Find the way to control and prevent the problem
6. Report the result

Chapter 2

Literature and theoretical review

2.1 Literature review

Competition in food industry is undergoing pressure for businesses to seek the competitive advantage strategy, especially in an economic downturn that is happening today. The best way to grow in the market and gain more profits is improving their productivity by reducing production cost and speeding up product to market

Process control is concept to focus on the resource utilization. The benefits of concept are to increase the productivity and reduce the cost by eliminating waste in process. Six Sigma is one of popular technique to control the process in various industries such as Electronics, Food and Automobiles (Damrongvanich & Senjuntichai, 2013; Kulpiya & Senjuntichai, 2014; Manohar & Balakrishna, 2015). It is a systematic tool to reduce the waste and meet the customer requirements. Kahiki Food Company (Manufacturer of frozen food in U.S.) was a studying company that Joseph Lazzaro et al., (2014) applied the Six Sigma to deal with the higher production cost. The increase of the labor cost, the transportation cost and the inventory cost were causal driver of this problem. Moreover, they tried to find the cost saving opportunities by following DMAIC methodology. At the beginning, they prioritized their products from the work-in-process (WIP) problem. Then they developed the value stream map (VSM) to specify the processes that need to be addressed. In the analyze phase, there are four steps for increasing the engagement of the team to analyze and identify the problem solution. First, they set the “zero-WIP” as the project objective and engaged all employee involvement to understand the problem definition. Second, they shared the study from VSM about current process problem. Third, they identified the root cause of problem by applying 5-Why analysis. There were three key root causes included lack of collaboration between production and packing process’s staff, the several times of machine breakdown and line primer. Therefore, they decided to develop the pull system between production and packing process by increasing the information flow process between two areas. Moreover, the standard operating procedure (SOP) was established how to fix the machine breakdown problem rapidly. Finally, the hypothesis testing was used to confirm the significant improvement.

The benefits of Six Sigma approach is not only for process improvement, but also for defect reduction. In 2011, Hung and Sung (2011) applied DMAIC methodology to reduce the process variation and the high defective rate in Taiwan Food Company. The studying company found the high defective rate in bun products. This had made the company loss in productivity and faced the increasing of complaints. At the beginning of DMAIC, the solving team was formulated and leaded by the Six Sigma black belt person to define the defect problem. When Pareto chart was used to prioritize the cause of problems, shrink of bun defect problem was the most complaints from customers. Then, they focused on production process of small custard bun which had many shrink product types. Team studied the process and collected the data indicated the defect rate of shrink of small custard bun was 0.45% defective rate in the last 6 months. Then, team used the statistical tool and Failure Mode and Effect Analysis (FMEA) to define the cause of problem. It was found the cause had been from high temperature in the fermentation process. To improve the process, the statistical methods included ANOVA and Design of Experiment had been used to find the optimum parameter of temperature. To minimize the defective rate after improvement, the defective rate of shrink in small custard bun was reduced to 0.141% or around 70% compared to before improvement.

The case study of Taiwan Food Company proved that Six Sigma is a systematic approach to reduce the defective rate in production process. In another case study, Six Sigma can be applied in packaging process of food shown in the research of Ditahardiyani et al., (2008) from Indonesia. They applied DMAIC methodology into primary packaging process of Cranberry drink which had high process variation and defective rate. To define the problem, they studied the Cranberry production and found that the case study company has two types of packaging process; primary and secondary ones. After analyzing the historical data, they found the high severity level of defect output from primary packaging process and can identify the main causes of problem including defective sachet, bad seal, blunt cutter and inappropriate weight. Then, they set the DPMO and Sigma level as the indicator of research. The current Six Sigma level based on DPMO method in each defect type found the unqualified level of Six Sigma in sachet defect type. To identify the root cause of problem, two quality tools including Cause and Effect diagram and FMEA were used in team's brainstorming action. At analyze phase, the root causes ware lack of procedure for material handling and no standard material specification. Therefore, they took the action to develop the SOP for material handling and define the standard of packaging material. Finally, the company got the success to increase the sigma level of sachet defect from 3.8 to 5.2 and set the control plan to control and monitor the primary packaging process.

Furthermore, the wide variety of analysis tools adapted in each phase of DMAIC methodology are another benefit of Six Sigma which can be applied to any businesses. In the example of Chakrabortty et al., (2012) applied Six Sigma concept to Food Company in Bangladesh. The company faced the problem of many types of defect of their products. The tools for the define phase were "Supplier, Input, Process, Output and Customer analysis" (SIPOC) and Voice of Customer analysis. Moreover, they established a Quality Function Deployment (QFD) to understand the relationship between each of defect type and factors. In the measure phase, they collected number of each defect type and applied analyzed it by Pareto chart in the analyze phase to identify which type of defect should be focused first by looking for the number of each defect type. Furthermore, they used "Analytic Hierarchy Process" (AHP) to prioritize the defect level. In the improve and control phase, they applied 5S philosophy to improve the process and prevent any potential problem by risk assessment and mistake proofing.

In the research of Pongpattanasili (2004), the use of Six Sigma approach in Thai Food Company is applying to improve the operational performance. It can generate not only the financial benefits but also capability of employees to solve the problem in their work. This research identifies eleven key success factors in Six Sigma approach to Thai Food Company;

1. Commitment of top management is the most important factor to support and motivate all of employees by setting the strategy model.
2. Company culture is difficult to change especially legacy employee's resist.
3. Good Communication plan is helpful to get employee involvement and engage them to understand the Six Sigma concept.
4. Infrastructure of company including resource and investment can enhance the opportunities for success in the Six Sigma approach.
5. Training can create employee understanding the Six Sigma and thinking for employees and increase the level of involvement.
6. Linking Six Sigma to the business strategy for the problem prioritization contributed the most direct impact to financial and operational objectives
7. Linking Six Sigma to end to end supply chain process to customer
8. Linking Six Sigma to the company's human resource
9. Linking Six Sigma to all suppliers to make them focus on quality
10. Understanding tool and technique of Six Sigma is the key factor when implementation. Project team members have to choose the appropriate tools and techniques that fit with the company.
11. Ability of project management such as time, cost and quality should be incorporated to define the objective, scope and the necessary resource.

According to Six Sigma tools and techniques, they conclude that many Thai Food Companies use the similar basic tool such as Cause and Effect diagram, Pareto diagram and Control chart and avoid using the powerful tools and techniques such as design of experiments, Taguchi methods and Failure Mode and Effect Analysis. Overall, Six Sigma can be implemented in Thai Food Company and all areas of businesses.

2.2 Theoretical considerations

2.2.1 Six Sigma

1) Historical and definition

Six Sigma approach was developed in 1980 by Bill Smith who was an employee of Motorola Company. At the beginning, Six Sigma was used to solve the increase of claim in Motorola Company and improve processes to the succeeded quality requirements and standards for complicated products. In 1988, General Electric succeeded to utilize Six Sigma for in-process improvement and can reduce cost around 1,500 million U.S. dollars [Folaron and Morgan, 2003]. Later, Six Sigma has become widely popular approach to in the wide range of industry such as Boeing, Toshiba, Seagate and Sony which can help them reduce the unnecessary cost [Harry, 1998]. Six Sigma has three distinct elements including measure, target and philosophy. Firstly, the measure is the statistical definition to determine the process variation from perfection. Secondly, the target of Six Sigma is 3.4 defects per million opportunities (DPMO) using the standard normal distribution to be the measurement system as shown in Figure 2.1 [www.sixsigma-institute.org].

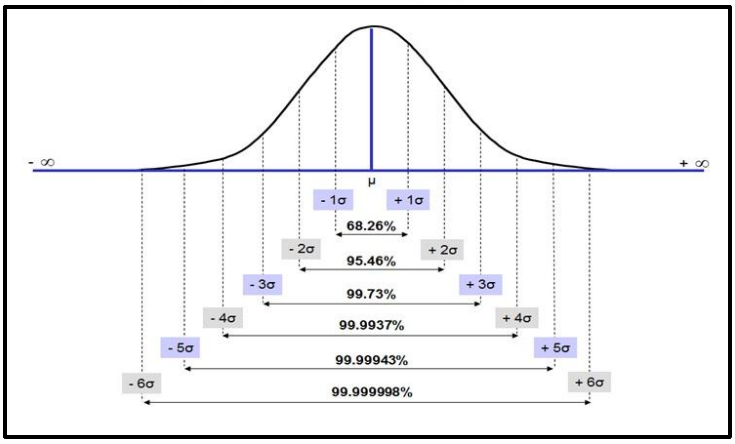


Figure 2.1: Standard normal distribution curve

From the normal distribution curve, the level of Six Sigma has the process performance at 99.999998% and accept 3.4 defects in the production of 1 million units known as 3.4 ppm (parts per million). The last element of Six Sigma is the philosophy of cost reduction by minimal of variation in products and processes.

2) Benefits of Six Sigma

Financial performance

Over the decades that Motorola utilizes Six Sigma as the basis tool for their on-going strategic improvement approach, the company can save more than 400 billion U.S. dollars and can increase their profit 20% every year [Pande et al, 2000]. For other companies, General Electric can save 2 billion U.S. dollars in three years after applying Six Sigma approach while Honeywell can save around 600 million U.S. dollars [Lee, 2002]. There are two main reasons that many companies applying Six Sigma can save the cost and gain more profitability. First is to reduce waste cost value from the poor quality product such as rework, warranty, complaint, product recall and product reputation. Second reason is to eliminate the waste in process. According to Taichi Ohno in 1988, there are seven types of waste that can impact the cost of performance and the efficiency of production. Table 2.1 shows the seven wastes and unnecessary cost that occur in process [Ohno, 1988].

Table 2.1: Seven wastes and unnecessary cost

Type of waste	Unnecessary cost
Waiting	Labor cost Overtime cost Penalty cost (Late delivery)
Defect	Rework cost Inspection cost Overhead cost
Processing	Processing cost Transportation cost

Type of waste	Unnecessary cost
Transportation	Transportation cost Damage cost Penalty cost (Late delivery)
Overproduction	Inventory cost
Inventory	Obsolescence costs Inventory cost
Motion	Labor cost Medical cost

Response to customer

Six Sigma is the concept focusing on prioritization to customer by setting their customer and improve the quality of product and service. Six Sigma concepts deploy the voice of customer into organization process. Every improvement in organization must increase the value of their product to satisfy the customer needs. General Electric Aircraft Engines is good evidence that GE Company tries to find out the customer requirement and focus to produce their product to satisfy the customer [Henderson and Evans, 2000]. Moreover, Six Sigma focuses to reduce the variation of product and service to gain more on performance and maintain their company reputation [Taguchi, 1986].

Organization learning

Using Six Sigma can generate learning of process investigation, company strategy and the statistical method into all of management levels. De Mast (2006) explains that Six Sigma can facilitate people at all levels to clearly understand their process and solve any problem in systematic method. Many organizations train their employees and put this knowledge to be a core competency of organization that gain a long-term competitive advantage.

3) DMAIC Methodology

DMAIC is the systematic solution that is widely used in many businesses. The methodology consists of five phases including Define, Measure, Analyze, Improve and Control. DMAIC can lead the team solve the problem starting from define of problem, find the appropriate way to improve and set the best practice and standard to ensure that the problem will not be re-occur in the future [Ramanan et al., 2014]. The details of DMAIC Methodology are as follows

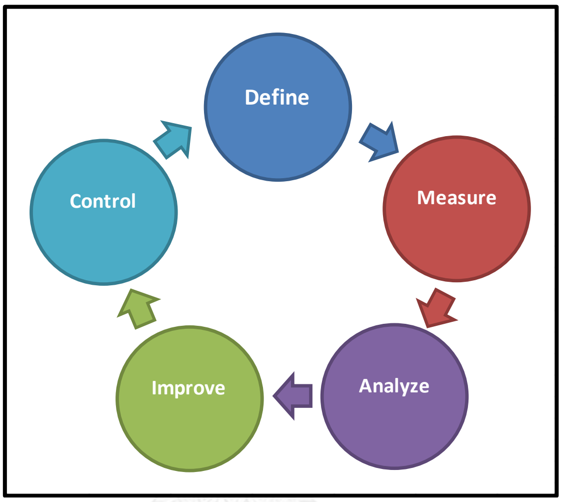


Figure 2.2: DMAIC Methodology

Define phase

This phase is to define the problem and set the objective by specific the detail of problem and identify the weak point timeline of process or product. At this phase, solving team is formed to and set the scope and schedule of the project. The key point of this phase is aligned understanding within team members and the top management.

Measure phase

This phase is to collect the current data to make the team members understand the current status of process. The objective of this phase is to analyze the current process using to measure the result and also the process capability. Then, identify the main cause of problem which is the most impact to the problem.

Measurement system analysis (MSA)

MSA is used to determine that the current measurement system can provide the accurate information and to ensure that the accuracy is sufficient to achieve the objective. According to Michael L. George, the good measurement system requires both accuracy and precision to set the right information data. That is the measurement have to approach the truth and get the same result when measure in repeatedly. The accuracy part is considered in three view including bias, stability and linearity. While precision part is considered in repeatability and reproducibility. AIAG (2002) defines the meaning of the word in relation to the measuring system are as follows.

- Bias: The difference of measure value under the same features and components.
- Stability: A change of the bias over times.
- Linearity: A change of the bias when changes on the measure.
- Repeatability: The variation of the measured values is measured by the same staff when repeatedly measure the same products.
- Reproducibility: The variation of the measured values is measured under the same tools but difference in conditions. Generally represents the difference between appraisers.

Process capability and process performance

Process capability represents the uniformity of process measured from process variation classified to two points; short term variation and long term variation. [Somerville and Montgomery, 1996] The study of process capability can be measured by collecting process parameter data. If the data is under the control limit, it can bring to the statistical method in the next step.

To assess the potential process improvement, there are two popular indicators; capability ratio and process capability developed by Fasser and Bretner (1992).

1. Capability Ratio (C_R) : The proportion between the variation of process and the range of control limits as shown in Equation 2.1

$$C_R = \frac{6\hat{\sigma}_{ST}}{USL-LSL} \tag{2.1}$$

2. Process capability (C_P): Normally, used when the process is under statistical control which can measure the potential process improvement in short and long term. The calculation of process capability as shown in Equation 2.2 to compare with acceptance criteria set by AIAG (1995) as shown in Table 2.2.

$$C_P = \frac{USL - \bar{X}}{3\hat{\sigma}_{ST}} \text{ or } \frac{\bar{X} - LSL}{3\hat{\sigma}_{ST}} \tag{2.2}$$

Table 2.2: The process capability requirement

Process capability analysis	Standard acceptance value
Process capability (C_{pk})	$\geq$ 1.33
Process performance (P_{pk})	$\geq$ 1.67

3. Process capability index (C_{Pk}): The adjustment of process capability (C_P) for calculation when the data distribution is not at the center. The calculation of process capability index is shown in Equation 8.3

$$C_{Pk} = \min\left(\frac{USL - \bar{X}}{3\hat{\sigma}_{ST}} ; \frac{\bar{X} - LSL}{3\hat{\sigma}_{ST}}\right) \tag{2.3}$$

Failure Mode and Effects Analysis (FMEA)

FMEA is a systematic method to identify, analyzed and document the risk management. Once are identified, the effects of these failures on performance and safety are evaluated, and appropriate actions are taken to eliminate or minimize the effects or risk of these potential failures [Stamatis, 2003].

The result of FMEA shows the value of Risk Priority Number (RPN) which shows the level of risk to be prioritized and needed to take action first. Mostly, RPN can be calculated from the score of three criteria including severity (S), occurrence (O) and detection (D).

Steps to determine Failure Mode and Effects Analysis

1. Identify relevant materials and associated process
2. Identify failure modes or any problems from materials and processes that may be occurred.
3. Determine effects of each failure mode in order to identify the impacts to product quality and safety especially customer.
4. Evaluate severity or critical level of failure mode to determine the severity or critical level of impact. Normally the severity level can be evaluated as severity description level in numeric score (such as 1-9).
5. Identify potential cause(s) of each failure mode that potential effect to process and performance.
6. Evaluate probability of occurrence of the cause of problem. Normally, the probability of cause of problem based historical data and experience.
7. Identify current controls to detect and prevent the cause of problem. This control can eliminate or reduce the probability of occurrence.
8. Determine effectiveness of current controls to estimate the difficulty level that cause of the problem will be prevented or detected. If some causes of problem are difficult to control, the detection score will be low and is not focused first.
9. Calculate Risk Priority Number (RPN) by multiplying the numerical score of severity (S), occurrence (O) and detection (D). However, RPN can apply the calculation to fit with any type of business. RPN is the score to prioritize the failure mode that needs to be solved.
10. Determine actions to mitigate risk of failure mode: To find the way to solve the problem or reduce the risk. This is very important step that Cross functional team needs to clearly understand the potential cause and identify the robust action plan.

Potential Failure Mode	Potential Effect of Failure	Severity	Occurrence	Detect	RPN	Recommendation Action

Figure 2.3: Failure Mode and Effects Analysis

Analyze phase

The objective is to find the cause of variation that occurs in the process. The data obtained from the measurement and analysis of data collection by hypothesis testing to identify only significant factors.

Hypothesis testing

Hypothesis testing is a part of statistical inference which is the test of unknown parameter by population sampling. The test will calculate the probability that null hypothesis is wrong.

Terms and concepts of hypothesis testing

1. Null Hypothesis ($\mathrm{H_0}$): The key assumption is tested to determine assumption that is true or not. The example shows in Equation 2.4 and 2.5.

$$\mathrm{H_0}: \mu_1 = \mu_2 \tag{2.4}$$

$$\mathrm{H_0}: \mu_1 - \mu_2 = 0 \tag{2.5}$$

2. Alternative Hypothesis ($\mathrm{H_a}$): Another assumption which can be true when there is enough evidence to reject the null hypothesis. The Equation of alternative hypothesis testing must be inversed from equation of null hypothesis as shown in Equation 2.6 and 2.7.

$$\mathrm{H_a}: \mu_1 \neq \mu_2 \tag{2.6}$$

$$H_a: \mu_1 - \mu_2 \neq 0 \tag{2.7}$$

3. P-value: is the probability of occurrence in the assumption of hypothesis testing which help to decide whether to accept or reject the null hypothesis. If p-value is less than or equal the significance level of the test, the null hypothesis must be rejected.

The benefits of hypothesis testing

- To determine the significance of parameter
- To determine the difference of two data sets
- To determine how statistical value such as mean and standard deviation difference from the specific value
- To estimate the probability that the hypothesis is true or not

For Six Sigma, hypothesis testing can be applied to analyze data for engineering improvement areas in three phases as following

1. Analyze: To consider whether the factors is significance to the cause of problem or not
2. Improve: To confirm whether the factors is significance for statistical method analysis
3. Control: To confirm whether the process is changed from standard or not

Step of hypothesis testing

1. Define the assumption
2. Identify the appropriate model
3. Identify the test is either one tailed or two tailed analysis
4. Formulate the Null and Alternative hypothesis
5. Decide the level of significance
6. Find the critical value of statistical test
7. Get a random sample of data

8. Calculate the test statistically
9. Decide whether to accept or reject Null Hypothesis (H_0)
10. Make a conclusion

Improve phase

This phase is to determine the suggested level of significant factors from the analyze phase. The statistical method using at the improve phase is such as ANOVA and Design of Experiment (DOE).

Analysis of Variance (ANOVA)

ANOVA can be used to compare three or more data sets to determine the statistical difference of mean from other data sets. The benefits of ANOVA are to confirm the significance of variable and to determine the best variable value for improvement. When use the statistical program to analyze in ANOVA method, it can show many data plots to analyze the result such as

- Residual plots: check the freedom of data that many not directly related to the factors

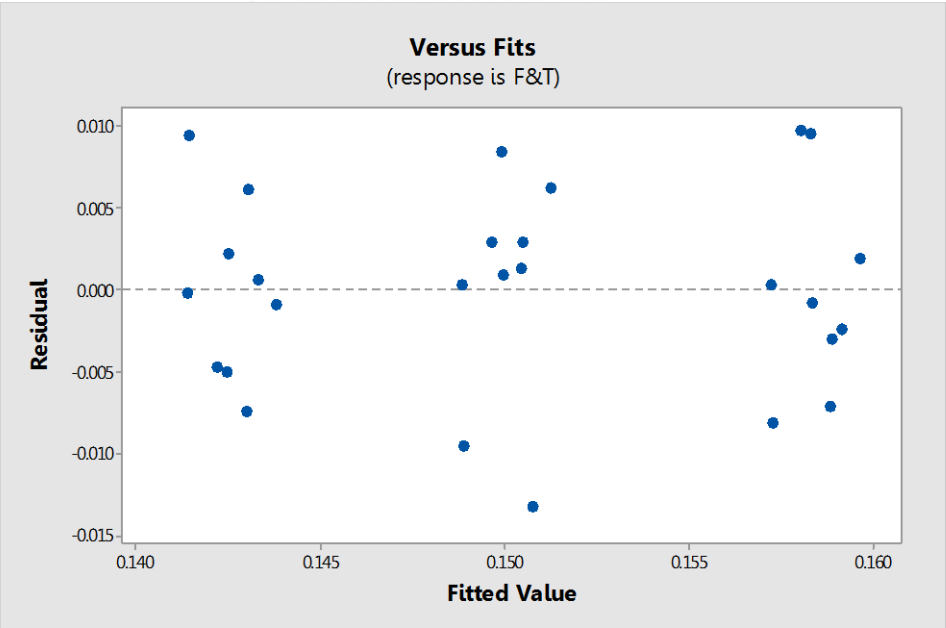


Figure 2.4: Residual plots

- Normality plots: check the distribution of data is normal distribution or not

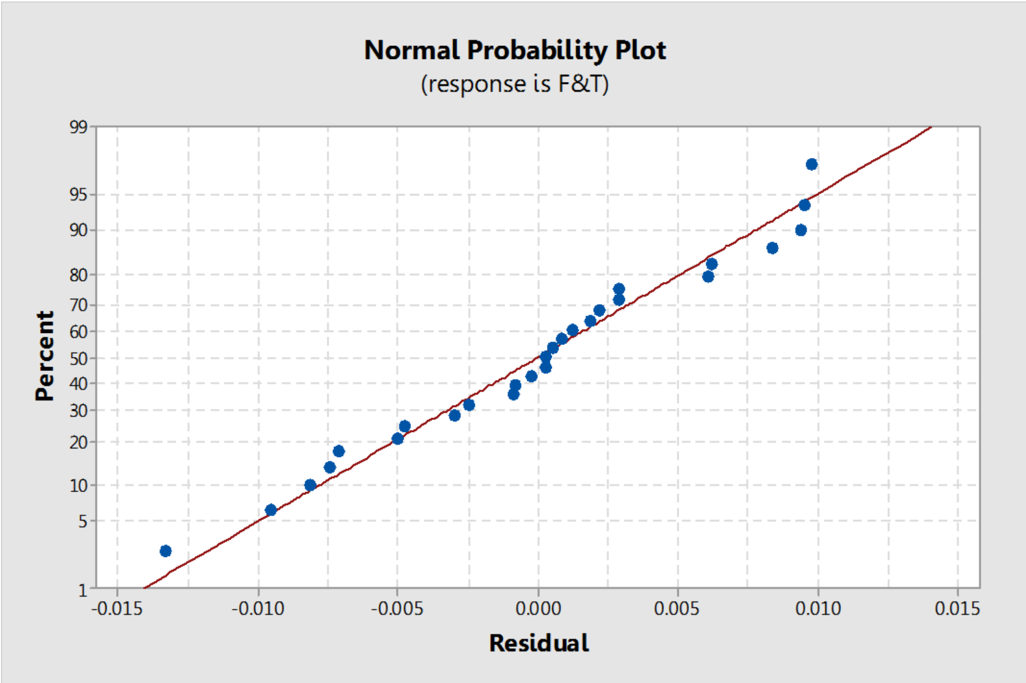


Figure 2.5: Normality plots

- Main effects plots: show the mean of factor in each level

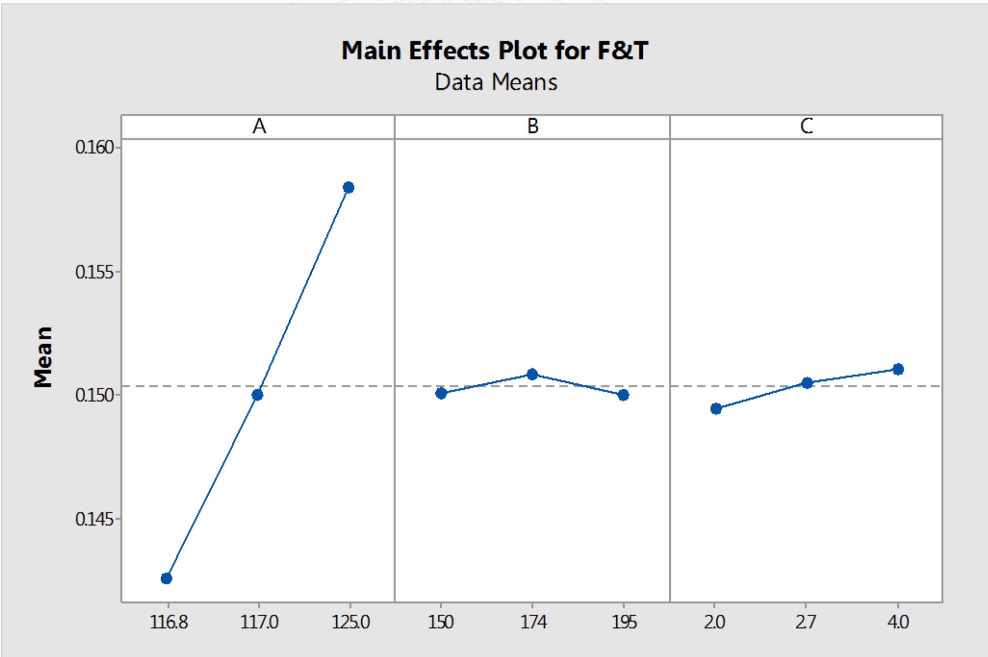


Figure 2.6: Main effects plots

- Interaction plots: show the mean of interaction factor (when analyze more than single factor)

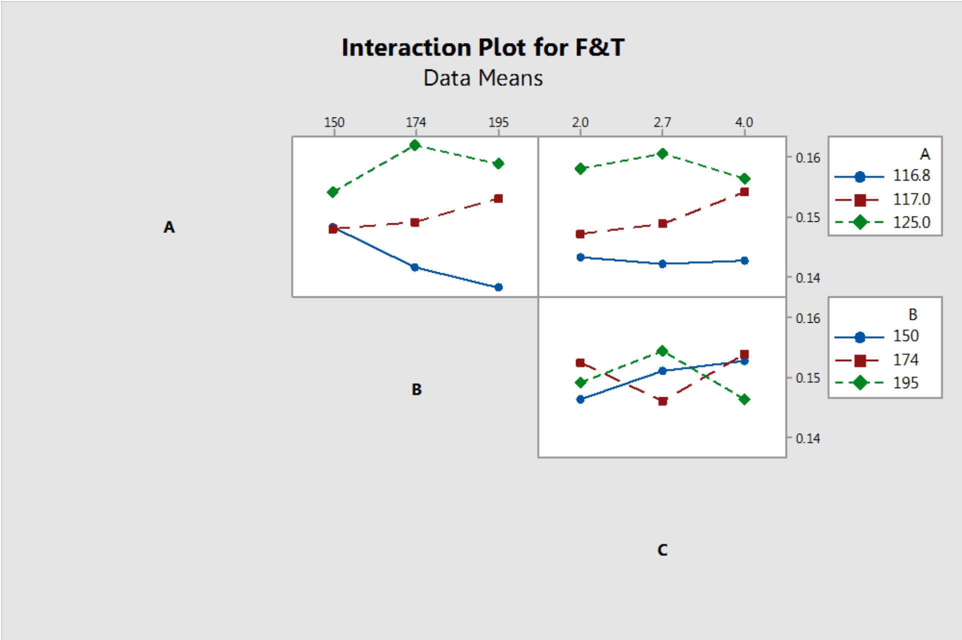


Figure 2.7: Interaction plots

Design of experiment (DOE)

DOE is the process of experiment planning for collecting the appropriate data using statistical method [Montgomery, 2001]. The objectives of DOE are to reduce the process variation and gain more benefits including

- To determine the suggested level to gain the best result and minimize the resources for improvement
- To determine the factor that is the most impact to the output
- To filter only significant factors for improvement
- To reduce the time and the number of trials when analyze many factors

The step of design of experiment

1. Define the problem in term of business such as cost, time, customer satisfaction and level of service
2. Set the measurable objectives

3. Identify the input and the level of them
4. Set the experiment strategy including full/half factorial design, the number of replications and the statistical program
5. Execute trial and closely monitor the process
6. Statistical analyze to get and conclude the result of experiment

Full factorial design

This type of experiment uses to determine the effect of combination factor by considering the effect and relationship of factors to response value. It can estimate the level of factor to gain the best result. Although full factorial design takes a lot of time and requires many resources but finally it can get more accurate result.

Control phase

This phase will control and monitor in order to maintain the process performance of the process using control charts.

Control Chart is a statistical tool to show the variation of process over times by plotting data in the order time. There are two key components of control chart including the center line which is the mean of data and control limits set into upper limit and lower limit. When the data is out of the control limits, the problem in process will be solved immediately [Kume, 1995]. There are many types of control chart for monitoring the performance of process depended on type of analysis data as shown in Figure 2.8 [Statit Software, 2007].

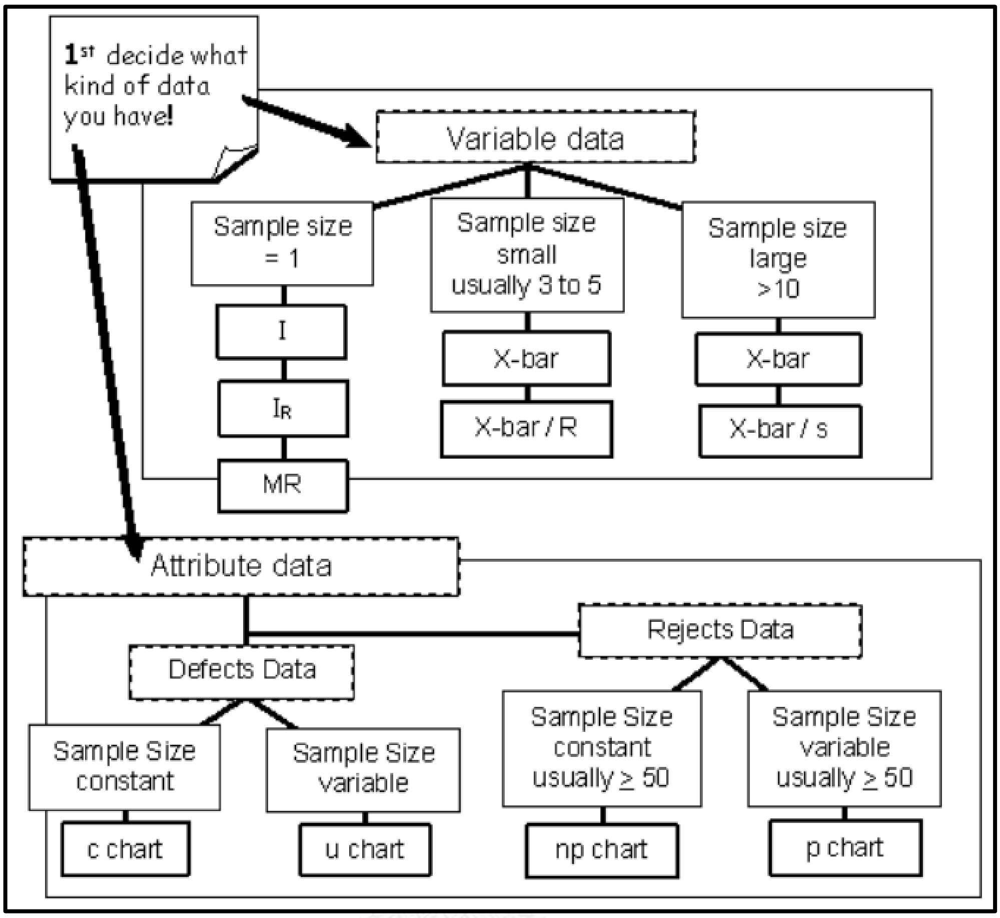


Figure 2.8: Type of control chart

When analyze the defect proportion which is the attribute data and come from variable sample size, p-chart is the appropriate type of control chart to monitoring the process improvement [Steel and Torrie, 1980].

The benefit of control chart

- To solve the problem immediately
- To control the quality of product
- To show the process capability
- To increase the productivity by defect reduction

4) Six Sigma analysis tools

Cause and Effect diagram

Cause and Effect diagram or cause & effect diagram is the popular tool to identify the causes of problem. Mostly it will be used when the solving team wants to brainstorm and organize the idea because it is easy to use and apply to any problem analysis. [Ishikawa, 1989] To group the cause of problem, 4M concept including man, machine, material and method is used for classification the cause of problem in these four groups.

The step of Cause and Effect diagram

1. Cleary understands the problem within the team: Make all of the team clearly understand the problem or issue
2. Brainstorm and identify the potential cost: Every idea should be suggested from every team member and avoid the discussion during this step. It can set the one person to be facilitators who encourage everyone focus to generate their ideas.
3. Categorize the cause of problem to the 4M group: Every causes of problem have to group to 4M under team agreement.
4. Review the diagram: Check that the diagram represents their collective understanding
5. Prioritize the main cause: Team should choose the key cause that needs to focus firstly or high possibility to occur and solve.
6. Collect the data: Start to collect the data to confirm that the key cause is significant impact to the problem.

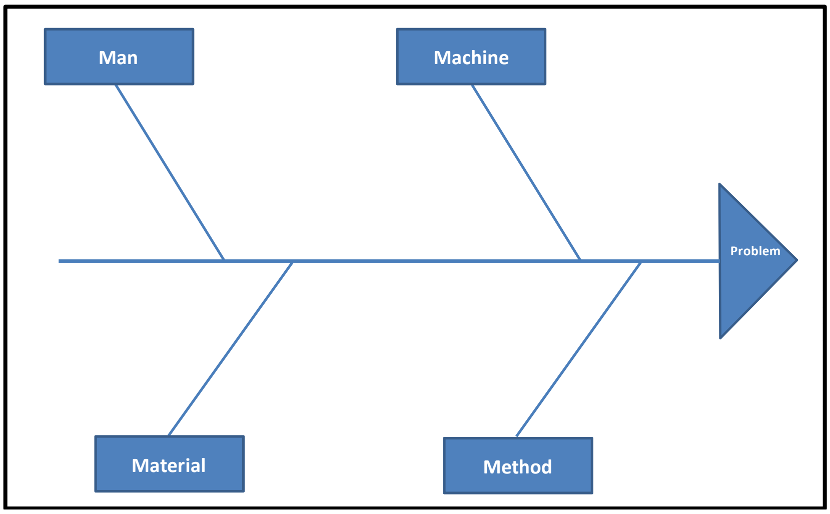


Figure 2.9: Cause and Effect diagram

Pareto diagram

Pareto is a bar chart that x-axis shows the category data such as type of defect and cause of problem. The height of the bar shows the countable number or proportion that in order from most to least. From this ordering, the diagram can show the category data that need to be focused because it significantly impacts to the problem more than others. The Pareto Principle developed by Vilfredo Pareto is used to prioritize the category data.

The step of Pareto diagram

1. Plot the frequency of occurrence in each category data
2. Order the category from most to least frequency
3. Calculate the cumulative frequency
4. Draw the bar chart to show the level of frequency and draw the line to show the cumulative frequency in percentage.

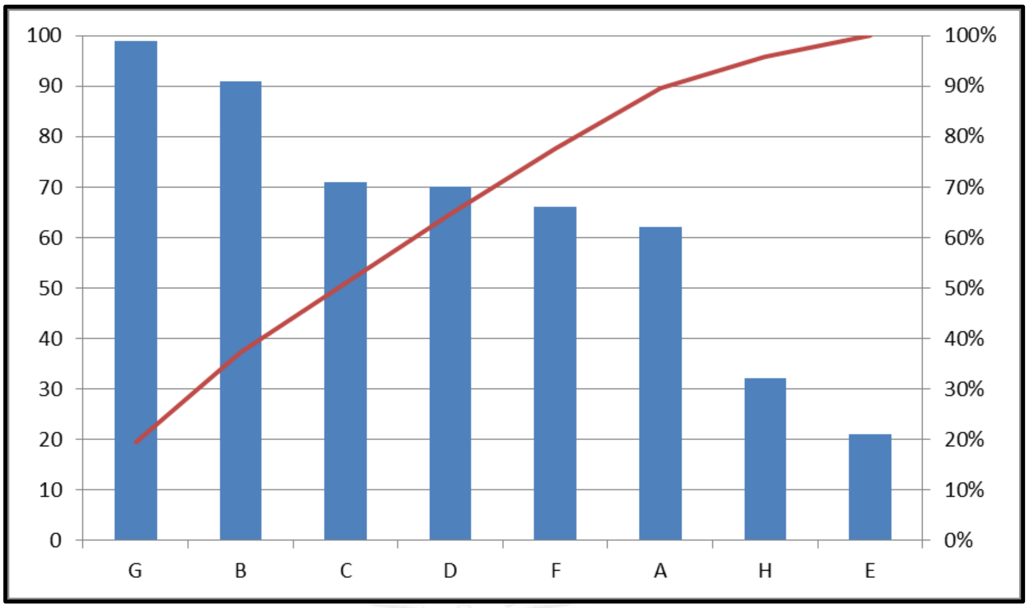


Figure 2.10: Pareto diagram

2.2.2 Steam Sterilization process

Steam sterilization is the moist heating to sterilize items that can withstand the moisture, vacuum, pressure and the high temperature. The key feature of steam sterilization is non-toxic because steam is the vapor states of water ado any chemical related process. Therefore, this process is popular in the food, pharmaceutical and medical device manufacturing process. However, steam sterilization is the process that has to be prevented the mistake. Otherwise the serious problem can be occurred such as personal injury, high maintenance cost and non-sterile products.

Key factors of steam sterilization

Principle of Steam Sterilizing has been set as a universal to focus on the six critical factors that can be particularly critical to steam sterilization.

1. Time

The sterilization time is a critical factor to kill all of organisms. Sterilization time is inversely to the temperature used for sterilization. If use the little of time, it have to increase the temperature to destroy the all of microorganism. Figure 2.11 shows the sterilization time versus temperature in steam sterilization process [Dion and Parker, 2013].

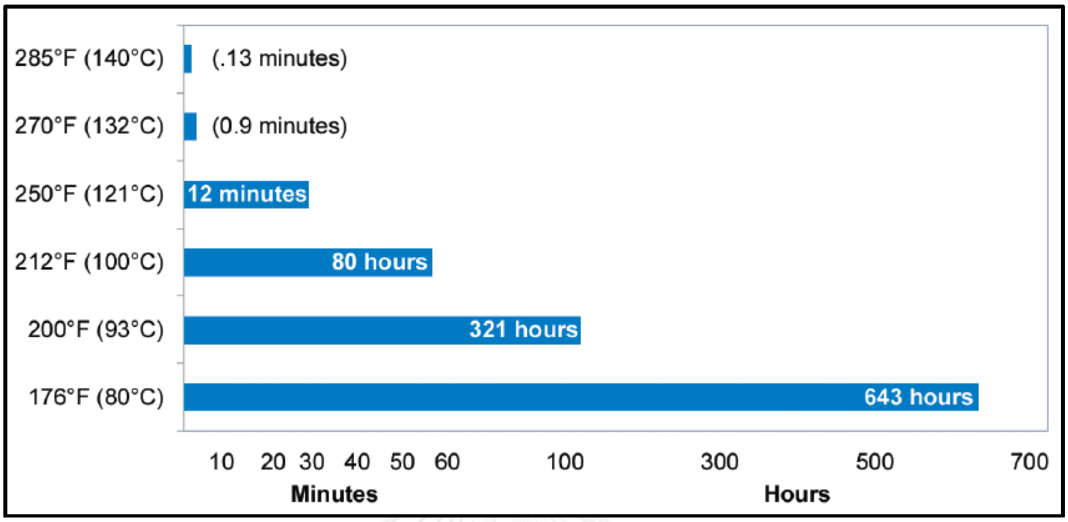


Figure 2.11: Sterilization time versus temperature

2. Temperature

Temperature is also a critical factor to sterilize items and directly relate to the time and pressure. Figure 2.11 demonstrated the increase of temperature significantly reduces the time required to sterilize items.

3. Moisture

Moisture in steam enhances steam ability to denature proteins in the cell of microorganism. Therefore, saturated steam is necessary in steam sterilization process. Superheated steam or steam containing excessive liquid water can cause failure of steam sterilization.

4. Direct steam contact

Direct steam contact with the surface of product to be sterilized. Steam will transfer its stored energy to the products. Lack of direct steam contact to all surfaces of product, product will not be sterilized.

5. Air removal

Air is the key barrier for poor heat distribution in the chamber and can be the main cause of failure to sterilize the product. Air must be removed from the chamber in the pre- conditioning phase by a series of vacuum pulses.

6. Drying

Drying is also one of important factors especially for wrapped products. During heating and exposure phase of steam sterilization process, condensation can be happened when steam contact with cooler surface in the chamber. Consequently condensation can be cause of re-contamination when product transferring from the chamber. Therefore, the wrapped products must be passed through drying process in post-conditioning phase.

Basic cycle of steam sterilization process

There are three phases of steam sterilization process

1. Pre-Conditioning phase: Air will be removed from chamber then steam will be loaded by vacuum and pressure.
2. Exposure phase: The temperature in chamber is increased to sterilize items. This phase also may be controlled by F_0 value which is used to benchmark the sterilization time.
3. Post- Conditioning phase: The load is cooled down and dried. Then, it makes the chamber back to atmosphere condition within the chamber by pressure. After finished this phase, the sterile item can be removed from the chamber.

Figure 2.12 show the level of pressure in steam sterilization cycle [Dion and Parker, 2013].

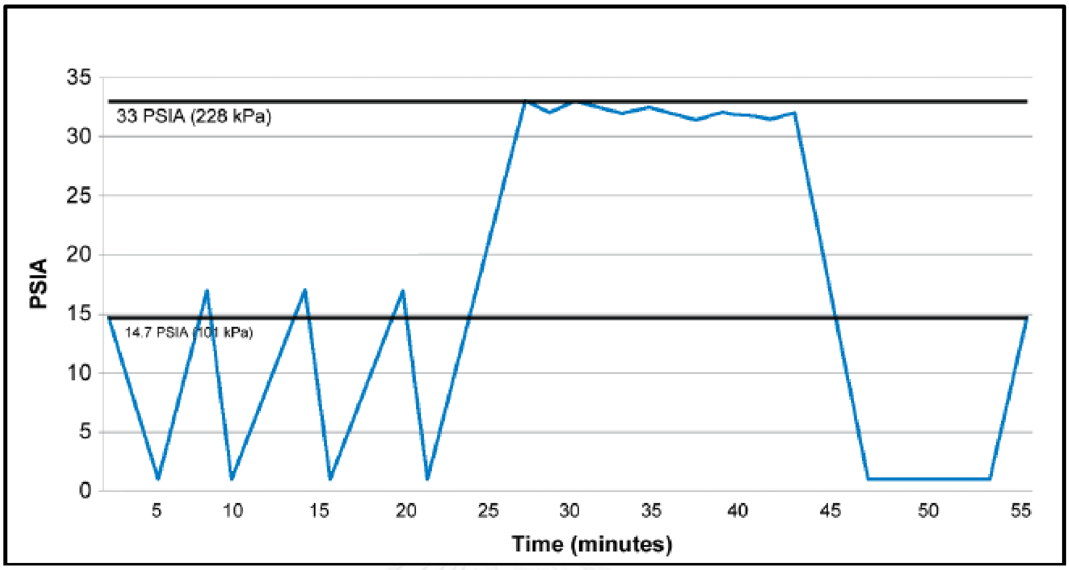


Figure 2.12: The pressure in steam sterilization cycle

The F_0 value is the required heating time for killing microorganisms. F_0 value can be varied based on the product/items being sterilized and heating temperature. The key benefit of F_0 value is to optimize the heating process and minimize the executive heating to avoid the damage of products. The calculation of F_0 value as followed the Equation 2.8

$$F_0 = \Delta t \sum 10^{\frac{T - T_b}{Z}} \tag{2.8}$$

Where Δt = Measurement interval

T = Heating temperature

T_b = Temperature for steam sterilization (Generally = 121.1℃)

Z = Temperature unit of logarithmic sterilization capability change

(Generally = 10 ℃ is used)

Chapter 3

Define phase

In this phase, the manufacturing process of Ready Rice is studied to identify and analyze which process step is the causal cause of the defect or damage on packaging materials. Therefore, the problem is determined and prioritized by studying the current process. The relevant data of current problem status will be collected to determine the research objective, scope and measurement.

3.1 Process analysis

To investigate and analyze the problem, the process analysis is firstly conducted to identify the problem in manufacturing process of Ready Rice product.

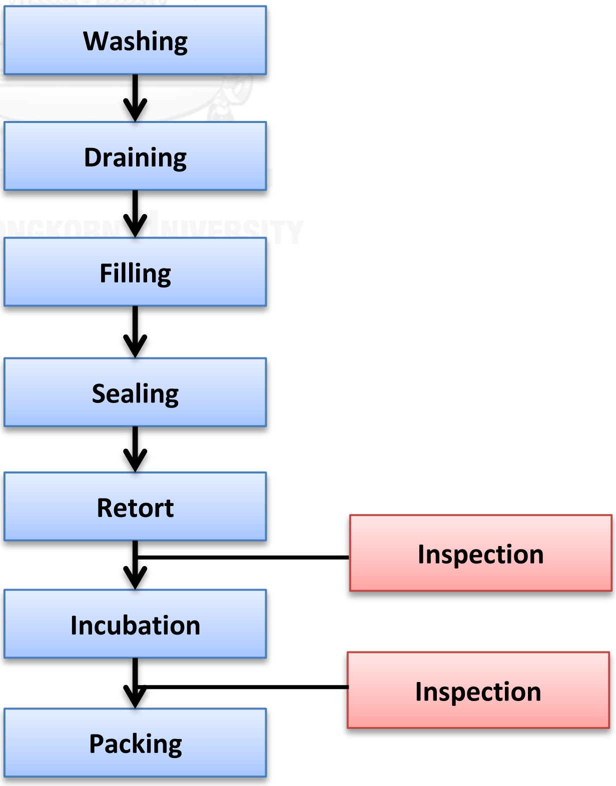


Figure 3.1: Process flow of Ready Rice production

There are seven process steps of Ready Rice manufacturing process as shown in Figure 3.1, starting from rice washing, draining, filling, sealing, retort, incubation and packing process. First process step is to wash the raw rice with clean water by manually before passing to the machineries process. The raw rice is inspected and sent by company's headquarter who has long expertise of rice production in the international market. For in-process inspection and contamination prevention process, the laser technology equipment is used to inspect and sort out any bugs and foreign matters from raw rice. Then, the rice is drained by putting on the shelf and leaving dry. Next, rice is passed through the automatic filling machine to fill the rice and soft water into the cup or tray at the setting quantity. The sealing machine is connected with filling machine by conveyor belt to close the mouth of cup or tray with plastic seal. Additionally, the date code is stamped at the bottom of the cup or tray after sealing. Before moving to the next process, every cup or tray has to be 100% inspected by inspector to sort out the defects such as the incomplete sealing line, air bubble at the sealing or missing of date code. The defects which are inspected in this process do not significantly impact the defective rate because they can bring back the rice to refill again. For next process, in-process product will pass through retort process which is the process to cook and sterilize rice by moist heat stream. Then products after retort process have to be closely inspected by inspectors to ensure that the defective products do not pass to the packing process and customer. The defect after retort process can be classified as two defect types, "Grade B" that can sell at the lower price and "Grade C" that have to be rejected. Before packing, Ready Rice products have to be incubated for 10-14 days until microbiological test result is available and passed test. Last step is the packing process to pack products in bundle shrink-wrapped film by passing through hot tunnel for shrink-wrapping and putting into the carton.

3.2 Statement of Ready Rice product problem

From the collective data during July 2014 to March 2015, it is found that the defective rate of Ready Rice product is around 5.14% which segregated as 2 grades.

Defect types in Ready Rice product

Defect in Ready Rice product can be classified into several types such as the illegible date code, the wrinkle of plastic seal, the out of shape of plastic cup, etc. The description and images of each defect type are represented in Table 3.1.

Table 3.1: The descriptions and images of defect type of Ready Rice product

Defect type	Description	Picture
Illegible date code	According to regulatory requirements, date code to indicate production date and expiry date of product must be available and legible on the product packaging. If date code is illegible, these are considered the defective product and have to be sorted out.	
Wrinkle of plastic seal	Wrinkle of plastic seal can lead to microbiological contamination of product. So, this defect has to be sorted out.	
Out of shape of plastic cup	Dented, distorted or swollen plastic cup. Consumer may perceive poor product quality and aesthetic.	
Out of shape of cup edge	Dented or distorted edge of plastic cup	

Defect type	Description	Picture
Rip of seal	Torn or hole at plastic seal. This can lead to microbiological contamination of product	
Physical contamination	Contamination by rice husk or other types of rice	
Under filling weight	Filling weight less than claim net weight. Not comply with regulation.	

From many types of defect in Ready Rice product, Pareto chart shown in Figure 3.2 and 3.3 represents the types of defect that are prioritized and need to be focused for both Grade B and Grade C products, respectively.

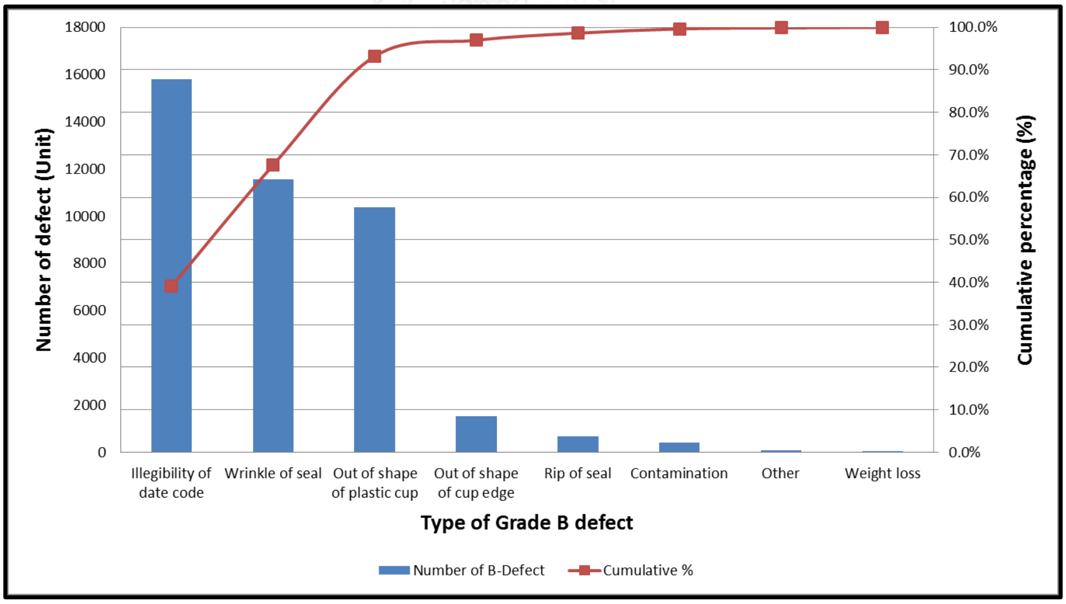


Figure 3.2: The numbers of each defect type of Grade B

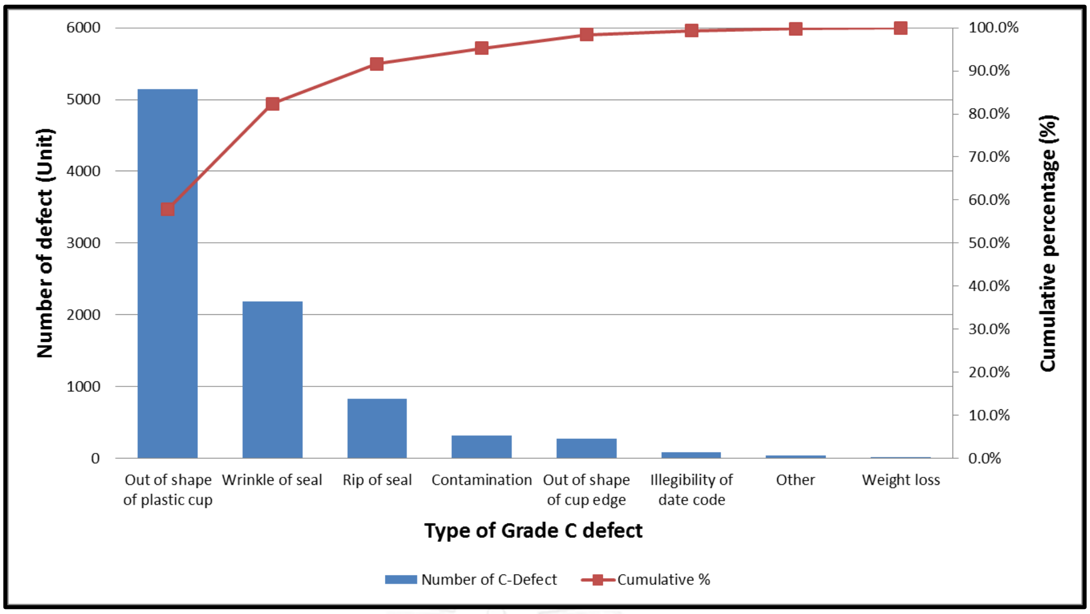


Figure 3.3: The number of each defect type of Grade C

Pareto chart of Grade B defect shown in Figure 3.2 represents three “Grade B” defect types majority; the illegible date code, the wrinkle of plastic seal and the out of shape of plastic cup, which contributed 93.2% of total number of Grade B defect. While Pareto chart of Grade C (Figure 3.3) shows the different majority of defect types. The out of shape of plastic cup, the wrinkle of seal and the rip of seal contribute 91.6% of total number of Grade C defect. The 80:20 concept of Pareto chart is applied to identify and prioritize the defect types that need to be focused. However, the different order of defect types based on the number of defect between Grade B and Grade C need to be considered the impact to waste cost value. Figure 3.4 shows the key defect type significantly impacted more than 80% out of total defect types by calculating the waste cost of each defect type based on Table 1.3.

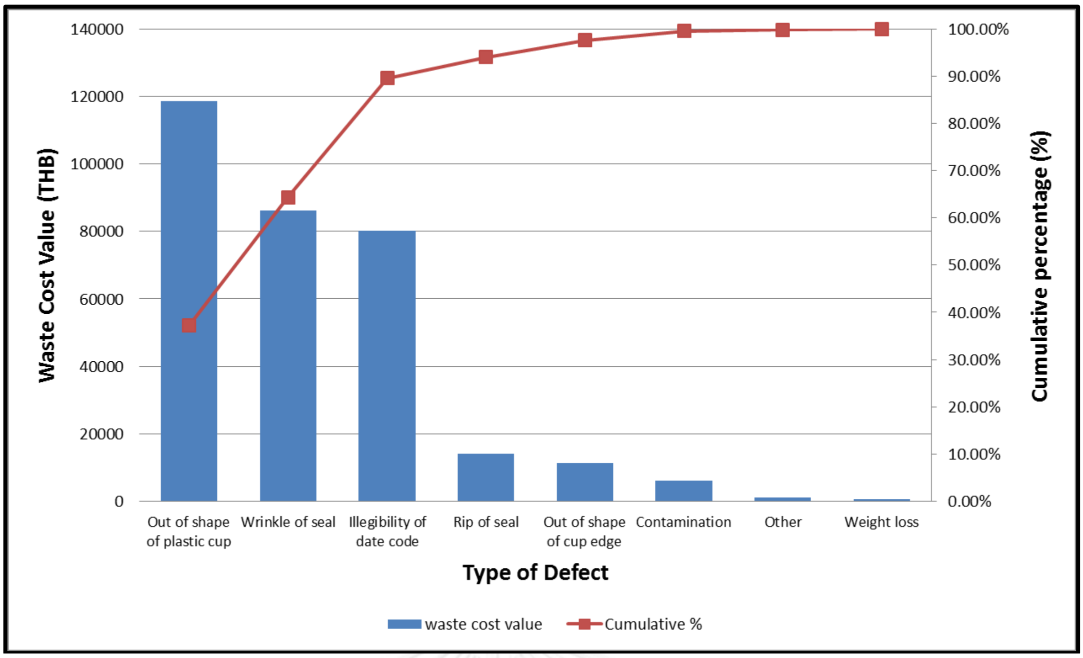


Figure 3.4: Waste cost value of each defect types

Pareto chart represents total waste cost of Grade B and Grade C defect type contributed the high waste cost in Ready Rice product. Therefore, there are three defect types, the out of shape of plastic cup, the wrinkle of plastic seal and the illegible date code contributed 89.58% of total waste cost value. In conclusion, this pilot study research will focus on these three types of defect and the company can apply this pilot study to other defect type in the future.

3.3 Research objective, scope and measurement

The objective of this research is to reduce the defective rate in Ready Rice product by focusing only three packaging defect types which include the out of shape, the wrinkle of seal and the illegible date code. The measurement of defect reduction rate is measured as percentage of waste.

3.4 Team setup

Team members are formed from cross-functional section of the company. This working team and the researcher as one of the members will plan, support and execute and research together. The team member has been selected based on their expertise in the production process and responsibility for these defect problems. The possible cause of the problem, the data collection, the experimental design and other supports are determined and executed by the researcher and team. The team consists of six professionals and one researcher as follows.

1. Product Engineer 1 person
2. Process Engineer 1 person
3. Production Engineer 1 person
4. Quality Control 1 person
5. Senior Advisor 1 person
6. Researcher 1 person

The main responsibility of researcher is included

1. Coordinate the research study
2. Design method for data collection
3. Design the experiment and record the results
4. Analyze the implementation results
5. Conclude the results
6. Design the control chart after process improvement

Chapter 4

Measure phase

This chapter is to determine the causes of the problems related with three defect types. First of all, the accuracy and precision of the measurement system for the capability analysis of current manufacturing process is measured. Secondly, the causes and effect diagram is defined by the associated team. Finally, the important causes are identified.

4.1 The measurement system analysis (MSA)

In the Ready Rice production, inspection processes are performed two times to check the packaging quality of Ready Rice product. The first inspection by production staffs will be performed right after product is stamped the date code. Staffs have to ensure that product unit is passed through every process steps. Additionally, the product is preliminary checked for quality of packaging such as good quality of seal, date code stamped completely and normal shape of cup. The defect found at this process step can be determined and reprocessed by taking the rice back to re-fill process. After the retort process, the second inspection is conducted by five inspectors to classify the defect type and severity level. Since this research focuses on defect reduction, therefore MSA must be performed to measure the precision and accuracy of the inspection staffs. MSA must be carries out for the inspection process for three types of defect. Table 4.1 shows the detail and picture of three defect types according to two severing grades called grade B and C.

Table 4.1: Examples of three types of defect in grade B and C

Type of Defect	Defect Name and Detail	Picture
Out of shape	Grade B: Minor out of shape of plastic cup	
Out of shape	Grade C: Major out of shape of plastic cup	
Wrinkle of seal	Grade B: Minor seal wrinkle	

Wrinkle of seal	Grade C: Major seal wrinkle that looks like a rip of seal	
Illegible date code	Grade B: Unreadable date code	
Illegible date code	Grade C: Ink dirt and cup look dirty	

Then, the sample size for analyzing the measurement system based on Fasser and Brettner (1992) shown in Table 4.2 is applied to define the number of units, the inspection staffs and the frequency of test.

Table 4.2: Sample size for analyzing the measurement system

The number of inspector (Man)	Minimum number of testing units (Units)	Minimum number of test frequency (Times)
1	24	5
2	18	4
>= 3	12	3

From Table 4.2, the number of inspectors who are assigned to perform inspection is three persons to inspect 30 units of samples with three times repeated inspection experiment.

4.1.1 The step of measurement system analysis in three defect types

There are 8 steps to analyze the measurement system for the out of shape of plastic cup, the wrinkle of seal and the illegible date code defect which are the attribute data.

1. Select master appraiser who can accurately classify the product quality and the severity level of defect. Then, this master appraiser provides training to other inspectors to ensure that all inspectors understand the defect type and severity level of defect.
2. Define the standard lots for the measurement system testing based on a study of Fasser and Brettner which suggested that the standard lots should include good, defect and marginal sample in the same proportion.
3. Select three appraisers who attend the training to determine the packaging defect types.
4. Place the test samples in a new random order in each inspection and allow the inspectors to perform their repeated assessments three times.
5. Perform inspection to determine if “defect or not” and collect the test results of three appraisers to analyze the accuracy and precision of the measurement system based on attribute defect types.

6. Perform test again following step 2 to 4 but change samples to include Grade B, Grade C and marginal samples. Collect test results of three inspectors to analyze the accuracy and precision of the measurement system based on attribute defect types.
7. Set the acceptance criteria to measure the test results in step 5 and 6 as shown in Table 4.3 and 4.4
8. Conclude the test results and find the way to improve if the result shows that the current measurement system does not meet the acceptance criteria.

Table 4.3: The acceptance criteria of the measurement system in testing of "Defect or not"

Measurement System	Acceptance Criteria
% Appraiser Score	100%
% Attribute Score	100%
% Screen Effective Score	100%
% Attribute Screen Effective Score	100%

1. Within appraiser: Analysis of repeatability of measurement system. This can be calculated by the Equation 4.1.

$$\frac{\text{Number of time of agreement}}{\text{Number of sample size}} \qquad (4.1)$$

2. Each appraiser vs. Standard: Analysis of measurement accuracy within appraisers (Individual effectiveness). This can be calculated by the Equation 4.2.

$$\frac{\text{Number of time of agreement and correctness}}{\text{Number of sample size}} \qquad (4.2)$$

3. Between appraiser: Analysis of reproducibility of measurement system. This can be calculated by the Equation 4.3.

$$\frac{\textbf{Number of time of agreement from all apraisers}}{\textbf{Number of sample size}} \tag{4.3}$$

4. All appraiser vs. Standard: Analysis of overall effectiveness of measurement system. This can be calculated by the Equation 4.4.

$$\frac{\textbf{Number of time of agreement and correctness from all appraisers}}{\textbf{Number of sample size}} \tag{4.4}$$

Table 4.4: The acceptance criteria of the measurement system in testing of “Two grade classification between Grade B and C”

Measurement System	Operator Effectiveness (O_E)	False Alarm Rate (I_{FA})	Miss Rate (I_{Miss})
Acceptable for the appraiser	$\geq$ 90%	$\leq$ 5%	$\leq$ 2%
May need improvement	$\geq$ 80%	$\leq$ 10%	$\leq$ 5%
Unacceptable for the appraiser – needs improvement	< 80%	> 10%	> 5%

4.1.2 Analysis of ability to classify the product as “Defect or Not”

The measurement system analysis in this stage is to measure the ability of appraisers to classify the good product and packaging defects. These three defect types are the attribute defects which can be classified by visual inspection of appraisers based on the quality of training. This analysis follows the step explained in 4.1.1 and the result of MSA of three defect types including the out of shape, the wrinkle of seal and the illegible date code are shown in Table 4.5, 4.6 and 4.7, respectively.

1. Operator effectiveness (O_E): the measurement of accuracy in each appraiser. This can be calculated by Equation 4.5.

$$\frac{\text{Number of correct decisions}}{\text{Total opportunities for a decisions}} \tag{4.5}$$

2. False alarm rate (I_{FA}): the measurement of error when appraiser decides the good product to be a defect. This can be calculated by Equation 4.6.

$$\frac{\text{Number of wrong decision in good product}}{\text{Total opportunities for a decisions good product}} \tag{4.6}$$

3. Miss rate (I_{Miss}): the measurement of error when appraiser decide the defect to be a good product. This can be calculated by Equation 4.7.

$$\frac{\text{Number of wrong decision in defect}}{\text{Total opportunities for a decisions defect}} \tag{4.7}$$

Table 4.5: The result of MSA to classify goods and the out of shape defect

No.	Answer	Inspector 1			Inspector 2			Inspector 3			Three assessments agree?	Three assessments agree with the standard?
		1	2	3	1	2	3	1	2	3		
1	P	P	P	P	P	P	P	P	P	P	Yes	Yes
2	P	P	P	P	P	P	P	P	P	P	Yes	Yes
3	P	P	P	P	P	P	P	P	P	P	Yes	Yes
4	P	P	P	P	P	P	P	P	P	P	Yes	Yes
5	P	P	P	P	P	P	P	P	P	P	Yes	Yes
6	P	P	P	P	P	P	P	P	P	P	Yes	Yes
7	P	P	P	P	P	P	P	P	P	P	Yes	Yes
8	P	P	P	P	P	P	P	P	P	P	Yes	Yes
9	P	P	P	P	P	P	P	P	P	P	Yes	Yes
10	P	P	P	P	P	P	P	P	P	P	Yes	Yes
11	D	D	D	D	D	D	D	D	D	D	Yes	Yes
12	D	D	D	D	D	D	D	D	D	D	Yes	Yes
13	D	D	D	D	D	D	D	D	D	D	Yes	Yes
14	D	D	D	D	D	D	D	D	D	D	Yes	Yes
15	D	D	D	D	D	D	D	D	D	D	Yes	Yes
16	D	D	D	D	D	D	D	D	D	D	Yes	Yes
17	D	D	D	D	D	D	D	D	D	D	Yes	Yes
18	D	D	D	D	D	D	D	D	D	D	Yes	Yes
19	D	D	D	D	D	D	D	D	D	D	Yes	Yes
20	D	D	D	D	D	D	D	D	D	D	Yes	Yes
21	P	P	P	P	P	P	P	P	P	P	Yes	Yes
22	D	D	D	D	D	D	D	D	D	D	Yes	Yes
23	P	P	P	P	P	P	P	P	P	P	Yes	Yes
24	D	D	D	D	D	D	D	D	D	D	Yes	Yes
25	P	P	P	P	P	P	P	P	P	P	Yes	Yes
26	D	D	D	D	D	D	D	D	D	D	Yes	Yes
27	D	D	D	D	D	D	D	D	D	D	Yes	Yes
28	P	P	P	P	P	P	P	P	P	P	Yes	Yes
29	D	D	D	D	D	D	D	D	D	D	Yes	Yes
30	D	D	D	D	D	D	D	D	D	D	Yes	Yes

P = Passed product D = The out of shape defect

Table 4.6: The result of MSA to classify goods and the wrinkle of seal defect

No.	Answer	Inspector 1			Inspector 2			Inspector 3			Three assessments agree?	Three assessments agree with the standard?
		1	2	3	1	2	3	1	2	3		
1	P	P	P	P	P	P	P	P	P	P	Yes	Yes
2	P	P	P	P	P	P	P	P	P	P	Yes	Yes
3	P	P	P	P	P	P	P	P	P	P	Yes	Yes
4	P	P	P	P	P	P	P	P	P	P	Yes	Yes
5	P	P	P	P	P	P	P	P	P	P	Yes	Yes
6	P	P	P	P	P	P	P	P	P	P	Yes	Yes
7	P	P	P	P	P	P	P	P	P	P	Yes	Yes
8	P	P	P	P	P	P	P	P	P	P	Yes	Yes
9	P	P	P	P	P	P	P	P	P	P	Yes	Yes
10	P	P	P	P	P	P	P	P	P	P	Yes	Yes
11	D	D	D	D	D	D	D	D	D	D	Yes	Yes
12	D	D	D	D	D	D	D	D	D	D	Yes	Yes
13	D	D	D	D	D	D	D	D	D	D	Yes	Yes
14	D	D	D	D	D	D	D	D	D	D	Yes	Yes
15	D	D	D	D	D	D	D	D	D	D	Yes	Yes
16	D	D	D	D	D	D	D	D	D	D	Yes	Yes
17	D	D	D	D	D	D	D	D	D	D	Yes	Yes
18	D	D	D	D	D	D	D	D	D	D	Yes	Yes
19	D	D	D	D	D	D	D	D	D	D	Yes	Yes
20	D	D	D	D	D	D	D	D	D	D	Yes	Yes
21	P	P	P	P	P	P	P	P	P	P	Yes	Yes
22	D	D	D	D	D	D	D	D	D	D	Yes	Yes
23	P	P	P	P	P	P	P	P	P	P	Yes	Yes
24	D	D	D	D	D	D	D	D	D	D	Yes	Yes
25	P	P	P	P	P	P	P	P	P	P	Yes	Yes
26	D	D	D	D	D	D	D	D	D	D	Yes	Yes
27	D	D	D	D	D	D	D	D	D	D	Yes	Yes
28	P	P	P	P	P	P	P	P	P	P	Yes	Yes
29	D	D	D	D	D	D	D	D	D	D	Yes	Yes
30	D	D	D	D	D	D	D	D	D	D	Yes	Yes

P = Passed product D = The wrinkle of seal defect

Table 4.7: The result of MSA to classify goods and the illegible date code defect

No.	Answer	Inspector 1			Inspector 2			Inspector 3			Three assessments agree?	Three assessments agree with the standard?
		1	2	3	1	2	3	1	2	3		
1	P	P	P	P	P	P	P	P	P	P	Yes	Yes
2	P	P	P	P	P	P	P	P	P	P	Yes	Yes
3	P	P	P	P	P	P	P	P	P	P	Yes	Yes
4	P	P	P	P	P	P	P	P	P	P	Yes	Yes
5	P	P	P	P	P	P	P	P	P	P	Yes	Yes
6	P	P	P	P	P	P	P	P	P	P	Yes	Yes
7	P	P	P	P	P	P	P	P	P	P	Yes	Yes
8	P	P	P	P	P	P	P	P	P	P	Yes	Yes
9	P	P	P	P	P	P	P	P	P	P	Yes	Yes
10	P	P	P	P	P	P	P	P	P	P	Yes	Yes
11	D	D	D	D	D	D	D	D	D	D	Yes	Yes
12	D	D	D	D	D	D	D	D	D	D	Yes	Yes
13	D	D	D	D	D	D	D	D	D	D	Yes	Yes
14	D	D	D	D	D	D	D	D	D	D	Yes	Yes
15	D	D	D	D	D	D	D	D	D	D	Yes	Yes
16	D	D	D	D	D	D	D	D	D	D	Yes	Yes
17	D	D	D	D	D	D	D	D	D	D	Yes	Yes
18	D	D	D	D	D	D	D	D	D	D	Yes	Yes
19	D	D	D	D	D	D	D	D	D	D	Yes	Yes
20	D	D	D	D	D	D	D	D	D	D	Yes	Yes
21	P	P	P	P	P	P	P	P	P	P	Yes	Yes
22	D	D	D	D	D	D	D	D	D	D	Yes	Yes
23	P	P	P	P	P	P	P	P	P	P	Yes	Yes
24	D	D	D	D	D	D	D	D	D	D	Yes	Yes
25	P	P	P	P	P	P	P	P	P	P	Yes	Yes
26	D	D	D	D	D	D	D	D	D	D	Yes	Yes
27	D	D	D	D	D	D	D	D	D	D	Yes	Yes
28	P	P	P	P	P	P	P	P	P	P	Yes	Yes
29	D	D	D	D	D	D	D	D	D	D	Yes	Yes
30	D	D	D	D	D	D	D	D	D	D	Yes	Yes

P = Passed product D = The illegible date code defect

Then, the accuracy and precision of the measuring system are analyzed using the testing data in Tables 4.5-4.7.

The result of MSA of three defect types is 100.00% for all four criteria as shown in Figure 4.1 and meets the company's acceptance criteria as specified in Table 4.3. It can be concluded that all of inspectors in this testing have competency and ability to classify the product if it is defect or not and re-training is not necessary.

Attribute Agreement Analysis for Result

Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95 % CI
1	30	30	100.00	(90.50, 100.00)
2	30	30	100.00	(90.50, 100.00)
3	30	30	100.00	(90.50, 100.00)

Matched: Appraiser agrees with him/herself across trials.

Each Appraiser vs. Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95 % CI
1	30	30	100.00	(90.50, 100.00)
2	30	30	100.00	(90.50, 100.00)
3	30	30	100.00	(90.50, 100.00)

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

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95 % CI
30	30	100.00	(90.50, 100.00)

Matched: All appraisers' assessments agree with each other.

All Appraisers vs. Standard

Assessment Agreement

# Inspected	# Matched	Percent	95 % CI
30	30	100.00	(90.50, 100.00)

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

Figure 4.1: The result of the "Measurement System Analysis" by Minitab

4.1.3 Analysis of ability to classify the grade of defect

When appraisers can classify accurately the good product and defect in previous stage, grade of defect classification is tested by following the step in 4.1.1 again with same appraisers. The sample products are changed to Grade B, Grade C and marginal products in the same proportion.

Table 4.8: The result of MSA to classify grade of defect for the out of shape defect

No.	Answer	Inspector 1			Inspector 2			Inspector 3			Three assessments agree?	Three assessments agree with the standard?
		1	2	3	1	2	3	1	2	3		
1	C	C	C	C	C	C	C	C	C	C	Yes	Yes
2	C	C	C	C	C	C	C	C	C	C	Yes	Yes
3	C	C	C	C	C	C	C	C	C	C	Yes	Yes
4	C	C	C	C	C	C	C	C	C	C	Yes	Yes
5	C	C	C	C	C	C	C	C	C	C	Yes	Yes
6	B	B	B	B	B	B	B	B	B	B	Yes	Yes
7	B	B	B	B	B	B	B	B	B	B	Yes	Yes
8	B	B	B	B	B	B	B	B	B	B	Yes	Yes
9	B	B	B	B	B	B	B	B	B	B	Yes	Yes
10	B	B	B	B	B	B	B	B	B	B	Yes	Yes
11	B	B	B	B	B	B	B	B	B	B	Yes	Yes
12	B	B	B	B	B	B	B	B	B	B	Yes	Yes
13	B	B	B	B	B	B	B	B	B	B	Yes	Yes
14	B	B	B	B	B	B	B	B	B	B	Yes	Yes
15	B	B	B	B	B	B	B	B	B	B	Yes	Yes
16	C	C	C	C	C	C	C	C	C	C	Yes	Yes
17	C	C	C	C	C	C	C	C	C	C	Yes	Yes
18	C	C	C	C	C	C	C	C	C	C	Yes	Yes
19	C	C	C	C	C	C	C	C	C	C	Yes	Yes
20	C	B	B	B	C	C	C	B	B	B	No	No
21	C	C	C	C	C	C	C	C	C	C	Yes	Yes
22	C	C	C	C	C	C	C	C	C	C	Yes	Yes
23	C	C	C	C	C	C	C	C	C	C	Yes	Yes
24	B	B	B	B	B	B	B	B	B	B	Yes	Yes
25	B	B	B	B	B	B	B	B	B	B	Yes	Yes
26	B	B	B	B	B	B	B	B	B	B	Yes	Yes
27	C	C	C	C	C	C	C	B	B	C	No	No
28	B	B	B	B	B	B	B	B	B	B	Yes	Yes
29	C	C	C	C	C	C	C	C	C	C	Yes	Yes
30	B	B	B	B	B	B	B	B	B	B	Yes	Yes

B = Grade B of the out of shape defect C = Grade C of the out of shape defect

Table 4.9: The result of MSA to classify grade of defect for the wrinkle of seal defect

No.	Answer	Inspector 1			Inspector 2			Inspector 3			Three assessments agree?	Three assessments agree with the standard?
		1	2	3	1	2	3	1	2	3		
1	B	B	B	B	B	B	B	B	B	B	Yes	Yes
2	B	B	B	B	B	B	B	B	B	B	Yes	Yes
3	B	B	B	B	B	B	B	B	B	B	Yes	Yes
4	B	B	B	B	B	B	B	B	B	B	Yes	Yes
5	B	B	B	B	B	B	B	B	B	B	Yes	Yes
6	B	B	B	B	B	B	B	B	B	B	Yes	Yes
7	B	B	B	B	B	B	B	B	B	B	Yes	Yes
8	B	B	B	B	B	B	B	C	C	C	No	No
9	B	B	C	B	B	C	B	C	C	C	No	No
10	B	B	B	B	B	B	B	B	B	B	Yes	Yes
11	C	B	B	B	C	C	C	C	C	C	No	No
12	C	C	C	C	C	C	C	C	C	C	Yes	Yes
13	C	C	C	C	C	C	C	C	C	C	Yes	Yes
14	C	C	C	C	C	C	C	C	C	C	Yes	Yes
15	C	B	B	B	C	C	C	C	C	C	No	No
16	C	C	C	C	C	C	C	C	C	C	Yes	Yes
17	C	C	C	C	C	C	C	C	C	C	Yes	Yes
18	C	C	C	C	C	C	C	C	C	C	Yes	Yes
19	C	C	C	C	C	C	C	C	C	C	Yes	Yes
20	C	B	C	C	C	C	C	C	C	C	No	No
21	B	B	B	B	B	B	B	B	B	B	Yes	Yes
22	C	C	C	C	C	C	C	C	C	C	Yes	Yes
23	B	C	B	B	B	B	B	C	C	C	No	No
24	C	C	C	C	C	C	C	C	C	C	Yes	Yes
25	B	B	B	B	B	B	B	B	B	B	Yes	Yes
26	C	C	C	C	C	C	C	C	C	C	Yes	Yes
27	B	B	B	B	B	B	B	B	B	B	Yes	Yes
28	C	C	C	C	C	C	C	C	C	C	Yes	Yes
29	B	C	C	C	B	B	C	C	C	C	No	No
30	C	C	C	C	C	C	C	C	C	C	Yes	Yes

B = Grade B of the wrinkle of seal defect C = Grade C of the wrinkle of seal defect

Table 4.10: The result of MSA to classify grade of defect for the illegible date code defect

No.	Answer	Inspector 1			Inspector 2			Inspector 3			Three assessments agree?	Three assessments agree with the standard?
		1	2	3	1	2	3	1	2	3		
1	B	B	B	B	B	B	B	B	B	B	Yes	Yes
2	B	B	B	B	B	B	B	B	B	B	Yes	Yes
3	B	B	B	B	B	B	B	B	B	B	Yes	Yes
4	B	B	B	B	B	B	B	B	B	B	Yes	Yes
5	B	B	B	B	B	B	B	B	B	B	Yes	Yes
6	C	C	C	C	C	C	C	C	C	C	Yes	Yes
7	C	C	C	C	C	C	C	C	C	C	Yes	Yes
8	C	C	C	C	C	C	C	C	C	C	Yes	Yes
9	C	C	C	C	C	C	C	C	C	C	Yes	Yes
10	C	C	C	C	C	C	C	C	C	C	Yes	Yes
11	B	B	B	B	B	B	B	B	B	B	Yes	Yes
12	B	B	B	B	B	B	B	B	B	B	Yes	Yes
13	B	B	B	B	B	B	B	B	B	B	Yes	Yes
14	B	B	B	B	B	B	B	B	B	B	Yes	Yes
15	B	B	B	B	B	B	B	B	B	B	Yes	Yes
16	C	C	C	C	C	C	C	C	C	C	Yes	Yes
17	C	C	C	C	C	C	C	C	C	C	Yes	Yes
18	C	C	C	C	C	C	C	C	C	C	Yes	Yes
19	C	C	C	C	C	C	C	C	C	C	Yes	Yes
20	C	C	C	C	C	C	C	C	C	C	Yes	Yes
21	C	C	C	C	C	C	C	C	C	C	Yes	Yes
22	C	C	C	C	C	C	C	C	C	C	Yes	Yes
23	C	C	C	C	C	C	C	C	C	C	Yes	Yes
24	C	C	C	C	C	C	C	C	C	C	Yes	Yes
25	C	C	C	C	C	C	C	C	C	C	Yes	Yes
26	B	B	B	B	B	B	B	B	B	B	Yes	Yes
27	B	B	B	B	B	B	B	B	B	B	Yes	Yes
28	B	B	B	B	B	B	B	B	B	B	Yes	Yes
29	B	B	B	B	B	B	B	B	B	B	Yes	Yes
30	B	B	B	B	B	B	B	B	B	B	Yes	Yes

B = Grade B of the illegible date code defect

C = Grade C of the illegible date code defect

Tables 4.8-4.10 show the result of MSA when focusing on grade of defect classification between Grade B and C for the out of shape, the wrinkle of seal and the illegible date code consequently.

The result of MSA from three appraisers calculated according to Equation 4.5-4.7 of three criteria is shown in Table 4.11.

Table 4.11: The result of MSA in “Two grade classification”

	Appraiser 1			Appraiser 2			Appraiser 3		
	O_E	I_{FA}	I_{Miss}	O_E	I_{FA}	I_{Miss}	O_E	I_{FA}	I_{Miss}
Out of shape	97%	0%	7%	100%	0%	0%	94%	0%	11%
Wrinkle of seal	87%	11%	16%	94%	7%	2%	87%	27%	0%
Illegible date code	100%	0%	0%	100%	0%	0%	100%	0%	0%

The result in Table 4.11 shows that there is only one appraiser (Appraiser 2) can be accepted by MSA criteria in Table 4.3. It can be suggested that Appraiser 2 is the qualified person to inspect three types of defect for this research.

4.2 Process capability analysis

Process capability is the measure of process variation which can be separately measured for short term and long term variation. The standard acceptance values of short and long term process capability are shown in Table 4.12 base on AIAG (1995).

Table 4.12: The process capability requirement

Process capability analysis	Standard acceptance value
Process capability (C_{pk})	$\geq$ 1.33
Process performance (P_{pk})	$\geq$ 1.67

The process capability of three types of defects is determined as follows;

4.2.1 The out of shape defect

From the historical data collection for the out of shape defect for the past nine months (July 2014-March 2015), the defect rate of the out of shape is 1.62% or 0.0162 as shown in Figure 4.2.

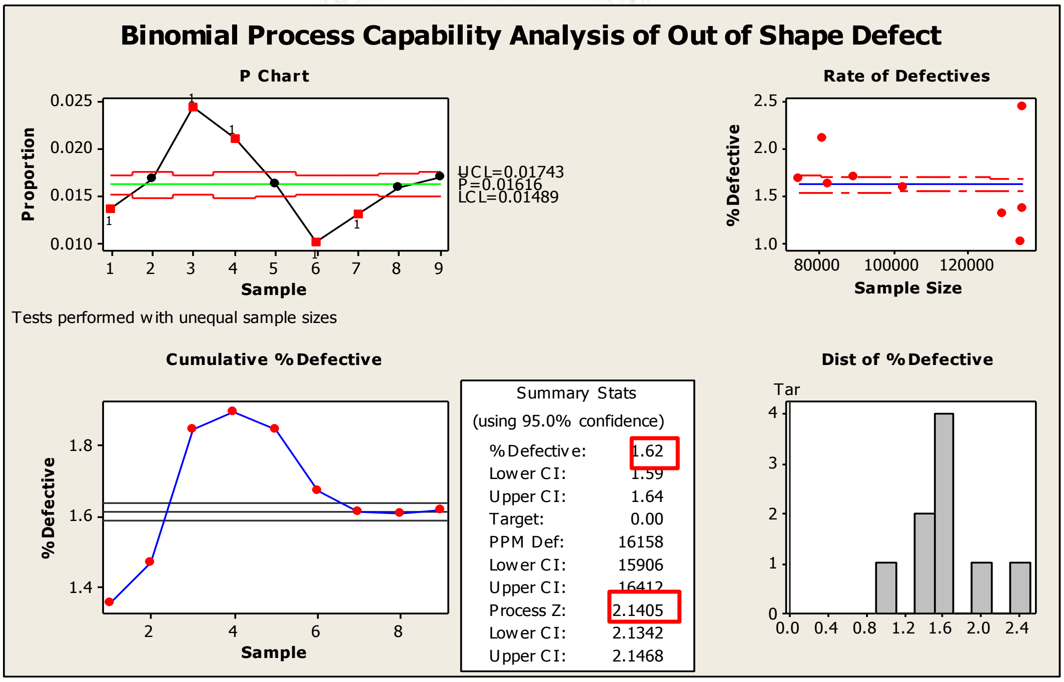


Figure 4.2: Process capability analysis of the out of shape defect before improvement

The C_{pk} and P_{pk} for the out of shape defect can be determined as follows

$$C_{pk} = \frac{1}{3} \times Z_{ST} \tag{4.8}$$

$$P_{pk} = \frac{1}{3} \times Z_{LT} \tag{4.9}$$

Where

Z_{LT} = Long term process which is the critical value found from the standard normal Table, P(Z<Z*) = 1- $\bar{\bar{P}}$

Z_{ST} = $Z_{LT} + 1.5$

$\bar{P}$ = Defective rate

Therefore P (Z<Z*) = 1- 0.0162 = 0.9838

Z_{LT} = 2.14

And Z_{ST} = 2.14 + 1.5 = 3.64

Therefore, the short term (C_{pk}) and long term (P_{pk}) process capability in the out of shape defect is

$$C_{pk} = \frac{1}{3} \times 3.64 = 1.213$$

And $$P_{pk} = \frac{1}{3} \times 2.14 = 0.713$$

When compared C_{pk} and P_{pk} of the out of shape defect with the standard acceptance value that defined the C_{pk} has to be greater than or equal to 1.33 and P_{pk} greater than or equal 1.67 accordingly. It concludes that both 2 value are less than standard. So, process capability need to be improved.

4.2.2 The wrinkle of seal defect

From the historical data collection of the wrinkle of seal defect within nine months, the proportion of the wrinkle of seal defect is 1.43% or 0.0143 that show in Figure 4.3.

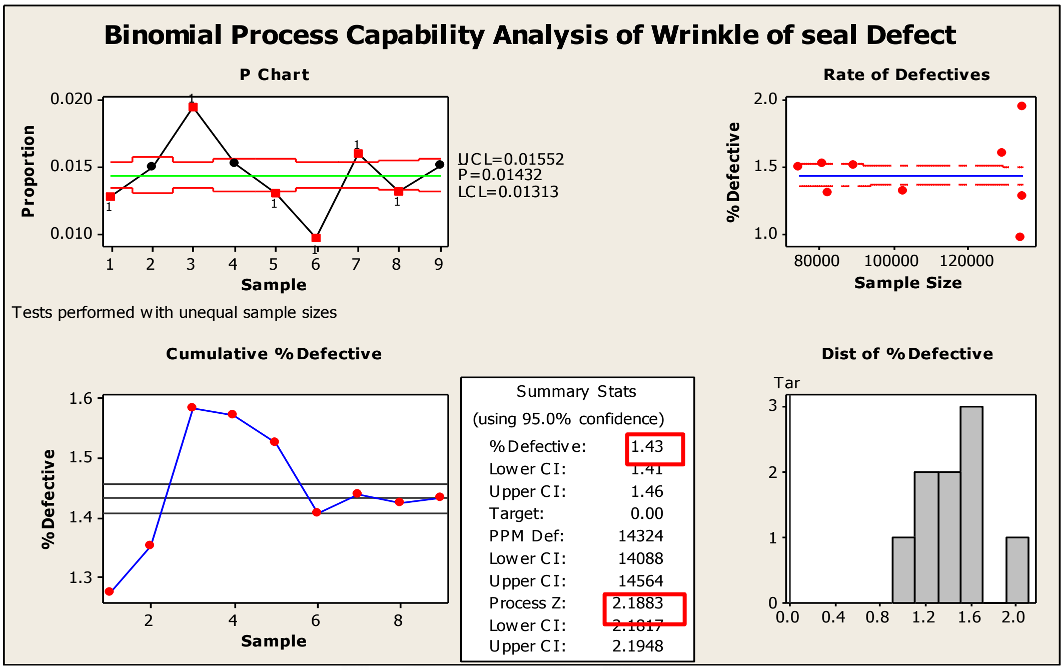


Figure 4.3: Process capability analysis of the wrinkle of seal defect before improvement

Where

Z_{LT} = Long term process which is the critical value found from the standard normal Table, P (Z<Z*) = 1- $\bar{\bar{P}}$

$Z_{ST} = Z_{LT} + 1.5$

$\bar{P}$ = Defective rate

Therefore P (Z<Z*) = 1- 0.0143 = 0.9857

Z_{LT} = 2.19

And Z_{ST} = 2.19 + 1.5 = 3.69

Therefore, the short term (C_{pk}) and long term (P_{pk}) process capability in the out of shape defect is

$$C_{pk} = \frac{1}{3} \times 3.69 = 1.23$$

And $$P_{pk} = \frac{1}{3} \times 2.19 = 0.73$$

When compared C_{pk} and P_{pk} of the wrinkle of seal defect with the standard acceptance value that defined the C_{pk} has to be greater than or equal to 1.33 and P_{pk} greater than or equal 1.67 accordingly. It concludes that both 2 value are less than standard. So, process capability need to be improved.

4.2.3 The illegible date code defect

From the historical data collection of the illegible date code defect within nine months, the proportion of the illegible date code defect is 1.66% or 0.0166 that show in Figure 4.4.

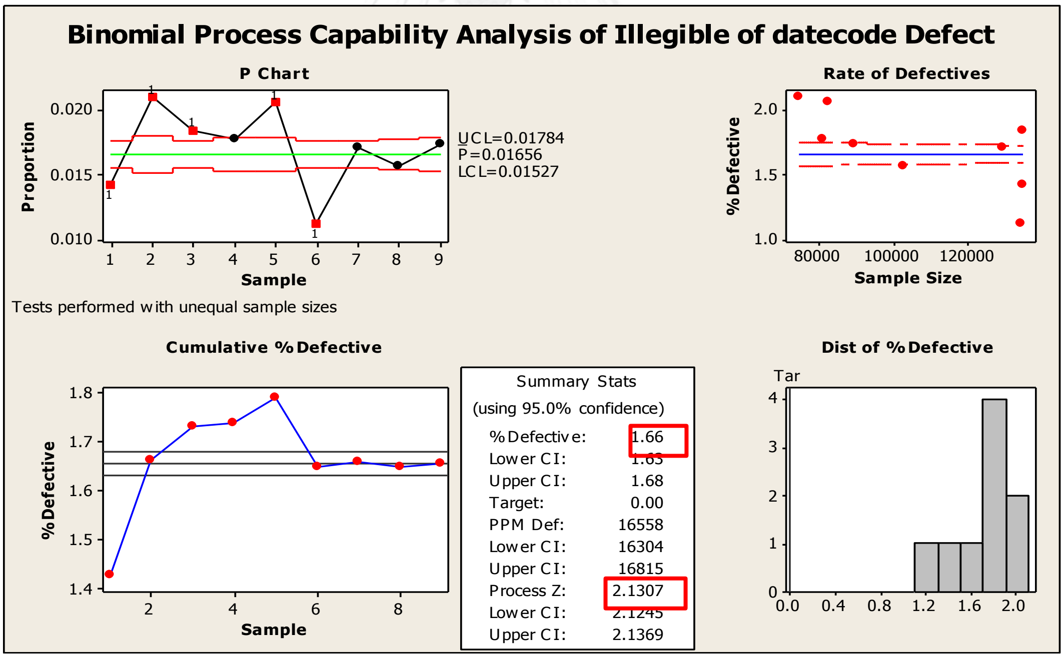


Figure 4.4: Process capability analysis of the illegible date code defect before improvement

Where

Z_{LT} = Long term process which is the critical value found from the standard normal Table, P (Z<Z*) = 1- $\overline{\overline{P}}$

Z_{ST} = $Z_{LT} + 1.5$

$\overline{P}$ = Defective rate

Therefore P (Z<Z*) = 1- 0.0166 = 0.9834

Z_{LT} = 2.13

And Z_{ST} = 2.13 + 1.5 = 3.63

Therefore, the short term (C_{pk}) and long term (P_{pk}) process capability in the out of shape defect is

$$C_{pk} = \frac{1}{3} \times 3.63 = 1.21$$

And $$P_{pk} = \frac{1}{3} \times 2.13 = 0.71$$

When compared C_{pk} and P_{pk} of the illegible date code defect with the standard acceptance value that defined the C_{pk} has to be greater than or equal to 1.33 and P_{pk} greater than or equal 1.67 accordingly. It concludes that both 2 value are less than standard. So, process capability need to be improved.

4.3 Identify the major causes of three defect types

To identify the causes that can be the cause of three defect types, there are four problem analysis tools as following;

4.3.1 Cause and Effect diagram

First step is analysis with Cause and Effect diagram to brainstorm the team member's idea. The causes will be classified into 4 groups including Man, Machine, Material and Method. From the team brainstorming, Cause and Effect diagrams of three defect types show in Figure 4.5- 4.7.

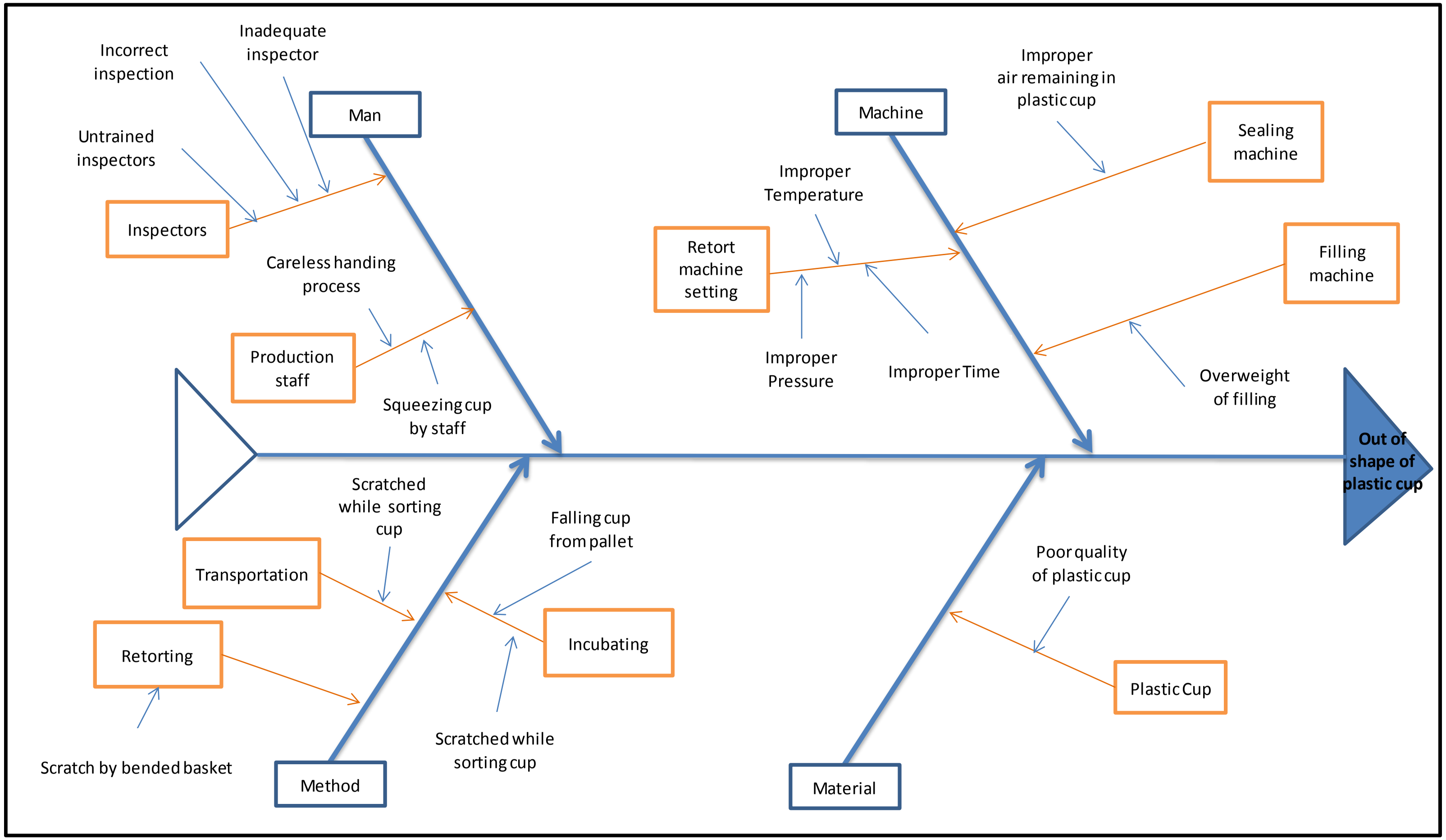


Figure 4.5: Cause and Effect diagram of the out of shape defect

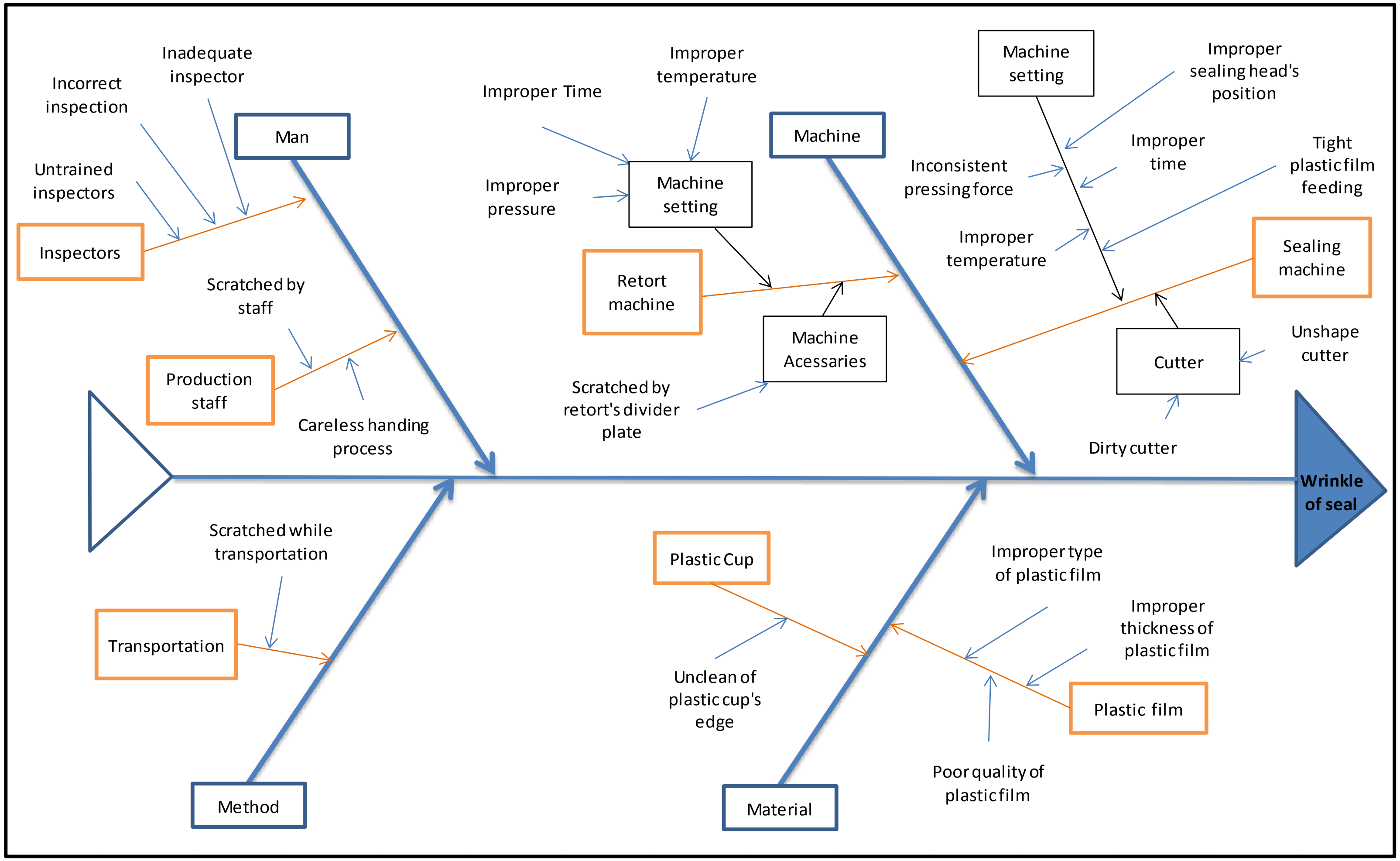


Figure 4.6: Cause and Effect diagram of the wrinkle of seal defect

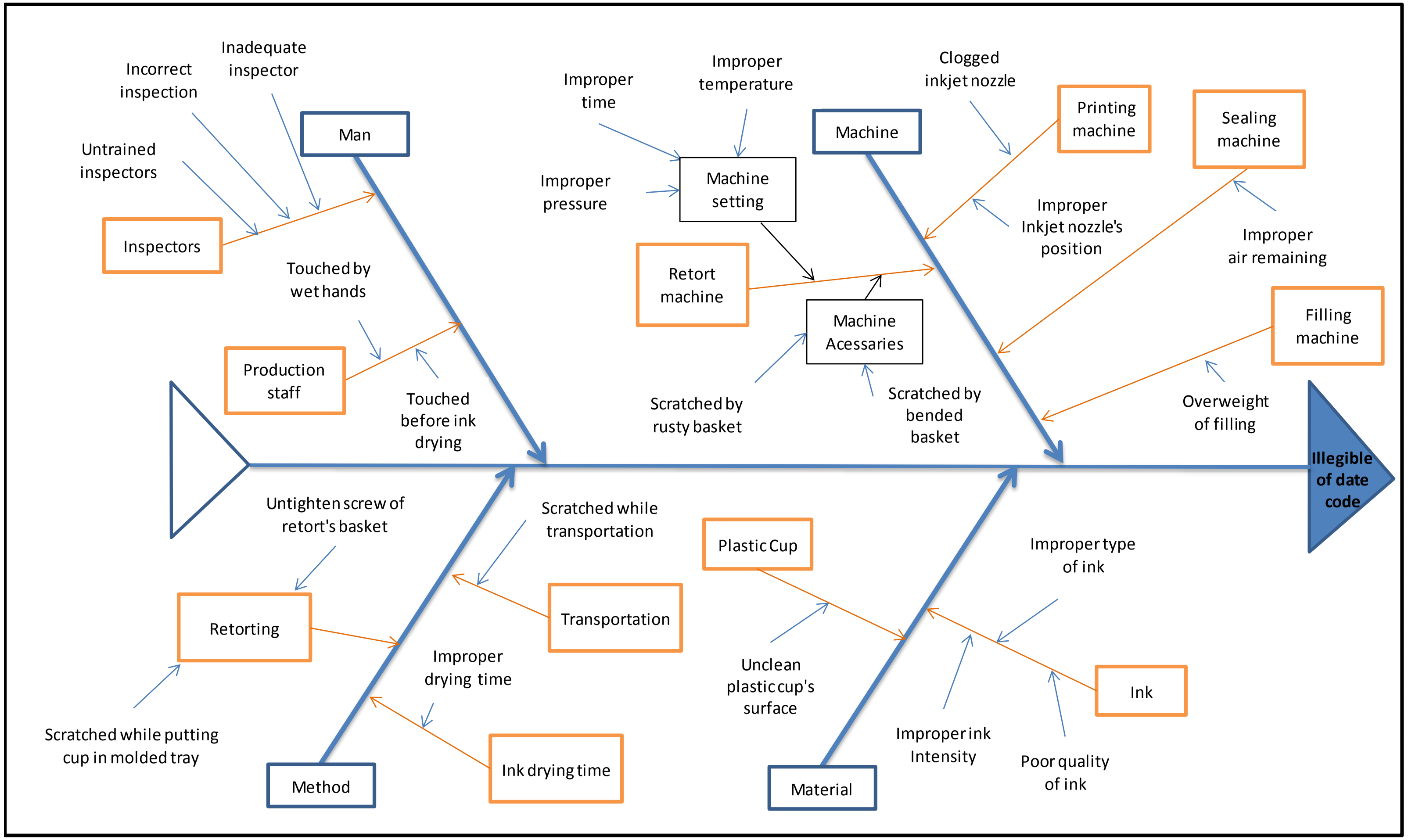


Figure 4.7: Cause and Effect diagram of the illegible date code

4.3.2 Failure Mode and Effects Analysis (FMEA)

When many causes are identified by brainstorming, the team members have to evaluate the importance of each cause by applying the concept of “Failure Mode and Effects Analysis” (FMEA). The importance of causes can be evaluated based on severity level of defect (S), probability of occurrence (O) and probability of detection (D) as shown in Table 4.13.

Table 4.13: The criteria of severity level, probability of occurrences and detection

Severity Level (S)	Point
Certainly cause of Grade C defect	5
Certainly cause of Grade B and potential cause of Grade C defect	4
Certainly cause of Grade B defect but not cause of Grade C	3
Potential cause of Grade B defect	2
No effect to product defect	1

Probability of Occurrences (O)	Point
Found defect every batch	5
Found defect every 5 batches	4
Found defect every 10 batches	3
Found defect every 20 batches	2
Rarely or unlikely defect found	1

Detection (D)	Point
Hard to detect by visual inspection	5
Poor detect by visual inspection	4
Moderately detect	3
High chance to detect	2
Easily detect by visual inspection	1

The average score of FMEA calculated from average of S x O x D score from 5 team members is shown in Table 4.14, 4.16 and 4.18. Then, the key causes that need to focus can be identified by using the concept of 80:20 from Pareto chart.

4.3.2.1 The key causes of the out of shape defect

Table 4.14: FMEA score of "the out of shape" causes

No.	Causes	Average SxOxD
1	Improper pressure of retort machine	58.2
2	Improper temperature of retort machine	45
3	Improper time of retort machine	21.4
4	Improper remaining air in cup	7.4
5	Overweight of filling	2
6	Falling cup from pallet in incubation process	17.6
7	Scratched while sorting cup in transportation process	9.2
8	Scratched while sorting cup in incubating process	9.2
9	Careless handing process	11.6
10	Scratched by bended basket	13.6
11	Poor quality of plastic cup	4.6
12	Squeezing cup by staff	7
13	Untrained inspector	6.6
14	Incorrect inspection	25.2
15	Inadequate inspector	2.6

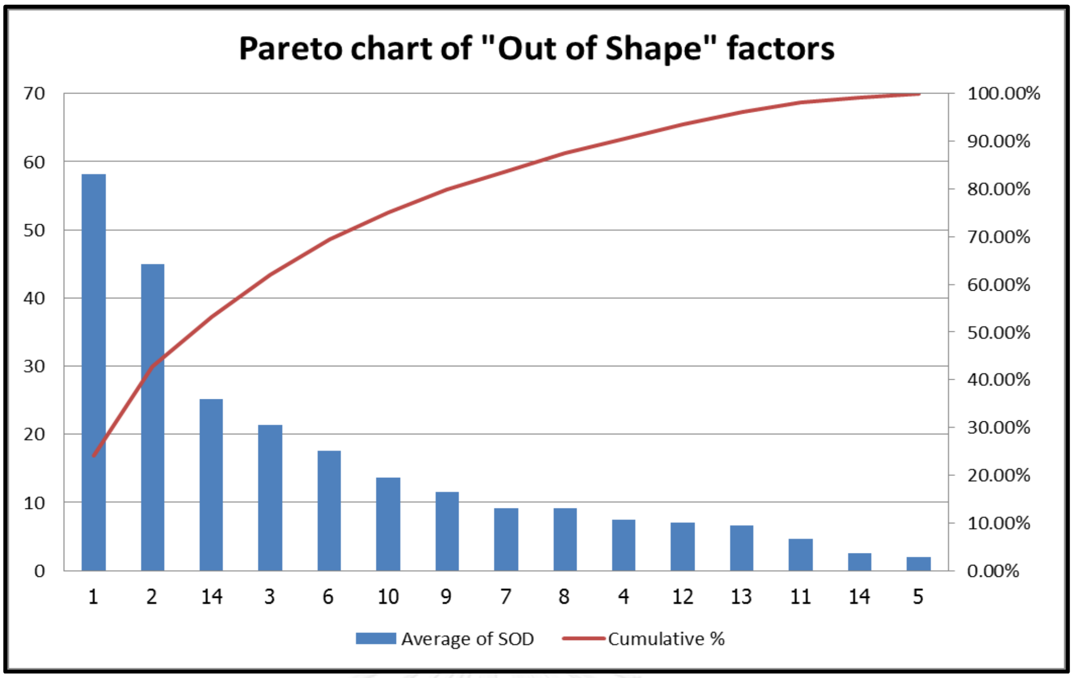


Figure 4.8: Pareto chart of the out of shape defect's causes

There are eight causes as shown in Figure 4.8 associated with the causes of the out of shape defect that cover 80% of score out of all causes. The details of each cause number can be explained as follows.

1. Number 1: Improper pressure of retort machine

    Pressure is one of major process parameters of retort machine to provide the optimal process condition to sterilize product in retort process. The improper value causes damage to the shape of cup.

2. Number 2: Improper temperature of retort machine

    The shape of plastic cup can be effected by temperature of retort machine in exposure stage which the temperature is raised rapidly.

3. Number 14: Incorrect inspection

    There is a chance that inspector makes the wrong decision by classifying the good product as the defect.

4. Number 3: Improper time of retort machine

    The time of retort machine set in each of stage might be improper and effect the shape of cup.

5. Number 6: Falling cup from pallet in incubation process

    At incubation process, there is a chance that the product falls from the pallet. The falling cup can be caused by the disordered sorting.

6. Number 10: Scratched by bended basket

    The bended basket of retort accessory can cause the damage like scratch on plastic cup because the basket is rotated during retort process.

7. Number 9: Careless handing process

    The out of shape of plastic cup can be caused from poor handling or careless handling by production staff.

8. Number 7: Scratched while sorting cup in transportation process

    Cart is used to transfer a cup between each of process. The cup sorting on the cart can make the cup out of shape because the cups are contacted with others.

From all causes described above, there are only two causes that can bring into the design of experiments study which are the pressure and temperature of retort machine. These two causes are weighed as the first and second important causes for the out of shape defect. Whereas other six causes will not be applied in the design of experiments study but will be controlled by control plan or recommended action as identified in Table 4.15.

Table 4.15: Control Plan and action of undesignable causes in the out of shape defect

No.	Causes	Control Plan/Recommended Action
14	Incorrect inspection	Staff training and qualification program
3	Improper time of retort machine	Retort time cannot be changed because it is derived based on the principle of sterility (F_0) to ensure that the microorganism has lost the ability to reproduce.
6	Falling cup from pallet in incubation process	Staff training and process control by shrink-wrapping the pallet
10	Scratched by bended basket	Preventive maintenance plan to check the performance and condition of machine accessories.
9	Careless handing process	Staff training and process control by installing CCTV.
7	Scratched while sorting cup in transportation process	Staff training and process control by developing standard pattern of sorting process.

4.3.2.2 The key causes of the wrinkle of seal defect

Table 4.16: FMEA score of “the wrinkle of seal “causes

No.	Causes	Average SxOxD
1	Improper pressure of retort machine	32.4
2	Improper temperature of retort machine	34.2
3	Improper time of retort machine	17.2
4	Inconsistent pressing force of sealing machine	28.8
5	Improper temperature of sealing machine	39.6
6	Improper time of sealing machine	21.6
7	Improper sealing head’s position	29.4
8	Tight plastic film feeding	8.6
9	Scratched while transportation	7.2
10	Unclean of plastic cup's edge	3.6
11	Improper type of plastic film	2
12	Improper thickness of plastic film	2.8
13	Poor quality of plastic film	4.2
14	Scratched by retort's divider plate	26
15	Unshaped cutter	6.2
16	Dirty cutter	2.8
17	Untrained inspector	6.6
18	Incorrect inspection	25.2
19	Inadequate inspector	2.6
20	Scratched by staff	11.8
21	Careless handing process	10.6

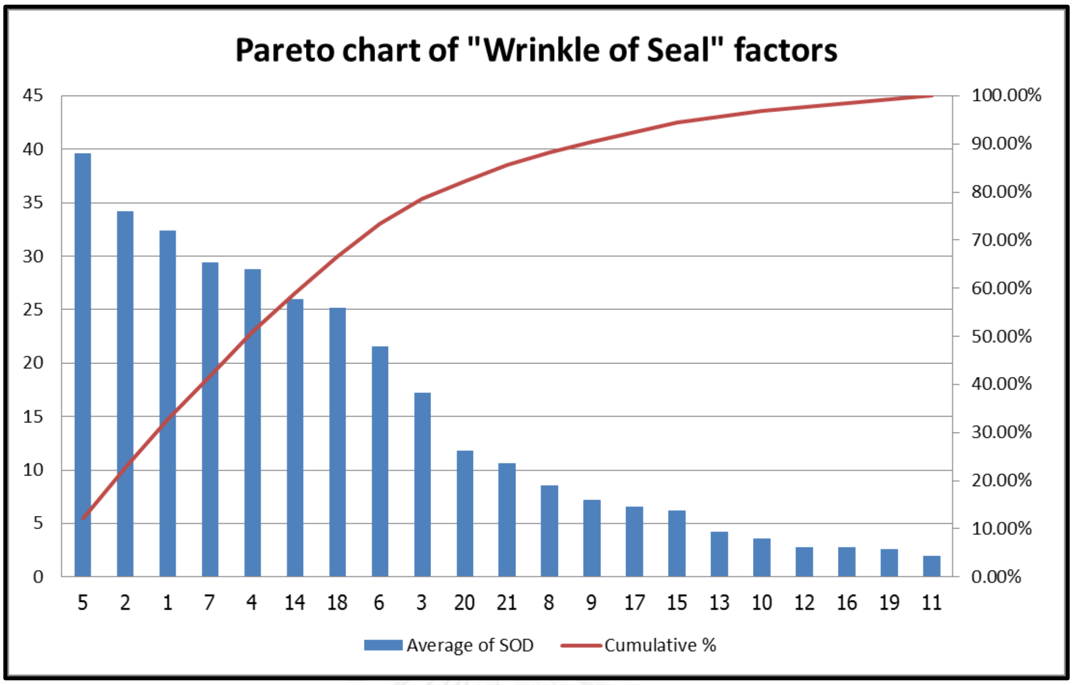


Figure 4.9: Pareto chart of the wrinkle of seal defect's causes

There are ten causes as shown in Figure 4.9 associated with the cause of the wrinkle of seal defect and cover 80% score of score out of all causes. The details of each cause number can be explained as follows.

1. Number 5: Improper temperature of sealing machine

    The temperature of sealing machine effects directly to the seal quality because it makes the plastic seal adhered to cup's edge. If the temperature is extremely high, it can make wrinkle on seal.

2. Number 2: Improper temperature of retort machine

    Because the seal adheres the cup's edge by the temperature of sealing machine, the seal can be effected by the temperature of retort machine as well.

3. Number 1: Improper pressure of retort machine

    It is similar to cause number 2. The pressure of retort machine can effect the wrinkle of seal when it is improper.

4. Number 7: Improper sealing head's position

    The position of sealing head is one of the setting procedures manually set by staff. Improper of position can effect to the seal position and tight adherence of seal.

5. Number 4: Inconsistent pressing force of sealing machine

    Pressing force effects directly to adherence of seal. If pressing force is not consistently, plastic seal and cup's edge cannot adhere to all surfaces.

6. Number 14: Scratched by retort's divider plate

    The divider plate is the retort machine's accessory to divide the layer of molded tray by putting the plate above the cup. There is a chance that divider plate scratches on the plastic seal during the chamber rotation at exposure phase.

7. Number 18: Incorrect inspection

    There is a chance that inspector makes the wrong decision by classifying the good product as the defect.

8. Number 6: Improper time of sealing machine

    Improper time of sealing machine can make the poor adhering between plastic seal and cup's edge.

9. Number 3: Improper time of retort machine

    Improper of time of retort machine either too long or too short may effect to the quality of seal.

10. Number 20: Scratched by staff

    When the staff touches the product, there are chances that their nails can make a scratch or wrinkle on the plastic film.

From all causes described above, there are four causes that can bring into the design of experiments study which are the pressure and temperature of retort machine, the temperature of sealing machine and the sealing time. Three causes are weighed as the top three ranking and another one is at ninth rank. Other six causes will not be corporated in the design of experiments but will be controlled by control plan or recommended action as identified in Table 4.17.

Table 4.17: Control Plan and action of undesignable causes in the wrinkle of seal defect

No.	Causes	Control Plan/Recommended Action
7	Improper sealing head’s position	Define the optimum value of machine process parameter setting
4	Sealing machine's pressure force	Preventive maintenance plan to check the performance and machine condition
14	Scratched by retort's divider plate	Preventive maintenance plan to check the performance and condition of machine accessories
18	Incorrect inspection	Staff training and qualification program
3	Improper time of retort machine	Retort time cannot be changed because it is derived based on the principle of sterility (F_0) to ensure that the microorganism has lost the ability to reproduce.
20	Scratched by staff	Every operation staffs have to wear rubber gloves.

4.1.2.3The key causes of The illegible date code defect

Table 4.18: FMEA score of “the illegible date code “causes

No.	Causes	Average SxOxD
1	Improper pressure of retort machine	45
2	Improper temperature of retort machine	21.2
3	Improper time of retort machine	18.6
4	Improper remaining air in cup	23.2
5	Overweight of filling	2.4
6	Clogged inkjet nozzle	25
7	Improper ink intensity	15.8
8	Improper inkjet nozzle's position	1.6
9	Improper ink drying time	3.2
10	Untighten screw of retort's basket	11.2
11	Scratched while putting cup in molded tray	12.4
12	Scratched while transportation	18.8
13	Improper of type of ink	1.8
14	Poor quality of ink	8
15	Unclean plastic cup's surface	4.4
16	Scratched by bended basket	15.8
17	Scratched by rusty basket	7.4
18	Touched by wet hands	13
19	Touched before ink drying	30.4
20	Untrained inspector	6.6
21	Incorrect inspection	25.2
22	Inadequate inspector	2.6

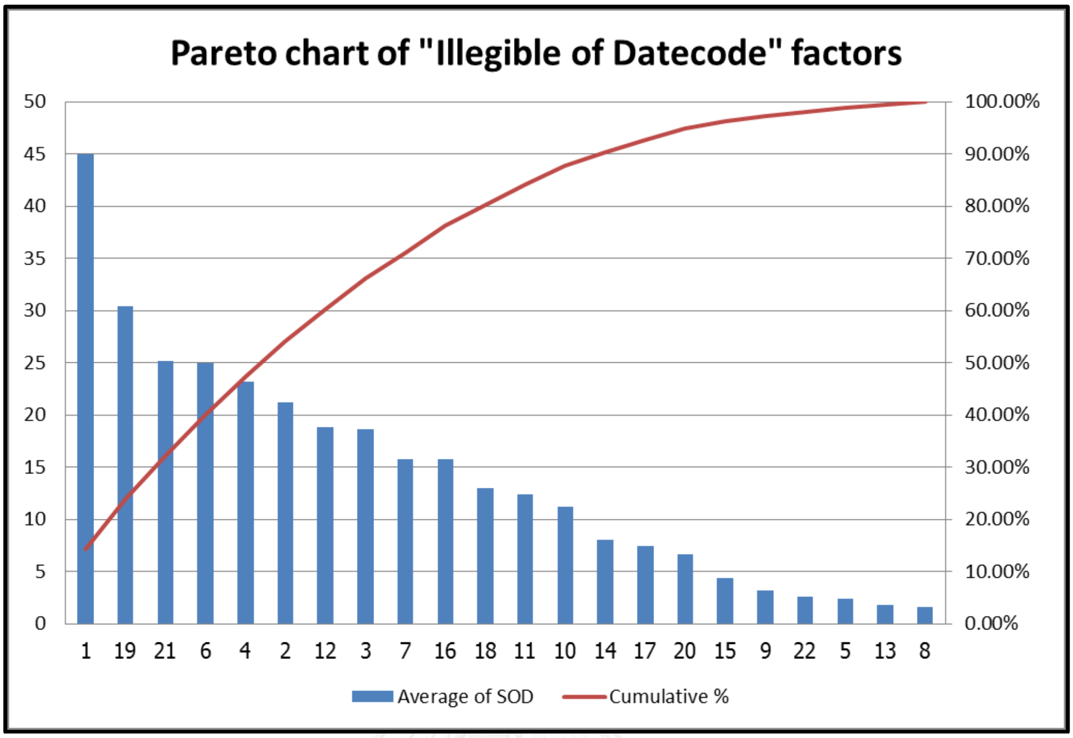


Figure 4.10: Pareto chart of the illegible date code defect's causes

There are eleven causes as shown in Figure 4.10 associated with the cause of the illegible date code defect and cover 80% score of score out of all causes. The details of each cause number can be explained as follows.

1. Number 1: Improper pressure of retort machine

   The illegible date code can occur from the out of shape of plastic cup by improper pressure. When the plastic cup is out of shape, it is scratched by divider plate and made the ink disappeared or illegible.

2. Number 19: Touched before ink drying

   When products pass through date code stamping process, ink needs some periods of time for drying. If ink is touched by staff while it is not properly dry, ink can be illegible.

3. Number 21: Incorrect inspection

   There is a chance that inspector makes the wrong decision by classifying the good product as the defect.

4. Number 6: Clogged inkjet nozzle

    When there are some clogs at inkjet nozzle, it makes the poor performance to eject the ink.

5. Number 4: Improper remaining air in cup

    Remaining air in cup can be set at the sealing machine by setting the vacuum value of machine. Improper remaining air in cup can cause the out of shape of plastic cup when they get the high pressure in retort machine. The out of shape while the product is in the retort basket can make the scratch defect.

6. Number 4: Improper temperature of retort machine

    The temperature of retort machine can make the ink fade off and be illegible.

7. Number 12: Scratched while transporting

    The transportation in between each process can make scratch defect such as scratch between plastic cup and scratch with the cart.

8. Number 3: Improper time of retort machine

    The longer time of retort process can make the ink fade off and be illegible from the pressure and temperature.

9. Number 7: Improper ink intensity

    The intensity of the inkjet machine may be not appropriate to use with plastic cup.

10. Number 16: Scratched by bended basket

    The bended of retort basket can scratch the plastic cup and make the illegible date code when the basket is rotated in retort machine.

11. Number 18: Touched by wet hands

    There is a possible chance that the wet hand of staff can make the ink faded off. The drying time of ink that the company set does not aware by the untrained staffs who touch the product when it is not completely dried.

From all causes described above, there are four causes that can bring into the design of experiments study which are the pressure and temperature of retort machine, the air remaining in plastic cup and the ink intensity. Other seven causes will not be included in the design of experiments study but will be controlled by control plan or recommended action identified as presented in Table 4.19.

Table 4.19: Control Plan and action of undesignable causes in the illegible date code defect

No.	Causes	Control Plan/Recommended Action
19	Touched before ink drying	Staff training and process control by adjusting the speed of conveyer to allow ink drying completely before reaching to staffs.
21	Incorrect inspection	Staff training and process control by developing standard defect and performing Gage R&R
6	Clogged inkjet nozzle	Preventive maintenance plan to check the performance and condition of machine accessories
12	Scratched while sorting cup in transportation process	Staff training and process control by developing standard pattern of sorting process.
3	Improper time of retort machine	Retort time cannot be changed because it is derived based on the principle of sterility (F_0) to ensure that the microorganism has lost the ability to reproduce.
16	Scratched by bended basket	Preventive maintenance plan to check the performance and condition of machine accessories
18	Touched by wet hands	Every operation staffs have to wear rubber gloves.

Chapter 5

Analysis phase

The objective of this chapter is to determine the causes of problem related to each defect type. The important factors prioritized in the previous chapter will be analyzed by using statistical method of hypothesis testing. The hypothesis testing will be used to identify the significant factors contributed to the defect problems in Ready Rice packaging. Then, the significance level of factors is set for design of experiments in the improve phase.

5.1 The pattern of experiment

The experiments for this research are performed for the hypothesis testing for two populations in order to identify the statistical significant factors for each defect type. The response of the test is the defective rate of each defect type.

5.2 Sample size for hypothesis testing

Statistical analysis based on hypothesis testing for two populations is the method to analyze the significant factors when the response is the proportion of defects. The sample size of hypothesis testing can be calculated following the Equation 5.1 or using the "Power and Sample size function in Minitab program.

$$n = \frac{(Z_{\alpha/2}\sqrt{p_1(1-p_1)} + Z_{\beta}\sqrt{p_2(1-p_2)})^2}{(p_2 - p_1)^2} \tag{5.1}$$

When; n = Sample Size

p_1 = Current defective rate

p_2 = Expected defective rate

α = Significance level

β = 1 – Power of test

Normally, the value of α and β based on Equation 5.1 are set at 0.05 and 0.2, respectively. However, the number product per batch of studying company is 3,888 units. Therefore, it would be better for the operators and inspectors to perform the experiment and inspection for sample size of 3,888 units. With the sample size of 3,888 units and the significance level of 0.05, the power of test calculated based on Equation 5.1 will be determined. If the power of test from calculation is greater than 0.8, the sample size of 3,888 units can be accepted for hypothesis testing.

5.2.1 Sample size for hypothesis testing based on the out of shape defect

The defective rate of the out of shape defect is expected to be reduced from 1.62% to 0.81%. Therefore, the power of test based on 3,888 units is calculated as follows.

$$3{,}888 = \frac{\left(Z_{0.05/2}\sqrt{0.0162(1-0.0162)} + Z_{\beta}\sqrt{0.0081(1-0.0081)}\right)^2}{(0.0081-0.0162)^2}$$

The calculation resulted from using Equation 5.1 and by Minitab are the same. The power of test shown in Figure 5.1 is around 0.903 which is greater than 0.8. Therefore, 3,888 units is the proper sample size for the out of shape defect's factors analysis.

Power and Sample Size

```
Test for Two Proportions

Testing proportion 1 = proportion 2 (versus not =)
Calculating power for proportion 2 = 0.0081
Alpha = 0.05


                 Sample
Proportion 1      Size       Power
      0.0162      3888    0.903335

The sample size is for each group.
```

Figure 5.1: Power and sample size for the out of shape defect factors analysis

5.2.2 Sample size for hypothesis testing based on the wrinkle of seal defect

The defective rate of the wrinkle of seal defect is expected to be reduced from 1.43% to 0.71%. Therefore, the power of test based on 3,888 units is calculated as follows.

$$3{,}888 = \frac{(Z_{0.05/2}\sqrt{0.0143(1-0.0143)} + Z_{\beta}\sqrt{0.0071(1-0.0071)})^2}{(0.0071-0.0143)^2}$$

The calculation resulted from using Equation 5.1 and by Minitab are the same. The power of test shown in Figure 5.2 is around 0.87 which is greater than 0.8. Therefore, 3,888 units is the proper sample size for the wrinkle of seal defect's factors analysis.

```
Power and Sample Size

Test for Two Proportions

Testing proportion 1 = proportion 2 (versus not =)
Calculating power for proportion 2 = 0.0071
Alpha = 0.05


                 Sample
Proportion 1       Size     Power
      0.0143       3888  0.869964

The sample size is for each group.
```

Figure 5.2: Power and sample size for the wrinkle of seal defect factors analysis

5.2.3 Sample size for hypothesis testing based on the illegible date code defect

The defective rate of the illegible date code defect is expected to be reduced from 1.66% to 0.83%. Therefore, the power of test based on 3,888 units is calculated as follows.

$$3{,}888 = \frac{(Z_{0.05/2}\sqrt{0.0166(1-0.0166)} + Z_{\beta}\sqrt{0.0083(1-0.0083)})^2}{(0.0083-0.0166)^2}$$

The calculation resulted from using Equation 5.1 and by Minitab are the same. The power of test shown in Figure 5.3 is around 0.91 which is greater than 0.8. Therefore, 3,888 units is the proper sample size for the illegible date code defect's factors analysis.

```
Power and Sample Size

Test for Two Proportions

Testing proportion 1 = proportion 2 (versus not =)
Calculating power for proportion 2 = 0.0083
Alpha = 0.05


                Sample
Proportion 1      Size     Power
      0.0166      3888  0.910095

The sample size is for each group.
```

Figure 5.3: Power and sample size for the illegible for date code defect factors analysis

5.3 The significant factors and factor levels for hypothesis testing

From the previous chapter, there are two, four and four significant factors effected to the out of shape, the wrinkle of seal and illegible date code defect, respectively. The details of each factor for each defect types are explained in Table 5.1-5.3.

Table 5.1: The details of significant factors effect to the out of shape defect

No.	Cause area	Factors	Detail	Testing level (Low and High)
1	Retort machine as shown in Figure 5.4	The pressure of retort machine	The level of the pressure can be set at retort machine regulator shown in Figure 5.5	Allowable minimum and maximum pressure of retort machine at exposure stage is 1,600 and 1,800

No.	Cause area	Factors	Detail	Testing level (Low and High)
2	Retort machine as shown in Figure 5.4	The temperature of retort machine	The level of the temperature can be set at retort machine regulator shown in Figure 5.5	Allowable minimum and maximum temperature of retort machine at exposure stage is 116 ℃ and 125 ℃, respectively

Figure 5.5: Retort machine

Figure 5.4: Retort machine regulator

Table 5.2: The details of significant factors effect to the wrinkle seal defect

No.	Cause area	Factors	Detail	Testing level (Low and High)
1	Retort machine as shown in Figure 5.4	The pressure of retort machine	The level of the pressure can be set at retort machine regulator shown in Figure 5.5	Allowable minimum and maximum pressure of retort machine at exposure stage is 1600 and 1800, respectively

No.	Cause area	Factors	Detail	Testing level (Low and High)
2	Retort machine as shown in Figure 5.4	The temperature of retort machine	The level of the temperature can be set at retort machine regulator shown in Figure 5.5	Allowable minimum and maximum temperature of retort machine at exposure stage is 116 ℃ and 125 ℃, respectively
3	Sealing machine as shown in Figure 5.6	The temperature of sealing machine	The level of the temperature can be set at sealing machine regulator shown in Figure 5.7	Allowable minimum and maximum temperature of sealing machine is 150 ℃ and 195 ℃, respectively
4	Sealing machine as shown in Figure 5.6	The time of sealing machine	The level of the time can be set at sealing machine regulator shown in Figure 5.7	Allowable minimum and maximum time of sealing machine is 2 and 4 second, respectively

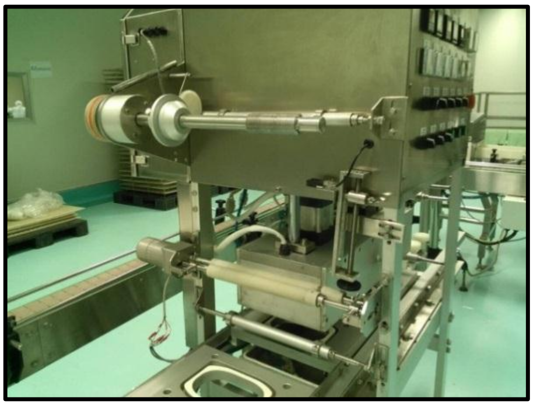


Figure 5.7: Sealing machine

Figure 5.6: Sealing machine regulator

Table 5.3: The details of significant factors effect to the illegible date code defect

No.	Cause area	Factors	Detail	Testing level (Low and High)
1	Retort machine as shown in Figure 5.4	The pressure of retort machine	The level of the pressure can be set at retort machine regulator shown in Figure 5.5	Allowable minimum and maximum pressure of retort machine at exposure stage is 1,600 and 1,800, respectively
2	Retort machine as shown in Figure 5.4	The temperat ure of retort machine	The level of the temperature can be set at retort machine regulator shown in Figure 5.5	Allowable minimum and maximum temperature of retort machine at exposure stage is 116 ℃ and 125 ℃, respectively
3	Sealing machine as shown in Figure 5.6	The vacuum of sealing machine	The level of the vacuum can be set at sealing machine regulator shown in Figure 5.7	Allowable minimum and maximum vacuum of sealing machine is 10 and 40 bars, respectively
4	Inkjet	The ink intensity of inkjet	The level of the ink intensity can be set at inkjet machine regulator	Allowable minimum and maximum ink intensity of inkjet is 10% and 90%, respectively

5.4 The procedure for the hypothesis testing and the result

To perform the hypothesis test to see whether the important factors of each defect type is significant, there are ten performing steps [WMG, 2015] to follow as presented in Table 5.4.

Table 5.4 shows the procedure of the hypothesis testing for the pressure of retort machine which is one of the important factors of the out of shape and the illegible date code defect. The responses of the hypothesis testing are p_1 and p_2 which are the defective rate when the pressure is set at 1,600 and 1,800 mbar, respectively.

Table 5.4: Ten performing steps for the significant factors of the pressure of retort

Step	Action	Result
1	Define the question.	The question is "Is there the significant difference in the defective rate when the pressure of retort machine is set at 1,600 (level 1) and 1,800 (level 2)".
2	Identify the appropriate model or test.	Z-test for two populations that are independent appropriate model.
3	Identify the type of hypothesis testing	The difference of defective rate is not specified, therefore the test is two-tailed test.
4	Formulate the Null and Alternative hypothesis.	$H_0: p_1 = p_2$ $H_1: p_1 \neq p_2$
5	Decide the level of significant.	The value will be 5% for a two tailed test.
6	Determine the P-value of the test statistic	P-value = 2 x ($Z > \|Z\|$ (from step 8))
7	Obtain a random sample of data.	Determine the P-value of test statistic with the sample size of 3,888 units (n), $\hat{p}_1$ and $\hat{p}_2$ have been found to be $\frac{47}{3,888}$ and $\frac{102}{3,888}$, respectively.
8	Calculate the test statistic (Z).	z = $\frac{\hat{p}_1 - \hat{p}_2}{\sqrt{\frac{p_1 q_1}{n_1} + \frac{p_2 q_2}{n_2}}}$ z = $\frac{0.0121 - 0.0262}{\sqrt{\frac{0.0121 \times 0.9879}{3,888} + \frac{0.0262 \times 0.9738}{3,888}}}$ z = -4.555
9	Decide whether to accept or reject H_0.	P-value < α, H_0 is rejected.
10	Draw a conclusion.	The different between defective rate when pressure is set at 1,600 and 1,800 mbar is statistically significant.

The result of hypothesis testing for “The pressure of retort machine” show the defective rate of 1600 and 1800 mbar pressure value at exposure phase is 1.21% and 2.62%, respectively. When bring both of defective rates to the test, the test statistic is -4.56 and p-value is less than 0.0005. In conclusion, “The pressure of retort machine” is the significant factor for the out of shape defect at 95% confidence level. Figure 5.10 shows the output of z-test by Minitab which is the same as shown in Table 5.4.

Test and CI for Two Proportions

```
Sample     X     N  Sample p
1         47  3888  0.012088
2        102  3888  0.026235


Difference = p (1) - p (2)
Estimate for difference:  -0.0141461
95% CI for difference:  (-0.0202321, -0.00806005)
Test for difference = 0 (vs not = 0):  Z = -4.56  P-Value = 0.000
```

Figure 5.8: The test output for the significant of “The pressure of retort machine” by Minitab

The procedures shown in Table 5.4 will be repeatedly performed to test if other factors such as the temperature of retort machine and time of sealing machine are significant factors.

Table 5.5 represents the sample proportion ($\hat{p}_1$and $\hat{p}_2$), the test statistic, P-value and the conclusion for all factors regarding to three defect types.

For the out of shape defect, the P-value of hypothesis testing shows that there is only one significant factor which is the pressure of retort machine. While there are three significant factors for the wrinkle of seal defect including the temperature of retort machine, temperature and time of sealing machine. Lastly, the pressure of retort machine and vacuum of sealing machine are significant factors for the illegible date code defect as shown by P-value less than 0.05.

Table 5.5: The summarize of hypothesis testing

Defect Type	Factors	Test Statistic (Z)	P-value	Conclusion
Out of shape	The pressure of retort machine	-4.56	0.000	Significant
	The temperature of retort machine	1.56	0.118	Not Significant
Wrinkle of seal	The pressure of retort machine	-0.67	0.505	Not Significant
	The temperature of retort machine	-6.92	0.000	Significant
	The temperature of sealing machine	-6.24	0.000	Significant
	The time of sealing machine	-2.69	0.007	Significant
Illegible date code	The pressure of retort machine	-4.01	0.000	Significant
	The temperature of retort machine	1.17	0.241	Not Significant
	The vacuum of sealing machine	-4.11	0.000	Significant
	The ink intensity of inkjet	1.61	0.107	Not Significant

Table 5.6 represents the factor and factor levels of each defect type for the design of experiments. The levels of each factor are set at the minimum, current and maximum value of each factor.

Table 5.6: Factor and factor level for the design of experiments

Defect Type	Factor	Type of data	Factor levels			
			Min	Current	Max	Scale
Out of shape	The pressure of retort machine	Variable Data	1600	1700	1800	mbar
Wrinkle of seal	The temperature of retort machine	Variable Data	116	117	125	℃
	The temperature of sealing machine	Variable Data	150	174	195	℃
	The time of sealing machine	Variable Data	2	2.7	4	Sec.
Illegible date code	The pressure of retort machine	Variable Data	1600	1700	1800	mbar
	The vacuum of sealing machine	Variable Data	10	23	40	bars

Chapter 6

Improve phase

This chapter will determine the most appropriate input values, each of which resulted in the least of defective rate in three defect types. The design of experiments (DOE) and the analysis of variance (ANOVA) are the tools to compare the effect of each factor whether it is related to these three defect types. Then, the test will be conducted repeatedly to confirm the results in order to improve the process.

6.1 Design of experiments

From the statistical analysis by the hypothesis testing in the previous phase, there is only one significant factor contributed to the out of shape defect. While there are three and two significant factors related to the wrinkle of seal and the illegible date code defect, respectively. It is possible that there are interactions between these significant factors. Therefore, the factorial design of experiments will be used to identify the most appropriate input that significantly effect to the defective rate of two defect types including the wrinkle of seal and the illegible date code. While One-way ANOVA will be used to analyze the single factor for the out of shape defect.

6.1.1 The number of trials for the experimental design

To determining the number of trials for three defect types, the appropriate design method of each defect type will be as follows;

For the out of shape defect, there is only one factor, the pressure of retort machine considered as variable data. The experiment will be conducted in 3 setting levels including maximum, middle and minimum level. Total trial runs should be at least 3 runs. However, the company wants to ensure the result accuracy because this defect type contributes the highest defective rate. Therefore, the number of total run will be 9 with 3 replicates for each level.

For the wrinkle of seal defect, there are three significant factors which are the temperature of retort machine, the sealing temperature and the sealing time. All of them are the variable data. The total number of runs is a x b x c where a, b and c are level of factors. For this experiments, a, b and c are set to 3 levels including maximum, middle and minimum. Therefore, the total number of runs is 3 x 3 x 3 that equal to 27 runs with the detail as shown in Table 6.1.

Table 6.1: Design of experiments for the wrinkle of seal defect

StdOrder	RunOrder	PtType	Blocks	Retort Temp (℃)	Sealing Temp (℃)	Sealing Time (Sec.)
21	1	1	1	125	150	4
15	2	1	1	117	174	4
18	3	1	1	117	195	4
11	4	1	1	117	150	2.7
19	5	1	1	125	150	2
26	6	1	1	125	195	2.7
4	7	1	1	116	174	2
12	8	1	1	117	150	4
27	9	1	1	125	195	4
14	10	1	1	117	174	2.7
7	11	1	1	116	195	2
20	12	1	1	125	150	2.7
1	13	1	1	116	150	2
23	14	1	1	125	174	2.7
6	15	1	1	116	174	4
2	16	1	1	116	150	2.7
22	17	1	1	125	174	2
16	18	1	1	117	195	2

3	19	1	1	116	150	4
8	20	1	1	116	195	2.7
9	21	1	1	116	195	4
25	22	1	1	125	195	2
10	23	1	1	117	150	2
17	24	1	1	117	195	2.7
13	25	1	1	117	174	2
24	26	1	1	125	174	4
5	27	1	1	116	174	2.7

For the illegible date code defect, there are two significant factors which are the pressure of retort machine and the vacuum of sealing machine. All of them are the variable data. The total number of runs is a x b where a and b are level of factors. For this experiments, a and b are set to 3 levels including maximum, middle and minimum. Moreover, it has to run 2 replicates for increasing the degree of freedom. Therefore, the total number of runs is 3 x 3 that equal to 9 runs with the detail as shown in Table 6.2.

Table 6.2: Design of experiments for the illegible date code defect

StdOrder	RunOrder	PtType	Blocks	Retort Pressure (mbar)	Vacuum (bars)
7	10	1	1	1800	10
5	11	1	1	1700	23
6	12	1	1	1700	40
8	13	1	1	1800	23
9	14	1	1	1800	40
1	15	1	1	1600	10
2	16	1	1	1600	23
4	17	1	1	1700	10
3	18	1	1	1600	40

16	1	1	2	1800	10
12	2	1	2	1600	40
15	3	1	2	1700	40
17	4	1	2	1800	23
13	5	1	2	1700	10
10	6	1	2	1600	10
18	7	1	2	1800	40
11	8	1	2	1600	23
14	9	1	2	1700	23

6.1.2 Sample size for design of experiments

To set the sample size for design of experiments, the research company requires to conduct the experiment in full capacity per batch as same as the process of factor analysis. Therefore, the sample size for each design of experiments is 3,888 units.

6.2 Analysis for the out of shape defect

With nine experimental runs and the sample size of 3,888 units per run, the number of defect for each run according to the out of shape is shown in Table 6.3. The proportion of defect as the response of the experiment is calculated and also shown in Table 6.3.

6.2.1 Analysis of experiment result

Due to the suggestion of Bisguard and Fuller (1994), the proportion of defect should be transformed to Freeman and Turkey (F&T) by following Equation 6.1. The transformation is made to satisfy the assumption of equal variance.

$$\mathrm{P\ (F\&T)} = \frac{arcsin\sqrt{\frac{n\hat{p}}{n+1}}+arcsin\sqrt{\frac{n\hat{p}+1}{n+1}}}{2} \tag{6.1}$$

Table 6.3: Result of the experiment for the out of shape defect

Std Order	Run Order	Retort Pressure (mbar)	$\hat{P}$	F & T
7	1	1800	0.026	0.162
3	2	1600	0.018	0.133
4	3	1700	0.013	0.116
9	4	1800	0.033	0.181
1	5	1600	0.012	0.110
2	6	1600	0.015	0.121
8	7	1800	0.028	0.168
5	8	1700	0.016	0.127
6	9	1700	0.014	0.117

There are four assumptions about the residuals to be checked for the analysis of variance as follows.

1. The residuals are normally distributed,
2. with mean = 0
3. with a common or equal variance σ^2
4. and independent.

The normality plot of residuals as presentation in Figure 6.1 shows that the plots resemble along a straight line. There is no pattern fail in the tails of the graph. The p-value according to Anderson-Darling (AD) test is 0.101 which is greater than 0.05. Therefore, at 95% confidence level, the normality assumption of residuals is satisfied.

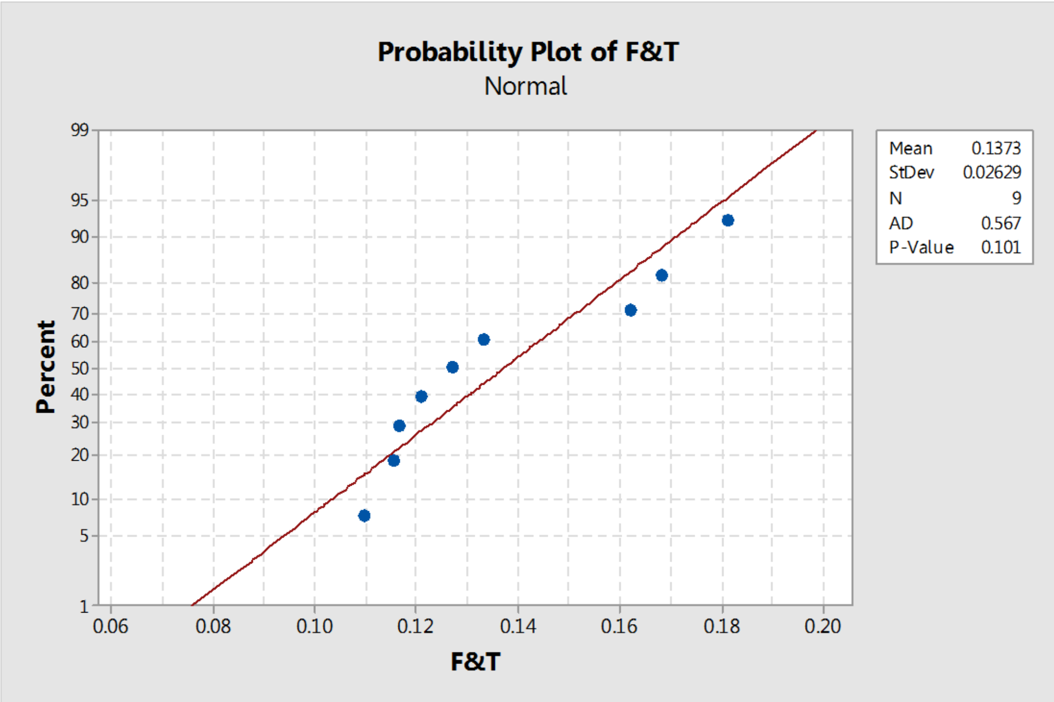


Figure 6.1: The normal probability plot for the analysis of the out of shape defect

To determine the independence of the residual value, the plot of "residuals versus order" generated by Minitab as shown in Figure 6.2 can be used to describe the relationship between residual of respond for the out of shape defect and observation order. The plots appear randomly without pattern. Therefore, it is concluded that the residuals are independent and aligned with assumption.

To determine the validity of common variance, the plot of "residual versus fits" generated by Minitab as shown in Figure 6.3 can be used to describe how residuals spread around the center line. The plots themselves appear as random around the zero line. Therefore, it can be concluded that the residual variance are homogeneous and aligned with assumption.

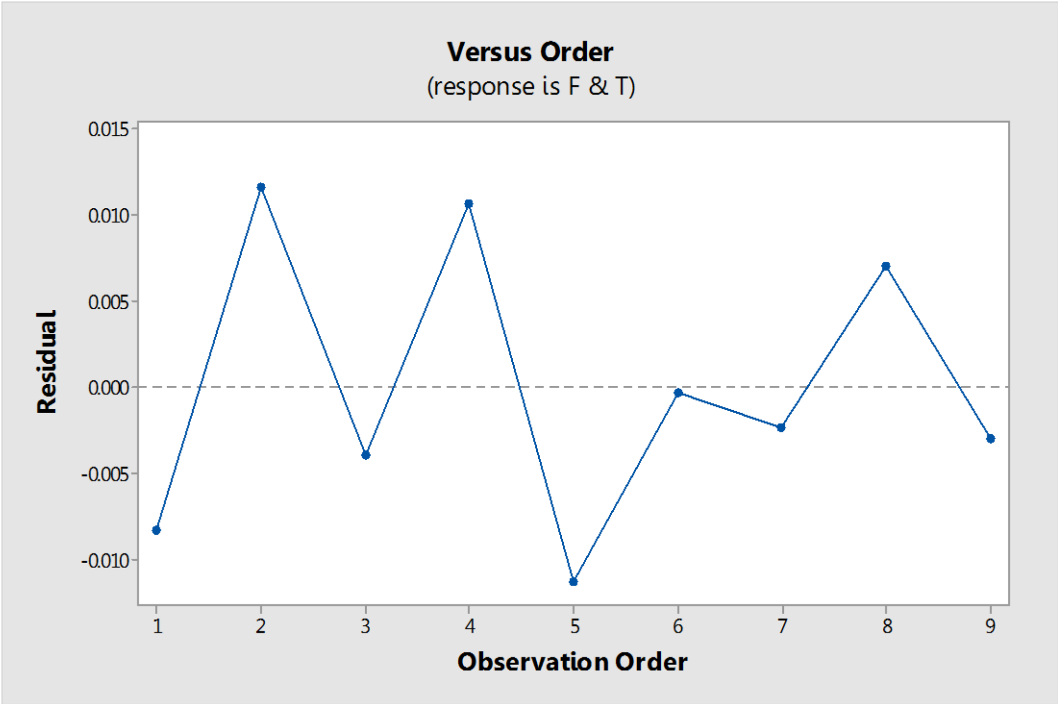


Figure 6.2: Plot of residual versus order for the analysis of the out of shape defect

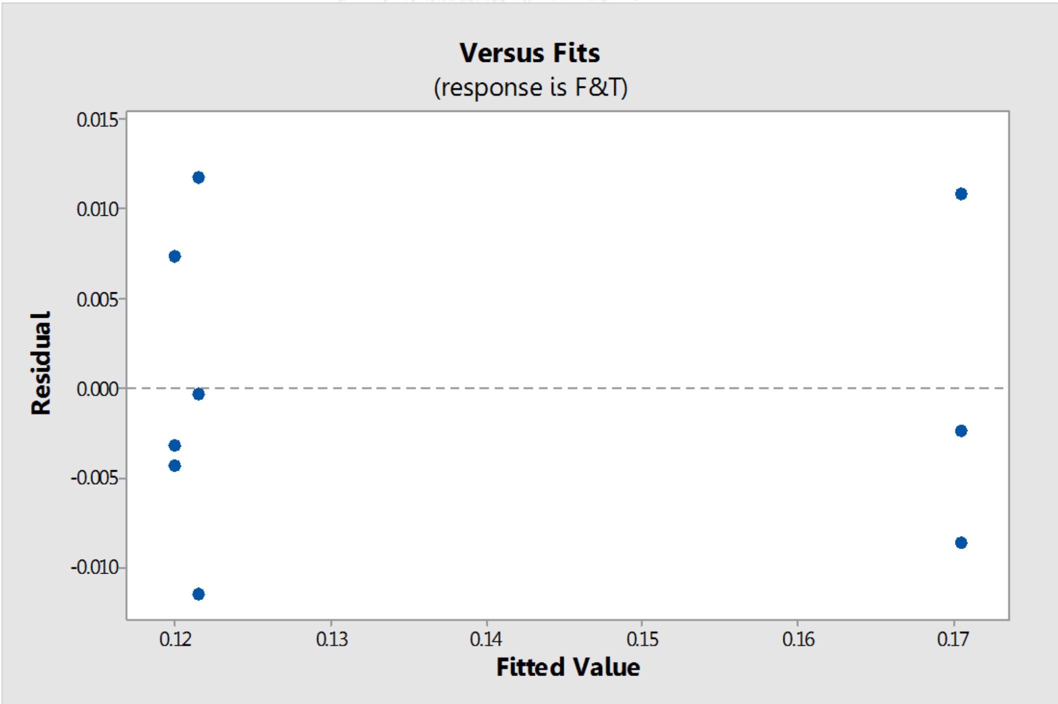


Figure 6.3: Plot of residual versus fits for the analysis of the out of shape defect

Figure 6.4 shows R-Sq and R-Sq (adj) of experiment is 90.35% and 87.13%, respectively. The high percentages of these two values prove that the accuracy of this model to predict the result is relatively high. P-value of retort pressure factor is less than 0.05 therefore, at the 95% confidence level, the retort pressure is significant factor for the out of shape defect.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Retort Pressure	2	0.004936	0.002468	28.08	0.001
Error	6	0.000527	0.000088		
Total	8	0.005464			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0093749	90.35%	87.13%	78.28%

Figure 6.4: The analysis of variance for the out of shape defect

When considering the main effect plot of the retort pressure as shown in Figure 6.5, it is found that high level (1800 mbar) of the retort pressure resulted in the highest defective rate. While the retort pressure setting at a middle level (1700 mbar) contributes the lowest defective rate. In term of technical perspective, the middle level of retort pressure can be considered as an appropriated parameter setting because the out of shape of plastic cup defect can be in the form of dented, distorted and swollen cup effected by too high or too low pressure value. In conclusion, the suggested value of the retort pressure should be set at 1700 mbar.

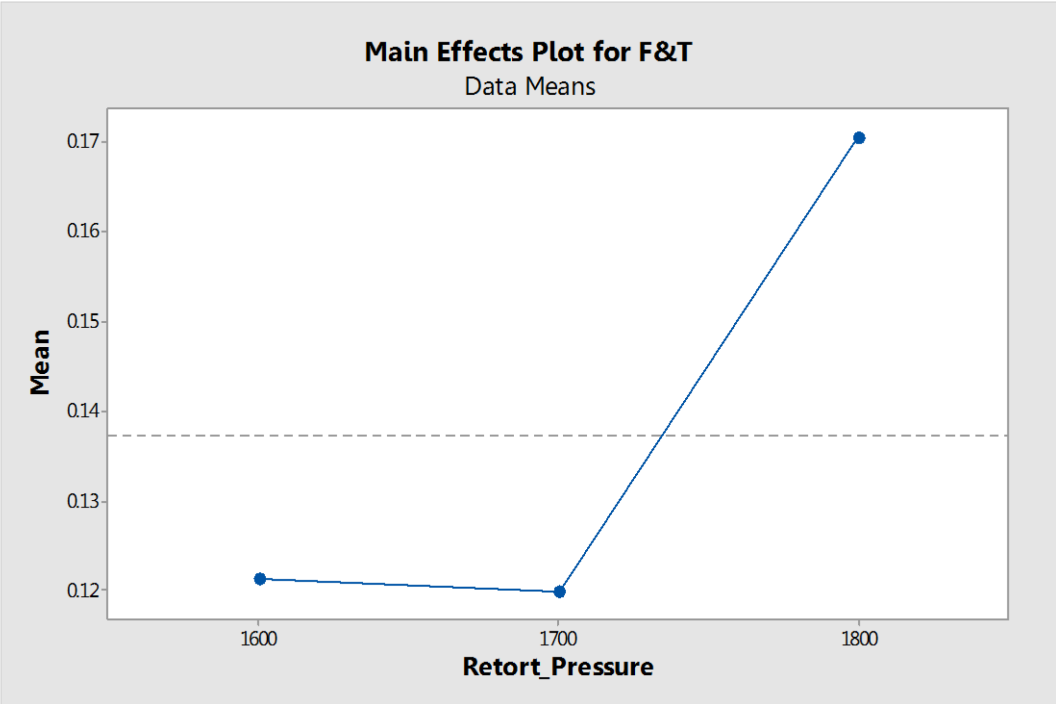


Figure 6.5: Main effect plot of retort pressure factor in the out of shape defect

6.2.2 Impact to the overall defect

After obtained suggested setting level of the retort pressure from the previous analysis according to the lowest defective rate for the out of shape defect. It has to consider if there is any impact to the overall defective rate because the change of setting level may contribute the increasing of the overall defect.

The same analysis that has been applied for the out of shape defect will be used with the overall defect. The suggested setting level of the retort pressure will be determined to obtain the lowest defective rate of overall defect and is compared with the level obtain based on the out of shape defect. If the results are the same, this result can be used in further step. The residual plots are constructed and shown in Figure 6.6. All plots do not reveal any violation of basic assumptions. Table 6.4 shows the overall defective rate in Freeman and Turkey (F & T) transformation.

Table 6.4: Result of experiment for the overall defect

Std Order	Run Order	Retort Pressure (mbar)	$\hat{P}$	F & T
7	1	1800	0.059	0.242
3	2	1600	0.048	0.219
4	3	1700	0.041	0.202
9	4	1800	0.059	0.243
1	5	1600	0.047	0.218
2	6	1600	0.046	0.214
8	7	1800	0.064	0.252
5	8	1700	0.043	0.208
6	9	1700	0.038	0.196

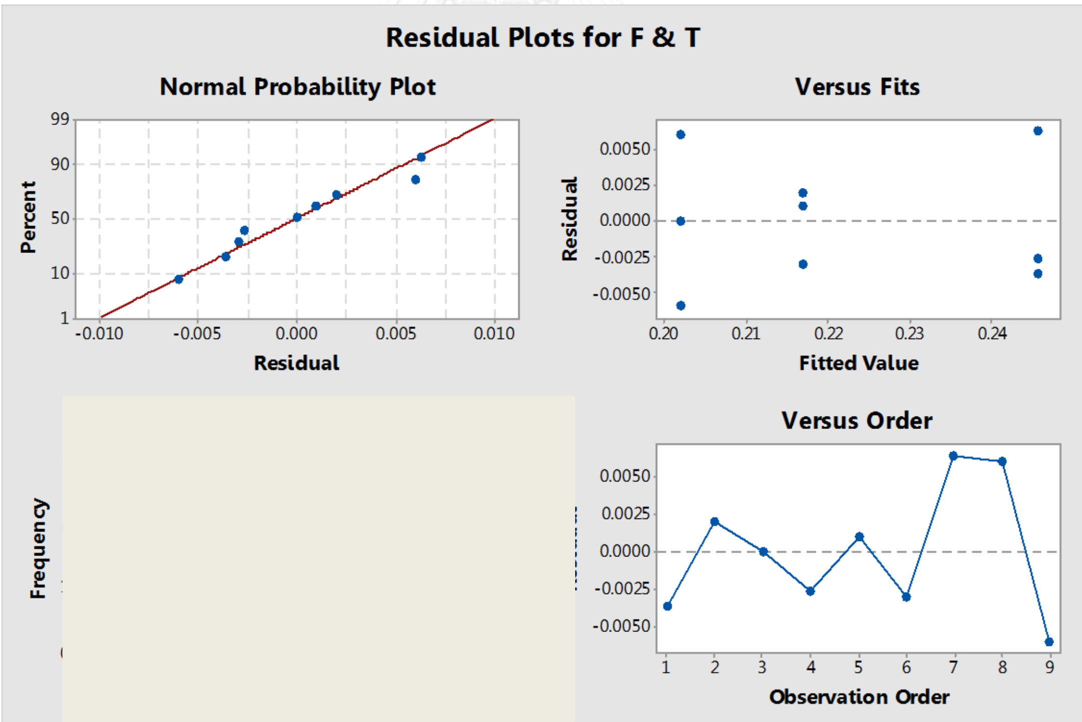


Figure 6.6: The residual plot for the overall defect by one-way ANOVA

Figure 6.7 shows R-Sq and R-Sq (adj) of experiment is 95.27% and 93.69%, respectively. The high percentages of these two values prove that the accuracy of this model to predict the result is relatively high. P-value of retort pressure factor is less than 0.05 therefore, at the 95% confidence level, the retort pressure is significant factor for the total defect.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Retort Pressure	2	0.002954	0.001477	60.41	0.000
Error	6	0.000147	0.000024		
Total	8	0.003100			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0049441	95.27%	93.69%	89.36%

Figure 6.7: The analysis of experiment for the overall defect by one-way ANOVA

When considering the main effect plot of the retort pressure as shown in Figure 6.8, it is found that high level (1800 mbar) of the retort pressure resulted in the highest defective rate. While the retort pressure setting at a middle level (1700 mbar) contributes the lowest defective rate. In conclusion, the suggested value of the retort pressure should be set at 1700 mbar.

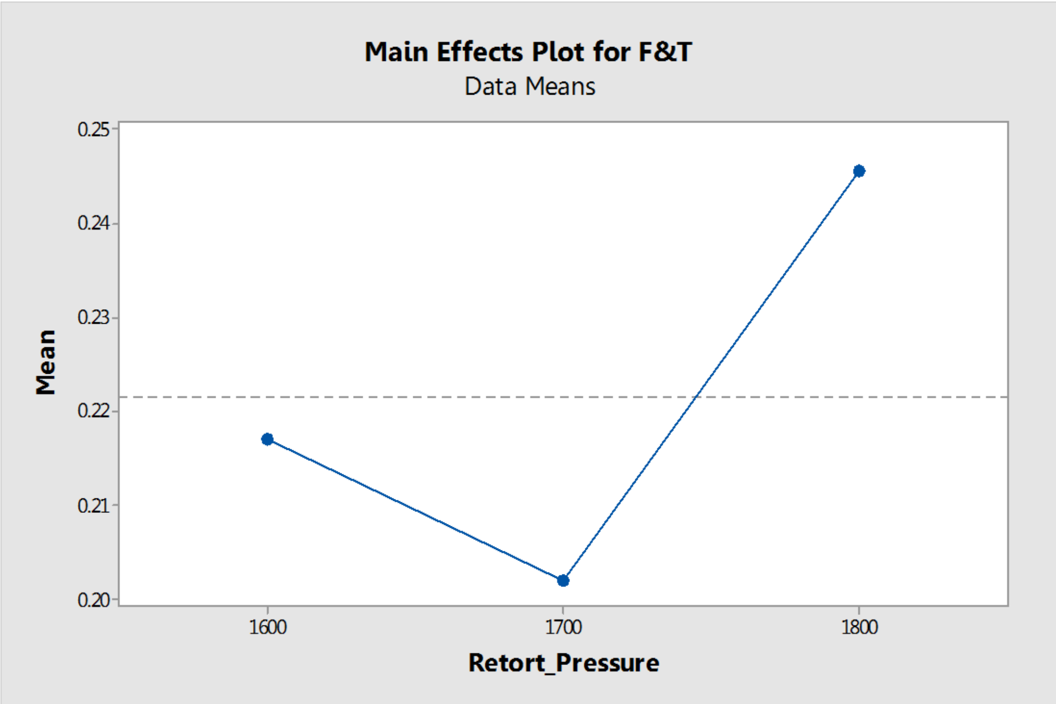


Figure 6.8: Main effect plot of retort pressure factor for the overall defect

In conclusion, the medium level setting at 1700 mbar of the retort pressure is confirmed the suggested setting level to get the lowest defective rate in both the out of shape and the overall defect.

6.3 Analysis of the wrinkle of seal defect

With twenty-seven experimental runs and the sample size of 3,888 units per run, the number of defect for each run according to the wrinkle of seal is shown in Table 6.5. The proportion of defect as the response of the experiment is calculated and also shown in Table 6.5.

6.3.1 Analysis of experiment result

Due to the suggestion of Bisguard and Fuller (1994), the proportion of defect should be transformed to Freeman and Turkey (F&T) by following Equation 6.1.

Table 6.5: Result of the experiment for the wrinkle of seal and total defect

Std Order	Run Order	Retort Temp	Sealing Temp	Sealing Time	Wrinkle of seal		Total	
					$\hat{P}$	F & T	$\hat{P}$	F & T
21	1	125	150	4	0.013	0.115	0.049	0.221
15	2	117	174	4	0.021	0.147	0.044	0.210
18	3	117	195	4	0.034	0.185	0.072	0.268
11	4	117	150	2.7	0.013	0.113	0.048	0.220
19	5	125	150	2	0.008	0.090	0.066	0.257
26	6	125	195	2.7	0.031	0.177	0.042	0.206
4	7	116	174	2	0.012	0.111	0.058	0.240
12	8	117	150	4	0.010	0.101	0.052	0.229
27	9	125	195	4	0.042	0.206	0.057	0.239
14	10	117	174	2.7	0.014	0.119	0.047	0.217
7	11	116	195	2	0.013	0.116	0.044	0.209
20	12	125	150	2.7	0.020	0.140	0.066	0.256
1	13	116	150	2	0.007	0.087	0.044	0.210
23	14	125	174	2.7	0.033	0.182	0.065	0.255
6	15	116	174	4	0.014	0.121	0.040	0.201
2	16	116	150	2.7	0.010	0.101	0.050	0.224
22	17	125	174	2	0.020	0.143	0.048	0.218
16	18	117	195	2	0.013	0.113	0.055	0.234
3	19	116	150	4	0.011	0.103	0.049	0.221
8	20	116	195	2.7	0.026	0.162	0.043	0.207
9	21	116	195	4	0.035	0.189	0.064	0.253
25	22	125	195	2	0.017	0.131	0.043	0.207
10	23	117	150	2	0.007	0.084	0.063	0.251
17	24	117	195	2.7	0.023	0.153	0.039	0.197
13	25	117	174	2	0.013	0.116	0.047	0.217
24	26	125	174	4	0.027	0.165	0.051	0.226

5	27	116	174	2.7	0.010	0.102	0.056	0.236

The normality plot of residuals as presentation in Figure 6.9 shows that the plots assemble along a straight line. There is no pattern fail in the tails of the graph. The p-value according to Anderson-Darling (AD) test is 0.052 which is greater than 0.05. Therefore, at 95% confidence level, the normality assumption of residuals is satisfied.

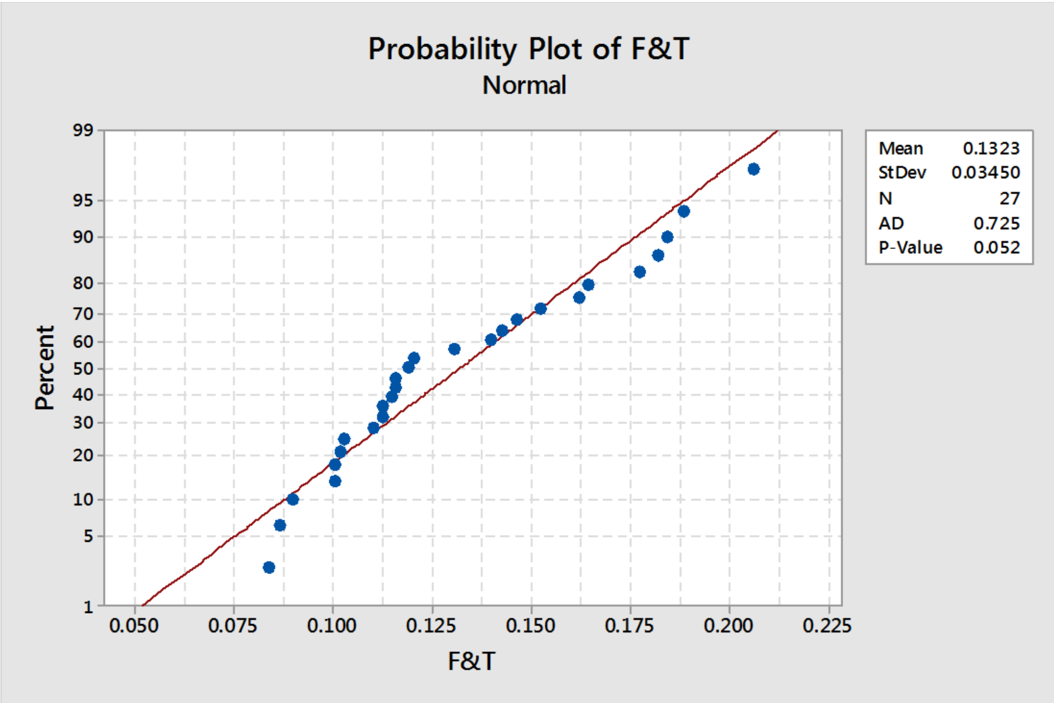


Figure 6.9: The normal probability plot for the analysis of the wrinkle of seal defect

To determine the independence of the residual value, the plot of "residuals versus order" generate by Minitab as shown in Figure 6.10 can be used to describe the relationship between residual of respond for the wrinkle of seal defect and observation order. The plots appear randomly and without pattern. Therefore, it is concluded that the residuals are independent and aligned with assumption.

To determine the validity of common variance, the plot of "residual versus fits" generated by Minitab as shown in Figure 6.11 can be used to describe how residuals spread around the center line. The plots themselves appear as random around the zero line. Therefore, it can be concluded that the residual variance are homogeneous and aligned with assumption.

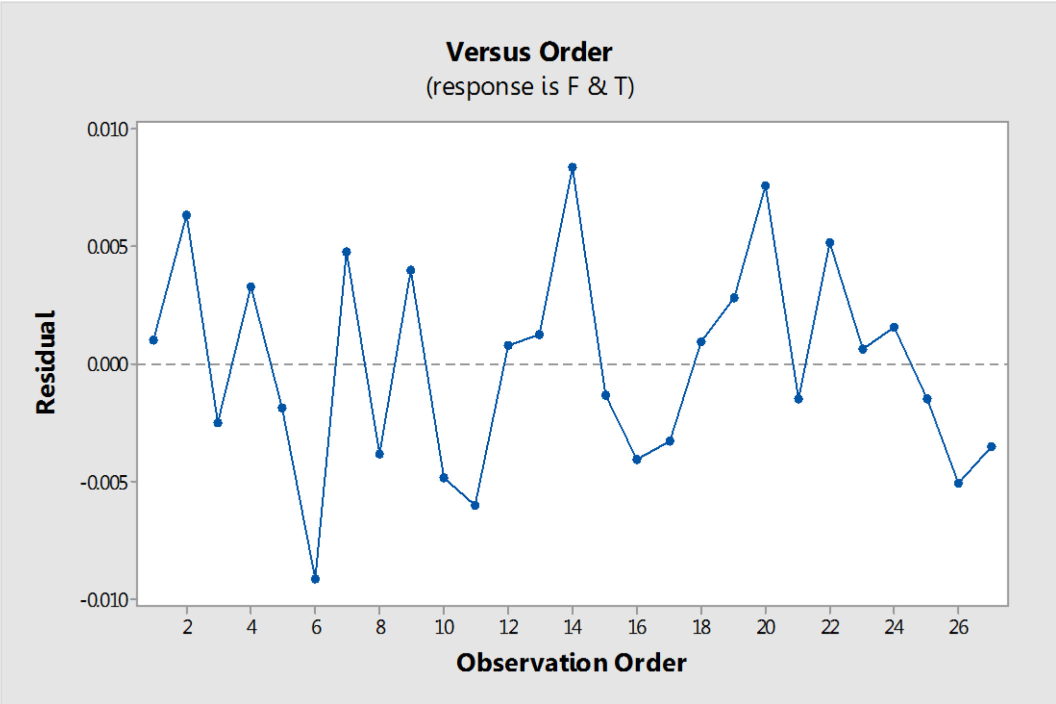


Figure 6.10: Residual versus order for the analysis of the wrinkle of seal defect

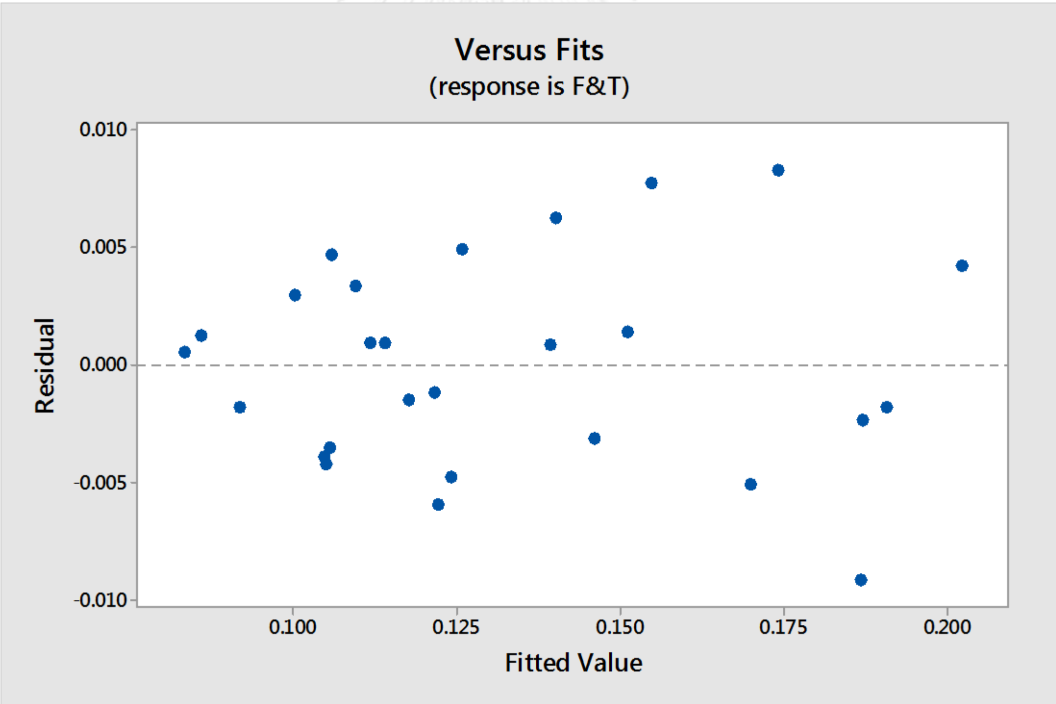


Figure 6.11: Residual versus fits for the analysis of the wrinkle of seal defect

Figure 6.12 shows R-Sq and R-Sq (adj) of experiment is 98.39% and 94.73%, respectively. The high percentages of these two values prove that the accuracy of this model to predict the result is relatively high. The interaction between 1) retort temperature and sealing temperature 2) sealing temperature and sealing time are significant due to the small p-value less than 0.05 the significance level.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Retort_Temp	2	0.004263	0.002131	34.02	0.000
Sealing_Temp	2	0.013817	0.006909	110.28	0.000
Sealing_Time	2	0.007027	0.003514	56.08	0.000
Retort_Temp*Sealing_Temp	4	0.001283	0.000321	5.12	0.024
Retort_Temp*Sealing_Time	4	0.000736	0.000184	2.94	0.091
Sealing_Temp*Sealing_Time	4	0.003280	0.000820	13.09	0.001
Error	8	0.000501	0.000063		
Total	26	0.030908			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0079151	98.38%	94.73%	81.53%

Figure 6.12: The analysis of experiment for the wrinkle of seal defect by Minitab

When considering the interaction plot between the sealing temperature and the sealing time in Figure 6.13, it is found that 150 °c of the sealing temperature and 2 second of the sealing time contributes the lowest defective rate. When the sealing temperature is set at 150 °c, the lowest defective rate presented in the interaction plot between the retort temperature and the sealing temperature is at 116°c of the retort temperature.

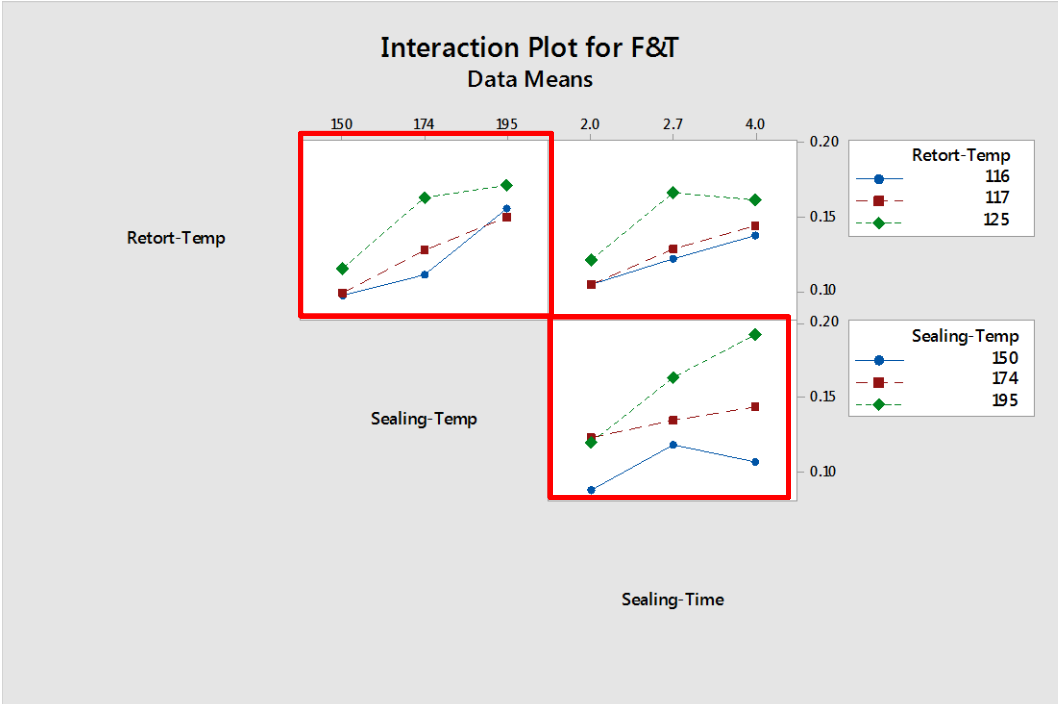


Figure 6.13: Interaction plot of three factors for the wrinkle of seal defect

6.3.2 Impact to the overall defect

After obtained suggested setting level of each factor from the previous analysis according to the lowest defective rate for the wrinkle of seal defect. It has to consider if there is any impact to the overall defective rate because some changes of setting level may contribute the increasing of the overall defect.

The same analysis that has been applied for the wrinkle of seal defect will be used with the overall defect. The suggested setting level of retort temperature, sealing temperature and sealing time will be determined to obtain the lowest defective rate of overall defect and is compared with the level obtain based on the wrinkle of seal defect. If the results are the same, this result can be used in further step. The residual plots are constructed and shown in Figure 6.14. All plots do not reveal any violation of basic assumptions. Table 6.5 shows the overall defective rate in Freeman and Turkey (F & T) transformation.

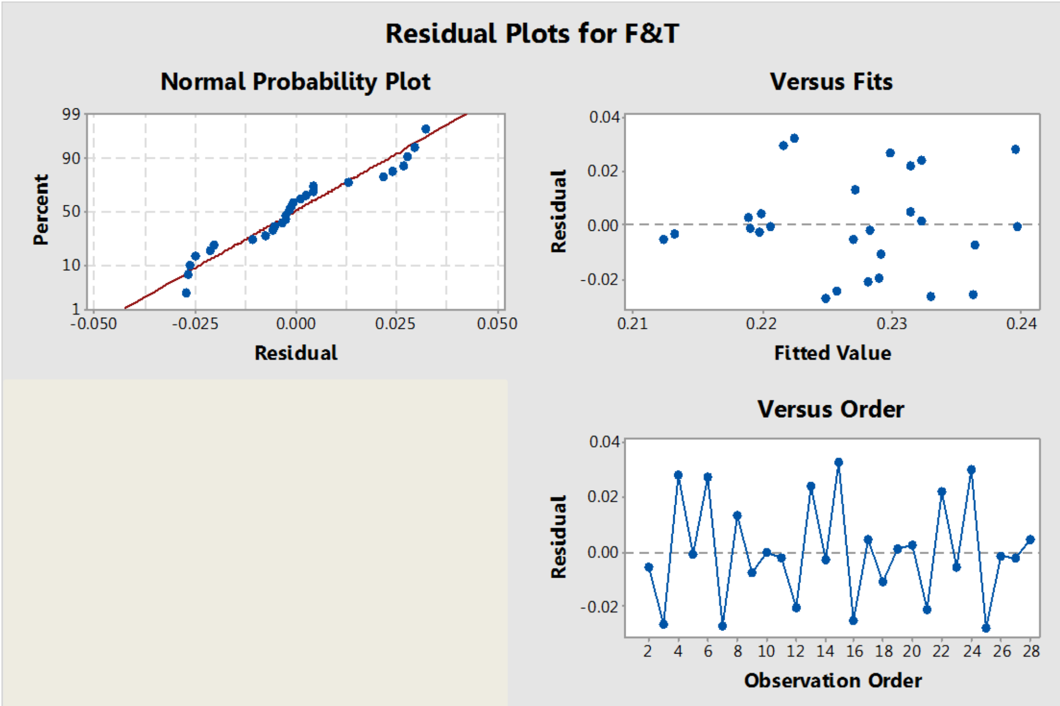


Figure 6.14: The residual plot for the overall defect by three-way ANOVA

Then, Figure 6.15 shows R-Sq and R-Sq (adj) of experiment are 98.25% and 94.31%, respectively. The high percentages of these two values prove that the accuracy of this model to predict the result is relatively high. With the confidence level of 95%, P-value of retort temperature factor and sealing temperature*sealing time is less than 0.05. It is proved these two cross factors directly contributed to total defective rate.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Retort-Temp	2	0.000363	0.000182	8.28	0.011
Sealing-Temp	2	0.000263	0.000132	5.99	0.026
Sealing-Time	2	0.000757	0.000378	17.25	0.001
Retort-Temp*Sealing-Temp	4	0.000035	0.000009	0.39	0.808
Retort-Temp*Sealing-Time	4	0.000052	0.000013	0.59	0.680
Sealing-Temp*Sealing-Time	4	0.008373	0.002093	95.42	0.000
Error	8	0.000175	0.000022		
Total	26	0.010018			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0046836	98.25%	94.31%	80.05%

Figure 6.15: The analysis of experiment for the overall defect by three-way ANOVA

When considering the interaction plot between the sealing temperature and the sealing time in Figure 6.16, it is found that 150 °c of the sealing temperature and 4 second of the sealing time contributes the lowest defective rate. When the retort temperature is set at 116 °c, the lowest defective rate presented in the main effect plot as shown in Figure 6.17.

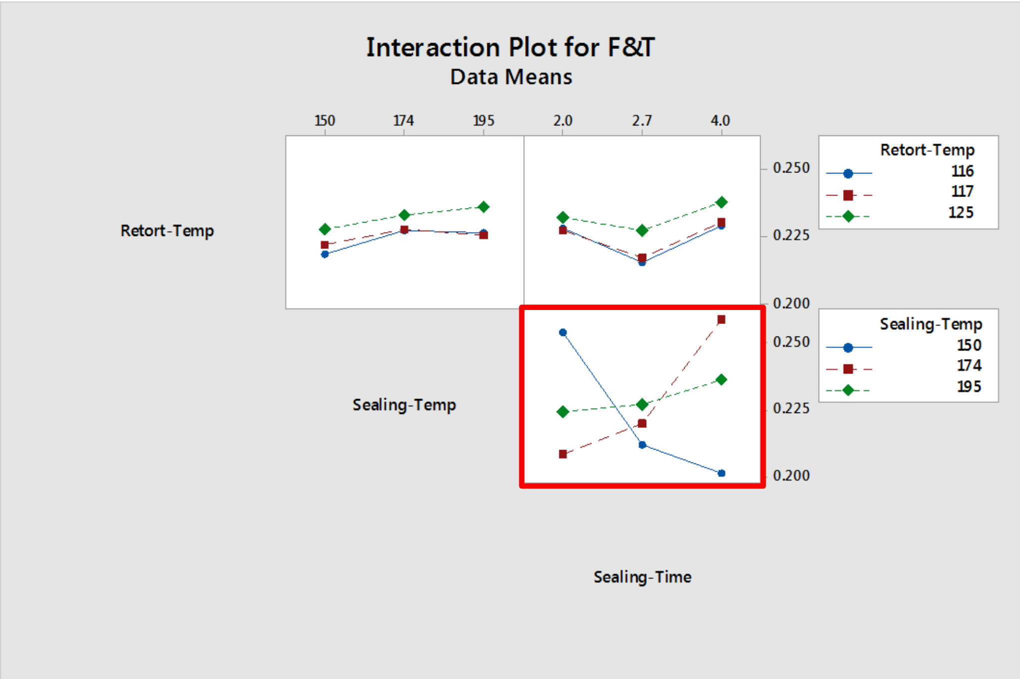


Figure 6.16 Interaction plot of three factors for the overall defect

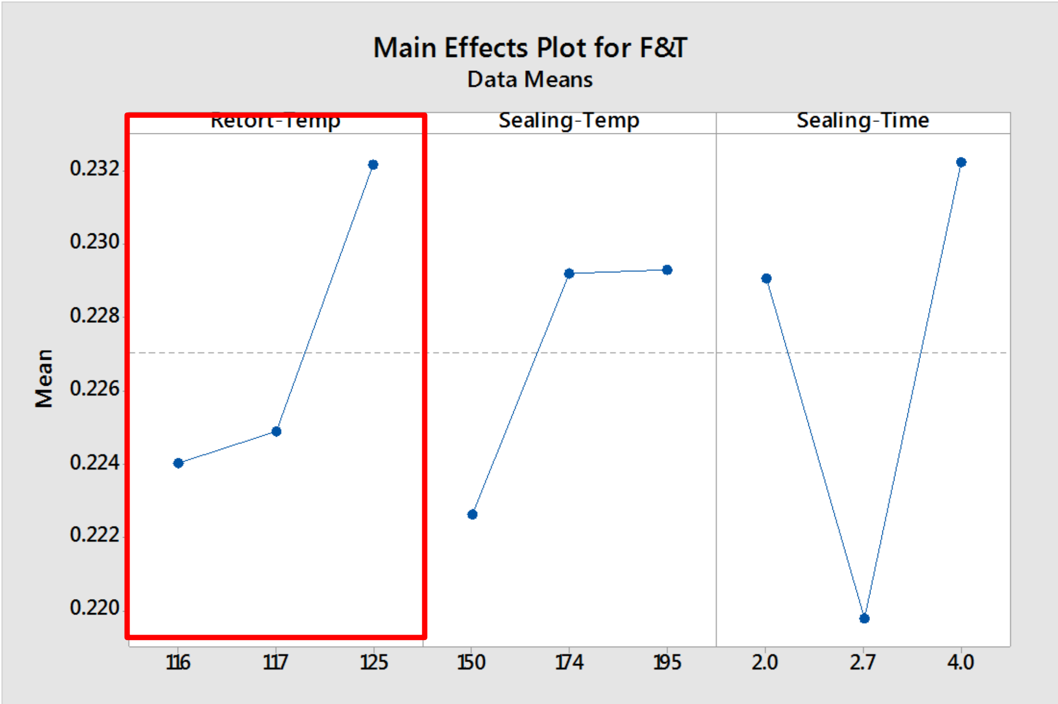


Figure 6.17: Main effect plot of three factors for the overall defect

When compare between the wrinkle of seal defect and the total defect analysis, the results are different in sealing time's suggested value. The analysis of the wrinkle of seal defect shows the low level (2 Sec.) is the suggested value while the overall defect analysis represents at high level (4 Sec.). After brainstorming with team members, it should set the sealing time at high level because sealing temperature and sealing time should be inverse value.

In conclusion, team member emphasize the impact of the overall defect and decide to set the machine by following the suggested value of total defect analysis. It means the level of three factors that the company should set are 116 °c of retort temperature, 150 °c of sealing temperature and 4 second of sealing time.

6.4 Analysis of the illegible date code defect

With eighteen experimental runs and the sample size of 3,888 units per run, the number of defect for each run according to the illegible date code is shown in Table 6.6.

The proportion of defect as the response of the experiment is calculated and also shown in Table 6.6.

6.4.1 Analysis of experiment result

Due to the suggestion of Bisguard and Fuller (1994), the proportion of defect should be transformed to Freeman and Turkey (F&T) by following Equation 6.1.

Table 6.6: Result of the experiment for the illegible date code and total defect

Std Order	Run Order	Blocks	Retort Pressure	Vacuum	Illegible date code		Total	
					$\widehat{P}$	F & T	$\widehat{P}$	F & T
7	10	1	1800	10	0.031	0.175	0.092	0.303
5	11	1	1700	23	0.018	0.134	0.053	0.231
6	12	1	1700	40	0.025	0.158	0.075	0.274
8	13	1	1800	23	0.029	0.170	0.086	0.294
9	14	1	1800	40	0.035	0.187	0.104	0.323
1	15	1	1600	10	0.011	0.105	0.056	0.236
2	16	1	1600	23	0.020	0.142	0.054	0.233
4	17	1	1700	10	0.011	0.107	0.034	0.185
3	18	1	1600	40	0.028	0.168	0.079	0.281
16	1	2	1800	10	0.030	0.172	0.089	0.298
12	2	2	1600	40	0.027	0.165	0.096	0.311
15	3	2	1700	40	0.023	0.152	0.069	0.262
17	4	2	1800	23	0.027	0.165	0.082	0.286
13	5	2	1700	10	0.014	0.119	0.042	0.206
10	6	2	1600	10	0.015	0.124	0.053	0.231
18	7	2	1800	40	0.032	0.180	0.097	0.312
11	8	2	1600	23	0.020	0.140	0.052	0.229
14	9	2	1700	23	0.017	0.131	0.051	0.226

The normality plot of residuals as presentation in Figure 6.18 shows that the plots assemble along a straight line. There is no pattern fail in the tails of the graph. The p-value according to Anderson-Darling (AD) test is 0.198 which is greater than 0.05. Therefore, at 95% confidence level, the normality assumption of residuals is satisfied.

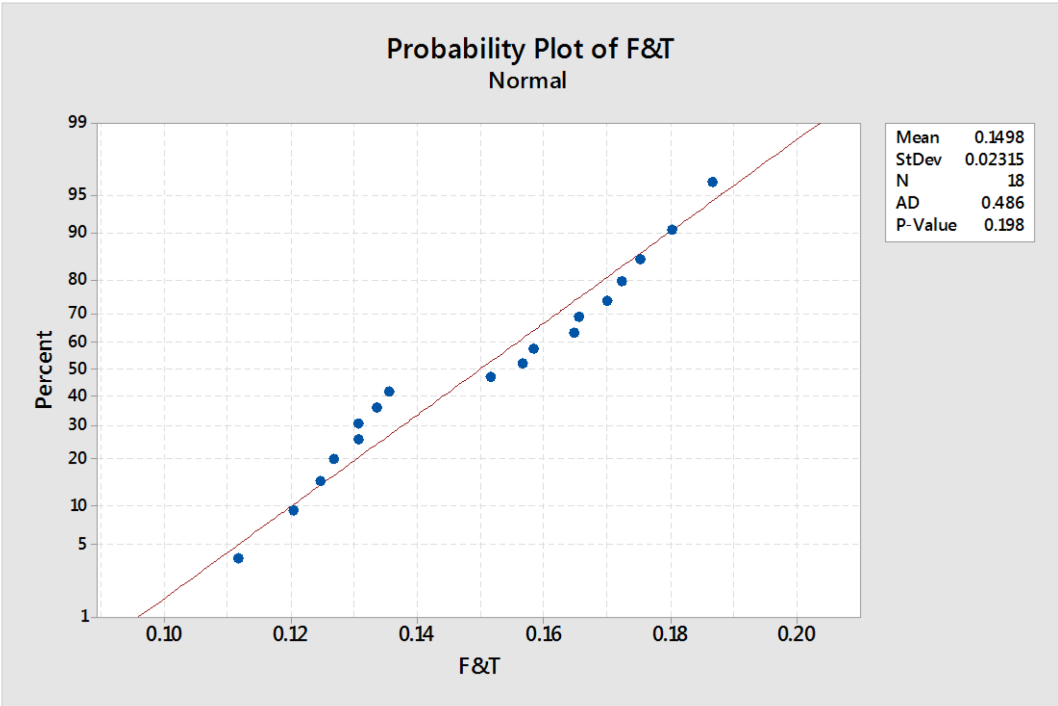


Figure 6.18: The normal probability plot of hypothesis testing for the illegible date code defect

To determine the independence of the residual value, the plot of “residuals versus order” generate by Minitab as shown in Figure 6.19 can be used to describe the relationship between residual of respond for the illegible date code defect and observation order. The plots appear randomly without pattern. Therefore, it is concluded that the residuals are independent and aligned with assumption.

To determine the validity of common variance, the plot of “residual versus fits” generated by Minitab as shown in Figure 6.20 can be used to describe how residuals spread around the center line. The plots themselves appear as random around the zero line. Therefore, it can be concluded that the residual variance are homogeneous and aligned with assumption.

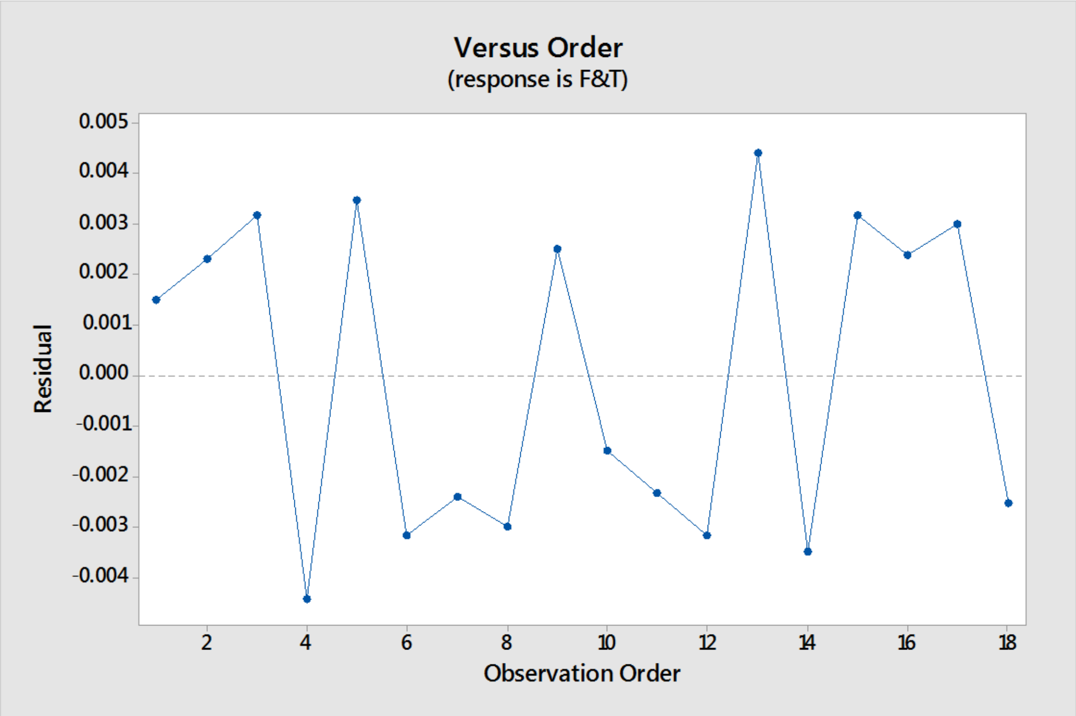


Figure 6.19: Residual versus order for the analysis of the illegible date code defect

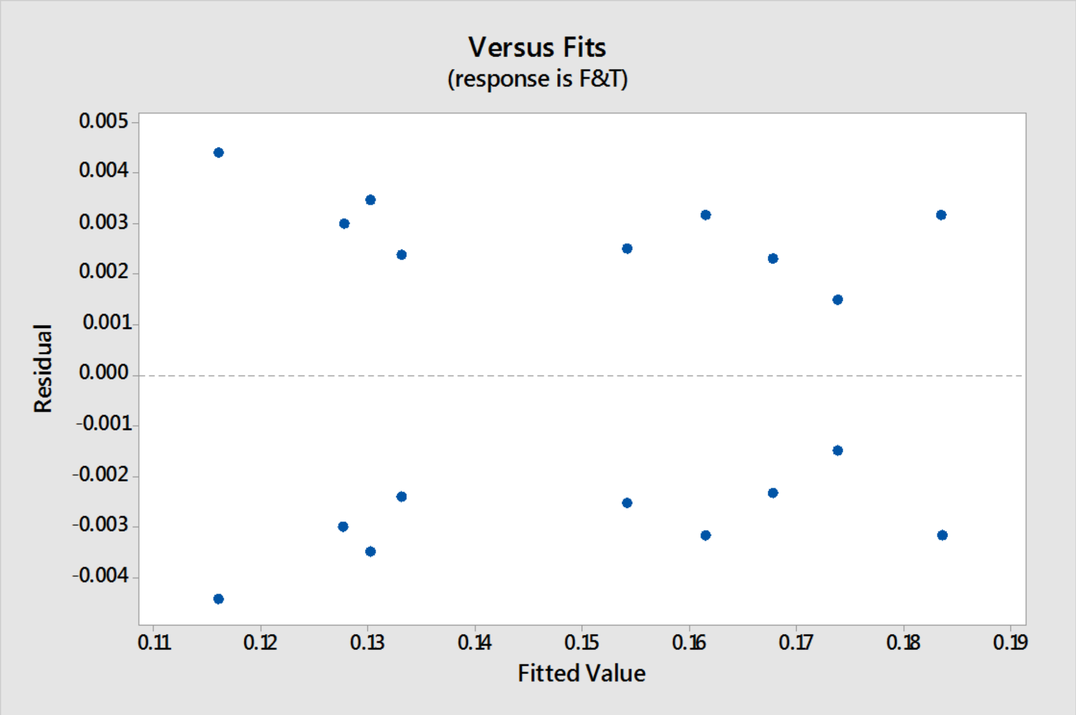


Figure 6.20: Residual versus fits for the analysis of the illegible date code defect

Figure 6.21 shows R-Sq and R-Sq (adj) of experiment is 97.04% and 94.41%, respectively. The high percentages of these two values prove that the accuracy of this model to predict the result is relatively high. The interaction between retort pressure and sealing vacuum is significant due to the small p-value less than 0.05 the significance level.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Retort_Pressure	2	0.005854	0.002927	81.56	0.000
Sealing_Vaccum	2	0.003669	0.001835	51.12	0.000
Retort_Pressure*Sealing_Vaccum	4	0.001063	0.000266	7.41	0.006
Error	9	0.000323	0.000036		
Total	17	0.010910			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0059907	97.04%	94.41%	88.16%

Figure 6.21: The analysis of experiment for the illegible date code defect by Minitab

When considering the interaction plot between the retort pressure and the sealing vacuum in Figure 6.22, it is found that 1700 mbar of the retort pressure and 10 bars of the sealing vacuum contribute the lowest defective rate.

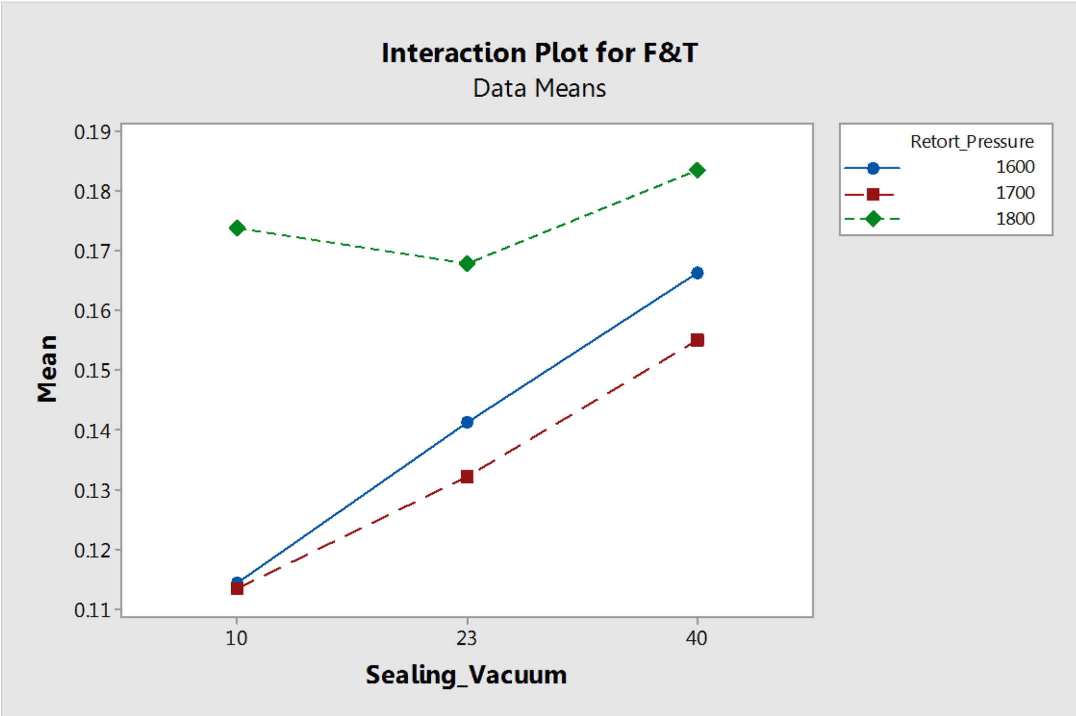


Figure 6.22: Interaction plot of two factors in the illegible date code defect

6.4.2 Impact to the overall defect

After obtained suggested setting level of each factor from the previous analysis according to the lowest defective rate for the illegible date code defect. It has to consider if there is any impact to the overall defective rate because some changes of setting level may contribute the increasing of the overall defect.

The same analysis that has been applied for the illegible date code defect will be used with the overall defect. The suggested setting level of retort pressure and sealing vacuum will be determined to obtain the lowest defective rate of overall defect and is compared with the level obtain based on the illegible date code defect. If the results are the same, this result can be used in further step. The residual plots are constructed and shown in Figure 6.23. All plots do not reveal any violation of basic assumptions. Table 6.6 shows the overall defective rate in Freeman and Turkey (F & T) transformation.

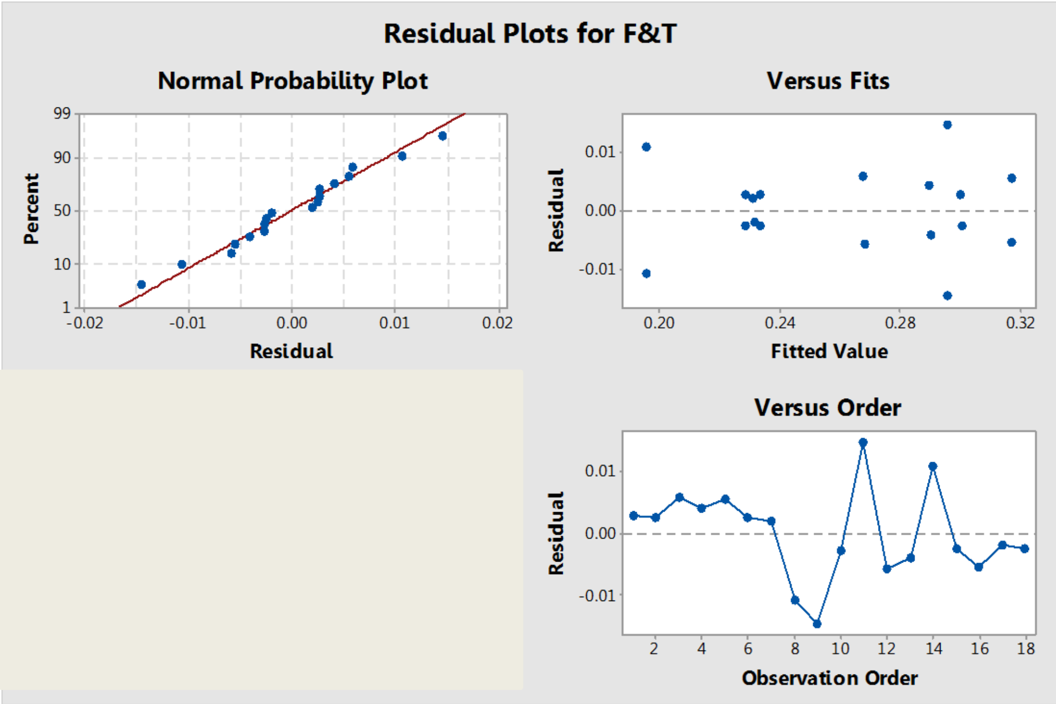


Figure 6.23: The residual plot for the overall defect by two-way ANOVA

Figure 6.24 shows R-Sq and R-Sq (adj) of experiment is 98.53% and 97.23%, respectively. The high percentages of these two values prove that the accuracy of this model to predict the result is relatively high. The interaction between retort pressure and sealing vacuum is significant due to the small p-value less than 0.05 the significance level.


```
Analysis of Variance

Source                            DF    Adj SS    Adj MS  F-Value  P-Value
  Block                            1  0.000000  0.000000     0.00    0.969
  Retort_Pressure                  2  0.016287  0.008144    74.41    0.000
  Sealing_Vacuum                   2  0.009064  0.004532    41.41    0.000
  Retort_Pressure*Sealing_Vacuum   4  0.002374  0.000594     5.42    0.021
Error                              8  0.000875  0.000109
Total                             17  0.028601


Model Summary

        S    R-sq  R-sq(adj)  R-sq(pred)
0.0104611  96.94%     93.50%      84.50%
```

Figure 6.24: The analysis of experiment for the overall defect by two-way ANOVA

When considering the interaction plot between the retort pressure and the sealing vacuum in Figure 6.25, it is found that 1700 mbar of the retort pressure and 10 bars of the sealing vacuum contribute the lowest defective rate. In conclusion, the suggested value of the retort pressure and the sealing vacuum should be set at 1700 mbar and 10 bars, respectively.

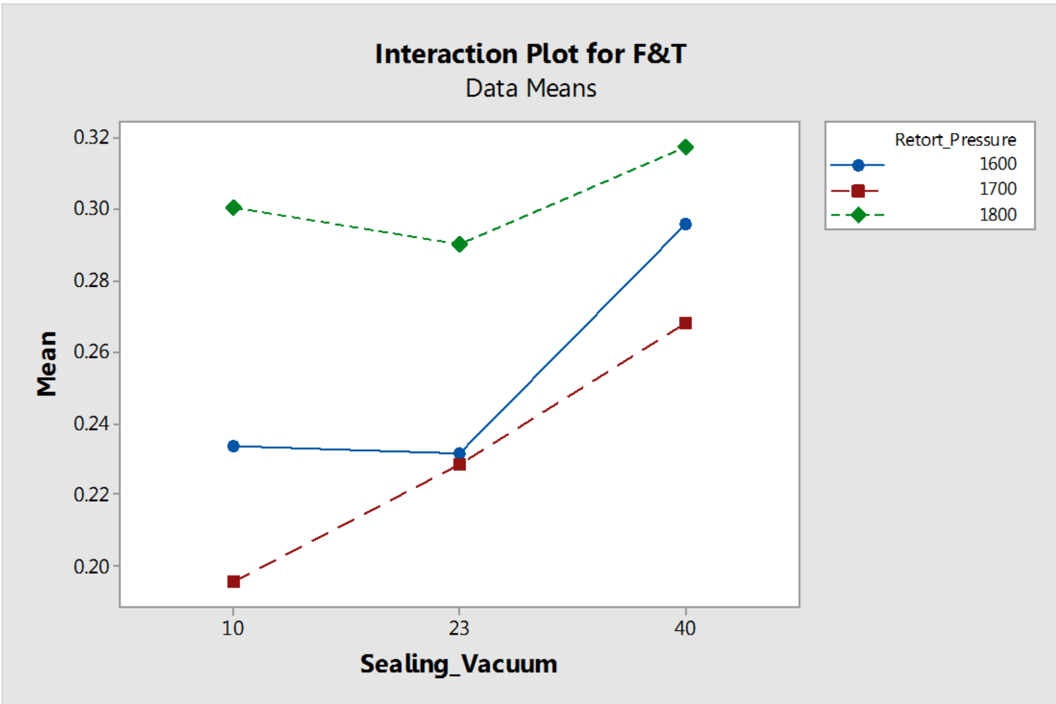


Figure 6.25: Interaction plot of two factors for the overall defect

After the design of experiments, Table 6.7-6.9 show the suggested level for each defect type.

Table 6.7: The suggested level for the out of shape and overall defect

No.	Factor	Suggested value based on		Unit
		Out of shape defect	Overall defect	
1	The pressure of retort machine	1700	1700	mbar

Table 6.8: The suggested level for the wrinkle of seal and overall defect

No.	Factor	Suggested value based on		Unit
		Wrinkle of seal defect	Overall defect	
2	The temperature of retort machine	116	116	°C
3	The temperature of sealing machine	150	150	°C
4	The sealing time of sealing machine	2	4	Second

Table 6.9: The suggested level for the illegible date code and overall defect

No.	Factor	Suggested value based on		Unit
		Illegible date code defect	Overall defect	
5	The pressure of retort machine	1700	1700	mbar
6	The vacuum of sealing machine	10	10	bars

Chapter 7

Control phase

The objective of this phase is to control and monitor the process in order to maintain the process performance by using the control charts. The important process parameters will be also set at the suggested value analyzed from the previous phase. The total defective rates will be determined in this phase and compared with the defective rate after improvement. When the result is successfully confirmed, the standard process parameters need to be set for a process control plan to ensure the robustness and consistency of the process to maintain the total defective rate.

7.1 Confirm the result

From the analysis in the previous phase, the suggested values according to the minimum defective rate of three defect types are summarized in Table 7.1. The level of these factors will be set and tested for 30 batches, 3,888 units per batch, to verify the test result after improvement.

Table 7.1: The suggested level for all important factors

Defect type	Factor	Suggested Value	Unit
The out of shape of plastic cup	Pressure of retort machine	1700	mbar
The wrinkle of seal	Temperature of retort machine	160	°C
The wrinkle of seal	Temperature of sealing machine	150	°C
The wrinkle of seal	Time of sealing machine	4	Second
The illegible date code	Pressure of retort machine	1700	mbar
The illegible date code	Vacuum of sealing machine	10	bars

7.1.1 Test methodology

Before the test, it needs to prepare machine and process equipment readiness. Training must be provided to the related operators and employees to clearly understand the control inputs of machines. The test methodology to test these three defect types is the same but different in factors and level of control factor as following below.

1. All raw and packaging materials used for 30 testing batches must be sourced from the same suppliers and passed quality inspection.
2. The suggested values have to be set according to the values in Table 7.1 at machine and process equipment.
3. Produce the Ready Rice product with the same batch size
4. Inspect the product after the retort process by the qualified inspectors who conducted the test in measure phase
5. Separate the type and grade of defects
6. Record the inspection result for further analysis

7.1.2 Monitoring using the control charts

To control the process, the control charts are developed to monitor the process performances. Because the study is related to the defective rate of three defect types and all defect types, the P-chart is the appropriate control chart to monitor the proportion of defects occurred in the production line. The sample size for confirmation testing will be the full machine capacity of 3,888 units which is the same sample size of the hypothesis testing. The results are collected for 30 batches to confirm the test.

7.1.3 Analysis of the result

The test was conducted for 30 batches in February 2016 to validate the suggested process parameter using the control chart for controlling the proportion of defect in the production process.

1. The control chart of the out of shape defect

The defective rate of the out of shape defect was collected for 30 batches to develop the P-chart in Figure 7.1. Then, the Upper control limits (UCL), Center line (CL) and Lower control limits (LCL) are calculated, as shown in Equation 7.1- 7.3, respectively.

$$\text{UCL} = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \tag{7.1}$$

$$\text{CL} = \bar{p} \tag{7.2}$$

and

$$\text{LCL} = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \tag{7.3}$$

For $\bar{p}$ = Average of defective rate

n = Sample size

The average of defective rate for the out of shape defect after improvement is 0.0067. Therefore, upper control limits (UCL), central line (CL) and lower control limits (LCL) is

$$\text{UCL} = 0.0067 + 3\sqrt{\frac{0.0067(1-0.0067)}{3888}} = 0.010653$$

$$\text{CL} = 0.0067$$

$$\text{LCL} = 0.0067 - 3\sqrt{\frac{0.0067(1-0.0067)}{3888}} = 0.002790$$

Figure 7.1 shows the defective rate for the out of shape defect are scattering around the center line within control limit and no any points are outside the upper and lower control limit. Moreover, the average defective rate of the out of shape after improvement is less than before improvement. It is confirmed that the improvement can reduce the defective rate of the out of shape and can bring the level of factor to minimize the total defective rate.

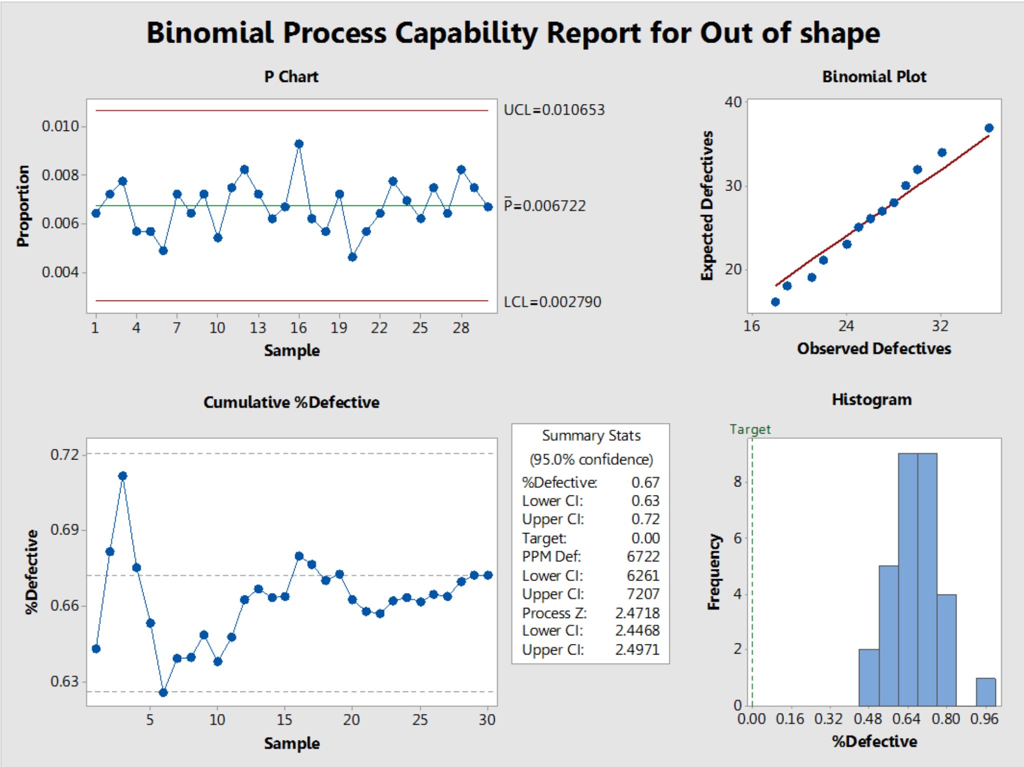


Figure 7.1: Process capability analysis of the out of shape defect after improvement

2. The control chart of the wrinkle of seal defect

The defective rate of the wrinkle of seal defect was collected for 30 batches to develop the P-chart in Figure 7.1. Then, the Upper control limits (UCL), Center line (CL) and Lower control limits (LCL) are calculated, following in Equation 7.1- 7.3, respectively. The average of defective rate in the wrinkle of seal defect after improvement is 0.0079. Therefore, upper control limits (UCL), central line (CL) and lower control limits (LCL) are

$$\text{UCL} = 0.0079 + 3\sqrt{\frac{0.0079(1-0.0079)}{3888}} = 0.012220$$

$$\text{CL} = 0.0079$$

$$\text{LCL} = 0.0079 - 3\sqrt{\frac{0.0079(1-0.0079)}{3888}} = 0.003675$$

Figure 7.2 shows the defective rate for the wrinkle of seal defect are scattering around the center line within control limit and no any points are outside the upper and lower control limit. Moreover, the average defective rate of the wrinkle of seal after improvement is less than before improvement. It is confirmed that the improvement can reduce the defective rate of the wrinkle of seal and can bring the level of factor to minimize the total defective rate.

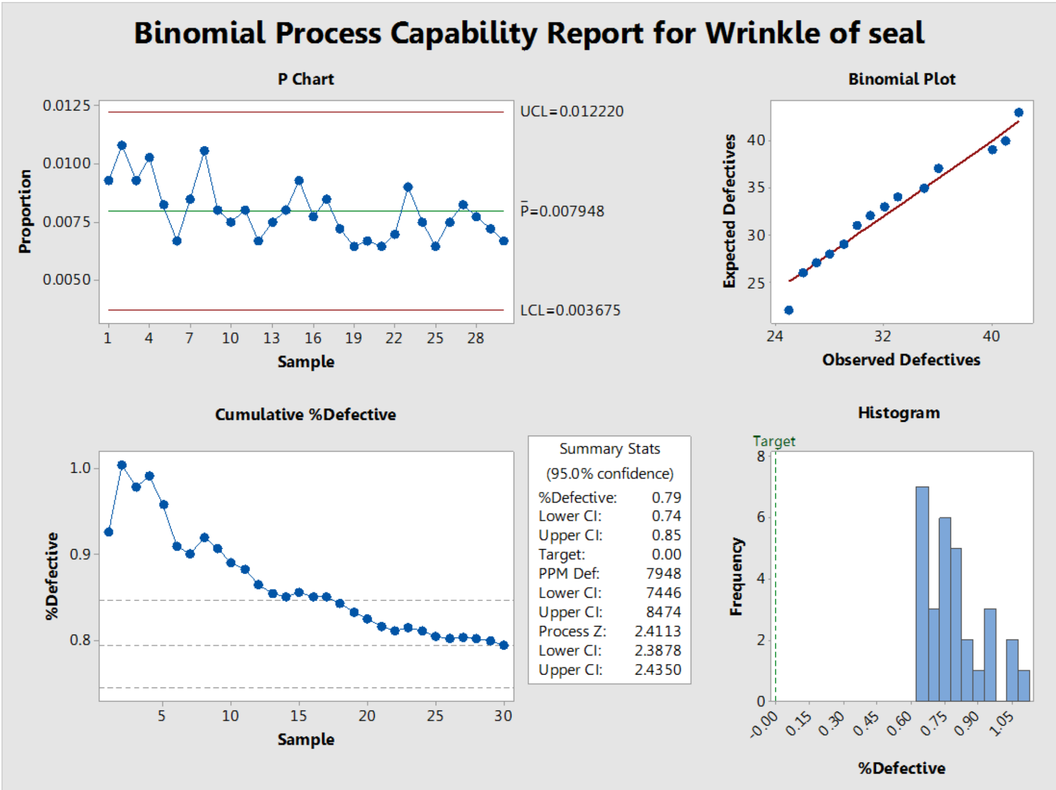


Figure 7.2: Process capability analysis of the wrinkle of seal defect after improvement

3. The control chart of the illegible date code defect

The defective rate of the illegible date code defect was collected for 30 batches to develop the P-chart in Figure 7.1. Then, the Upper control limits (UCL), Center line (CL) and Lower control limits (LCL) are calculated, as shown in Equation 7.1- 7.3, respectively. The average of defective rate in the illegible date code defect after improvement is 0.0079. Therefore, upper control limits (UCL), central line (CL) and lower control limits (LCL) are

$$UCL = 0.0033 + 3\sqrt{\frac{0.0033(1-0.0033)}{3888}} = 0.006012$$

$$CL = 0.0033$$

$$LCL = 0.0033 - 3\sqrt{\frac{0.0033(1-0.0033)}{3888}} = 0.000521$$

Figure 7.3 shows the defective rate for the illegible date code defect are scattering around the center line within control limit and no any points are outside the upper and lower control limit. Moreover, the average defective rate of the illegible date code after improvement is less than before improvement. It is confirmed that the improvement can reduce the defective rate of the illegible date code and can bring the level of factor to minimize the total defective rate.

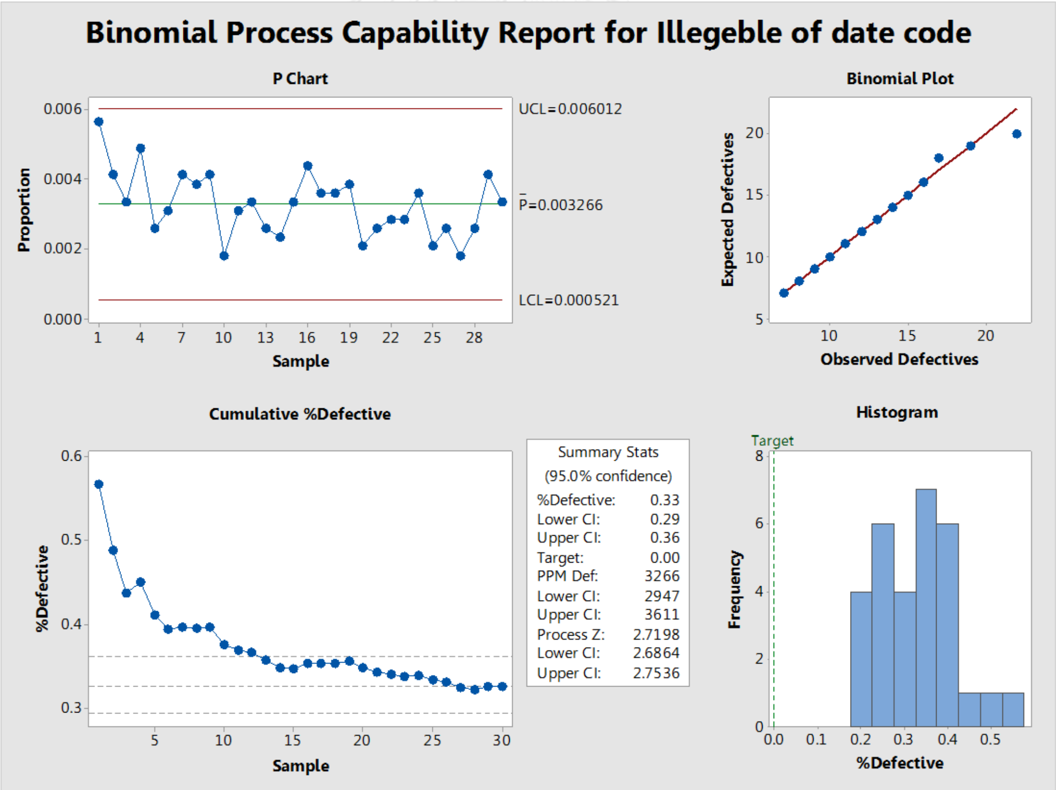


Figure 7.3: Process capability analysis of the illegible date code defect after improvement

7.2 After improvement

After improvement by controlling the key factors of the production process of Ready Rice product, the process performance can be summarized in two respects which are the defective rate and the waste cost.

7.2.1 Process capability and process performance

The defective rate of three defect types; the out of shape, the wrinkle of seal and the illegible date code can be summarized using the process capability analysis. Then, the results between before and after improvement will be compared.

1. The out of shape defect reduction

The historical data of the out of shape defect were collected for nine months, the defect rate before improvement of the out of shape defect is 1.62%. After improvement by setting of the retort pressure at 1700 mbar, the defective rate of the out of shape defect for 30 batches is 0.67% as shown in Figure 7.1. The defective rate after improvement for 30 batched is reduced by 58.64%.

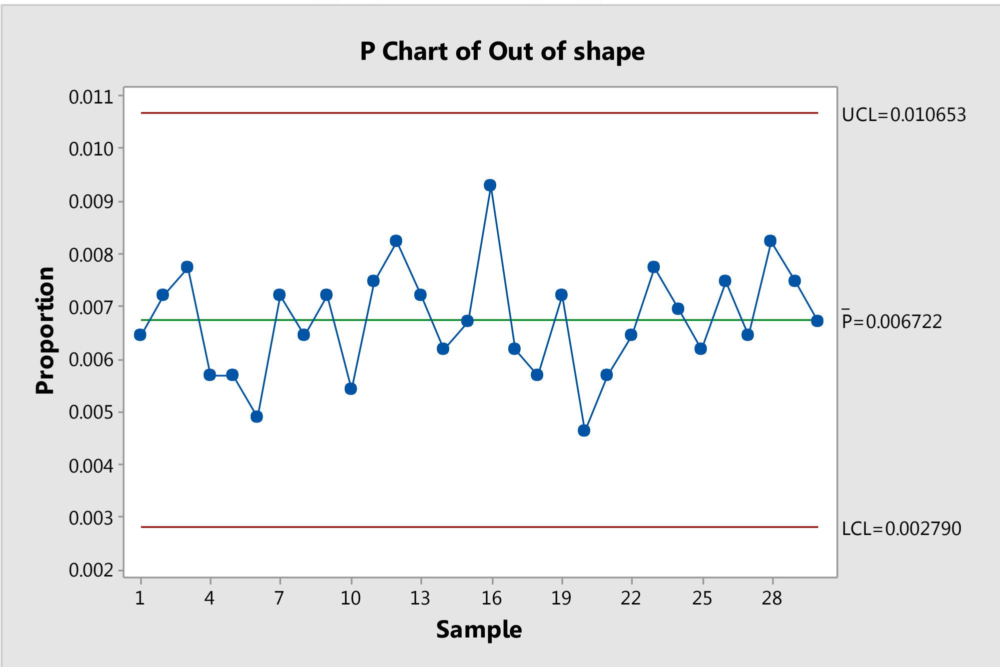


Figure 7.4: The control chart of the out of shape defect

When considering the process capability analysis of the out of shape defect after improvement in Table 7.2, the defective rate of the out of shape defect is 0.67%. The short term (C_{pk}) and long term (P_{pk}) process capability in the out of shape defect can be calculated by using Equation 4.8 and 4.9, respectively, as follows.

$$Z_{LT} = 2.473$$

$$Z_{ST} = 2.473 + 1.5 = 3.973$$

Therefore, the short term (C_{pk}) and long term (P_{pk}) process capability for the out of shape defect are

$$C_{pk} = \frac{1}{3} \times 3.973 = 1.324$$

And $$P_{pk} = \frac{1}{3} \times 2.473 = 0.824$$

When comparing the process capability for the out of shape defect between before and after improvement, the short term (C_{pk}) and long term (P_{pk}) value of previous setting are 1.213 and 0.713, respectively compared to the short term and long term in current setting are 1.324 and 0.824, respectively. It can be concluded that the process capability for the out of shape defect is improved.

Table 7.2: Defective rate and process capability for the out of shape defect

Term of improvement	Defective rate	The number of defects (PPM)	Z_{LT}	Z_{ST}	P_{pk}	C_{pk}
Before	0.0162	16,200	2.14	3.64	0.71	1.21
After	0.0067	6,700	2.47	3.97	0.82	1.32

2. The wrinkle of seal defect reduction

The historical data of the wrinkle of seal defect were collected for nine months, the defect rate before improvement of the wrinkle of seal defect is 1.43%. After improvement by setting of retort temperature, sealing temperature and sealing time, the defective rate of the wrinkle of seal defect for 30 batches is 0.79% as shown in Figure 7.2. The defective rate after improvement for 30 batches is reduced by 44.76%.

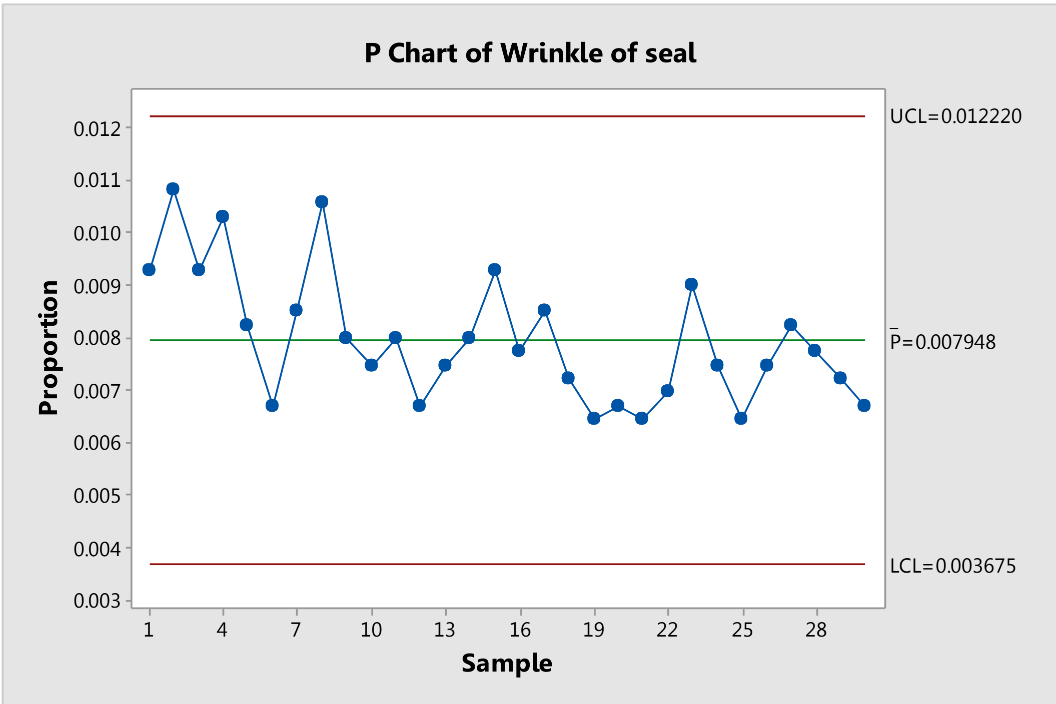


Figure 7.5: The control chart of the wrinkle of seal defect

When considering the process capability analysis of the wrinkle of seal defect after improvement in Table 7.3, the defective rate of the wrinkle of seal defect is 0.79%. The short term (C_{pk}) and long term (P_{pk}) process capability in the wrinkle of seal defect can be calculated by using Equation 4.8 and 4.9, respectively, as follows,

$$Z_{LT} = 2.414$$
$$Z_{ST} = 2.414 + 1.5 = 3.914$$

Therefore, the short term (C_{pk}) and long term (P_{pk}) process capability for the wrinkle of seal defect are

$$C_{pk} = \frac{1}{3} \times 3.914 = 1.305$$

And $$P_{pk} = \frac{1}{3} \times 2.414 = 0.805$$

When comparing the process capability for the wrinkle of seal defect between before and after improvement, the short term (C_{pk}) and long term (P_{pk}) value of previous setting are 1.230 and 0.730, respectively compared to the short term and long term in current setting are 1.305 and 0.80, respectively. It can be concluded that the process capability for the wrinkle of seal defect is improved.

Table 7.3: Defective rate and process capability for the wrinkle of seal defect

Term of improvement	Defective rate	The number of defects (PPM)	Z_{LT}	Z_{ST}	P_{pk}	C_{pk}
Before	0.0143	14,300	2.19	3.69	0.73	1.23
After	0.0079	7,900	2.41	3.91	0.81	1.31

3. The illegible date code reduction

The historical data of the illegible date code defect were collected for nine months, the defect rate before improvement of the illegible date code defect is 1.66%. After improvement by setting of retort pressure and sealing vacuum, the defective rate of the illegible date code defect is 0.33% as shown in Figure 7.3. The defective rate after improvement for 30 batches is reduced by 80.12%.

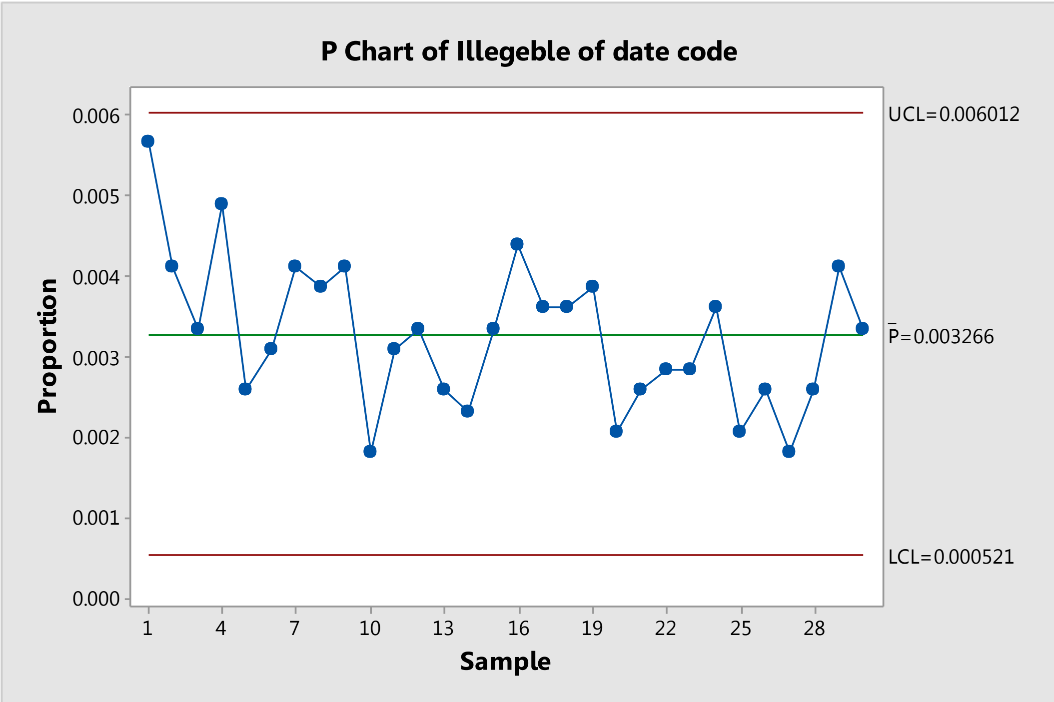


Figure 7.6: The control chart of the illegible date code defect

When considering the process capability analysis of the illegible date code defect after improvement in Table 7.4, the defective rate of the illegible date code defect is 0.33%. The short term (C_{pk}) and long term (P_{pk}) process capability in illegible date code defect can be calculated by using Equation 4.8 and 4.9, respectively, as follows,

$$Z_{LT} = 2.716$$

$$Z_{ST} = 2.716 + 1.5 = 4.216$$

Therefore, the short term (C_{pk}) and long term (P_{pk}) process capability for the illegible date code defect are

$$C_{pk} = \frac{1}{3} \times 4.216 = 1.405$$

And $$P_{pk} = \frac{1}{3} \times 2.716 = 0.905$$

When comparing the process capability for the illegible date code defect between before and after improvement, the short term (C_{pk}) and long term (P_{pk}) value of previous setting are 1.210 and 0.710, respectively compared to the short term and long term in current setting are 1.405 and 0.905, respectively. It can be concluded that the process capability for the illegible date code defect improved.

Table 7.4: Defective rate and process capability for the illegible date code defect

Term of improvement	Defective rate	The number of defects (PPM)	Z_{LT}	Z_{ST}	P_{pk}	C_{pk}
Before	0.0166	16,600	2.19	3.69	0.71	1.21
After	0.0033	3,300	2.72	4.21	0.91	1.41

4. Total defect reduction

After improvement by setting all significant parameters at suggested value shown in Table 7.1, the total defective rate is reduced to 2.24% as shown in Figure 7.4. The total defective rate after improvement for 30 batches is reduced by 56.42%.

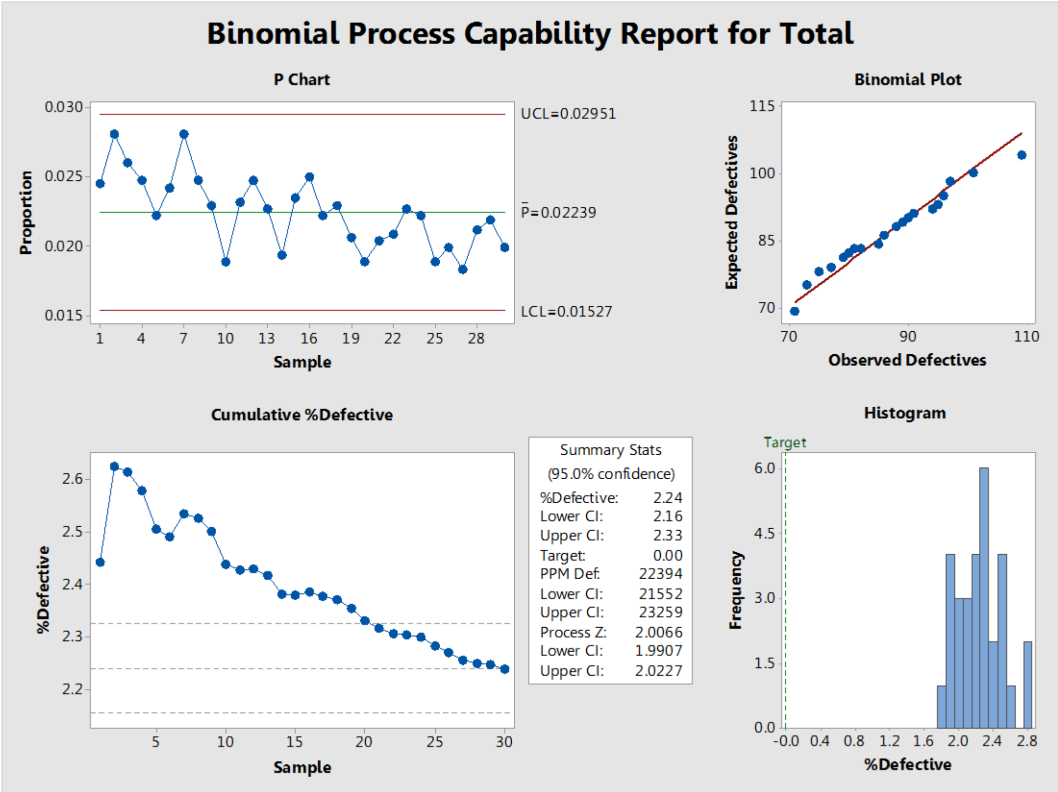


Figure 7.7: Process capability analysis of the total defect after improvement

When considering the process capability analysis of the total defect after improvement in Table 7.5, the defective rate of total defect is 2.24%. The short term (C_{pk}) and long term (P_{pk}) process capability in the total defect can be calculated by using Equation 4.8 and 4.9, respectively, as follows,

$$Z_{LT} = 2.006$$

$$Z_{ST} = 2.006 + 1.5 = 3.506$$

Therefore, the short term (C_{pk}) and long term (P_{pk}) process capability for the total defect are

$$C_{pk} = \frac{1}{3} \times 3.506 = 1.168$$

And

$$P_{pk} = \frac{1}{3} \times 2.006 = 0.668$$

When comparing the process capability for the total defect between before and after improvement, the short term (C_{pk}) and long term (P_{pk}) value of previous setting are 3.131 and 1.631, respectively compared to the short term and long term in current setting are 1.168 and 0.668, respectively. It can be concluded that the process capability for the total defect is improved.

Table 7.5: Defective rate and process capability for the total defect

Term of improvement	Defective rate	The number of defects (PPM)	Z_{LT}	Z_{ST}	P_{pk}	C_{pk}
Before	0.0514	51,400	1.63	3.13	0.54	1.04
After	0.0224	22,400	2.01	3.51	0.67	1.17

7.2.2 The waste cost

Before the improvement, the total defective rate was 5.14% segregated in two defective grades called Grade B and Grade C with different cost. The total waste cost after improvement will be comparatively shown in Table 7.6.

Table 7.6: Total waste cost value compares between before and after the improvement

	Waste grade	Average number of defects per month (Units)	Total Waste Cost Value per month (Baht)	
Before	B	4,497	22,485	35,342
	C	989	12,857	
After	B	2,626	13,130	16,549
	C	263	3,419	

Total waste cost per month is reduced by 41.60% and 73.41% for Grade B and Grade C defect, respectively. As the result of the improvement, the company can reduce the waste cost by 225,516 THB per year.

7.2.3 Impact to cost and capacity of process improvement

After the process improvement by setting the sealing time at 4 seconds from the current setting of 2.7 seconds, the cycle time of sealing machine is increased. This setting might has an impact to the process capacity. The sealing time per batch is increased from 39 minutes to 52 minutes. Therefore, the cycle time per batch after improvement is increased by 13 minutes which are slightly impact to process capacity. Since the maximum number of batch per day is three therefore, the processing time is increased by 39 minutes per day.

Figure 7.8 shows the defective rate before and after improvement for three defect types, other type and all types together.

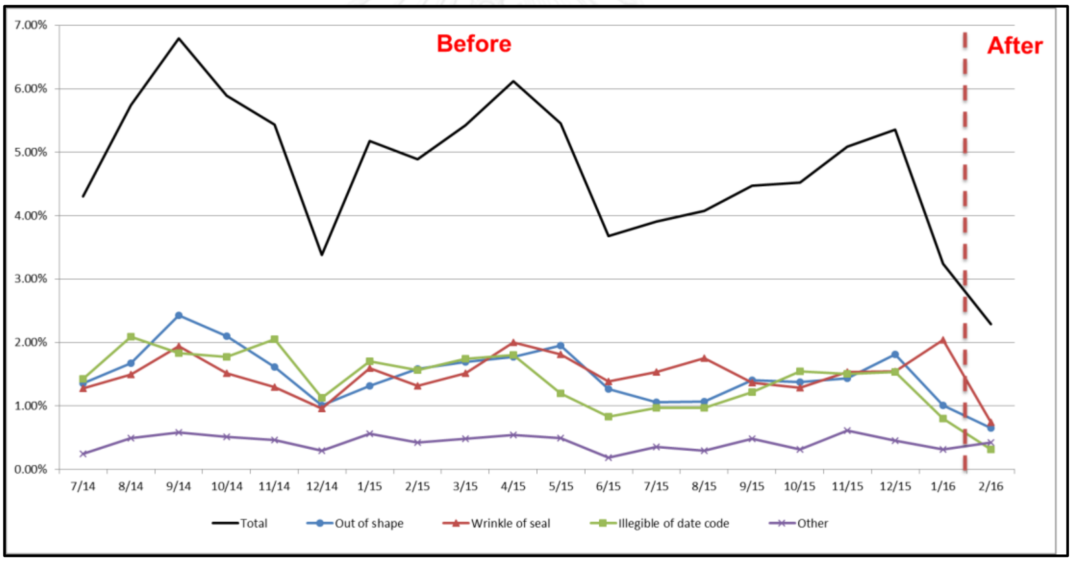


Figure 7.8: The defective rate before and after improvement

As shown in Figure7.8, total defective rate was fluctuated during July 2014 to February 2016. Total defective rate before improvement in the first nine months, July 2014 to March 2015 was very high except in December 2014. Based on data analysis, the lower total defective rate in December 2014 might be from high production volume and less defects from continuous production runs. Moreover, according to the company's information, the cross functional team was formed in June 2015 to reduce the defective rate. From team's brainstorming, the pressure of retort machine had been adjusted from 1770 to 1700 mbar. Hence, the total defective rate was reduced to 3.68%. However, the higher defective rate in quarter 4, 2015 was contributed from execution of design of experiment in improve phase of this study. Finally, the total defect and three defect types was reduced to 2.24% after improvement in February 2016.

Furthermore, there is no significant difference in other defective rate. In conclusion, the change of parameter after improvement to minimize three defect types is not negatively impact to other defects.

Chapter 8

Conclusion and Suggestion

The objective of this research is to reduce the defects of three defect types including the out of shape, the wrinkle of seal and the illegible date code defect by applying Six Sigma. The research process follows the DMAIC methodology consisting of 5 phases: define, measure, analyze, improve and control. The summaries of research outcome in each phase are as follows.

8.1 Define phase

This phase is to study production process of Ready Rice product size 500 gram and identify the key problems impacted to the production process performance. From data collection of defect recorded during July 2014 to March 2015, the overall defective rate was 5.14%, approximately causing the loss of 320,000 THB. There are three types of defect which are the out of shape, the wrinkle of seal and the illegible date code defect contributed the high impact to waste cost value of company. Therefore, the objective of process improvement is to reduce the number of defects of these three defect types by applying the Six Sigma concept which is the useful technique for defect reduction.

8.2 Measure phase

This phase is to analyze the accuracy and precision of the company's measurement system of the inspection process. The step of analysis is to select three appraisers to inspect 30 product samples for three times. The measurement result shows only one appraiser has been met the acceptance criteria of measurement system analysis. Therefore, the product after improvement will be inspected by this qualified appraiser in this research.

The process capability according to three defect types was analyzed in this phase. The C_{pk} and P_{pk} are determined for three defects and found to be less than 1.33 and 1.67, respectively. Therefore, research team was formed from cross functional team to identify the Cause and Effect diagrams for each defect. The FMEA was applied to evaluate and prioritize the level of cause of three defects. It is found that there are six, five and seven important cause for the out of shape, the wrinkle of seal and the illegible date code defect, respectively.

8.3 Analyze phase

This phase is to test that the important causes and factors are statistically significant to the defective rate of three defect type. The response of the test is the proportion of defect and 3,888 units of sample size were used. Hypothesis testing result at 95% confidence indicates that the pressure of retort is the only one key factor that effect to the defective rate of the out of shape defect. While there are three main factors which are the temperature of retort machine, the temperature of sealing and the sealing time that effect the defective rate of the wrinkle of seal. Finally, the pressure of the retort machine and the remaining air in cup are the significant factors of the illegible date code defect.

8.4 Improve phase

This phase is to determine the appropriate setting value for each factor subject to minimum number of defect. The factorial design of experiments was employed for three levels, the minimum, the current and the maximum value of each factor. Therefore, for the out of shape defect with one significant factor, one-way ANOVA with three levels was applied. While 3x3x3 factorial design was used for three significant factors of the wrinkle of seal defect. Finally, 3x3 factorial design for two significant factors of the illegible date code defect.

From the analysis of one-way ANOVA, the results with respect to the proportion of the out of shape defect and the overall defect yield the same suggested value of the retort pressure at 1700 mbar.

From the analysis of three way ANOVA, it is found that there is the interaction between the sealing temperature and sealing time at 95% confidence level for the proportion of wrinkle of seal defect. There is also the effect of the retort temperature alone on the proportion of the wrinkle of seal. However, the suggested values for each factor with respect to the proportion of the wrinkle of seal defect are slightly different with respect to the proportion of overall defect.

From the analysis of two-way ANOVA, the results with respect to the proportion of the illegible date code defect and the overall defect yield the same suggested value of the pressure of retort machine at 1700 mbar and 10 mbar of sealing vacuum.

For the overall point of view, the suggested level of each factor shown in Table 8.1.

Table 8.1: The suggested level of each factor

No.	Factor	Suggested Value	Unit
1	Pressure of retort machine	1700	mbar
2	Temperature of retort machine	160	°C
3	Temperature of sealing machine	150	°C
4	Time of sealing machine	4	Second
5	Vacuum of sealing machine	10	bars

8.5 Control phase

This phase is to control and monitor the process by using the P-chart as shown in Table 8.2. The process is implemented at 1700 mbar of the retort machine's pressure, 160 °C of the retort's machine temperature, 150 °C of the sealing machine's temperature, 4 second of the sealing time and 10 mbar of the sealing vacuum. With 30 trials, the overall defective rate can be reduced from 5.14% to 2.24%. The defective rate of the out of shape is reduced by 58.64% from 1.62% to 0.67% while the defective rate of the wrinkle of seal is reduced by 44.75% from 1.43% to 0.79%. The defective rate of the illegible date code defect is reduced by 80.12% from 1.66% to 0.33%. After important, the company can reduce waste cost by 53.17% from 35,342 THB per month to 16,549 THB per month.

Table 8.2: The lower and upper limit of P-chart for three defect types

Defect type	Lower limit	Upper limit
Out of shape	0.00279	0.01065
Wrinkle of seal	0.00367	0.01222
Illegible date code	0.00052	0.00601

8.6 Research summary

This research is to minimize the defective rate of three defect types including the out of shape, the wrinkle of seal and the illegible date code defect by applying Six Sigma concept. The research outcome can be summarized at each phase as shown in Table 8.3.

Table 8.3: Research summaries for each phase of Six Sigma

Phase	Defect type			
	The out of shape	The wrinkle of seal	The illegible date code	Overall
Define	$\hat{P}$= 1.62 %	$\hat{P}$ = 1.43 %	$\hat{P}$ = 1.66 %	$\hat{P}$= 5.14 %
Measure	Process capability before improvement C_{pk} = 1.21 and P_{pk} = 0.71 There are 8 input factors	Process capability before improvement C_{pk} = 1.23 and P_{pk} = 0.73 There are 10 input factors	Process capability before improvement C_{pk} = 1.21 and P_{pk} = 0.71 There are 11 input factors	Process capability before improvement C_{pk} = 1.04 and P_{pk} = 0.54
Analyze	Significant factor is 1. Retort machine pressure	Significant factors are 1. Retort machine temperature 2. Sealing temperature 3. Sealing time	Significant factors are 1. Retort machine pressure 2. Vacuum of sealing machine	
Improve	One-way ANOVA with the suggested value at 1700 mbar of retort machine pressure	The factorial design with the suggested value as followed; 1. Retort machine temperature	The factorial design with the suggested value as followed; 1. Retort machine	

Phase	Defect type			
	The out of shape	The wrinkle of seal	The illegible date code	Overall
		= 160 °c 2. Sealing temperature = 150 °c 3. Sealing time = 4 Sec.	pressure = 1700 mbar 2. Sealing vacuum = 10 mbar	
Control	After improvement C_{pk} = 1.32 and P_{pk} = 0.82 $\bar{P}$ = 0.67 %	After improvement C_{pk} = 1.31 and P_{pk} = 0.81 $\bar{P}$ = 0.79 %	After improvement C_{pk} = 1.41 and P_{pk} = 0.91 $\bar{P}$ = 0.33 %	After improvement C_{pk} = 1.17 and P_{pk} = 0.67 $\bar{P}$ = 2.24 %
Conclusion	The defective rate is decreased by 58.64% The cost is reduced by 58.34%	The defective rate is decreased by 44.75% The cost is reduced by 42.17%	The defective rate is decreased by 80.12% The cost is reduced by 76.00%	The defective rate is decreased by 56.42% The cost is reduced by 53.17%

8.7 Research limitation

1. The scope of research study is only Ready Rice product size 150 grams. Therefore, the factors and level of factors for other size of product might be different from this analysis.

2. Because the retort's temperature directly effects to quality of sterilization process and shelf life of product. Therefore, the company had already successfully validated sterilization process by setting retort's temperature not less than 160 °c to achieve the F_0 value and ensure that the microorganisms can be fully killed. Consequently, the company does not allow to set retort's temperature less than 160 °c.

8.8 Research suggestion

1. There are other factors related to human such as throwing, dropping, scratching the cup and touching before ink drying contributed to the defective rate but human factors are not included in design of experiments study. Therefore, the process performance can be improved with respect to the human factors though the training and developing program as well as the quality assurance system.
2. The study of this research is for Ready Rice product size 150 grams, the same procedure can be applied to other sizes of product.
3. From design of experiment study, the result is shown the setting pressure at 1800 mbar of retort machine contributed the very high defective rate in the out of shape and the illegible date code defect. While the pressure at 1600 and 1700 mbar are resulted in slightly difference of defective rate. If the company needs to find the suggested value to reduce more defective rate, they should conduct design of experiment at pressure range in between 1600-1700 mbar and analyze results by applying ANOVA tool.
4. The result of "Measurement System Analysis" shows there is only one inspector met MSA criteria. The company should provide training to other inspectors to clearly understand the inspection and defect criteria and qualify them until meeting MSA criteria. The company benefit is to avoid the over rejection rate from unqualified inspector.

5. Although process capability of all defect types were increased after improvement but it is still lower than 1.33 criteria (industrial norm). If the company requires to increase their process capability, the company should consider to reduce the process variation as same as defective rate.
6. The suggested parameters show the pressure of retort machine at 1700 mbar contributes the lowest defective rate with respect to the out of shape and the illegible date code defect. From technical perspective, the date code is illegible from scratching with divider plate when the plastic cup is swollen. When taking into consideration, the correlation of these two defect types by using the regression analysis, Multiple R value is 0.912 as shown in Figure 8.1 while Figure 8.2 shows the correlation plot between the out of shape and illegible date code defect. Therefore, it can be concluded the reduction of defect rate from both defect types can be further improved together.

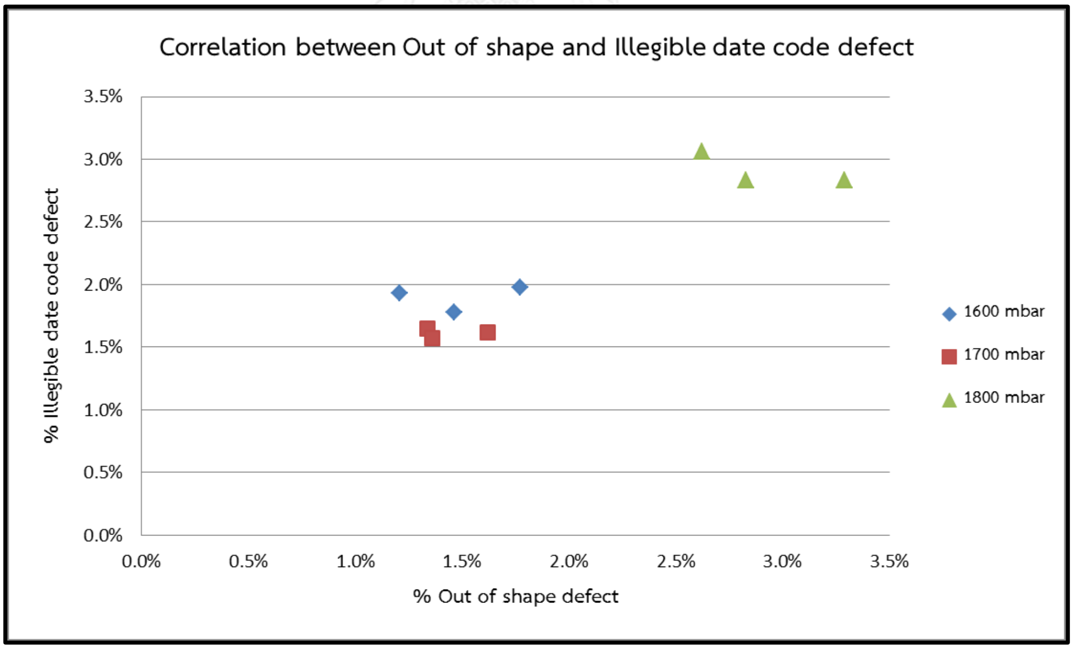


Figure 8.1: Correlation plot between the out of shape and the illegible date code defect

APPENDIX

Appendix A

Failure Mode and Effect Analysis Score

Table A1: Failure Mode and Effect Analysis of out of shape defect

No.	Factors	S	O	D	RPN	S	O	D	RPN	S	O	D	RPN	S	O	D	RPN	S	O	D	RPN	AVG
1	Inappropriate of retorting machine's pressure	5	4	3	60	5	5	3	75	4	3	3	36	5	4	3	60	5	4	3	60	58.2
2	Inappropriate of retorting machine's temperature	4	3	3	36	5	5	3	75	3	3	3	27	5	4	3	60	3	3	3	27	45
3	Inappropriate of retorting machine's time	3	3	3	27	3	3	3	27	3	2	3	18	3	3	3	27	2	2	2	8	21.4
4	Inappropriate of air remaining in cup	3	2	3	18	3	1	2	6	2	2	2	8	2	1	2	4	1	1	1	1	7.4
5	Overweight of cup	2	1	2	4	2	1	1	2	2	1	1	2	1	1	1	1	1	1	1	1	2
6	Dropping cup	3	2	3	18	3	3	3	27	3	3	3	27	2	2	2	8	2	2	2	8	17.6
7	Cup sorting in transportation process	3	2	3	18	2	1	2	4	2	2	3	12	2	2	2	8	1	2	2	4	9.2
8	Cup sorting in incubating process	3	2	3	18	2	1	2	4	2	2	3	12	2	2	2	8	1	2	2	4	9.2
9	Throwing cup by staff	4	2	3	24	3	1	2	6	2	2	3	12	2	2	2	8	2	2	2	8	11.6
10	Scratch by bended basket	4	2	3	24	3	2	2	12	2	2	2	8	3	2	2	12	3	2	2	12	13.6
11	Cup quality	4	2	1	8	4	1	1	4	3	1	1	3	5	1	1	5	3	1	1	3	4.6
12	Squeezing cup by staff	4	1	3	12	4	1	2	8	2	1	1	2	3	2	2	12	1	1	1	1	7
13	Untrained inspectors	3	2	2	12	3	2	1	6	4	2	1	8	4	1	1	4	3	1	1	3	6.6
14	Error of inspectors	3	3	4	36	3	2	4	24	3	3	3	27	4	3	1	12	3	3	3	27	25.2
15	Lack of inspector	2	2	2	8	1	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	2.6

Table A2: Failure Mode and Effect Analysis of wrinkle of seal defect

No.	Factors	S	O	D	RPN	S	O	D	RPN	S	O	D	RPN	S	O	D	RPN	S	O	D	RPN	AVG
1	Retort machine's pressure	4	3	3	36	4	3	3	36	3	3	3	27	3	3	3	27	4	3	3	36	32.4
2	Retort machine's temperature	5	3	3	45	4	3	3	36	3	3	3	27	3	3	3	27	4	3	3	36	34.2
3	Retort machine's time	2	3	3	18	3	3	3	27	3	3	3	27	2	2	2	8	2	1	3	6	17.2
4	Sealing machine's pressing force	3	3	2	18	3	3	3	27	4	3	3	36	4	3	3	36	3	3	3	27	28.8
5	Sealing temperature	5	3	3	45	5	3	3	45	4	3	3	36	4	3	3	36	5	3	3	45	41.4
6	Sealing time	3	2	2	12	4	3	3	36	3	3	3	27	3	3	3	27	2	1	3	6	21.6
7	Sealing head position	3	2	2	12	4	3	3	36	4	3	3	36	4	3	3	36	3	3	3	27	29.4
8	Plastic film feeding	3	2	3	18	2	2	2	8	3	2	2	12	2	1	2	4	1	1	1	1	8.6
9	Scratch while transportation	2	1	3	6	2	1	3	6	2	2	2	8	3	2	2	12	2	1	2	4	7.2
10	Unclean of plastic cup's edge	2	1	2	4	2	1	1	2	2	1	2	4	2	1	3	6	2	1	1	2	3.6
11	Type of plastic film	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
12	Thickness of plastic film	2	1	1	2	2	1	1	2	1	1	1	1	2	2	2	8	1	1	1	1	2.8
13	Plastic film quality	3	1	1	3	3	1	2	6	3	1	2	6	3	1	1	3	3	1	1	3	4.2
14	Scratch by retort's divider plate	4	3	2	24	3	3	3	27	3	3	3	27	4	2	2	16	4	3	3	36	26
15	Unsharp of cutter	2	2	2	8	2	2	2	8	3	2	2	12	2	1	1	2	1	1	1	1	6.2
16	Dirty cutter	1	1	2	2	1	1	2	2	2	2	2	8	1	1	1	1	1	1	1	1	2.8
17	Untrained inspectors	3	2	2	12	3	2	1	6	4	2	1	8	4	1	1	4	3	1	1	3	6.6
18	Error of inspectors	3	3	4	36	3	2	4	24	3	3	3	27	4	3	1	12	3	3	3	27	25.2
19	Lack of inspector	2	2	2	8	1	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	2.6
20	Scratch by staff	3	2	3	18	3	1	3	9	3	2	3	18	2	2	2	8	2	1	3	6	11.8
21	Throwing cup by staff	3	2	3	18	3	1	3	9	3	2	2	12	2	2	2	8	2	1	3	6	10.6

Table A3: Failure Mode and Effect Analysis of illegible of date code defect

		Production Engineer				Product Engineer				Quality Control				Process Engineer				Senior Advisor				
No.	Factors	S	O	D	RPN	S	O	D	RPN	S	O	D	RPN	S	O	D	RPN	S	O	D	RPN	Average
1	Inappropriate of retorting machine's pressure	5	4	3	60	5	2	3	30	4	4	3	48	3	3	3	27	5	4	3	60	45
2	Inappropriate of retorting machine's temperature	4	2	2	16	3	2	3	18	3	2	3	18	3	3	3	27	3	3	3	27	21.2
3	Inappropriate of retorting machine's time	3	2	2	12	3	2	3	18	3	2	3	18	3	3	3	27	2	3	3	18	18.6
4	Inappropriate of air remaining in cup	3	1	5	15	4	2	4	32	3	2	4	24	3	2	3	18	3	3	3	27	23.2
5	Overweight of cup	2	1	2	4	1	1	2	2	1	1	1	1	2	1	2	4	1	1	1	1	2.4
6	Inkjet head problem	5	3	2	30	4	2	2	16	3	3	3	27	4	3	3	36	4	2	2	16	25
7	Ink intensity	4	2	3	24	3	2	3	18	3	3	3	27	2	2	2	8	2	1	1	2	15.8
8	Inappropriate of inkjet nozzle's position	1	2	1	2	2	1	1	2	1	1	1	1	2	1	1	2	1	1	1	1	1.6
9	Ink drying time	3	2	1	6	4	1	1	4	2	1	1	2	2	1	1	2	2	1	1	2	3.2
10	Untighten screw of retort's basket	4	2	3	24	4	1	2	8	3	2	2	12	2	1	3	6	3	1	2	6	11.2
11	Scratch while putting cup in molded tray	4	3	2	24	3	1	2	6	3	2	2	12	2	2	2	8	2	2	3	12	12.4
12	Scratch while transportation	3	2	4	24	2	2	4	16	3	2	4	24	2	2	3	12	3	2	3	18	18.8
13	Inappropriate of type of ink	3	1	1	3	2	1	1	2	2	1	1	2	1	1	1	1	1	1	1	1	1.8
14	Ink quality	5	2	1	10	4	1	2	8	4	1	1	4	5	2	1	10	4	2	1	8	8
15	Uncleaned of plastic cup's surface	3	1	2	6	2	1	3	6	2	1	2	4	2	1	2	4	1	1	2	2	4.4
16	Scratch by bended basket	4	2	3	24	4	1	2	8	4	1	2	8	3	3	3	27	3	2	2	12	15.8
17	Scratch by rusty basket	4	1	2	8	4	1	2	8	3	1	2	6	3	2	2	12	3	1	1	3	7.4
18	Touching by wet hands	3	2	4	24	2	1	4	8	3	1	3	9	2	2	3	12	2	2	3	12	13
19	Touching before ink drying	4	3	4	48	5	1	4	20	4	3	3	36	4	2	3	24	4	2	3	24	30.4
20	Untrained inspectors	3	2	2	12	3	2	1	6	4	2	1	8	4	1	1	4	3	1	1	3	6.6
21	Error of inspectors	3	3	4	36	3	2	4	24	3	3	3	27	4	3	1	12	3	3	3	27	25.2
22	Lack of inspector	2	2	2	8	1	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	2.6

Appendix B

Test of Significant by Hypothesis Testing

Factors of out of shape defect

1. Hypothesis testing - Inappropriate of retorting machine's pressure

The parameters used in the test are p_1 and p_2 which is the defective rate of out of shape defect found by setting the retorting machine's pressure at 1600 and 1800 mbar respectively.

The Null and Alternative hypothesis are

$$H_o: \ p_1 = p_2$$
$$H_1: \ p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure A1, the defective rate of out of shape defect is 1.21% and 2.62% when set the retorting machine's pressure at 1600 mbar and 1800 mbar respectively.

Test and CI for Two Proportions

```
Sample     X     N  Sample p
1         47  3888  0.012088
2        102  3888  0.026235


Difference = p (1) - p (2)
Estimate for difference:  -0.0141461
95% CI for difference:  (-0.0202321, -0.00806005)
Test for difference = 0 (vs not = 0):  Z = -4.56  P-Value = 0.000
```

Figure B1: Test of significant result in "Inappropriate of retorting machine's pressure" factor

The statistical testing of this factor is 0.00 at 0.05 of p-value. Therefore, it concludes that the inappropriate of retorting machine's pressure is the significant factor to contribute the defective rate of out of shape defect at 95% confident level.

2. Hypothesis testing - Inappropriate of retorting machine's temperature

The parameters used in the test are p_1 and p_2 which is the defective rate of out of shape defect found by setting the retorting machine's temperature at 116 and 125 ℃ respectively.

The Null and Alternative hypothesis are

$$H_o : p_1 = p_2$$
$$H_1 : p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure B2, the defective rate of out of shape defect is 1.39% and 1.00% when set the retorting machine's temperature at 116 and 125 ℃ respectively.

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       54  3888  0.013889
2       39  3888  0.010031


Difference = p (1) - p (2)
Estimate for difference:  0.00385802
95% CI for difference:  (-0.000973478, 0.00868953)
Test for difference = 0 (vs not = 0):  Z = 1.56  P-Value = 0.118
```

Figure B2: Test of significant result in “Inappropriate of retorting machine's temperature” factor

The statistical testing of this factor is 0.118 at 0.05 of p-value. Therefore, it concludes that the inappropriate of retorting machine's temperature is not the significant factor to contribute the defective rate of out of shape defect at 95% confident level.

Factors of wrinkle of seal defect

1. Hypothesis testing - Inappropriate of retorting machine's pressure

The parameters used in the test are p_1 and p_2 which is the defective rate of wrinkle of seal defect found by setting the retorting machine's pressure at 1600 and 1800 mbar respectively.

The Null and Alternative hypothesis are

$$H_o : p_1 = p_2$$
$$H_1 : p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure B3, the defective rate of wrinkle of seal defect is 0.98% and 1.13% when set the retorting machine's pressure at 1600 mbar and 1800 mbar respectively.

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       38  3888  0.009774
2       44  3888  0.011317


Difference = p (1) - p (2)
Estimate for difference:  -0.00154321
95% CI for difference:  (-0.00608382, 0.00299740)
Test for difference = 0 (vs not = 0):  Z = -0.67  P-Value = 0.505
```

Figure B3: Test of significant result in “Inappropriate of retorting machine's pressure” factor

The statistical testing of this factor is 0.505 at 0.05 of p-value. Therefore, it concludes that the inappropriate of retorting machine's pressure is not the significant factor to contribute the defective rate of wrinkle of seal defect at 95% confident level.

2. Hypothesis testing - Inappropriate of retorting machine's temperature

The parameters used in the test are p_1 and p_2 which is the defective rate of wrinkle of seal defect found by setting the retorting machine's temperature at 116 and 125 ℃ respectively.

The Null and Alternative hypothesis are

$$H_o : p_1 = p_2$$
$$H_1 : p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure B4, the defective rate of wrinkle of seal defect is 1.03% and 3.32% when set the retorting machine's temperature at 116 and 125 ℃ respectively.

Test and CI for Two Proportions

```
Sample    X     N  Sample p
1        40  3888  0.010288
2       129  3888  0.033179


Difference = p (1) - p (2)
Estimate for difference:  -0.0228909
95% CI for difference:  (-0.0293527, -0.0164292)
Test for difference = 0 (vs not = 0):  Z = -6.92  P-Value = 0.000
```

Figure B4: Test of significant result in “Inappropriate of retorting machine's temperature” factor

The statistical testing of this factor is 0.000 at 0.05 of p-value. Therefore, it concludes that the inappropriate of retorting machine's temperature is the significant factor to contribute the defective rate of out of shape defect at 95% confident level.

3. Hypothesis testing - Inappropriate of sealing machine's temperature

The parameters used in the test are p_1 and p_2 which is the defective rate of wrinkle of seal defect found by setting the retorting machine's temperature at 150 and 195 ℃ respectively.

The Null and Alternative hypothesis are

$$H_o : p_1 = p_2$$
$$H_1 : p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure B5, the defective rate of wrinkle of seal defect is 1.26% and 3.40% when set the retorting machine's temperature at 150 and 195 ℃ respectively.

Test and CI for Two Proportions

```
Sample    X     N  Sample p
1        49  3888  0.012603
2       132  3888  0.033951


Difference = p (1) - p (2)
Estimate for difference:  -0.0213477
95% CI for difference:  (-0.0280336, -0.0146619)
Test for difference = 0 (vs not = 0):  Z = -6.24  P-Value = 0.000
```

Figure B5: Test of significant result in “Inappropriate of sealing machine's temperature” factor

The statistical testing of this factor is 0.000 at 0.05 of p-value. Therefore, it concludes that the inappropriate of retorting machine's temperature is the significant factor to contribute the defective rate of out of shape defect at 95% confident level.

4. Hypothesis testing - Inappropriate of sealing machine's time

The parameters used in the test are p_1 and p_2 which is the defective rate of wrinkle of seal defect found by setting the retorting machine's time at 2 and 4 seconds respectively.

The Null and Alternative hypothesis are

$$H_o : p_1 = p_2$$
$$H_1 : p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure B6, the defective rate of wrinkle of seal defect is 1.34% and 2.13% when set the retorting machine's time at 2 and 4 seconds respectively.

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       52  3888  0.013374
2       83  3888  0.021348


Difference = p (1) - p (2)
Estimate for difference:  -0.00797325
95% CI for difference:  (-0.0137767, -0.00216984)
Test for difference = 0 (vs not = 0):  Z = -2.69  P-Value = 0.007
```

Figure B6: Test of significant result in “Inappropriate of sealing machine's time” factor

The statistical testing of this factor is 0.007 at 0.05 of p-value. Therefore, it concludes that the inappropriate of retorting machine's temperature is the significant factor to contribute the defective rate of out of shape defect at 95% confident level.

Factors of illegible of date code defect

1. Hypothesis testing - Inappropriate of retorting machine's pressure

The parameters used in the test are p_1 and p_2 which is the defective rate of illegible of date code defect found by setting the retorting machine's pressure at 1600 and 1800 mbar respectively.

The Null and Alternative hypothesis are

$$H_o : p_1 = p_2$$
$$H_1 : p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure B7, the defective rate of illegible of date code defect is 1.54% and 2.88% when set the retorting machine's pressure at 1600 mbar and 1800 mbar respectively.

Test and CI for Two Proportions

```
Sample    X     N  Sample p
1        60  3888  0.015432
2       112  3888  0.028807


Difference = p (1) - p (2)
Estimate for difference:  -0.0133745
95% CI for difference:  (-0.0199055, -0.00684349)
Test for difference = 0 (vs not = 0):  Z = -4.01  P-Value = 0.000
```

Figure B7: Test of significant result in “Inappropriate of retorting machine's pressure” factor

The statistical testing of this factor is 0.00 at 0.05 of p-value. Therefore, it concludes that the inappropriate of retorting machine's pressure is the significant factor to contribute the defective rate of illegible of date code defect at 95% confident level.

2. Hypothesis testing - Inappropriate of retorting machine's temperature

The parameters used in the test are p_1 and p_2 which is the defective rate of illegible of date code defect found by setting the retorting machine's temperature at 116 and 125 ℃ respectively.

The Null and Alternative hypothesis are

$$H_o : p_1 = p_2$$
$$H_1 : p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure B8, the defective rate of illegible of date code defect is 1.77% and 1.44% when set the retorting machine's temperature at 116 and 125 ℃ respectively.

Test and CI for Two Proportions

```
Sample    X     N  Sample p
1        69  3888  0.017747
2        56  3888  0.014403


Difference = p (1) - p (2)
Estimate for difference:  0.00334362
95% CI for difference:  (-0.00224648, 0.00893372)
Test for difference = 0 (vs not = 0):  Z = 1.17  P-Value = 0.241
```

Figure B8: Test of significant result in “Inappropriate of retorting machine's temperature” factor

The statistical testing of this factor is 0.241 at 0.05 of p-value. Therefore, it concludes that the inappropriate of retorting machine's temperature is not the significant factor to contribute the defective rate of illegible of date code defect at 95% confident level.

3. Hypothesis testing - Inappropriate of air remaining in cup

The parameters used in the test are p_1 and p_2 which is the defective rate of illegible of date code defect found by setting the sealing machine's vacuum at 10 and 40 mbar respectively.

The Null and Alternative hypothesis are

$$H_o : p_1 = p_2$$
$$H_1 : p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure B9, the defective rate of illegible of date code defect is 1.23% and 2.49% when set the sealing machine's vacuum at 10 and 40 mbar respectively.

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       48  3888  0.012346
2       97  3888  0.024949


Difference = p (1) - p (2)
Estimate for difference:  -0.0126029
95% CI for difference:  (-0.0186097, -0.00659603)
Test for difference = 0 (vs not = 0):  Z = -4.11  P-Value = 0.000
```

Figure B9: Test of significant result in “Inappropriate of retorting machine's temperature” factor

The statistical testing of this factor is 0.000 at 0.05 of p-value. Therefore, it concludes that the inappropriate of air remaining in cup is the significant factor to contribute the defective rate of illegible of date code defect at 95% confident level.

4. Hypothesis testing - Inappropriate of ink intensity

The parameters used in the test are p_1 and p_2 which is the defective rate of illegible of date code defect found by setting ink intensity of inkjet to stamp the date code at 10 and 90 % respectively.

The Null and Alternative hypothesis are

$$H_o : p_1 = p_2$$
$$H_1 : p_1 \neq p_2$$

From the result of statistical testing by Minitab as shown in Figure B9, the defective rate of illegible of date code defect is 1.16% and 0.80% when set the ink intensity of inkjet to stamp the date code at 10 and 90 % respectively.

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       45  3888  0.011574
2       31  3888  0.007973


Difference = p (1) - p (2)
Estimate for difference:  0.00360082
95% CI for difference:  (-0.000771610, 0.00797326)
Test for difference = 0 (vs not = 0):  Z = 1.61  P-Value = 0.107
```

Figure B9: Test of significant result in “Inappropriate of retorting machine's temperature” factor

The statistical testing of this factor is 0.107 at 0.05 of p-value. Therefore, it concludes that the inappropriate of ink intensity is not the significant factor to contribute the defective rate of illegible of date code defect at 95% confident level.

Appendix C

Result confirm

Table C1: The result confirm of total defect

No.	Sample Size	Grade B	Grade C	Total	% Defect
1	3,888	84	11	95	2.44%
2	3,888	101	8	109	2.80%
3	3,888	91	10	101	2.60%
4	3,888	90	6	96	2.47%
5	3,888	76	10	86	2.21%
6	3,888	86	8	94	2.42%
7	3,888	105	4	109	2.80%
8	3,888	82	14	96	2.47%
9	3,888	75	14	89	2.29%
10	3,888	68	5	73	1.88%
11	3,888	72	18	90	2.31%
12	3,888	79	17	96	2.47%
13	3,888	75	13	88	2.26%
14	3,888	70	5	75	1.93%
15	3,888	88	3	91	2.34%
16	3,888	90	7	97	2.49%
17	3,888	81	5	86	2.21%
18	3,888	77	12	89	2.29%
19	3,888	76	4	80	2.06%
20	3,888	70	3	73	1.88%
21	3,888	77	2	79	2.03%
22	3,888	72	9	81	2.08%
23	3,888	80	8	88	2.26%
24	3,888	74	12	86	2.21%
25	3,888	66	7	73	1.88%
26	3,888	72	5	77	1.98%
27	3,888	59	12	71	1.83%
28	3,888	69	13	82	2.11%
29	3,888	80	5	85	2.19%
30	3,888	66	11	77	1.98%

Table C2: The result confirm of out of shape defect

No.	Sample Size	Out of shape	% Defect
1	3,888	25	0.64%
2	3,888	28	0.72%
3	3,888	30	0.77%
4	3,888	22	0.57%
5	3,888	22	0.57%
6	3,888	19	0.49%
7	3,888	28	0.72%
8	3,888	25	0.64%
9	3,888	28	0.72%
10	3,888	21	0.54%
11	3,888	29	0.75%
12	3,888	32	0.82%
13	3,888	28	0.72%
14	3,888	24	0.62%
15	3,888	26	0.67%
16	3,888	36	0.93%
17	3,888	24	0.62%
18	3,888	22	0.57%
19	3,888	28	0.72%
20	3,888	18	0.46%
21	3,888	22	0.57%
22	3,888	25	0.64%
23	3,888	30	0.77%
24	3,888	27	0.69%
25	3,888	24	0.62%
26	3,888	29	0.75%
27	3,888	25	0.64%
28	3,888	32	0.82%
29	3,888	29	0.75%
30	3,888	26	0.67%

Table C3: The result confirm of wrinkle of seal defect

No.	Sample Size	Wrinkle of seal	% Defect
1	3,888	36	0.93%
2	3,888	42	1.08%
3	3,888	36	0.93%
4	3,888	40	1.03%
5	3,888	32	0.82%
6	3,888	26	0.67%
7	3,888	33	0.85%
8	3,888	41	1.05%
9	3,888	31	0.80%
10	3,888	29	0.75%
11	3,888	31	0.80%
12	3,888	26	0.67%
13	3,888	29	0.75%
14	3,888	31	0.80%
15	3,888	36	0.93%
16	3,888	30	0.77%
17	3,888	33	0.85%
18	3,888	28	0.72%
19	3,888	25	0.64%
20	3,888	26	0.67%
21	3,888	25	0.64%
22	3,888	27	0.69%
23	3,888	35	0.90%
24	3,888	29	0.75%
25	3,888	25	0.64%
26	3,888	29	0.75%
27	3,888	32	0.82%
28	3,888	30	0.77%
29	3,888	28	0.72%
30	3,888	26	0.67%

Table C4: The result confirm of illegible of date code defect

No.	Sample Size	Illegible of date code	% Defect
1	3,888	22	0.57%
2	3,888	16	0.41%
3	3,888	13	0.33%
4	3,888	19	0.49%
5	3,888	10	0.26%
6	3,888	12	0.31%
7	3,888	16	0.41%
8	3,888	15	0.39%
9	3,888	16	0.41%
10	3,888	7	0.18%
11	3,888	12	0.31%
12	3,888	13	0.33%
13	3,888	10	0.26%
14	3,888	9	0.23%
15	3,888	13	0.33%
16	3,888	17	0.44%
17	3,888	14	0.36%
18	3,888	14	0.36%
19	3,888	15	0.39%
20	3,888	8	0.21%
21	3,888	10	0.26%
22	3,888	11	0.28%
23	3,888	11	0.28%
24	3,888	14	0.36%
25	3,888	8	0.21%
26	3,888	10	0.26%
27	3,888	7	0.18%
28	3,888	10	0.26%
29	3,888	16	0.41%
30	3,888	13	0.33%

Appendix D

Form checklist

Sealing Machine

Product/Code: ___________________

Date:______________ Operator:______________

Batch No.__________ Engineer: _____________

Time check (hh:mm)	Sealing Temperature (°C)					Sealing Time (sec.)	Vacuum (bars.)	Vacuum Time (sec.)
	No. 1	No. 2	No. 3	No. 4	No. 5			

Figure D1: Checklist of sealing machine

Retort Machine

Product/Code: ___________________

Date:______________ Operator:______________

Batch No.__________ Engineer: _____________

<table>
<tr><th>Step</th><th>Temperature (°C)</th><th>Time (Minutes)</th><th>Pressure (mbar)</th><th>Rotation speed (rpm)</th><th>Action</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td rowspan="3"></td><td rowspan="3">Cut</td></tr>
<tr><td>2</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td>F0 Process Time</td><td></td><td></td><td>Sterilization</td></tr>
<tr><td>5</td><td></td><td></td><td></td><td rowspan="5"></td><td rowspan="5">Cooling</td></tr>
<tr><td>6</td><td></td><td></td><td></td></tr>
<tr><td>7</td><td></td><td></td><td></td></tr>
<tr><td>8</td><td></td><td></td><td></td></tr>
<tr><td>9</td><td></td><td></td><td></td></tr>
</table>

Figure D2: Checklist of retort machine

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