DEFECTS REDUCTION IN CORRUGATED PAPERBOARD MANUFACTURING PROCESS

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Engineering Management
Regional Centre for Manufacturing Systems Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2014

การลดข้อบกพร่องในกระบวนการผลิตแผ่นกระดาษลูกฟูก

นางสาวชนิศากก์ ไกรรัศมี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาการจัดการทางวิศวกรรม ภาควิชาศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2557

Thesis Title	DEFECTS REDUCTION IN CORRUGATED PAPERBOARD MANUFACTURING PROCESS
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Field of Study	Engineering Management
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ชนิศาก์ ไกรรัศมี : การลดข้อบกพร่องในกระบวนการผลิตแผ่นกระดาษลูกฟูก (DEFECTS REDUCTION IN CORRUGATED PAPERBOARD MANUFACTURING PROCESS) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.ปารเมศ ชุติมา, 176 หน้า.

งานวิจัยนี้นำเสนอการประยุกต์ใช้วิธีการซิกซ์ซิกม่า เพื่อปรับปรุงกระบวนการในอุตสาหกรรมผลิตแผ่นกระดาษลูกฟูก โดยใช้เปอร์เซนต์ข้อบกพร่องเป็นตัวชี้วัดของการปรับปรุงกระบวน การผลิต งานวิจัยนี้ดำเนินงานตามขั้นตอน DMAIC โดยแบ่งขั้นตอนการทำงาน เป็น 5 ระยะ ดังต่อไปนี้ ระยะแรก คือระยะการนิยามปัญหา (Define Phase) ประกอบด้วย การกำหนดปัญหา จุดประสงค์ ขอบเขต และการจัดตั้งคณะวิจัย โดยจากการศึกษาข้อมูลระหว่างเดือน กุมภาพันธ์ ถึง มีนาคม ปี พ.ศ. 2557 พบว่ากระบวนการผลิตแผ่นกระดาษลูกฟูกเป็นภาคส่วนที่มีปริมาณ ของเสียสูงที่สุด คิดเป็น 2.87% ของปริมาณการผลิตรวม ระยะที่สอง คือระยะการตรวจวัดปัญหา (Measure Phase) เริ่มจากการทำการตรวจสอบระบบการวัด ซึ่งได้ผลการตรวจสอบผ่าน เกณฑ์การยอมรับ จากนั้นทำการระดมความคิด เพื่อหาปัจจัยนำเข้าที่ส่งผลต่อการเกิด การ ล่อนพองในกระบวนการผลิตแผ่นกระดาษลูกฟูก คัดกรองปัจจัยต่างๆและจัดลำดับความสำคัญ ด้วยเกณฑ์คะแนนของการวิเคราะห์ ลักษณะข้อบกพร่องและผลกระทบ ทำให้เหลือ ปัจจัยหลัก 4 ปัจจัยเป็นกรณีศึกษา ระยะที่สาม คือระยะการวิเคราะห์ปัญหา (Analyze Phase) ทำการวิเคราะห์ปัจจัยทั้ง 4 ด้วยวิธีการทางสถิติ ทำให้สรุปได้ว่าปัจจัยเหล่านี้มีผลต่อการเกิดปัญหาล่อนพองอย่าง แท้จริง ระยะที่สี่ คือระยะ การแก้ไขปรับปรุงกระบวนการ (Improvement Phase) ได้ออกแบบการ ทดลองแบบแฟคทอเรียล โดยทำการทดลองซ้ำ 2 ครั้ง เพื่อทดสอบปัจจัย ที่มีนัยสำคัญต่อการเกิดล่อนพอง รวมทั้งหาค่าการตั้งค่าเครื่องจักรที่เหมาะสมของแต่ละปัจจัย และระยะสุดท้าย คือระยะ การควบคุมกระบวนการ (Control Phase) มีการปรับแผนการควบคุม การตั้งค่าเครื่องจักร โดยใช้แบบฟอร์มในการตรวจสอบ และแผนภูมิในการติดตามตรวจสอบ ปริมาณการล่อนพอง เพื่อตรวจจับความผิดปกติที่เกิดขึ้น ในกระบวนการผลิตแผ่นกระดาษลูกฟูก

หลังจากการปรับปรุง พบว่าปริมาณการเกิดล่อนพองในกระบวนการผลิตแผ่นกระดาษลูกฟูกลดลงเหลือ 1.89% ซึ่งเป็นการลดปริมาณข้อบกพร่อง 34.14%

ภาควิชา ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต ลายมือชื่อนิสิต ....

ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

สาขาวิชา การจัดการทางวิศวกรรม

ปีการศึกษา 2557

5571230521 : MAJOR ENGINEERING MANAGEMENT

KEYWORDS: SIX SIGMA / DEFECT REDUCTION / BISTER DEFECT / CORRUGATING PROCESS / CORRUGATED PAPERBOARD

CHANISA GRIRASAMEE: DEFECTS REDUCTION IN CORRUGATED PAPERBOARD MANUFACTURING PROCESS. ADVISOR: ASST. PROF. PARAMES CHUTIMA, Ph.D., 176 pp.

This research utilized the application of Six Sigma method to reduce defect in corrugated paperboard production process. Percentage of defect is used as the indicator to measure improved performance. This research followed DMAIC Six Sigma approach that is divided into 5 phases. First, Define phase, the project chapter was set up consisting of statement of problem, objectives, scopes, and team members. The defect data was collected from February to March 2014. Findings show that the corrugated paperboard production process created the greatest defect, mainly blister defect, which is 2.87% of total production volume. Second, Measure phase, the measuring system was analyzed and the result met the acceptance criteria. Then, all possible causes were identified by brainstorming within the team and prioritized until merely four factors remain. Third, Analyze phase, analysis was done on the four factors by using statistical method and it was verified that the four factors contributed to occurrence of blister defect. Forth, Improve phase, full factorial design of experiment was applied to test the significance of factors affecting the blister defect, as well as to find the optimum of each factor. The last, Control phase, the control plan was updated to control the setting of the four factors at the proper level using check sheets. In addition, the control chart was set up to monitor the stability of blister defect and to eliminate the special causes.

After the implementation, the average blister defect from corrugated paperboard production process is reduced to 1.89%, which was calculated as 34.14% of defect reduction.

Department: Regional Centre for Manufacturing Systems Engineering

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Advisor's Signature ....

Field of Study: Engineering Management

Academic Year: 2014

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my thesis advisor, Associate Professor Parames Chutima. Ph.D. Without his assistance and dedicated involvement in every step throughout the process, this paper would never have been accomplished. I would like to thank you very much for your support, guidance and understanding all through the duration of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Master’s study.

Besides my thesis advisor, I would like to thank the rest of my thesis committee: Assistant Professor Manop Reodecha, Ph.D., Assistant Professor Jeerapat Ngaoprasertwong, and Assistant Professor Boonwa Thampitakkul for their encouragement, insightful comments, and immense knowledge I am able to acquire.

My sincere thanks also goes to the owner and all the team members of the company case study who participated and helped me conduct the research, provide helpful assistance about the information in the corrugating production process, as well as suggest useful comments regarding the problems in the factory.

In addition, I would like to express my appreciation to my friends for giving great support all along. Most importantly, none of this could have happened without my beloved family for nurturing and supporting me in every aspect throughout my life.

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CHAPTER1

INTRODUCTION

Background of the Study

The four core packaging base materials in packaging industry nowadays are paper, plastic, glass and metal. Of these, paper packaging became the leading material due to its features such as low cost, light, easy to process and can be degraded. In fact, paper products are experiencing rapid growth and able to draw from a wider range of raw materials. Paper is not as fragile as glass, nor as heavy as metal, nor does it cause the same environmental problems as plastic. Paper products use Life Cycle Assessment (LCA) technology for quantitative assessment, which makes them one of the most promising green packaging materials. Thus, paper packaging accounts for 36 percent, 3 percent (**Figure 1.1**) higher than plastic packaging, which ranks the second in the year 2012 (canadean, 2014). Moreover, paper boxes, cartons, bags, barrels, pulp molding products and other products have become important components of the modern packaging industry. They are widely used to sell, package and transport food, beverage, light industrial products, health care products, cosmetics, electronics, home appliances, clothing, toys, sports supplies and other products. As it is safe for consumer use and environmentally sensitive, paper packaging is widely used in daily life and recognized as the most promising and highest potential of all packaging materials (South, 2014).

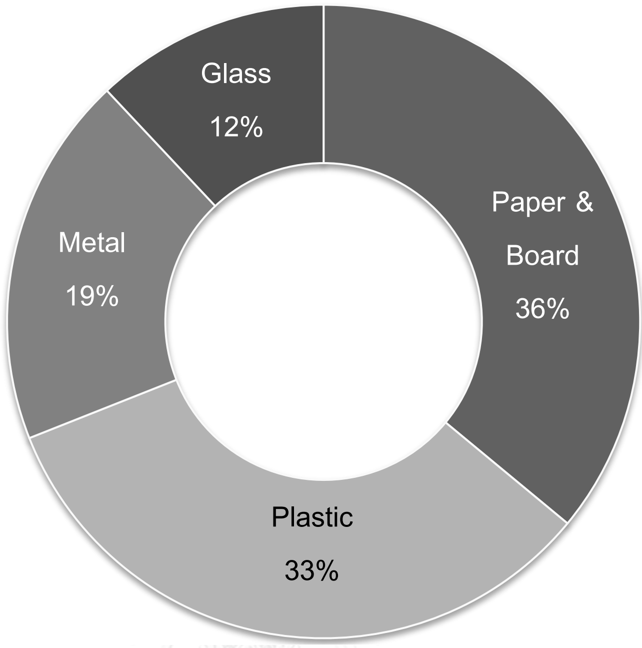


Figure 1.1: Major Packing Materials

Secretary General of the Thai Corrugated Packaging Association exposed that Thailand has 800 to 1,000 corrugated board and box factories of all sizes, which about 90 percent are concentrated in and around Bangkok. Thailand's economic growth depends on trends in global economic development. The demand in Thailand continues to grow based on the needs in paper packaging. Rising minimum wage means good news in terms of rising purchasing power that follows, on the other hand, this will also affect the cost of investment. However, there are many factors to be concerned as well regarding production such as fluctuation of Kraft paper price (Aliexpress, 2014) (shown in **Figure 1.2**), rising of fuel prices, machinery, and other equipment. Good planning and operation is needed in order to maintain company's benefit.

In upcoming year with opening of the ASEAN Economic Community (AEC), Thai industry has to prepare for greater competition. A consistent growth in performance improvement is necessary in order to acclimatize to the current situation and acquire an opportunity in the existing market. To maintain the company's benefit and enhance company's operating efficiency, in-house barriers such as wastes or other non-value added activities need to be minimized and eliminated as much as possible. Thus, this will be passing on the value to the customers (South, 2011, 2013)

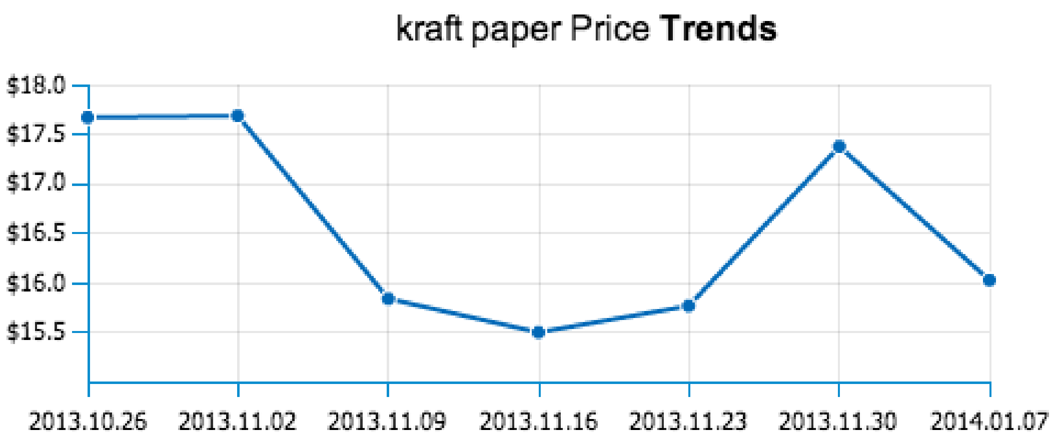


Figure 1.2: Kraft Paper Price Trends

1.2 The Company's Background

The company was established in May 1995, on 10 rais of land in Samut Sakorn province. The company is a consortium between alliance groups; one is proficient in Kraft paper corrugated fiberboard and another in corrugated paper box manufacturing, with the investment of THB 64.8 million. The company has the modern manufacturing equipment to produce and distribute many high quality types of paper including three-layered (B-flute and C-flute), five-layered (BC-flute), Regular Slot Carton (RSC) and Die-cut corrugated carton boxes. The company also offers printing service conform to customer's requirements utilizing FLEXO printing which can print four colors all at once with good quality. Moreover, the company also provides product design and customer service such as designing shape, size, and box compression strength and various types of packing for specific purposes. The various options and quality provide by the company have proven a number of satisfied customers so far. To ensure and satisfy needs of customers, the company has been certified by ISO 9001:2008, ISO 14001:2004, TLS (Thai Labor-Standard) 8001-2546, and ISO 50001:2011 (in process) to guarantee that products and services are safe, reliable, and good in quality. The organization chart of the company is shown in **Figure 1.3**.

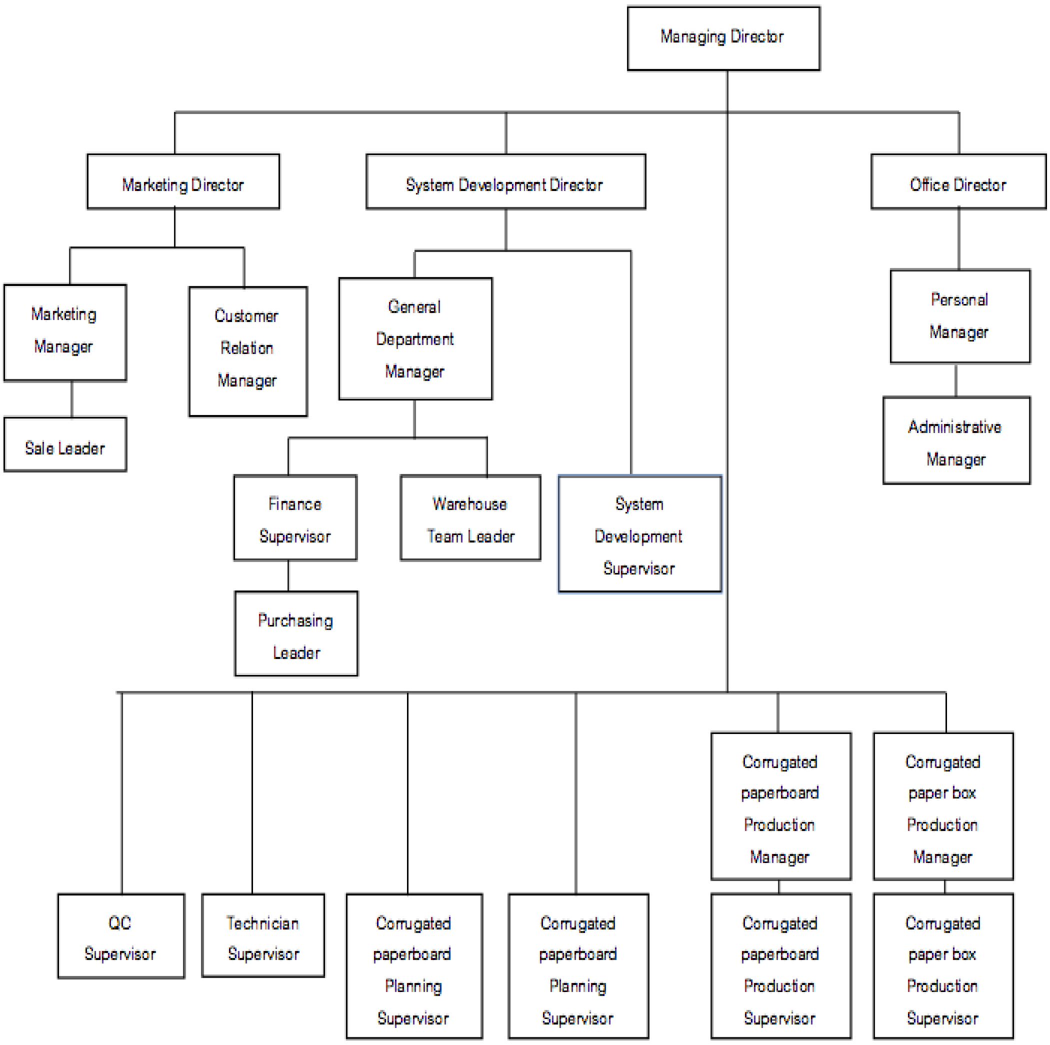


Figure 1.3: The Company's Organization

1.3 The Company's Production Process

The company provides mainly two types of product including *Corrugated Paperboard* (**Figure 1.4**) and *Corrugated Paper Box* (**Figure 1.5**). Both products are produced continuously in the same production line; however, the production of corrugated paperboard is finished ahead in the corrugating process.

Figure 1.4: Corrugated Paperboard

Figure 1.5: Corrugated Paper Box

The company production process is demonstrated as shown in **Figure 1.6**. Once customers place an order, the planning department will take the responsibility to contact with suppliers and order raw materials. Then, the raw material, which is paper rolls, will be prepared for production processes including Corrugating Process, Printing Process, Die-cutting Process, Stitching and/or Gluing Process, Quality Control (QC) and Bundling, and Shipping, respectively.

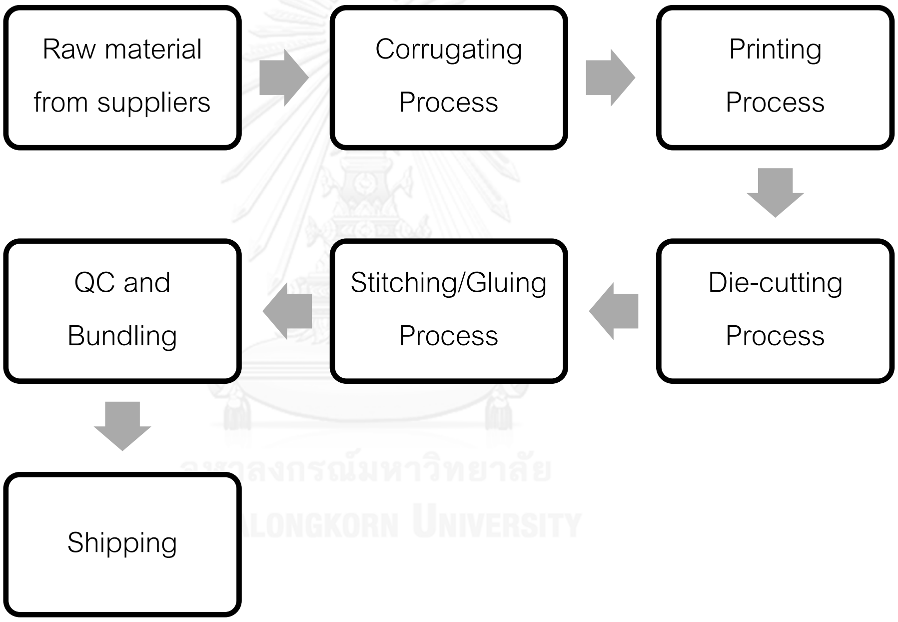


Figure 1.6: The Company's Production Line

Corrugating Process – Brown paper craft rolls are set and transported through the corrugator where the paper gets crimped and glued to form corrugated paperboard; B, C, and BC flute (**Figure 1.7**). Three large rolls of paper are necessary. One forms the corrugated medium, and the other two form the liners on each side of the medium. The top board is normally called the single-face linerboard, and the bottom layer often called a double-face linerboard. Then, the corrugated paperboard is cut according to the required dimension on the cutting machine. **Figure 1.8** demonstrates corrugating process step by step (Mahakalkar, 2013)

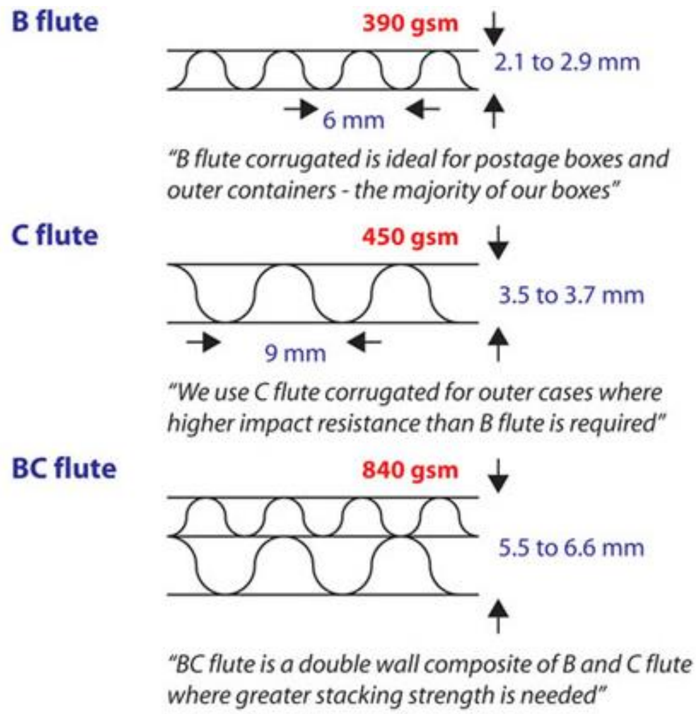


Figure 1.7: Types of Flute

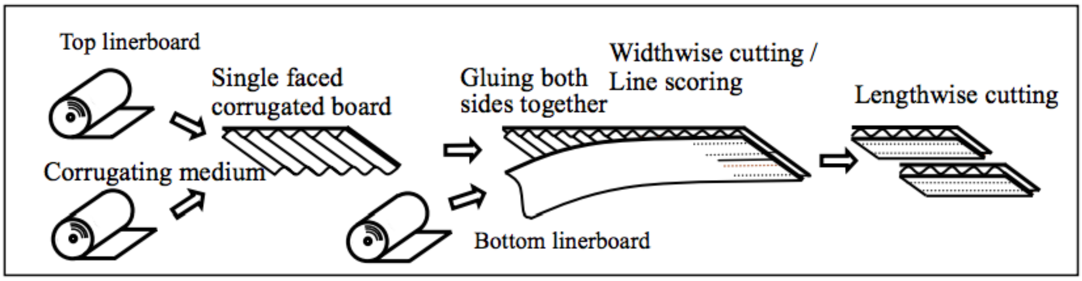


Figure 1.8: Corrugating Process

However, merely corrugating process will be focused in this research as the process creates the greatest defect for the company. Detail of the defect will be clarified in the next sections.

1.4 The Company’s Production volume

The company process operation is run both in dayshift and nightshift, 6 days a week. Each shift may operate in different process and amount depending on the order. The production volume of corrugated paper box is recorded weekly during February and March 2014 as shown in **Figure 1.9**. The number of production volume slightly fluctuated based on the demand and supply, as there were varying orders with different requirements of paper type, paper quality, size, design, thickness, and other options. However, the company’s manufacturing capacity on average is 394 tons weekly or 1,577 tons monthly, or 20,504 tons annually.

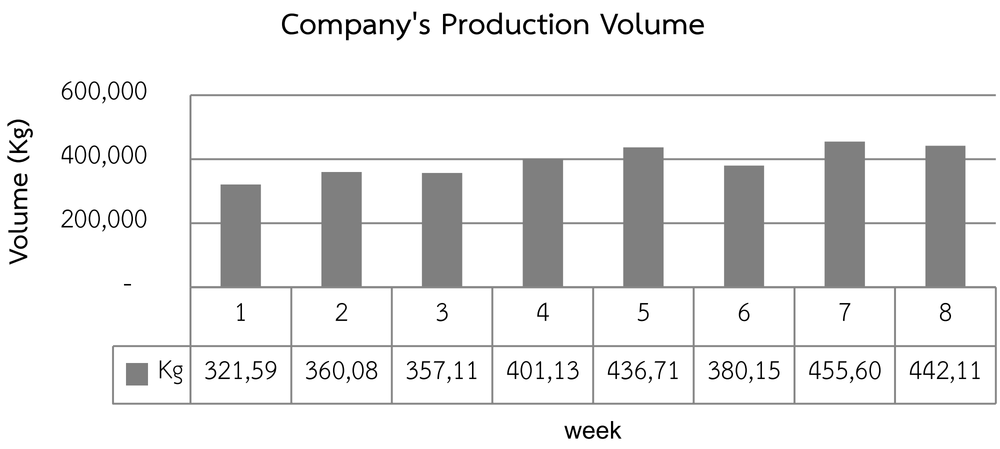


Figure 1.9: Weekly The Company’s Production Volume

1.5 The Company's Waste

Waste of the company can be categorized into three types of waste which are production waste, zero waste, and overrun. However, the zero waste and overrun are uncontrollable waste thus they will be excluded in the research. **Table 1.1** shows the waste that significantly affects the company's loss, the majority of waste is generated from corrugating production process making corrugated perperboard which is approximately 2.87% of production volume or 87.19% of overall waste (**Figure 1.10**).

Table 1.1: Waste in Corrugated Paper Box Production Line

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Total (kg)	% waste of production
Corrugated Paperoard	9,139	11,198	10,137	10,389	15,379	11,438	11,417	11,329	90,426	2.87%
Corrugated Paper Box	923	827	1,240	912	2,226	1,528	1,822	1,603	11,081	0.35%
Warehouse	230	284	258	220	352	285	276	304	2,209	0.07%
Total (kg)	10,292	12,309	11,635	11,521	17,957	13,251	13,515	13,236	103,716	3.29%

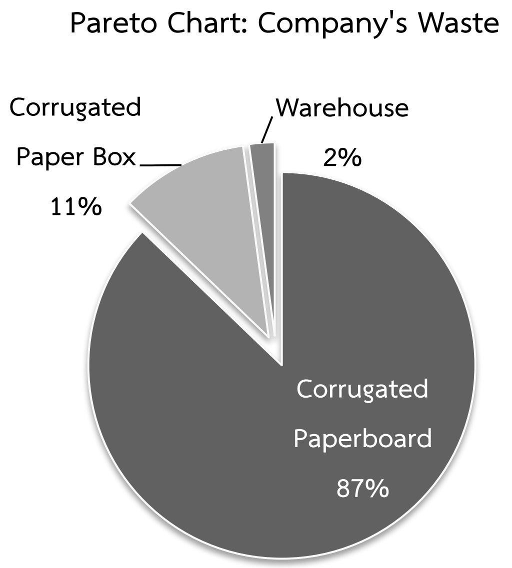


Figure 1.10: The Company's Waste Categorization

Corrugated paper box is ranked second and is generated from prinitng, die-cuttin, gluing, and stitching process. **Table 1.2** presents the weekly wastes volume in kg, waste from printing process is the largest which accounted 88.5% of waste in the corrugated paper box production line (**Figure 1.11**). However, it is only 0.35% of production volume.

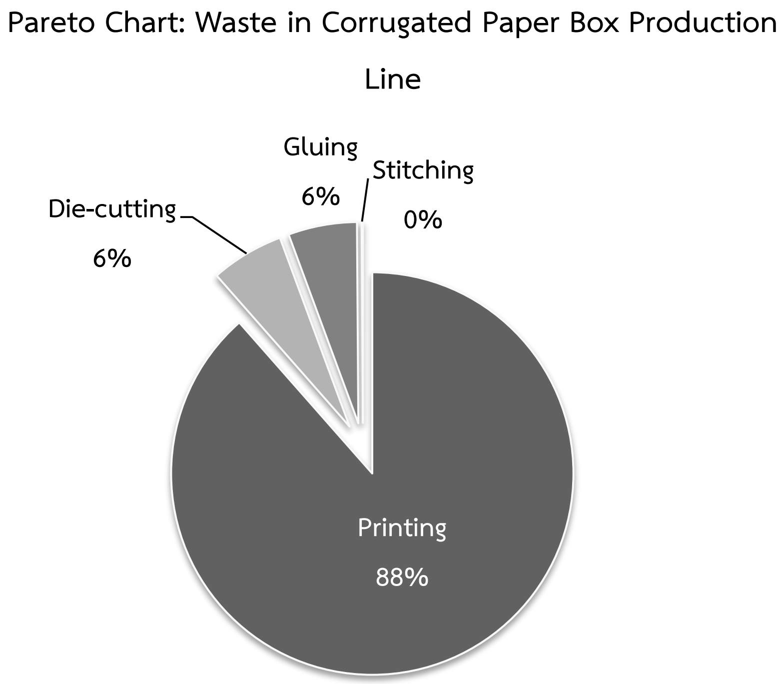


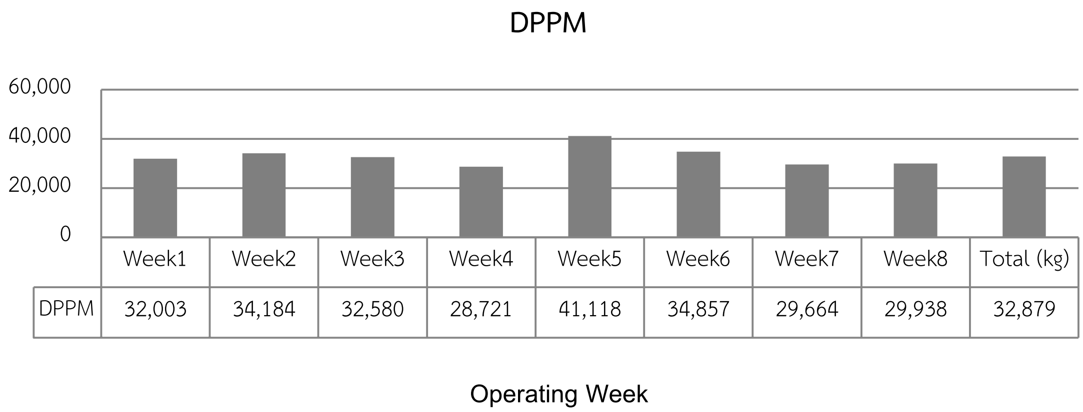
Figure 1.11: Waste in Corrugated Paper Box Production Line

Table 1.2: Weekly Waste Categorization of Corrugated Paper Box Production Process

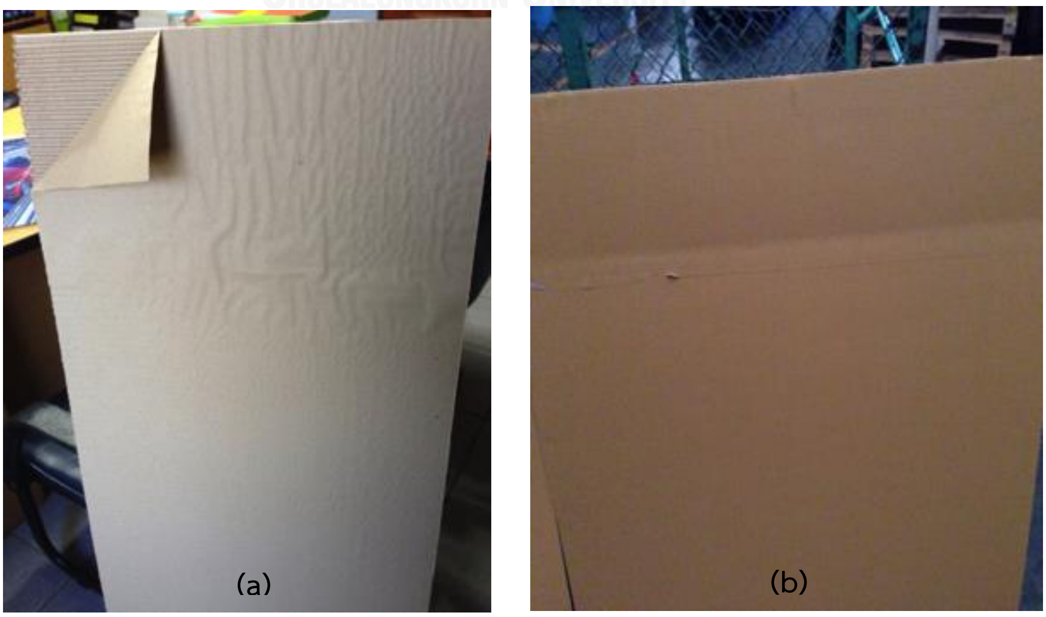
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Total (kg)
Printing	793	701	1,075	799	2,097	1,295	1,634	1,413	9,807
Die-cutting	93	35	77	61	104	170	0	110	650
Gluing	37	91	88	40	25	63	188	80	612
Stitching	0	0	0	12	0	0	0	0	12
Total (kg)	923	827	1,240	912	2,226	1,528	1,822	1,603	11,081

1.6 Statement of Problem

As aforementioned, the greatest waste that affects the company loss is created from corrugating process producing corrugated paperboard. The wastes can be calculated as Defective Part Per Million (DPPM) as shown in **Figure 1.12** and can be categorized into four types of defect as shown in **Figure 1.13**



	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Total (kg)
DPPM	32,003	34,184	32,580	28,721	41,118	34,857	29,664	29,938	32,879



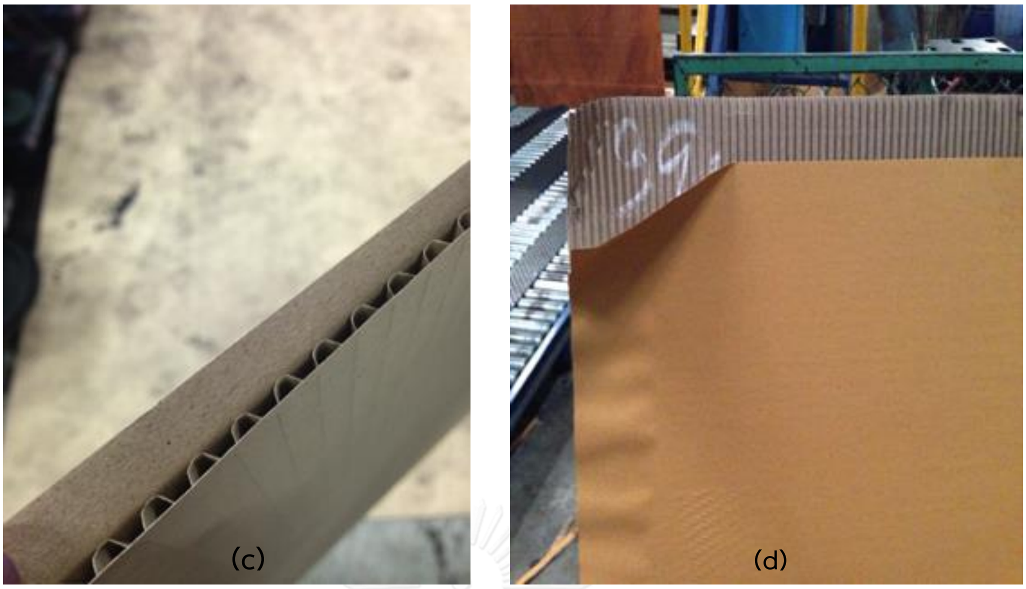


Figure 1.13: Types of Defect (a) Blister (b) Skew silted and scored alignment (c) Edge overlap (d) Unconnected glue at the edge

Table 1.3: Defect Categorization of Corrugating Process

Defect	Volume (kg)	Percentage	Cumulative
Blister	58,596	64.80%	64.80%
Skew silted and scored alignment	17,633	19.50%	84.30%
Edge overlap	7,505	8.30%	92.60%
Unconnected glue at the edge	6,692	7.40%	100.00%

The defect data will be plotted in Pareto Chart as shown in **Figure 1.14**. The graph shows that blister is the outstanding defect occurrence in the corrugating process, which can be calculated as loss of approximately THB 0.59 million per month or THB 7.03 million per year. This is the wastage of money as the defected product cannot be reworked and have to be undoubtedly disposed. Thus, reduction of the blister defect will highly improve overall production efficiency as well as reduce cost of investment.

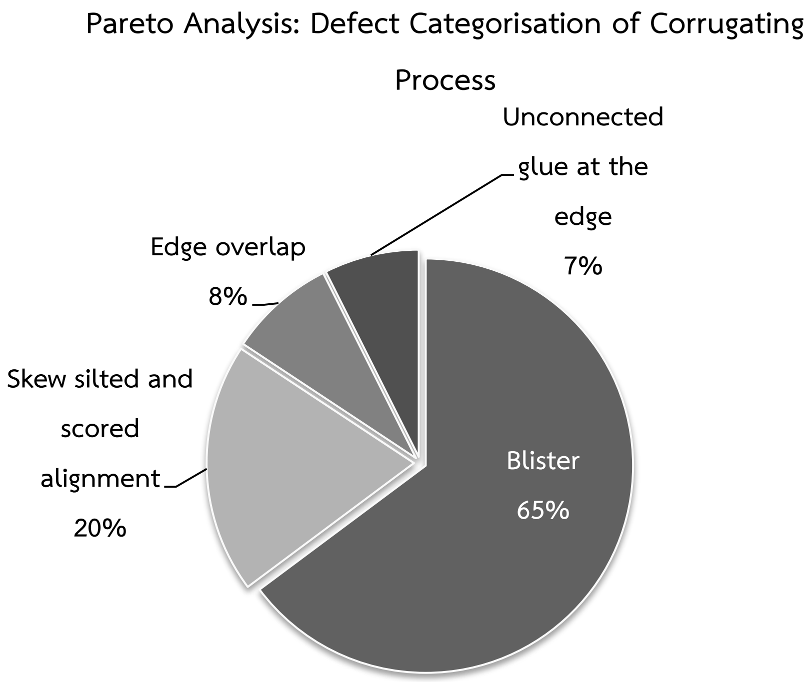


Figure 1.14: Pareto Analysis of The Company’s Defect Corrugating Process

1.7 Objective

The objective of this research is to reduce blister defect in the corrugating process of corrugated paperboard production

1.8 Scope

Indicator of this research is percentage of waste in a corrugating production process based on 125 gram Kraft paper thickness

1.9 Expected Benefits

Reduction of blister defect that occurred from corrugating process

Reduction of cost of investment in corrugating process

Increasing customers' trust as delivered products are produced conform to requirements

Increasing quality of the products before sending to the next process as well as delivering to customers

Improving manufacturing process and competency of the company

Adapting this method to improve other operation processes of the company in the future and application for other related businesses

1.10 Methodology

In this research, concept of Six Sigma is applied in order to minimize the blister defect. Since Six Sigma has clear steps and systematic methods to track the problems for strong data analysis and implementation. DMAIC approach is used as a framework and other QC tools are utilized in each stage in methodology section. DMAIC process aids identifying the causes and effects as well as developing the method to prevent and improve the problems.

Define – List all defect creation, using Pareto Analysis to prioritize and identify the major cause of defect

Measure – Gather all information related to the research utilizing Gage R&R to ensure accuracy of data from measuring instrument and measuring method. Cause-and-Effect Diagram, Cause-and-Effect Matrix and Failure Mode and Effect Analysis (FMEA) process are used to prioritize and find parameters most impacted the defect to be analyzed and improved

Analyze – Analyze the affected parameters from the measure stage utilizing Hypothesis testing

Improve – Utilize Design of Experiment (DOE) to propose an improvement method of interested factors. Since the solution is implemented, collect post-improvement result

Control – Set up control plan and work instruction for possible improvement, and create a control chart to maintain proper level of defect in the future

CHAPTER 2
LITERATURE REVIEW

The literature review is a fundamental part for research development as it provides the conceptual framework, practical issues, current case studies and knowledge sources from journals, researches and textbooks. The objective of the review of literature in this dissertation is to comprehend theoretical frameworks based on current practices, journal or textbooks to apply into the company in order to evaluate the current performance and create an effective future implementation plan to identify, reduce and eliminate defects and to enhance production efficiency of the chosen production line.

2.1 History of Six Sigma

Six Sigma program was resulting a series of changes in the area of quality in the late 1970s, since Motorola officially launched it in 1987 and developed the Six Sigma concept by the top-level management together with CEO Robert Galvin. In a memo to all employees of Motorola, the goal of "achieving Six-Sigma capability by 1992" is formulated after implementing some internal experiment in 1987 (Bhote, 1989). The reduction in process variation was resulted cost savings of US$13 billion and increase in labor productivity improvement of 204% over the period 1987–1997 (Losianowycz, 1999).

In early 1990s, many electronic companies such as IBM, DEC, and Texas Instruments launched Six Sigma initiatives after Motorola had been successful. Nevertheless, it was not, when GE and Allied Signal started Six Sigma as strategic initiatives that a prompt propagation took place in non-electronic industries all over the world in 1995 (Hendricks and Kelbaugh, 1998). In the year of 1997, Korean companies, Samsung and LG groups, introduced Six Sigma project within the companies. The outcome was amazing with the cost saving of US$150 million reported by Samsung SDI (Samsung SDI, 2000a). Recently, applying Six Sigma in large Korean companies creates an exponentially growth as well as a strong vertical deployment into many small- and medium-size organizations.

2.2 What is Six Sigma?

Sigma (σ) has become the statistical symbol and metric of process variation that initiates from a Greek alphabet letter. Measurement of sigma scale is ideally correlated to characteristics of defects-per-unit, parts-per-million defectives, and the failure probability (Park et. al.,1999). At many organizations, Six Sigma simply means a quality measurement that strives for near perfection. Six Sigma is a data-driven approach and methodology for getting rid of defects in any process; from manufacturing to transactional and from product to service. The statistical representation of Six Sigma explains quantitatively on how a process is performing. A defect of Six Sigma is defined as anything outside of customer specifications. A process must not create more than 3.4 defects per one million opportunities (DPMO) under the assumption that the process average may drift over the long term by as much as 1.5 standard deviations. The Six Sigma opportunity is then the total quantity of chances for a defect.

Six Sigma have been defined in several ways. One definition is from Tomkins (1997), stated that Six Sigma is “a program aimed at the near elimination of defects from every process, product, and transaction.” Another is described by Harry (1998) that Six Sigma is “a strategic initiative to enhance profitability, increase market share and improve customer satisfaction through statistical tools that can lead to breakthrough quantum gains in quality.” Park et. al. (1999) believes that Six Sigma is a “new strategic model of management innovation for company survival in this 21st century, which suggests statistical measurement, management strategy and quality culture.”, which is conveys a method of creating good products, services, and processes through statistical measurement of quality level.

Major purpose of any Six Sigma implementation is improving customer satisfaction in terms of processes capability. This can be possible done by focusing on Critical-to-Quality (CTQ) characteristics and implementing improvement actions pursuing to constantly reduce processes variability in terms of CTQ. These actions can be executed by involvement of every employee (Brun, 2011).

2.3 Six Sigma Development

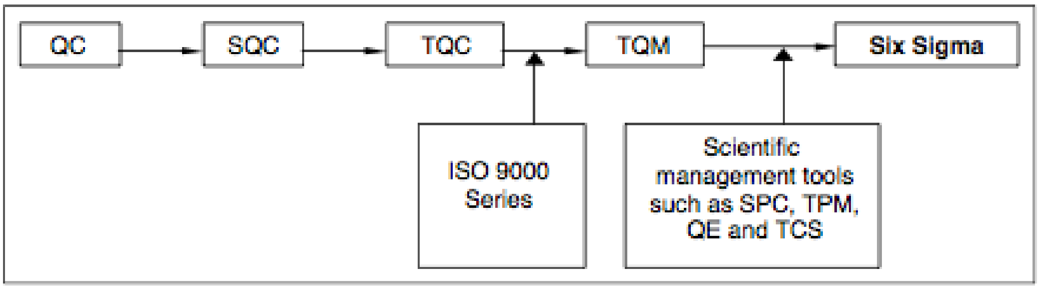


Figure 2.15: Development process of Six Sigma in quality management

The main concepts of total quality management (TQM) can be considered as the father of Six Sigma since several of the principles establishing the basis of TQM are also dominant in Six Sigma. Total quality is described as a company's culture, attitude and organization striving to provide customers satisfaction on product and services based upon their requirements (Brun, 2011).

Word of "Total Quality Control" (TQC) was actually generated from the key concept of Armand Feigenbaum's book in 1951, then many other quality gurus such as Deming, Juran and Ishikawa contributed to the body of knowledge known as TQM in the present as well. The International Standards Organization (ISO) is a management approach of TQM constructing for quality centralization in an organization, aiming at long-term success through the customer satisfaction, as well as creating benefits to all the organization's members and to society. TQM expects to integrate every organization's departments to emphasis on meeting customer needs and company-wide organizational goals. Thus, continuous improvement of company's processes can be strived by exploiting knowledge and experience of all stakeholders in the organization utilizing TQM as a guideline (Brun, 2011). **Figure 2.15** demonstrates the development process of Six Sigma in quality management.

It is apparently noticed that Six Sigma has been inspired by TQM with the similar based list of principles. However, there are three main differences that worthwhile to be considered. (1) TQM is objected to a process's final result, while Six Sigma aims at eliminating errors, reducing the variability of the processes, (2) TQM mostly delivers broad guidelines for quality management, while Six Sigma commends detailed applicative methodologies (DMAIC for existing processes and DFSS for new ones), as well as concentrates its attention on numeric certification of improvements and related savings, (3) TQM ensures alignment of projects with strategic goals of the organization, which is much less than Six Sigma approach as top-down management leadership performs a crucial role in empowering the successful deployment of tools and techniques (Brun, 2011).

Therefore, many authors are considering Six Sigma as an evolution of TQM. Black and Revere (2006) states that "Six Sigma emerged from the abundant environment created by Total Quality Management" while Klefsjö et al. (2001) regards Six Sigma as a "methodology to apply within the larger TQM's framework".

2.4 Six Sigma vs. Kaizen

Six Sigma and Kaizen are both work towards continuous improvement as increasing efficiency and eliminating waste. However, there are different in management philosophies.

In terms of process form, Kaizen aims to create improvement through standardizations eliminating waste and increasing efficiency in all aspects of a business. Six Sigma is more specific process improvement that focusing on quality improvement of the final product by examining the related potential causes for failure in quality and reducing the reasons for these defects. Thus, examining all the processes of a particular business is not necessary.

In terms of implementation, Kaizen has to focus on improvement in large scope when incorporated into a business process; the function of each employee is observed with regardless of level. Six Sigma is more mathematical applied for implementation, as measurement of processes deviation from perfection is required. The implementation of Six Sigma is more intensely rooted in analysis and mathematical equation in order to reach aiming of zero defects at product completion.

Applying both approaches can help companies save a lot of money and time, however depends on the goals of a company. If a company deals with issues related to the final product and working on ways of achieving less defect occurrence, Six Sigma would be the ideal approach. Conversely, if a company wishes to create more of a complete business makeover concerning efficiency and waste elimination, Kaizen would be more suitable choice. Thus, it is important to distinguish the fundamental differences between the two.

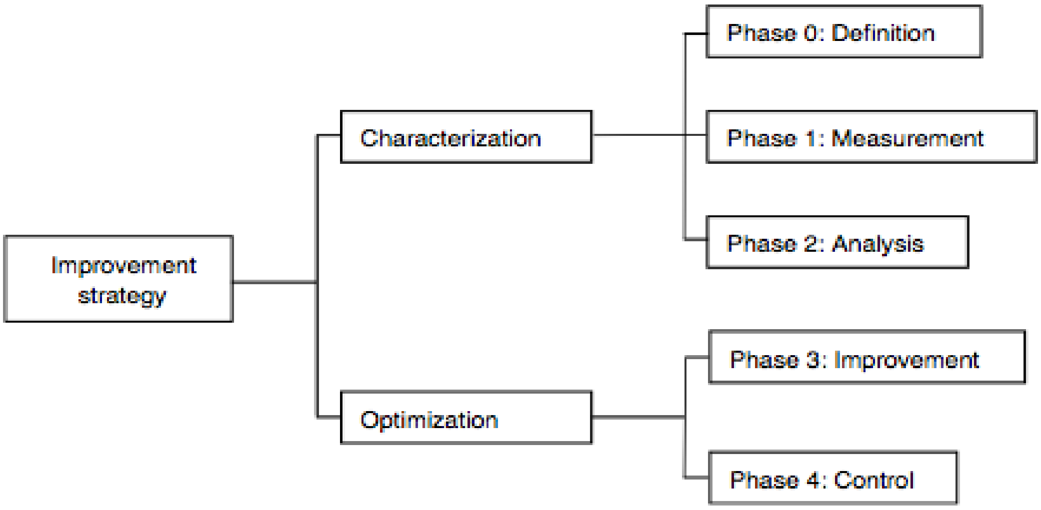


Figure 2.16: DMAIC Process

2.5 Six Sigma Framework

DMAIC (define-measure-analyze-improve-control) process is perhaps the most important methodology in Six Sigma formalizing improvement methodology and works well as a breakthrough strategy. DMAIC is similar in operation as its ancestors in manufacturing problem solving, such as PDCA (Plan-Do-Check-Act) of Deming and the Seven Step method of Juran and Gryna (Balakrishnan et al., 1995) (Mast, 2012). Most of Six Sigma companies adopt this methodology as improvements and results can be real performed, and works identically well on variation, cycle time, yield, design, and other factors. The process is divided into five phases as shown in **Figure 2.16**. Definition, Measurement, and Analysis Phase are classified as characteristic, while Improvement and Control Phase are grouped as optimization. The major activities in each phase are described as follow:

2.5.1 Define Phase

Define phase is the first state begins with determining whether the Six Sigma methodology suitable for solving the problem. The main deliverable for this phase is the project charter of the DMAIC cycle, which is statement of the scope, objectives, and participants in the project. The project charter should provide description of roles, responsibilities, outlines the project objectives, defines the authority of the project, as well as identifies the main stakeholders. Vital parts of the project charter are the business case, problem statement, the project scope, and the goal statement. Besides, in this phase, a list of critical to quality (CTQ) characteristics should be developed (L. Cano, 2012)

2.5.2 Measure Phase

The Measure phase is the second stage of DMAIC Six Sigma approach. Major objective of this phase is to gather as much as information from the current process in order to make accuracy on process operations. The crucial tasks in this phase are to create a detailed process map, to collect baseline data, and to summarize the collected data. The process map is normally developed from the Define phase providing a visual representation of the process under research, as well as additional awareness of process inefficiencies, for example, cycle times or bottlenecks, non-added value to the process (L. Cano, 2012).

Measurement System Analysis (MSA)

(Sahay, 2010) stated that accuracy of data is highly important to statistical analysis. Inaccurate and non-repeatable measurements of the measuring instrument and measuring method, the data can lead to significant measurement error. Ignoring the measurement process can waste money by diverting the effort in fixing the wrong problem and controlling process. There are several affect the reliability of measurements including differences in measurement procedures, differences among operators, instrument repeatability and reproducibility, and instrument calibration and resolution.

The Measurement System Analysis (MSA) is usually known as gauge R&R, where R&R stands for repeatability and reproducibility. The purpose of Gage R&R is to determine the part of variation in the data resulting from the variation in the measurement system. Originally, gauge R&R was conducted using a tubular method based on ranges and control charts; however, now the studies are analyzed using ANOVA techniques.

Considering the concepts involved in MSA, some of the principal definitions are used as follow (L. Cano, 2012):

Accuracy: The familiarity of agreement between a test result and the accepted reference value

Trueness: The familiarity of agreement between the average value attained from a large series of test results and an accepted reference value.

Precision: The familiarity of agreement between independent test results obtained under specified conditions.

Repeatability: Precision under repeatability conditions (where independent test results are achieved using the same method on identical test items in the same workplace by the same operator using the same equipment within short intervals of time).

Reproducibility: Precision under reproducibility conditions (where test results are achieved using the same method on identical test items in different workplaces with different operators using different equipment).

In summary, repeatability of a measuring instrument means how well the instrument enables to measure repeatedly the same characteristic under the same condition. While, reproducibility refers to the variation due to different operators using the same measuring instrument at different period of time, as well as different environment conditions (Burdick, 2005)

Pareto Analysis

Pareto analysis is a technique that can be used in numerous stages of a Six Sigma DMAIC approach project. In Measure phase, the Pareto analysis is used to prioritize the possible causes of defects and then focus on the important ones.

The Pareto principle is the basis of Pareto analysis applying to many procedures in real life. Generally, the Pareto principle implies that the most effort of about 80 percent is due to a partial number of main actions of approximately 20 percent, which is known as the 80/20 rule. For example, in terms of production, 80 percent of cost of quality is produced by 20 percent of the sources of error. Pareto chart is a tool using for searching these main actions.

In problem-solving methods, identification of the root causes of a problem is critical to finding strong solutions. To identify the possible causes, several techniques can be used such as brainstorming, cause-and-effect diagrams, affinity diagrams, and other tools. Once the possible causes have been recognized, the main characteristics that lead to measuring the significance of a problem can be selected in various ways. The natural result should be followed Pareto principle, an 80/20 distribution of the causes. Otherwise, data have to be arranged by grouping or dividing the causes depending on the distribution have been reached, shown in **Figure 2.17**.

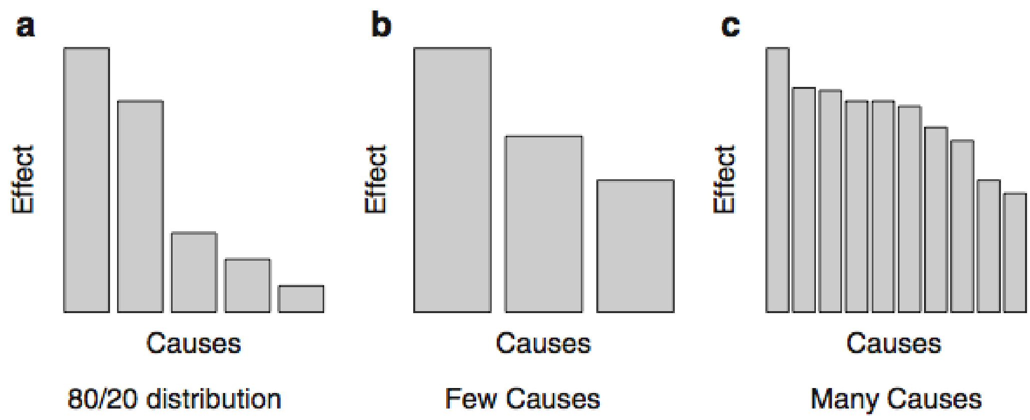


Figure 2.17: Types of Pareto Chart

Cause-and-Effect diagram

Cause-and-effect diagram, Ishikawa diagram or fishbone diagram is an effective tool for a problem-solving process. It is a useful technique to activate ideas by brainstorming in order to list all perceived sources (causes) with respect to outcomes (effect) of individual. A constructed cause-and-effect diagram is shown below in the **Figure 2.18**, all possibly causes are often identified based the considering on six main cause factors including man, machine, material, method, measurement, and environment (5M1E), which are contributed to the effect (Brun, 2011).

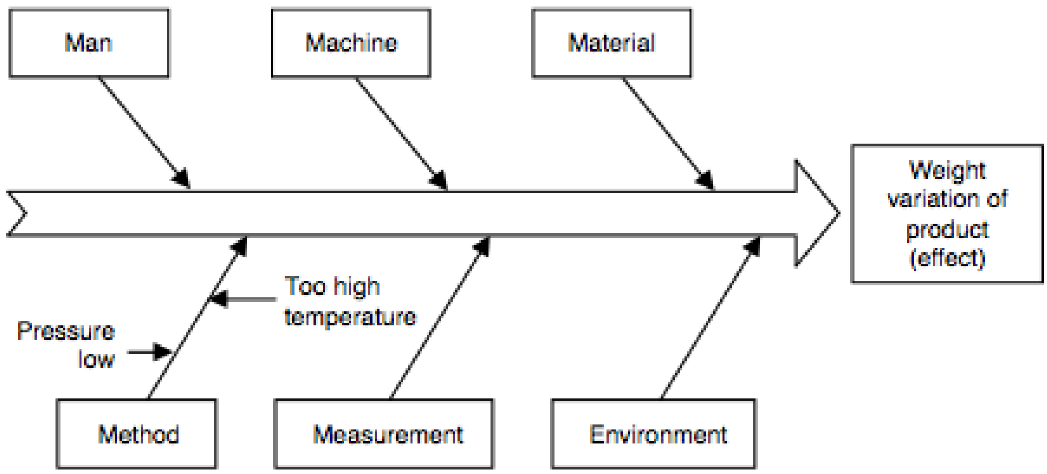


Figure 2.18: Cause-and-effect diagram

Failure Modes and Effects Analysis (FMEA)

FMEA is a tool providing set of guidelines, a process, and a form of identifying and ranking potential failures and problems in order to simplify process improvement. The activities on FMEA, a manager, improvement team, or process owner can focus the energy and resources of prevention, monitoring, and response plans where they are most likely to succeed. The method of FMEA has many applications, not only looking for the problems in work processes and improvement but also in data-collection activities, Voice of the Customer efforts and procedures (Brun, 2011).

FMEA is classified into two types, which are Design FMEA and Process FMEA. The design FMEA applications mainly contain component, subsystem, and main system, whereas process FMEA applications include assembly machines, work stations, measures, purchasing, training of operators, and tests. Proper execution of FMEA will provide benefits of (1) Preventing possible failures and reducing warranty costs, (2) Improving product functionality and robustness, (3) Reducing level of day-to-day manufacturing problems, (4) Improving safety of products and implementation processes, and (5) Reducing business process problems (Brun, 2011).

Within a design FMEA, input of manufacturing process is significant to ensure that the process will produce to design specifications. Knowledgeable representation from design, test, reliability, materials, service, and manufacturing or process organizations are all sections that should be considered by a team. The design FMEA should be complied documents that provide insight into the design intent, which is a list of what the design is expected to do (Brun, 2011).

FMEA type (design or process):					Project name/description:							Date (Orig.):				
Responsibility:							Prepared by:					Date (Rev.):				
Core team:												Date (Key):				
Design FMEA (Item/ Function) Process FMEA (Function/ Require.)	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Controls	Detec	RPN	Recommended Actions	Responsibility and Target Completion Date	Actions Taken	Sev	Occur	Detec	RPN

Figure 2.19: Blank FMEA form

Figure 2.19 shows the blank design FMEA tabular, including guideline as shown in the **Table 2.4** below.

Table 2.4: Guideline of design FMEA tabular

Guideline	Description
Header information	Information about the system and about when the FMEA was created and by whom
Item/function	Contains the name and number of the considered item. Includes a brief explanation of the function of the item task
Potential failure mode	Explains ways a design could fail to perform its proposed function
Potential effect of failure	Compose of the effects of the failure mode on the function from customer point of view, either internally or externally
Severity	Evaluates the significance of the effect of the potential failure mode to the next component, subsystem, or system, if it should occur. Estimation is scaled raking from 1 to 10 where 10 is the most serious, 5 is low and 0 is no effect.
Classification	Includes optional information such as critical characteristics that may require additional process controls
Potential cause of failure	Indicates a design weakness that causes the potential failure mode
Occurrence	Estimates the likelihood that a specific cause will occur. Estimation is usually scored from 1 to 10 where 10 refers to almost inevitable failure, 5 is low, and 1 is unlikely failure

Guideline	Description
Current design controls	Lists activities such as design verification tests, design reviews, DOEs, and tolerance analysis that ensure occurrence criteria
Detection	Assessment of the ability of the current design control to detect the subsequent failure mode. Assessment is based on a 1 to 10 scale, where 10 means absolute uncertainty or uncontrollable, 5 means moderate chance that the design control will detect a potential cause, and 1 means design control will almost certainly detect a potential cause
Risk priority number (RPN)	RPN is product of severity, occurrence, and detection rankings. The score will be prioritized and concerned
Recommended action	Intent of this entry is to institute actions
Responsibility for recommended action	Documents the organization and individual responsibility for recommended action
Actions taken	Describes implementation action and effective date
Resulting RPN	Contains the recalculated RPN resulting from corrective actions that affected previous severity, occurrence, and detection rankings. Blanks indicate no action

A team should consider with knowledgeable representation from design, process, quality, reliability, tooling, and operators for a process FMEA to ensure appropriate focus on significant design needs. The blank FMEA can be used for a design FMEA and a process FMEA concurrently. Examples of design FMEA and process FMEA are shown in the **Figure 2.20** and **2.21**, respectively.

System		FMEA Number	1234
x Subsystem		Page 1	of 1
Component 01.03/Body Closures	Design Responsibility Body Engineering	Prepared By	A. Tate-X6412-Body Engineering
Model Year(s)/Vehicle(s) 199X/Lion 4door/Wagon	Key Date 9X 03 01 ER	FMEA Date (Orig.) 8X 03 22	(Rev.) 8X 07 14

Item Function	Potential Failure Mode	Potential Effect(s) Of Failure	Sev	Class	Potential Cause(s)/ Mechanism of Failure	Occur	Current Design Controls	Detec	RPN	Recommended Action(s)	Responsibility and Target Completion Date	Action Taken	Sev	Occ	Det	RPN
Front door L.H. HBHX-0000-A • Ingress to and egress from vehicle • Occupant protection from weather, noise, and side impact • Support anchorage for door hardware including mirror, hinges, latch and window regulator	Corroded interior lower door panels	Deteriorated life of door leading to: • Unsatisfactory appearance due to rust through paint over time • Impaired function of interior door hardness	7		Upper edge of protective wax application specified for inner door panels is too low	6	Vehicle general durability Test vah. T-118 T-109 T-301	7	294	Add laboratory accelerated corrosion testing	A Tate-Body Engineering 8X 09 30	Based on test result (test no. 1481) upper edge spec raised 125 mm	7	2	2	28
					Insufficient wax thickness specified	4	Vehicle general durability Testing (as above)	7	196	Add laboratory accelerated corrosion testing Conduct design of experiments (DOE) on wax thickness	Combine w/test For wax upper Edge verification A Tate body Engineering 9X 01 15	Test results (test no. 1481) show specified thickness is adequate. DOE shows 25% variation in specified thickness is acceptable.	7	2	2	28

Figure 2.20: Example of Design FEMA

FMEA type (design or process) : Process					Project Name/Description : Cheetah/Change surface finish of part								Date(Orig.) : 4/14			
Responsibility : Paula Hinkle							Prepared by : Paula Hinkle						Date(Rev.) : 6/15			
Core Team : Sam Smith, Harry Adams, Hilton Dean, Harry Hawkins, Sue Watkins													Date(Key) :			
Design FMEA (Item/ Function) Process FMEA (Function/ Require.)	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Controls	Detec	RPN	Recommended Actions	Responsibility and Target Completion Date	Actions Taken	Sev	Occur	Detec	RPN
Solder dipping	Excessive Solder wire Protrusion	Short to Shield cover	9		Flux wire termination	6	100% inspection	3	162	Automation/DOE/ 100% with go/no go gauge	Sam Smith 6/4	Done	9	4	2	72
	Interlock base damage	Visual defects	7		Long solder time	8	Automatic solder tool	3	168	Automation/DOE/ Define visual criteria	Harry Adams 5/15	Done	7	4	2	56
			7		High temp	8	Automatic solder tool/ SPC	3	168	Automation/DOE	Hilton Dean 5/15	Done	7	4	2	56
	Delamination of interlock base	Visual defects	7		See interlock Base damage	8	Automatic solder tool/ SPC	3	168	Automation/DOE	Sue Watkins 5/15	Done	7	4	2	56
			7		Moisture in Interlock base	5	No	7	245	Inform supplier to Control molding cond.	Harry Hawkins 5/15	Done	7	2	7	98
	Oxidization of golden plating pins	Contact problem/no signal	8		Not being Cleaned in time	7	Clean in 30 minutes after solder dip	5	280	Improve quality of Plating define criteria With customer	Sam Smith 5/15	Done	8	2	5	80
Marking	Marking permanency	Legible marking /customer unsatisfaction	6		Marking ink	4	SPC	2	48	None						
			6		Curing	5	UV energy and SPC	3	90	None						
			6		Smooth Marking surface	8	None	6	288	Rough surface	Sam Smith 5/15	Change Interlock Texture surface	6	3	6	108

Figure 2.21: Example of Process FEMA

2.5.3 Analyze Phase

Analyze phase is the third phase of the DMAIC, focusing on identifying the roots causes of the problem under the research. With in Six Sigma methodology the root causes will not be simply as normal problem-solving strategies, however must to be validated by data called “fact-based decisions”. All the knowledge gathered during the Define and Measure phases including the process map, the collected data, and others information should be used to determine the root causes.

Statistical analysis is conducted offering authority to the Analyze phase and sets Six Sigma apart from other problem solving strategies. Potential root causes commonly will be validated throughout statistical techniques, such as Analysis of Variance (ANOVA), Correlation, Scatterplot, or Chi-square analysis (L. Cano, 2012).

Hypothesis Testing

For statistical interpretation, to confirm or certify some assumptions about the analyzed process, hypothesis testing is proposed. The hypotheses are importantly related to the parameters of the probability distribution of the data. For instance, if the existed data from a process are normally distributed and need to be verified whether the mean of the process has changed with respect to the historical mean, the following hypothesis test should be established:

$$H_0 : \mu = \mu_0,$$

$$H_1 : \mu \neq \mu_0,$$

where H_0 implies the null hypothesis and H_1 represents the alternative hypothesis. Hence we are testing H_0 (the mean has not changed) versus H_1 (the mean has changed).

Hypothesis testing can be performed in two ways, which are one-sided tests and two-sided tests. An example of the latter shown below is used to check whether the mean of a process has increased:

$$H_0 : \mu = \mu_0,$$

$$H_1 : \mu > \mu_0,$$

This kind of Hypothesis testing aims to find evidence about the refutability of the null hypothesis based on probability theory as to check if a new condition (denoted by the alternative hypothesis) is arising. Subsequently, the null hypothesis will be rejected if the data do not have enough evidence. A term of enough evidence is determined through the threshold expressing as significant level (α) or confidence intervals, where 5 percent significant level is normally accepted value in most cases.

A statistic based on probability distribution is calculated in order to validate whether the data support the alternative hypothesis. If the value of the statistic performs within the rejection region, then the null hypothesis is rejected. Whereas, the statistic is outside the rejection region, meaning that there is not enough evidence to accept the alternative hypothesis (even it is true).

Generally, the refutability of the null hypothesis is evaluated through the p-value resulted from the hypothesis test. H_0 should not be rejected if the p-value is larger than α, then otherwise H_0 must be rejected.

The p-value is not truly interpreted as the probability that the null hypothesis is true. In fact, the p-value is the probability of finding a more extreme sample than currently used one to perform the hypothesis test. Therefore, small p-value refer to the probability of finding a more extreme sample is small, and then the null hypothesis should be rejected. Otherwise, large p-value implies that the null hypothesis should not be rejected. Large p-value is determined by the significance level (α). Practically, if p-value is less than α, then H_0 is rejected. Otherwise, H_0 is not rejected.

2.5.4 Improve Phase

The objective of the Improve phase is to determine a solution to the problem at hand. Brainstorming is commonly used to generate a set of potential solutions. It is important in this phase to involve people who will perform the process regularly. Their input can be invaluable. In some cases, they even provide the best potential solution ideas because of their process knowledge. In other words, the combination of experience and scientific analysis is a guarantee of success.

In addition, you must keep in mind that the term “best” does not mean the same thing to all people. What the team should strive to find is the best overall solution. A solution criteria list is another good tool to assist in selecting the best solution.

Prior to implementation, the team must be sure that the proposed solution actually works. Pilot programs, computer simulations, and segmented implementation are all possibilities at this point.

The team should also create a future state process map as part of the Improve phase. This must be done so that the process can be performed as many times as necessary to ensure that the correct implementation of the solution is accomplished.

Design of Experiments (DOE)

DOE is used in many industrial sectors, for example, in the development and optimization of manufacturing processes. DOE implicates creating a set of experiment representative with respects of a specified problem.

Full factorial DOE

Full factorial design of experiments is the basis of all classical experimental designs, which is used in step of screening, optimization, and robustness testing. The objective is to define the main effect of factors, interaction effect among factors, and to demonstrate how the factors may be presented (Eriksson, 2008).

Full factorial designs are normally used with two to four factors as more factors the number of experiments necessitated trend to be too demanding. This research will consider two-level factorial designs assigning as a high level and low level to each factor, these are then used to construct orthogonal array of the experiment. Regularly, notation of the high level is commonly used +1, and the low level is -1. Moreover, as the center level usually chosen for replication, thus will be denoted by 0. These are called standard and extended notations operating in a coded -1 to 1 unit as shown in **Figure 2.22** (Eriksson, 2008).

Item	Low	High	Center
Standard notation	–	+	0
Extended notation	−1	+1	0
Example; temperature	100°C	200°C	150°C
Example; pH	7	9	8
Example; Catalyst (A, B)	A	B	N/A

Figure 2.22: Notation and Codes for Input Factor and Levels

The 2^2 Full Factorial Design

2^2 full factorial design is the simplest way of all kinds, performing only two-level design in two factors. In **Figure 2.23**, factor x_1 represents the molar ratio of two reacting compound varying between 1 to 1.5, and factor x_2 represents the reaction temperature varying between 25°C to 100°C. Then the success reaction were monitored and measured as response, y_3. Thus, there are four possible combinations which are low-low, low-high, high-low, and high-high, corresponding to the first four rows of the design. Moreover, there are three additional replicated experiments conducted at the center of experimental region locating midway between low and high levels (Eriksson, 2008).

	Factors		Factors		Response
	Original unit		Coded unit		%
Exp. no	x_1	x_2	x_1	x_2	y_3
1	1	25	-	-	80.4
2	1.5	25	+	-	72.4
3	1	100	-	+	94.4
4	1.5	100	+	+	90.6
5	1.25	62.5	0	0	84.5
6	1.25	62.5	0	0	85.2
7	1.25	62.5	0	0	83.8

Figure 2.23: The 2^2 Full Factorial Design

The 2^3 Full Factorial Design

2^3 full factorial design is the two-level full factorial design with three factors. The design matrix shown in **Figure 2.24** is an example of CakeMix application, with using flour, shortening, and egg. The design will have eight rows based on the number of factorial part. The first column of the factor, flour, is created by writing minus and plus signs alternatingly in eight rows. Next, a pair of minus and plus signs continuously in the first eight rows will be formed the second column, shortening. Finally, the third column, egg, is created by minus four signs followed by four plus signs (Eriksson, 2008).

Design Matrix				Experimental matrix			
Exp No	Flour	Shortening	Egg	Flour	Shortening	Egg	Taste
1	-	-	-	200	50	50	3.52
2	+	-	-	400	50	50	3.66
3	-	+	-	200	100	50	4.74
4	+	+	-	400	100	50	5.2
5	-	-	+	200	50	100	5.38
6	+	-	+	400	50	100	5.9
7	-	+	+	200	100	100	4.36
8	+	+	+	400	100	100	4.86
9	0	0	0	300	75	75	4.68
10	0	0	0	300	75	75	4.73
11	0	0	0	300	75	75	4.61

Figure 2.24: The 2^3 Full Factorial Design

The 2^4 and 2^5 Full Factorial Design

For 2^4 design, there will be 16 cases of experiment. The pattern of the leftmost column in the table shown in **Figure 2.25,** in the blue area, is a series of alternating minus and plus signs. In the second and the third column is completely filled 16 rows by continuously pairs of minus and plus signs, and four of minus and plus signs, respectively. Finally, the fourth column is created by eight minus signs and then eight plus signs.

The construction of 2^5 design is similarly to 2^4 design excepting the number of rows and columns, which is include of 32 rows and 5 columns. The first four columns are created as same as the 2^4 design pattern and the fifth column is showing in sixteen of minus signs followed by sixteen of plus signs to compete the 32 running experiments. However, the 2^5 full factorial design is not greatly used in industrial practice due to the large number of experiment trails. Instead, the experiment exists an efficient factional factorial design in 16 runs, which is practically as good as the full factorial design counterpart.

	X 1	X 2	X 3	X 4	X 5
1	-	-	-	-	-
2	+	-	-	-	-
3	-	+	-	-	-
4	+	+	-	-	-
5	-	-	+	-	-
6	+	-	+	-	-
7	-	+	+	-	-
8	+	+	+	-	-
9	-	-	-	+	-
10	+	-	-	+	-
11	-	+	-	+	-
12	+	+	-	+	-
13	-	-	+	+	-
14	+	-	+	+	-
15	-	+	+	+	-
16	+	+	+	+	-
17	-	-	-	-	+
18	+	-	-	-	+
19	-	+	-	-	+
20	+	+	-	-	+
21	-	-	+	-	+
22	+	-	+	-	+
23	-	+	+	-	+
24	+	+	+	-	+
25	-	-	-	+	+
26	+	-	-	+	+
27	-	+	-	+	+
28	+	+	-	+	+
29	-	-	+	+	+
30	+	-	+	+	+
31	-	+	+	+	+
32	+	+	+	+	+

Figure 2.25: The 2^4 and 2^5 Full Factorial Designs (Eriksson et al., 2008)

Fractional factorial DOE

The number of experiments is dramatically increased when five or more factors are used, shown in the **Figure 2.26.** Therefore, there are only two to four factors that are realistic alternatives for full factorial design. The number of runs in the leftmost column showing the most manageable number of the two-level fractional factorial design.

No of investigated factors (k)	No of runs Full factorial	No of runs Fractional factorial
2	4	---
3	8	4
4	16	8
5	32	16
6	64	16
7	128	16
8	256	16
9	512	32
10	1024	32

Figure 2.26: The Number of Experiments of Full Factorial and Fractional Factorial Designs with the Number of Factors from 2 to 10

In short, when considering few factors, two-level full factorial designs are experimentally practical and economically defendable. Whereas more than four factors, using fractional factorial design is more favorable.

2.5.5 Control Phase

Control phase, the final phase of DMAIC, mainly objective to maintain the improvements that have achieved in the Improve phase. During the Control phase, any traditional operations should be developed and any new potential ideas should be discussed. To assure CTQ characteristics quality, key input variables have to be controlled differently from the traditional procedure. Moreover, to create a sustainable improvement environment within organization, all the participants related to the process have to make an effort (L. Cano, 2012).

A control plan lists all product and process inspection points required to deliver a defect-free consequence, which is fundamental for maintaining process control over the long run. The control plan template is shown in **Figure 2.27** as well as the detailed description for each column are listed in **Table 2.5**, which can be adapted to any number of physical or transactional work processes.

Control Plan

Control Plan												
Control Plan Number:							Date (Orig.):					
Part Number:							Date (Rev.):					
Part Name/Description:							Key Contact:					
Supplier/Plant:							Core Team:					
Part /Process Number	Process Name/ Operation Description	Machine, Device, Jig, Tools for Mfg.	Characteristics			Special Char. Class	Methods					Reaction Plan
			No.	Product	Process		Product/ Process/ Specification/ Tolerance	Evaluation/ Measurement Technique	Sample		Control Method	
									Size	Freq.		

Figure 2.27: Control Plan Template

Table 2.5: Control Plan Column Description

No.	Column	Description
1	Header information	Enter the header information as required.
2	Part/Process Number	This item number is usually referenced from the Process Flow Chart. If multiple part numbers require (assembly), list the individual part numbers and their processes accordingly.
3	Process Name/ Operation Description	All steps in the manufacturing of a component are normally described in a process flow diagram. Identify the process/operation name from the flow diagram that best describes the activity being addressed.
4	Machine, Device, Jig, Tools for Manufacturing	For each operation that is described, name the processing equipment as appropriate.
5	Number	Enter a cross reference number from all applicable documents such as, but not limited to, process flow diagram, numbered blue print, FMEAs, and sketches (computer generated or otherwise), if required.
6	Product	Product Characteristics are the features or properties of a part, component or assembly that are described on drawings or other primary engineering information. The Core Team should identify the Special Product Characteristics that are a compilation of important Product Characteristics from all sources. All Special Characteristics must be listed on the Control Plan. In addition, the manufacturer may list other Product Characteristics for which process controls are routinely tracked during normal operations.

No.	Column	Description
7	Process	Process Characteristics are the process variable (input variables) that has a cause and effect relationship with the identified Product Characteristic. A Process Characteristic can only be measured at the time it occurs. The Core Team should identify Process Characteristics for which variation must be controlled to minimize product variation. There could be one or more Process Characteristics listed for each Product Characteristic. In some processes one Process Characteristic may affect several Product Characteristics.
8	Special Characteristic Classification	Use the appropriate classification to designate the type of special characteristic or this field can be left blank for other undesignated characteristics. Please refer to the Danaher Motion Quality Manual to see the descriptive terms and symbols.
9	Product/ Process/ Specification/ Tolerance	Specification/tolerance may be obtained from the engineering documents.
10	Evaluation/ Measurement Technique	This column identifies the measurement system being used. This could include gages, fixtures, tools, and/or test equipment required to measure the part/process/manufacturing equipment. An analysis of the reproducibility, repeatability and accuracy of the measurement system should be done prior to relying on a measurement system and improvements made accordingly.
11	Sample Size/Frequency	When sampling is required list the corresponding sample size and frequency.

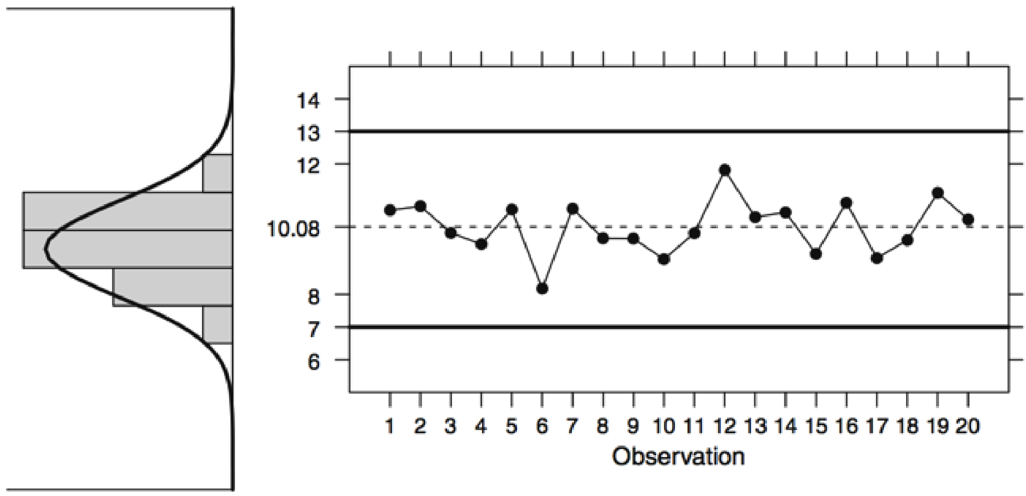
No.	Column	Description
12	Control Method	This column contains a brief description of how the operation will be controlled, including procedure numbers where applicable. The control method utilized should be based on effective analysis of the process. The control method is determined by the type of existing process. Operations may be controlled by, but are not limited to, Statistical Process Control, inspection, attribute data, mistake-proofing, (automated/non-automated), and sampling plans. The Control Plan descriptions should reflect the planning and strategy being implemented in the manufacturing process. If elaborate control procedures are used, the plan will typically reference the procedure document by a specific identification name and/or number. The method of control should be continually evaluated for effectiveness of process control. For example, significant changes in the process or process capability should lead to an evaluation of the control method.
13	Reaction Plan	The reaction plan specifies the corrective actions necessary to avoid producing nonconforming products or operating out of control. The actions should normally be the responsibility of the people closest to the process, the operator, job setter, or supervisor, and be clearly designated in the plan. Provisions should be made for documenting. In all cases, suspect and nonconforming products must be clearly identified and quarantined, and disposition made by the responsible person designated in the reaction plan. This column may also refer to a specific reaction plan number and identify the person responsible for the reaction plan.

Control Chart

Control chart is used as a tool for monitoring the performance of variables involved in processes. Vertical axis or y-axis represents the monitoring variable. The values of characteristics are plotted depending on type of data uses, which can be individual values or group means. Hence, the horizontal axis or x-axis of the chart indicates number of the set of items evaluated. The values are plotted as pointed and connected with straight lines showing the pattern of changes in the process performance. Together with three important horizontal lines appearing for variable observation during monitoring, which are:

1. Center Line (CL): The line represents the mean of the sampled variables, monitoring values around the mean
2. Lower Control Limit (LCL): The line of below value, very unlikely for the variable to occur
3. Upper Control Limit (UCL): The line of above value, the counterpart of the LCL. The LCL and UCL are symmetric when the probability distribution of the variable is normal (L. Cano, 2012)

The process will be performed statistically under control when the individual observations of the X are within the control limits, UCL and LCL. The customer will surely not accept the data beyond specification limits or the process. Normal control limits refer to the range between the mean and three standard deviations ($\mu \pm 3\sigma$). For a normal probability distribution, the limits comprise of 99.7 percent of the data. As a result, there is only 0.3 percent of chance for and individual observation to be



outside the specification limits, shown in **Figure 2.28** (L. Cano, 2012).

Figure 2.28: Relate Information Between Control Charts and Probability Distribution

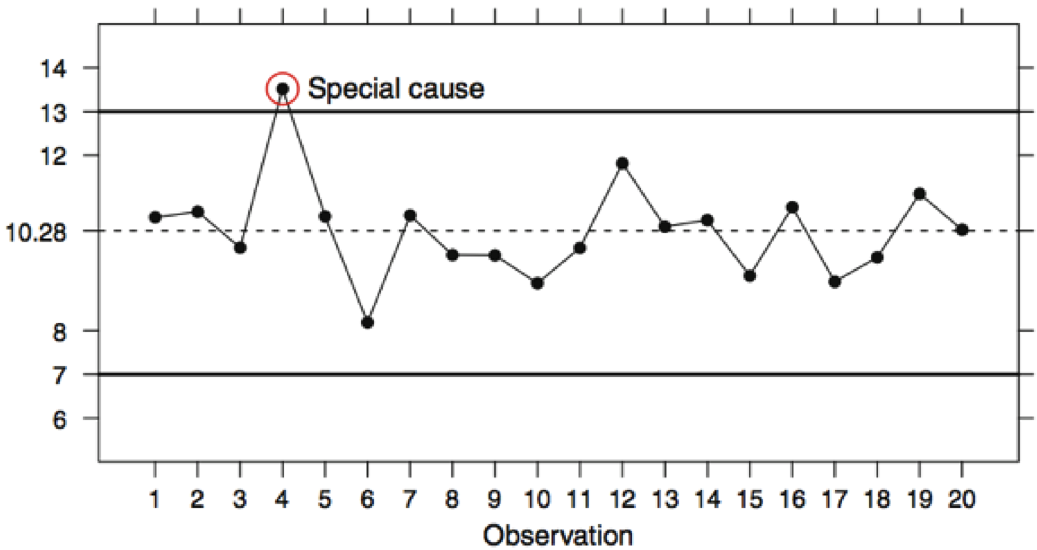


Figure 2.29: Special Causes of Individual Points Locating Outside the Control Limits

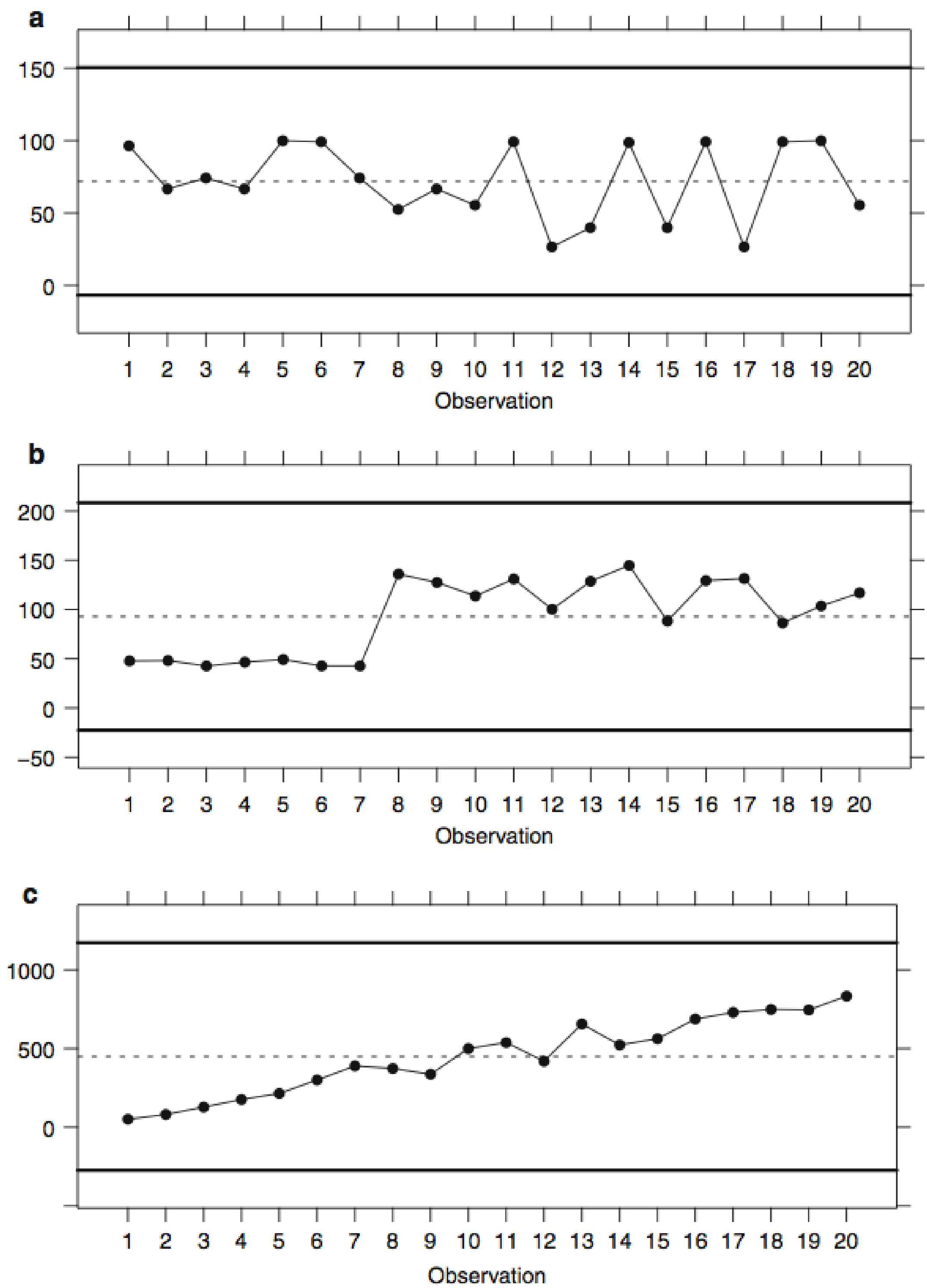


Figure 2.30: Pattern of Special Causes in form of (a) Seasonality, (b) Shifts, and (c) Trends

Individual points within the control limits are common causes, where as the points outside the control limits is counted as special causes (see **Figure 2.29**). Common causes occur from randomness while special causes happen from prompt variability that is not a result of randomness. Therefore, a point outside the control limits has to be identified, analyzed, and eliminated. Since special causes can generate other stubborn problems in a process. There are three patterns shown in **Figure 2.30** identifying the special causes in form of trends, shifts, and seasonality. Besides, showing nine or more points to one side of the mean, or two out of three points outside the center line plus or minus two standard deviations can be evidence of out-of-control process as well.

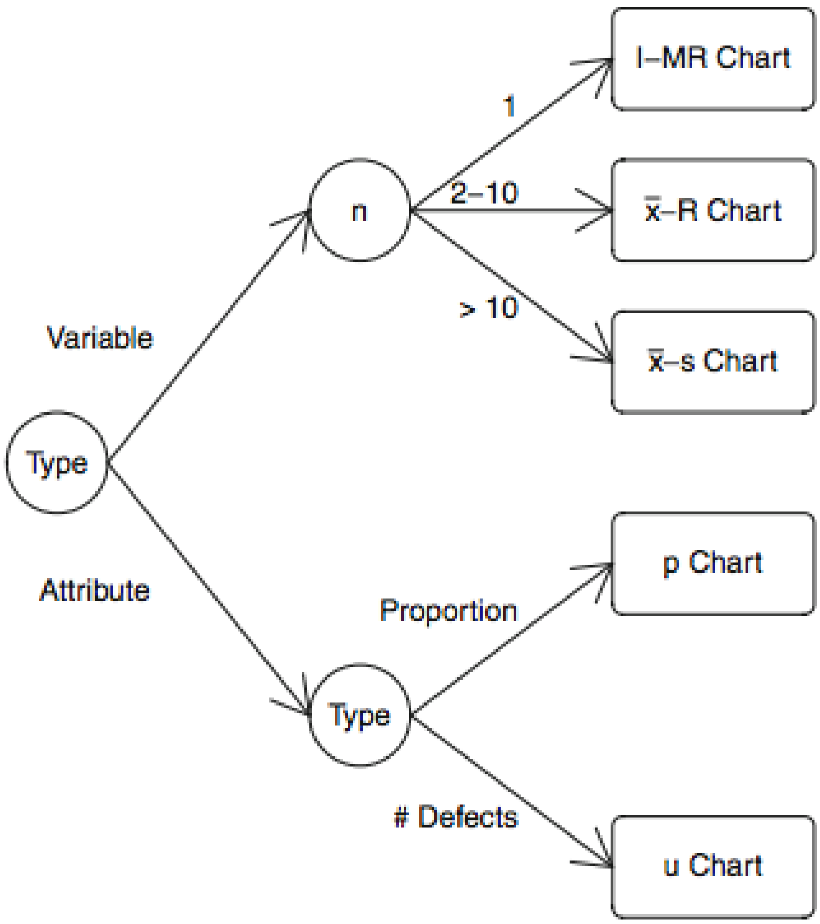


Figure 2.31: Decision for Type of Control Chart

As mentioned, there are many types of control charts can be used subject to the type of variable being monitored. For continuous variables, individual and moving-range charts (I/MR charts) is suitable for complete monitoring and average and range charts ($\bar{x}$ – R) or average and standard deviation charts ($\bar{x}$ – s) can be used for randomized monitoring through samples. For qualitative variables (attribute data), p charts and u charts are properly used to control the proportion of defects and to control the number of defects per unit, respectively. A summarize tree shown in **Figure 2.31** is usable for making a decision on selecting type of control charts (L. Cano, 2012).

2.6 Related Researches

(Mukhopadhyay, 2006)

An Indian textile company decided to use Six Sigma DMAIC methods to correct the major quality problem of packing rejection of yarn cones (wounded yarn into conical-shaped packages). Customers rejected the cones due to undesirable weight variation. In define phase, data were collected on packing rejection from December 2012 to May 2003 and Pareto chart is applied to figure out the facing problem. The result showed that 65% of rejections due to over- and under-weight of yarn cones, were Ne 2=42sP, Ne 4=12sP, Ne 2=20sP, Ne 1=30sV, Ne 3=20sP, Ne 3=12sP. However, the Pareto chart in terms of sales volume found that the major counts were Ne 2=42sP, Ne 4=12sP, Ne 2=20sP, Ne 3=12sP, and Ne 3=20sP, which was more than 75% of the revenue. In measure phase, data of the actual count, gross cheese weight, and moisture contents were measured and collected from the final two steps of post spinning, then the existing sigma level was calculated. The combined value of yield (Y_{RT}) and the overall defective parts per million (PPM) of the two steps were 0.5525 and 593302, respectively. Thus, the current and the target sigma level were 1.3 and 2.017 in sequence. Next, analysis phase, to investigate the cause of weight variation on the basis of the collected data, statistical hypothesis tests were performed. The observed weight was meaningfully more than the set weight of yarn at the assembly winding stage. Moreover, the gross yarn weight between left and right sides of a machine was found a significant difference at this stage. This happened regardless of all assembly winding machines were attached of electronic length measuring devices (LMDs) on, due to inadequate capability performing of LMDs. Therefore, to increase the sensitivity performance of LMDs, implementing proper calibration procedures in some machines and replacing LMDs in other machines were achieved in the implementation phase. As a result, cone weight variation was reduced significantly. Finally, regression analysis was performed for the polyester yarn of count $4/12^{'s}$ and relation was found between gross yarn weight and length of yarn. This relationship was used to arrive at the optimum parameter level and for the future control.

(Rohini, 2011)

This study proposes the DMAIC Six Sigma to improve the process in the Operation Theatre of a Corporate Multispecialty Hospital in Bangalore, India, with the study of six months period. The study merely focuses on operation timing of OT, as it is the main bottleneck. Several tools such as Measures of central tendency & Measures of Dispersion fish bone analysis model, Pareto charts, and graphical representations were applied for data analysis. After implementation, the hospital can save cost from first cases delay and cancellation events of Rs 64,530, 000.

(Vishnuvarthanan, 2013)

Adhesives play a fundamental role in many modern technologies, and adhesive failure can have catastrophic consequences. It is, therefore, valuable to understand the factors important for the production of a good durable adhesive bond. The additives are also used to enrich the properties. The objective of this paper is to increase the drying speed of the starch adhesive by adding suitable additives and thereby increasing the production speed of corrugated board manufacturing. The other functional additives that could be incorporated in minor amounts for better drying speed are studied and selected. Their properties such as drying speed, strength, viscosity and pH are tested. The results from the tests are compared and the best additive for fast drying is selected.

(Damrongseree, 2014)

The research applied DMAIC Six Sigma approach as aims to reduce the defect in recycle process of hard disk drive media. Percentage of the defect before implementing Six Sigma is 23 percent. Sunray and cluster defects are the major problems found which is 9.64 and 5.96 percent, respectively. Cause-and-Effect Diagram and FMEA are utilized to find out the major causes of each defect. There are five main factors cause the sunray defect including (1) gramload of rubber pusher, (2) spindle speed during tape move up, (3) spindle speed during tape move down, (4) dwell time of tape at inner of media, and (5) traverse speed of tape. While cause affect cluster defect occurs from setting of a DSP removal process, which can be categorized into four main part which are (1) stopper height of DSP holder, (2) positions of vacuum holder I, (3) position of vacuum holder II, and (4) position of vacuum holder III. Then, the factors are all performed in improve phase using one-half factional factorial design and full factorial design for sunray and cluster defect, respectively. The result reported that factor (1), (2), and (5) significantly influence to sunray defect, and factor (1), (2), and (3) affect importantly affect the cluster defect. Afterward, the Response Surface Methodology (RSM) is developed to control the optimum setting of these three factors of both defects. In conclusion, with the implementation of optimal setting machine, defective rate can be reduced from 9.64

percent of sunray defect and 5.96 percent of cluster defect to 5.96 and 0.98 percent, respectively.

(Suriyasuphapong, 2014)

The study followed DMAIC steps to improve an assembly process in hard disk drive manufacturing. The indicator proving the improvement performance is the process capability index (C_{pk}) and the reduction of the defective rate from bending defects of hard disk drive media. The project charter was set up in the define phase. The measuring system and the process capability were analyzed and the potential causes of the bending were brainstormed and prioritized through FMEA in the measure phase. Next, the fractional factorial design was developed to test the significance of factor influencing the bending value in the analyze phase. In the improve phase, the experiment was conducted to specify the optimum conditions on each input factor that provide the least bending value. The finest setting was 3.25 in-lb of clamp screw torque, 3.00 mm of screw bit height, and 2.50 lbs of vertical force on disk clamp and motor. Finally, control plan and X-bar and S charts were established in the control phase. By implementation, the average bending value was decreased from 5.12 percent to 3.43 percent, as well as the C_{pk} was increased from 0.69 to 1.39, above the standard of 1.33.

(Jenjiwattanakul, 2012)

This research applied the Six Sigma method for defect reduction in the printing process. The research followed five steps according to DMAIC approach; (1) Define phase, defined the problems of the factory case study and found that Plastic printing process created the largest amount of defects of 41,759 kg from the overall production of 357,486 kg, which is equivalent to 11.68%, (2) Measure phase, starting with the inspection of measurement system to make sure that it is met acceptance criteria. Next, the possible problems were listed using fish bone diagram and obtained 20 factors. Then, screened the factors with Cause and Effect Matrix, and applied FMEA technique to analyze and prioritize until achieved 3 significant factors, (3) Analysis phase, the three factors were analyzed using statistical method which verified that these factors contributed to defect occurrence. 4) Improvement phase, factorial experimental design was established to conduct experiment with two duplications in order to attain optimal value of each factor, and (5) Control Phase, control chart was set up as a guideline to control and minimize the defect amount since the improvement have achieved. After implementation, the results were improved by reduction of percentage of defect from 11.68 percent to 1.53 percent.

CHAPTER 3
DEFINE PHASE

Define phase is the initial phase of the study on DMAIC Six Sigma method. This is an important step as it aims to define the path of the research implementation. This phase will include the study of corrugating process, statement of problem, indicator, and forming a team.

3.1 Study of Corrugating Process

The purposes of studying the company’s processes are to create an understanding on current situation of the operation before collecting data, identifying the indicator, setting objectives, and figuring out the causes that influence the occurrence of defects in corrugated board manufacturing process of the research. However, the corrugating process will be the only focus of this research since the greatest defect generated comes from this process.

A corrugator is a set of machines in line; producing single, double or triple paperboard by bringing together three, five or seven sheets of paper and is achieved in a continuous process. The corrugator can be divided into five main sections including Single Facer, Bridge, Double Backer, Slitting and Scoring, and Stacker as shown in **Figure 3.32** (BOXES, 2009)

The reels of paper are fed into the corrugator. The paper is treated with heat and steam, and then fed between large corrugating rolls; this gives the paper its fluted shape in the single facer. Starch is applied to the tips of the flutes on one side and the inner liner is glued to the fluting. The corrugated fluting medium with one liner attached to it is called single face web and travels along the machine towards double backer where the single face web meets the outer liner and forms the corrugated board. The corrugated board is then cut and stacked.

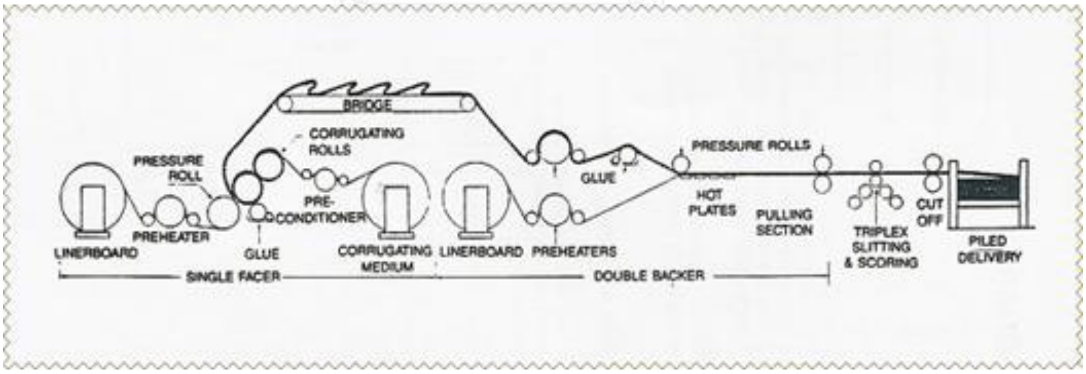


Figure 3.32: Corrugator Machine

The main parts of a corrugator are the splicer and reelstand. These parts are the machines feeding the paper rolls into the corrugator and allowing rolls to be changed without interrupting the production of corrugated paperboard.

Single Facer

Single facer is the section where the joining of corrugated medium to top liner takes place. This machine transforms the paper into a series of connected curves called "flutes" by applying corrugating rolls that are large cylinders with a corrugated profile. Thus, the corrugating rolls need to be changed, when the flute profile has to be altered.

Bridge

The bridge is located above the based machine linking between single facer and double backer. It empowers the double backer to run at different speeds from the single facer particularly when reel or order changes take place. The change can be achieved by forming the single face web as festoons that are controlled at the single facer station as shown in **Figure 3.33 (Company, 2005).**

Figure 3.33: Bridge Festoons

Double Backer

Double backer is the section next to single facer, gluing the outer liner to the fluting that runs through the bridge to obtain single, double or triple paperboard. The single face web is preheated and adhesive is applied to the tips of the flutes. The outer liner is then bonded to the single face web to form corrugated paperboard. This step is a complicated operation that requires great expertise in the preheating, moisture control and gluing processes.

The single face web is combined with the outer liner and the corrugated paperboard is formed. Hot plates are the next stage of heating section; it ensures that the bond is strong by crystallizing the glue and removing moisture.

Rotary shear

After the corrugated paperboard emerges from the double backer, it passes under a rotary shear that cuts across the whole width of the web. Rotary shear is used to cut out damaged lengths of paperboard or to affect a change over from one grade of paperboard to another.

Slitting and Scoring

Slits and scores of the corrugated paperboard perform in the machine direction. The operation is based on the style of the finished box conforming to the order.

Cut-off

Cut-off is the section where the corrugated paperboard is cut to the exact required lengths to achieve the corrugated sheets used in the creation of corrugated packaging.

Stacker

Last section of the corrugator machine is the stacker. Corrugated sheets are automatically stacked, and moved directly to the conversion machine or delivered to a converting plant.

3.2 Statement of Problem

The company's operation runs in two shifts a day, six days a week. The production volume of the company is collected weekly during February and March 2014 as shown in the **Figure 3.34**. Loads of work generally depends on the demand, which causes slight fluctuation on the graph, as there are varying orders with different requirements of paper type, paper quality, size, design, thickness, and other options. However, the company's manufacturing capacity on average is 394 tons weekly or 1,577 tons monthly, or 20,504 tons annually.

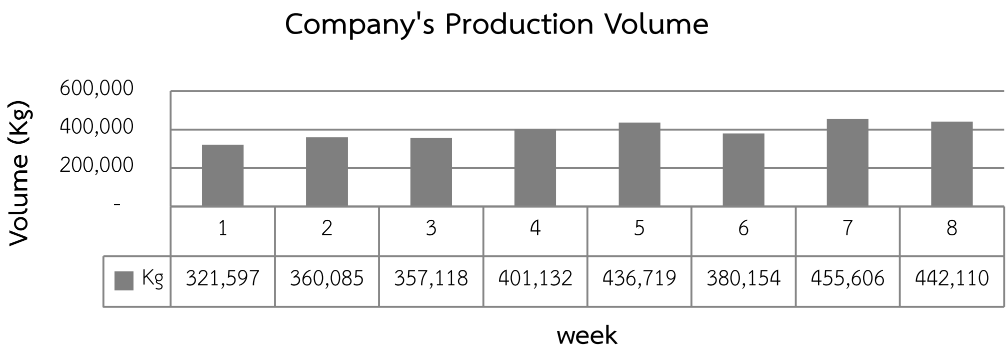


Figure 3.34: The Company's Production Volume Operating Weekly

Waste of the company can be categorized into three types which are production waste, zero waste, and overrun. Nevertheless, the zero waste and overrun are uncontrollable and are counted as scrap, hence they will be excluded in this research. **Table 3.6** shows significant wastes that cause the company's loss, the majority of waste is generated from corrugating production process which is approximately 2.87% of production volume. Pareto chart shown in **Figure 3.35** clarifies that wastes produced from corrugated paperboard production create the largest effect on overall production waste of 87.19%.

Table 3.6: The Company's Defect Catagorization

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Total (kg)	% waste of production
Corrugated Paperoard	9,139	11,198	10,137	10,389	15,379	11,438	11,417	11,329	90,426	2.87%
Corrugated Paper Box	923	827	1,240	912	2,226	1,528	1,822	1,603	11,081	0.35%
Warehouse	230	284	258	220	352	285	276	304	2,209	0.07%
Total (kg)	10,292	12,309	11,635	11,521	17,957	13,251	13,515	13,236	103,716	3.29%

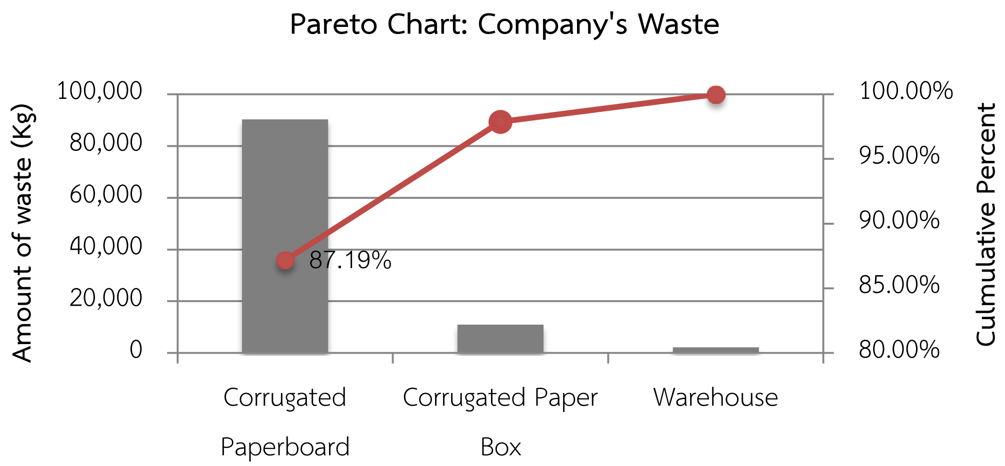


Figure 3.35: Pareto Chart of The Company's Defect

Therefore, the research will be focused on reducing defects from the corrugated paperboard manufacturing process, which would be most beneficial to the company since defects significantly affect the company's loss and reputation. The defects in corrugating process can be classified into four main categories including Blister, Skew silted and scored alignment, Edge overlap, and Unconnected glue at the edge. **Table 3.7** shows that Blister is the greatest defect occurred during the period, which was 64.8% of total defects. Skew silted and scored alignment defect is slightly high, however, it is much less significant compared to Blister.

Table 3.7: Defect Categorization of Corrugating Process

Defect	Volume (kg)	Percentage	Cumulative Percent
Blisters	58,596	64.80%	64.80%
Skew silted and scored alignment	17,633	19.50%	84.30%
Edge overlap	7,505	8.30%	92.60%
Unconnected glue at the edge	6,692	7.40%	100.00%

Pareto Chart of the defects is plotted as shown in the **Figure 3.36**. The graph shows that Blister is the most outstanding defect in the corrugating process, which can be calculated to the loss of approximately THB 0.59 million per month or THB 7.03 million per year. Since the defects cannot be reworked and have to be undoubtedly disposed as scrap, the reduction of the blister defect will highly improve overall production efficiency as well as reduce cost of investment.

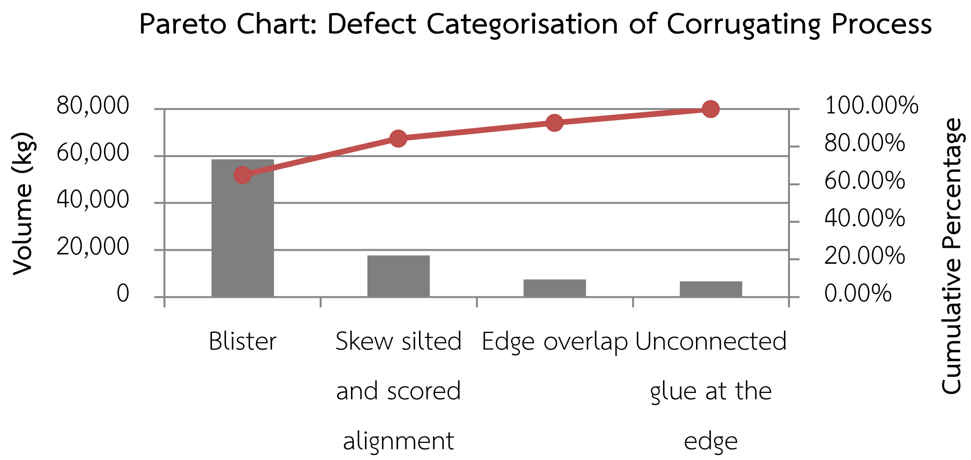


Figure 3.36: Pareto Chart of Company's Defect in Corrugating Process

The causes of blister defect occur from two cases, either while running or at startup.

Blisters – while running

This kind of defect occurs in the center of single-face web or across a substation portion of the web at high speed. The defect may be continuous but it normally starts in periodic football-shaped unbounded areas. There are four main conditions causing the defect as shown in **Table 3.8** (PRESS, 1997).

Table 3.8: Conditions and Causes of Blister Defect While Running Corrugator Machine

Conditions	Causes
A soaked apart sheet shows adhesive was correctly applied to the medium and initial contact was made with the liner	Lack of heat as shown by white glue lines Inaccurate pressure roll crown Wet streak in liner or medium Tension of liner or medium not uniform across sheet Adhesive's gel temperature is too high Excess heat as presented by crystalline glue lines Improper adjusting of pressure roll
A smeared glue pattern on the medium caused by loss of control of the medium on the lower corrugating roll before the lower corrugating roll/ applicator roll nip	Insufficient vacuum or pressure Clogged vacuum holes Dirty corrugating rolls Low corrugating roll nip pressure Worn corrugating roll bearings Low heat of corrugating roll
A smeared glue pattern on the liner caused by medium fluffing before pressure roll/lower corrugating roll nip	Increase gap

Conditions	Causes
No glue on liner	Glue roll/corrugating roll gap too wide Glue roll/meter roll gap too small Stream shower condensate dripping on glue roll Gelled starch on splash apron wiping glue off medium Starch level too low in glue pan Insufficient/no contact between lower corrugating roll and pressure roll

Blisters – at startup

There is a condition with two causes leading to blister defect at startup as shown in **Table 3.9** (PRESS, 1997).

Table 3.9: Condition and Causes of Blister Defect at Startup Corrugator

Condition	Causes
Blister caused by a temporary out-of-round condition on the lower corrugating roll and/or pressure roll after the single facer is stopped for a period of time. The blister ends a short period of time after startup	Condensate collecting inside lower corrugator roll and/or pressure roll Warp of the lower corrugating roll caused by vacuum systems where lower corrugator roll is not heated or where a vacuum chamber above the lower corrugating roll is employed to achieve the vacuum

3.3 Indicator

From the study of problems in corrugated paperboard manufacturing process, blister is the greatest defect occurred in the process, which is 2.87% of the total defects. The aim of the research is to reduce percent defect to about a half.

Figures that will be used to indicate amount of blister defect in the company case study is percentage of the defect, which can be calculated as follow:

$$\% \text{ defect} = \frac{\text{defect volume (kg)}}{\text{total production volume (kg)}} \times 100$$

3.4 Forming a team

In order to improve quality of the corrugated paperboard manufacturing process by minimizing the blister defect efficiently using Six Sigma method, a working team needs to be established. To form the team, members who have experience and technical expertise in the corrugating process, as well as knowledgeable in Six Sigma within the organization are selected as follow:

Production Manager

Process Engineer

Product Engineer

Quality Control Manager

Maintenance Engineer

Planning Manager

3.5 Summary

Since the corrugated paperboard manufacturing process was studied and the defect data was collected during weeks from February to March 2014. The data were analyzed and compared by plotting through the Pareto chart, which shows that the majority of waste is occurred from corrugating process and the defect type that has the greatest effect on the company's loss is blister defect. As a result, the research will be attentive to improve the corrugating production process and minimize blister defect.

CHAPTER 4
MEASURE PHASE

Since defining problem was done in the define phase, further researching data, theories, and other related parameters are highly significant for successful implementation. Firstly, this chapter will discuss the initial causes of the problem, starting from testing of measuring equipment to ensure that the measured data are satisfied using *Gage Repeatability and Reproducibility*. After the measurement is assured, next task is brainstorming among the production team in order to analyze and identify the possible causes of problems utilizing *Cause and Effect Diagram*. Finally, all possible causes will be prioritized through *Failure Mode and Effect Analysis (FMEA)* for selection of the most significant factors affecting the problem and for further phase of analysis.

4.1 Gage Repeatability and Reproducibility

System for measuring the blister defect from corrugating production process is normally performed by visual inspection, which creates potential for error occurrence during the operation. Thus, performing Gage R&R before starting inspection is an important step in order to ensure that examination process completed by inspectors and measuring instruments are 100% precise. Then, the result of blister defect can be confirmed.

To perform Gage R&R for analyzing measurement system accuracy of corrugated paperboard manufacturing process, the following steps are:

1. Select team members who are experienced in the corrugating process of making corrugated paperboard and are able to distinguish between good product and bad product for inspection of 20 samples
2. The samples will be classified into three different groups including 7 samples of good products, 7 samples of bad products, and 6 samples of half good and half bad products.
3. Select three well-organized inspectors who are able to inspect the defect precisely.
4. Randomly choose one out of three inspectors to appraise the samples checking whether they are good or bad.
5. Assign all three inspectors to examine the samples. The testing will run randomly. A volunteer assessor will take the responsibility to check the result and record it onto the form for each of inspectors.
6. The recorded data will be analyzed to evaluate accuracy of the measuring system.

Table 4.10: Gage R&R Attribute Data Study

Sample No.	Correct Radom Selected Sample Result	Inspector A		Inspector B		Inspector C	
		1	2	1	2	1	2
1	G	G	G	G	G	G	G
2	G	G	G	G	G	G	G
3	B	B	B	B	B	B	B
4	G	G	G	G	G	G	G
5	B	B	B	B	B	B	B
6	B	B	B	B	B	B	B
7	G	G	G	G	G	G	G
8	G	G	G	G	G	G	G
9	G	G	G	G	G	G	G
10	B	B	B	B	B	B	B
11	G	G	G	G	G	G	G
12	B	B	B	B	B	B	B
13	G	G	G	G	G	G	G
14	G	G	G	G	G	G	G
15	B	B	B	B	B	B	B
16	B	B	B	B	B	B	B
17	G	G	G	G	G	G	G
18	G	G	G	G	G	G	G
19	B	B	B	B	B	B	B
20	G	G	G	G	G	G	G

Note: "G" represents a Good sample and "B" represents a Bad sample

After the observation is done, the attribute data from **Table 4.10** is analyzed using Minitab and the overall result is showed in **Figure 4.36**. The assessment agreement of 100 percent (indicated by blue dots) within Appraisers and between appraiser and standard demonstrates that each individual inspector agrees with him/herself across the trials, as well as the appraisers' assessment across trials agrees with the known standard of 95 percent confidence interval (indicated by blue crosses and red line). More detailed information is presented in **Figure 4.37** and **Figure 4.40**, respectively.

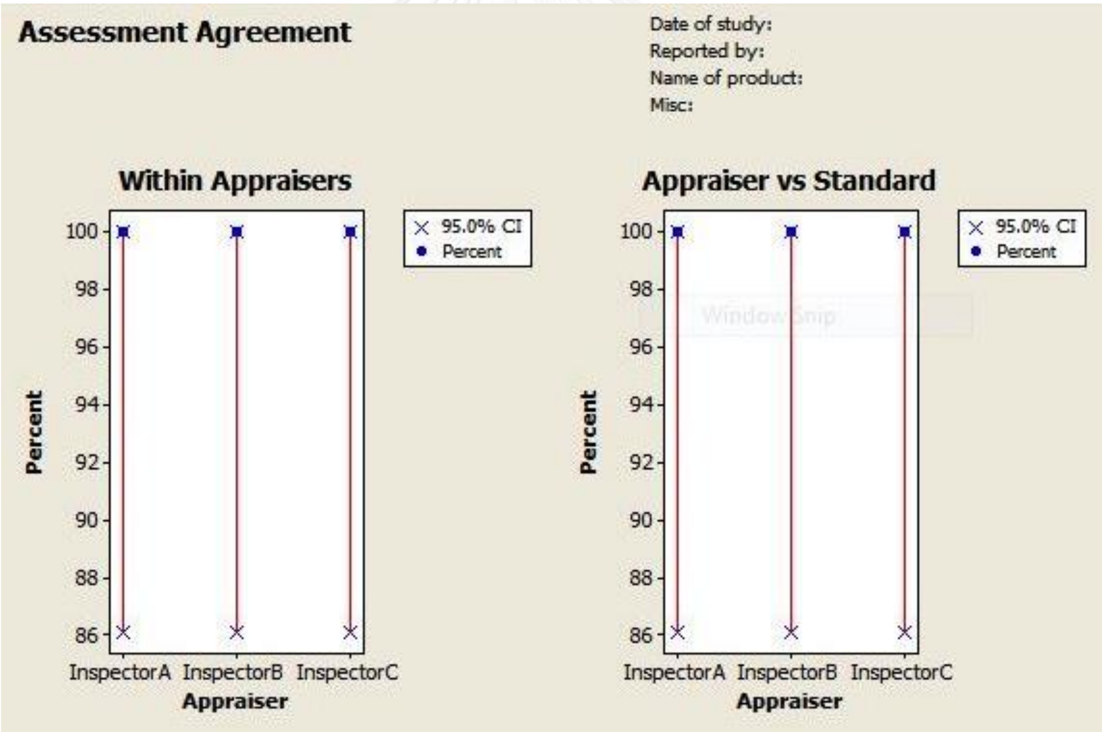


Figure 4.37: Assessment Agreement

Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
InspectorA	20	20	100.00	(86.09, 100.00)
InspectorB	20	20	100.00	(86.09, 100.00)
InspectorC	20	20	100.00	(86.09, 100.00)

Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
InspectorA	B	1	0.223607	4.47214	0.0000
	G	1	0.223607	4.47214	0.0000
InspectorB	B	1	0.223607	4.47214	0.0000
	G	1	0.223607	4.47214	0.0000
InspectorC	B	1	0.223607	4.47214	0.0000
	G	1	0.223607	4.47214	0.0000

Figure 4.38: Assessment Agreement Within Appraisers

The assessment agreement result within Appraisers (see **Figure 4.37**) shows that the agreement percentage within each individual appraiser is all 100 percent, which means every appraiser fully agrees with themselves across the two assessments made on each candidate. In addition, the observe agreement is greater than the change agreement and the measurement system is excellent as kappa showing positive value and greater than 0.9, respectively.

Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
InspectorA	20	20	100.00	(86.09, 100.00)
InspectorB	20	20	100.00	(86.09, 100.00)
InspectorC	20	20	100.00	(86.09, 100.00)

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

Assessment Disagreement

Appraiser	# G / B	Percent	# B / G	Percent	# Mixed	Percent
InspectorA	0	0.00	0	0.00	0	0.00
InspectorB	0	0.00	0	0.00	0	0.00
InspectorC	0	0.00	0	0.00	0	0.00

G / B: Assessments across trials = G / standard = B.
B / G: Assessments across trials = B / standard = G.
Mixed: Assessments across trials are not identical.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
InspectorA	B	1	0.158114	6.32456	0.0000
	G	1	0.158114	6.32456	0.0000
InspectorB	B	1	0.158114	6.32456	0.0000
	G	1	0.158114	6.32456	0.0000
InspectorC	B	1	0.158114	6.32456	0.0000
	G	1	0.158114	6.32456	0.0000

Figure 4.39: Assessment Agreement of Each Appraisers versus Standard

The agreement percentage between each appraiser and the standard is 100 percent for the three inspectors and the kappa value of 1 indicates that the measurement system is absolutely accurate (see **Figure 4.38**).

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
20	20	100.00	(86.09, 100.00)

Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
B	1	0.0577350	17.3205	0.0000
G	1	0.0577350	17.3205	0.0000

Figure 4.40: Assessment Agreement Between Appraisers

The 100 percent of agreement percentage and kappa of 1 between different appraisers (see **Figure 4.39**) present that all appraisers' assessments totally agree with each other.

All Appraisers vs Standard

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
20	20	100.00	(86.09, 100.00)

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

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
B	1	0.0912871	10.9545	0.0000
G	1	0.0912871	10.9545	0.0000

Figure 4.41: Assessment Agreement of All Appraisers versus Standard

Overall agreement percentage of both within and between appraisers of 100 percent and kappa value of 1 shown in **Figure 4.40** indicates that the measurement system is precisely performed.

Table 4.11: Summary of Gage R&R Result

Criteria	Inspector A	Inspector B	Inspector C	All Inspectors
% Repeatability of Inspector	100%	100%	100%	
% Unbiasedness of Inspector	100%	100%	100%	
% Repeatability Efficiency of Inspection				100%
% Unbiased Efficiency of Inspection				100%

From the result of assessment agreements by Minitab, conclusion can be made as shown in **Table 4.11**. The summary shows that repeatability and unbiasedness percentage of individual inspector is all 100 percent. As well as repeatability efficiency and unbiased efficiency percentage of inspection among all the inspectors are also 100 percent. Thus, the measuring system of corrugated paperboard manufacturing process detecting blister defect has high accuracy and precision.

4.2 Cause-and-Effect Diagram

The production team brainstormed all possible causes of the blister defect through the cause and effect diagram by classifying causes into six routes based on 5M1E principle including *Man, Machine, Material, Method, Measurement*, and *Environment* as shown in the **Figure 4.41**.

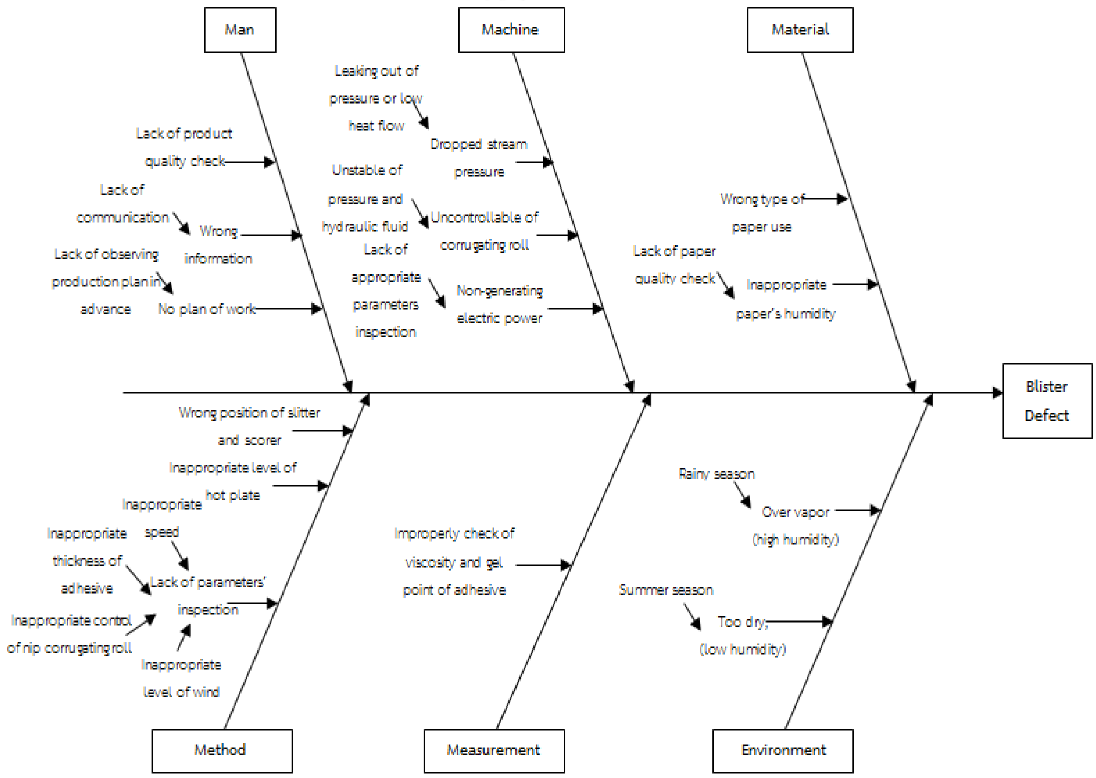


Figure 4.42: Cause and Effect Diagram

Man

1. Lack of constant quality check during the running of machine; no choose at random practice to check the quality of product in various aspects such as adhesive attachment. This may result in customers receiving defected products.
2. Lack of communication between shifts. Sometimes employees find problems during the production process and did not inform the employees in next shift. In addition, lack of communication also occurs during production process when problems are not reported along the way.
3. No checking of the production plan or examining the plan in advance, which can cause the blister defect by interruption of production.

Machine

1. Steam generated from boiler does not reach the right amount of pressure (7 bar) when the machine is running. Sometimes pressure may drop due to leakage or low heat flow.
2. Uncontrollability of corrugating rolls due to low pressure and hydraulic fluid.
3. Lack of appropriate inspection of mechanical equipment and value of significant parameters for generating electric power.

Material

1. Size, weight, and grade of paper are not checked before use
2. Lack of paper humidity inspection

Method

1. Lack of parameters inspection before running the corrugator machine, the parameters are as follow:
2. Speed at changing order
3. Temperature of paper and angle of nip at corrugating roll
4. Wind pressure for compression of medium (especially for large gram of paper)
5. Thickness of adhesive
6. Inappropriate level of hot plates at assembling double-facer
7. Inappropriate temperature of hot plates at finished product
8. Wrong position of slitter and scorer

Measurement

1. Viscosity and gel point of glue adhesive are not properly checked

Environment

1. Over vapor due to high humidity in rainy season

2. Too dry due to low humidity in summer season

4.3 Cause-and-Effect matrix

After the causes of the blister defect in corrugating process are identified and listed during brainstorming through Cause-and-Effect diagram, all 18 causes are then analyzed and prioritized. The causes are rated within the team using Cause-and-Effect Matrix shown in **Table 4.12**. The score range is from 0 to 10, where

10 refers that the cause has extreme effect on blister defect

0 refers that the cause has no effect on blister defect

Table 4.12: Cause-and-Effect Matrix Analysis

Route	No.	Cause	Relation of score						
			Production manager	Process Engineer	Product Engineer	QC Manager	Maintenance Engineer	Planning Manager	Total score
Man	1	Low frequency of product quality check	9	9	9	10	2	8	47
	2	Wrong information/less communication	4	8	5	2	2	0	21
	3	No plan of work	4	3	2	0	0	7	16
Machine	1	Low stream pressure	4	2	3	0	7	0	16
	2	Insufficient hydraulic power	5	2	2	0	7	0	16
	3	Inappropriate level of electric power	4	2	3	0	8	0	17
Material	1	Wrong type of paper used	10	8	10	9	0	9	46
	2	Lack of paper humidity inspection	3	7	7	4	0	0	21

Route	No.	Cause	Relation of score						
			Production manager	Process Engineer	Product Engineer	QC Manager	Maintenance Engineer	Planning Manager	Total score
Method	1	Inappropriate setting of speed	10	10	9	9	6	8	52
	2	Inappropriate temperature and angle of nip of corrugating roll	10	10	10	9	6	8	53
	3	Inappropriate wind pressure for compression of medium	9	9	10	8	6	6	48
	4	Inappropriate thickness of adhesive	9	10	10	9	5	8	51
	5	Inappropriate level of hot plates	10	10	8	8	6	7	49
	6	Inappropriate temperature of hot plates	10	10	9	8	6	8	51
	7	Wrong position of slitter and scorer	4	7	5	2	2	0	20
Measure-ment	1	Improper checkup of viscosity and gel point of adhesive	9	10	9	9	3	2	42
Environ-ment	1	Over vapor (humidity is higher than standard)	6	2	1	0	0	0	9
	2	Too dry (humidity is lower than standard)	6	2	1	0	0	0	9

The causes are prioritized and ranked in Pareto chart and Table as shown in **Figure 4.43**. Nine causes have outstanding results on the graph, which indicate that they significantly affect the occurrence of blister defect in corrugating process (TAPPI PRESS, 1997)

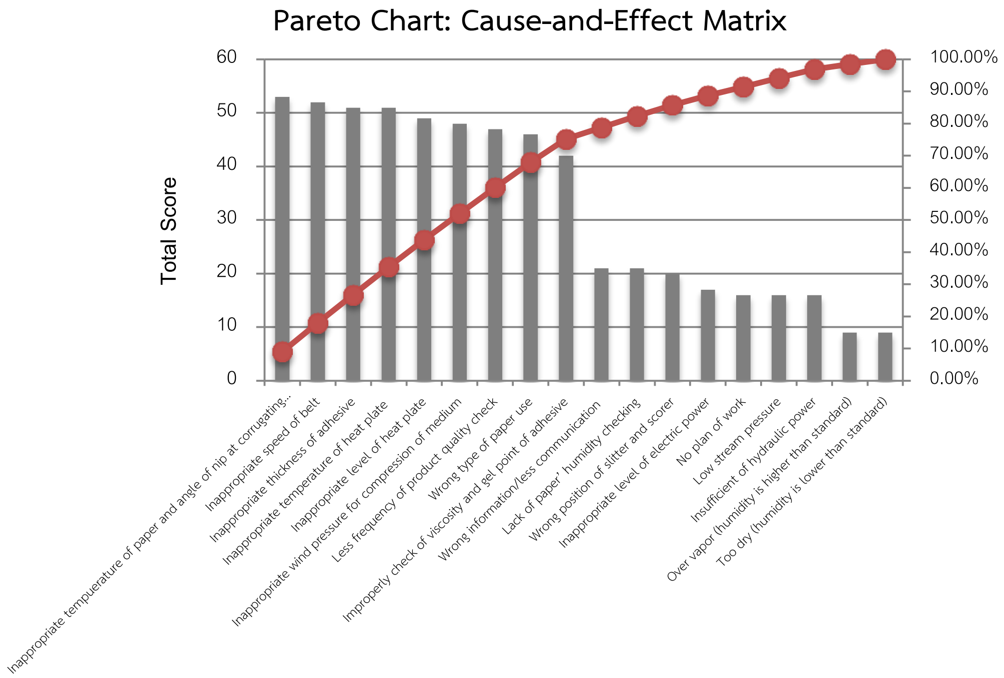


Figure 4.43: Pareto Chart of Cause-and-Effect Matrix

Table 4.13: First Five Ranks of Cause-and-Effect Matrix

Order	Cause	Related Score
1	Inappropriate temperature of paper and angle of nip at corrugating roll	53
2	Inappropriate speed of belt	52
3	Inappropriate thickness of adhesive	51
4	Inappropriate temperature of hot plates	51
5	Inappropriate level of hot plates	49
6	Inappropriate wind pressure for compression of medium	48
7	Low frequency of product quality check	47
8	Wrong type of paper used	46
9	Improper check up of viscosity and gel point of adhesive	42

Table 4.13 presents the first nine ranked score achieved from Cause-and-Effect Matrix, which consists of

1. Inappropriate temperature of paper and angle of nip at corrugating roll – Corrugating roll nip is the first step of heating and pressing the paper feeding

from paper reel. Appropriateness and consistency of the temperature are necessary for removing moisture in the paper to the right value. And the angle of the nip at corrugating roll helps limit the area of treatment as required.

2. Inappropriate speed of belt – Constancy of speed throughout the operation not only influence the controlling of moisture in the paper, but is also significant to the congruence of attachment between single facer and double backer to form corrugated paperboard.
3. Inappropriate thickness of adhesive – Thickness of adhesive has to be consistent with the temperature used to form a perfect surface board. Thus, the thickness has to be measured with equivalence along the operation.
4. Inappropriate temperature of hot plates – Right temperature of hot plates aids the crystallization of adhesive when the double-face liner is connected to single-face web forming corrugated sheet.
5. Inappropriate level of hot plates – Hot plates work together with temperature. They can be moved up and down in order to press the corrugated paperboard right after the bonding to create a smooth and fine surface on both side of the board.
6. Inappropriate wind pressure for compression of medium – Medium is the corrugated part called flute that requires wind pressure to compress and

form a curved shape. Thus, improper level of wind pressure might damage the constancy of the corrugated medium.

7. Low frequency of product quality check – Lack of frequent inspection since the corrugated paperboard is formed, which cause the blister defect that may lead to customers acquiring defected products.
8. Wrong type of paper used – Setting of corrugator machine not congruent to the type of inserted paper causes defect during the production.
9. Improper check up of viscosity and gel point of adhesive – Lack of inspection of adhesive viscosity and gel point might affect time of bonding of corrugated paperboard.

4.4 Failure Mode and Effect Analysis

The factors obtained from Cause-and-Effect Matrix will be applied for a thorough analysis utilizing Failure Mode and Effect Analysis (FMEA) as shown in **Table 4.14**. The analysis is evaluated based on the criteria demonstrated in Appendix A1, A2, and A3, for Severity (SEV), Occurrence (OCC), and Detection (DET), respectively.

Table 4.14: Failure Mode and Effect Analysis Result

Item	Key Process Input	Potential Failure Mode	SEV	Potential Cause	OCC	Current Control	DET	Recommended action	RPN
1	Inappropriate angle of nip at corrugating roll	Corrugating roll nip is not be set at the appropriate angle and congruent to paper's property	9	No inspection of positioning corrugating roll nip	9	No work manual at working place	8	Check the angle of corrugating roll nip congruent to the type of paper use	648
2	Unstable temperature of paper at corrugating roll	Temperature is diverged throughout the pressing paper at corrugating roll nip	7	Lack of checking temperature at the corrugating roll before running the process in each batch	3	Frequently check the temperature when changing order or batch by set up fixed temperature depending on type of paper use	2	Create a sign or work manual in every station of running corrugating roll	42
2	Inappropriate setting of speed	Speed is set improperly corresponding to production process	9	No production plan and checking of speed during operation	8	No sign for changing speed at the control panel	8	Setting a humidity detector and auto-speed adjustment	576
3	Inappropriate thickness of adhesive	Non standard thickness of adhesive	8	Lack of adhesive inspection before and during operation	8	No sign for no glue or improper glue thickness on liner	8	Setting auto glue's thickness adjustment device	512
4	Inappropriate temperature of hot plates	Temperature is set improperly throughout hot plates and not slightly reduced to the surrounded atmospheric temperature	8	Lack of checking temperature during operation	8	No use of temperature gauge	7	Create work instruction	448
5	Inappropriate level of hot plates	Level of hot plates is not be set at the right position corresponding to type of paper	6	Automatically setting. Adjustment cannot be done manually when needed	4	No inspection during process run	6	Establishing the manual console for emergency case	144

Item	Key Process Input	Potential Failure Mode	SEV	Potential Cause	OCC	Current Control	DET	Recommended action	RPN
6	Inappropriate wind pressure for compression of medium	Medium is not be compressed well due to low wind pressure	5	No inspection of wind pressure before running corrugator machine	4	Check wind pressure before running process	6	Create work instruction	120
7	Less frequency of product quality check	Blister defected product are delivered to customers	5	Quality check is conducted every 40 products	6	Check more frequently for every 10-20 product	3	Hide more employees	90
8	Wrong type of paper use	Paper is used incongruent to the setting machine and required order	4	No inspection before use	5	Check required paper conform to the production plan	3	Create work instruction	60
9	Improperly check of viscosity and gel point of adhesive	Viscosity and gel point of glue is not suitable for use	4	No testing adhesive's properties	4	Available manual for adhesive's quality check	3	-	48

Table 4.15: Total RPN Score

Order	Cause	Related Score
1	Inappropriate temperature of paper and angle of nip at corrugating roll	53
2	Inappropriate speed of belt	52
3	Inappropriate thickness of adhesive	51
4	Inappropriate temperature of hot plates	51
5	Inappropriate level of hot plates	49
6	Inappropriate wind pressure for compression of medium	48
7	Low frequency of product quality check	47
8	Wrong type of paper used	46
9	Improper checkup of viscosity and gel point of adhesive	42

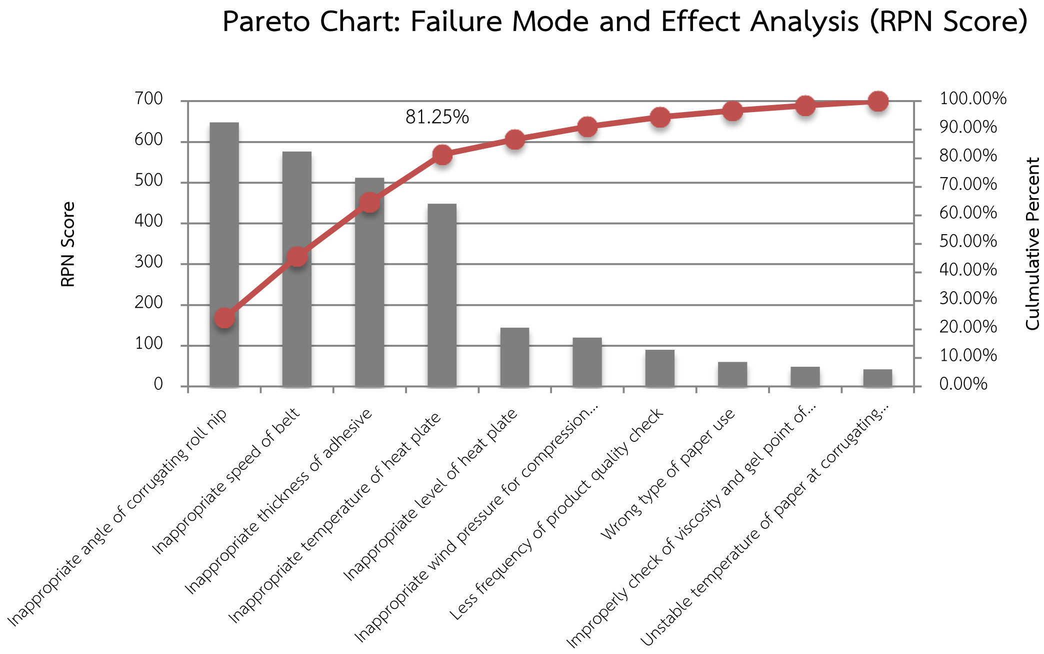


Figure 4.44: Pareto Chart of Failure Mode and Effect Analysis (RPN Score)

From FMEA, **Table 4.15** shows RPN score of each factor and the total RPN score for all ten factors is 2,688. All factors are then sorted in descending order and plotted as shown in Pareto chart shown in **Figure 4.43**, which shows that there are four factors with outstanding RPN score from the total factors. Thus, the factors will be further used for analysis in the next session.

Table 4.16: First Four Ranks of Factors based on RPN, FMEA

Item	Key Process Input	RPN
1	Inappropriate angle of corrugating roll nip	648
2	Inappropriate speed of belt	576
3	Inappropriate thickness of adhesive	512
4	Inappropriate temperature of hot plates	448

Table 4.16 shows the selected factors of the first four ranks according to RPN score including inappropriate angle corrugating roll nip, inappropriate speed of belt, inappropriate thickness of adhesive, and inappropriate temperature of hot plates. The combined RPN of the four factors is counted as 81.25% of the total score.

4.5 Summary

This measure phase started from verifying the capability of measurement system of employees and manufacturing instruments by using Gage Repeatability and Reproducibility (Gage R&R), to contribute data. The observed data were analyzed utilizing Minitab; the assessment agreement result indicated that the measurement system is acceptable. As the assessment percentage of analysis within appraisers, each appraiser versus standard, between appraisers, and all appraisers versus standard are all 100 percent capability proofed.

Next, in order to measure causes of problem in corrugating production process, brainstorming in the team is importantly conducted by dividing causes in to six roots following Cause-and-Effect Diagram and 18 causes were listed. Then all 18 causes were sorted out by using Cause-and-Effect Matrix and FMEA until there are only 9 factors and later final 4 factors were selected according to outstanding score shown in Pareto chart, respectively. The final four factors are Angle of corrugating roll nip, Speed of belt, Thickness of adhesive, and Temperature of hot plates.

CHAPTER 5
ANALYZE PHASE

In this chapter, the four factors selected from the previous chapter utilizing FMEA will be analyzed by using statistical analysis. The analysis will start from establishing hypothesis follow by performing hypothesis testing in order to test and screen which factors significantly cause the problem of blister defect in corrugating production process. The screening will be performed independently on each factor before further performing Design of Experiment (DOE) in the next chapter.

5.1 Hypothesis Testing

The factors from the chapter 4 include (1) Angle of corrugating roll nip, (2) Speed of belt, (3) Thickness of adhesive, and (4) Temperature of hot plates. Each factor will be divided into two levels, a maximum level and minimum level in order to screen figure out the significant factors cause to blister defect.

For hypothesis testing, corrugator will be operated until 1,000 kilogram of corrugated paperboards. The defect product which also include tiny blister on paperboard will be measured in kilogram because as the production runs continuously, inspector may not be able to check and collect all defect products time to time. Thus, measuring in kilogram would be more accurate.

Throughout the experiment of testing each factor, the same type of paper, 125 gram Kraft paper thickness of top liner, bottom liner, and medium from the same supplier will be used. Same materials are used in order to avoid interruption during the experiment as well as to prevent an error that can occurred from using different sort of material. Moreover, most of the defects occur when using 125 gram Kraft paper thickness, the lowest gram of paper used in the factory, due to fineness of the paper which causes difficulty when processing at variety of conditions.

5.2.1 Angle of Corrugating Roll Nip

Corrugating roll nip is a tool used during the beginning of corrugating process for pressing and pulling heated paper before using as a single liner, bottom liner and medium; thus there are three sections of corrugating roll nip. The paper should be pressed at an appropriate temperature as the corrugating roll nip stretches and expands the paper’s pore to be ready for absorption with glue and attachment. According to history record of the company, the angle of corrugating roll nip is set vary between 90 and 180 degrees, where are not clearly difference in result. Therefore, the experiment will be tested by measuring the angle of corrugating nip right at 90 and 180 degree with the same running speed in order to observe the difference of paper between these two levels.

During experimentation, the paper will be set at the angles of 90 and 180 degrees and pressed at the same temperature at 150 degree Celsius. Method of setting angle corrugating roll nip is shown in **Figure 5.45** and **Figure 5.46**, which is 90 degree and 180 degree respectively. The lower bar is fixed while another bar is adjustable; setting the adjustable bar perpendicularly on top of corrugating roll and opposite to the fixed bar will create 90 degree and 180 degree, respectively. For temperature checking, portable equipment is used, shown in **Figure 5.47**, to control to temperature at 150 degree Celsius for both two different angles of corrugating roll nip.

Figure 5.45: Angle of Corrugating Roll Nip at 90 Degree

Figure 5.46: Angle of Corrugating Roll Nip at 180 Degree

Figure 5.47: Portable Equipment for Temperature Checking

Steps of experimenting corrugating production process for different angles of corrugating roll nip

1. Prepare paper roll with the same type follow by the division of paper into two groups, 1,000 kilograms each.
2. Run the experiment under the same machine, the same environment, and the same team of employees for both two groups of testing.
3. Set the angle of corrugating roll nip at 90 degree as one group and 180 degree as the other group as well as check the temperature of the paper on corrugating roll for both angles to be operated at 150 degree Celsius.
4. Start the experiment at two different angles of corrugating roll nip
5. Inspect the blister defect and record the result.

Assumption

$H_0 : P_1 = P_2$; There is no difference between the percentage of blister defect from different angle of corrugating roll nip

$H_1 : P_1 \neq P_2$; There is a difference between percentage of the blister defect from different angle of corrugating roll nip

Where P_1 = percent of blister defect from corrugating roll nip at angle of 90 degree

$P_2 \neq$ percent of blister defect from corrugating roll nip at angle of 180 degree

Table 5.17: Result from Experimenting Corrugating Roll Nip in Different Angles

Corrugating roll nip angle	Amount of sample (kg)	Amount of blister defect (kg)	Percent of blister defect
90	1000	13	1.3%
180	1000	35	3.5%

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       13  1000  0.013000
2       35  1000  0.035000


Difference = p (1) - p (2)
Estimate for difference:  -0.022
95% CI for difference:  (-0.0353804, -0.00861960)
Test for difference = 0 (vs not = 0):  Z = -3.22  P-Value = 0.001

Fisher's exact test: P-Value = 0.002
```

Figure 5.48: Statistical Result from Two Proportions Testing of Corrugating Roll Nip

From Minitab analysis, **Figure 5.48** shows that P-value is 0.002, which is less than 0.05; thus, null hypothesis (H_0) is rejected. Different angles of corrugating roll nip have significant effect on blister defect at 95 percent significant level.

5.2.2 Speed of Belt

Speed of corrugating belt has to be controlled in order to maintain appropriate humidity of the paper along the single liner process. Since the corrugating belt contains heat, high speed is not suitable for the paper with high humidity, while low speed is not proper for the paper with low humidity. Appropriate humidity of the paper is necessary for well attachment; very dehydrated or very moist paper will not be able to absorb glue perfectly. As a result, speed of the corrugating belt needs to be frequently observed along with the humidity of the paper (see **Figure 5.49**). However, normally speed that the company uses is varied around 130 to 140 meters per minute, which is no distinctly difference in defected volume. Thus, the experiment will be performed at 120 and 150 meter per minute to observe the significant difference between these two levels.

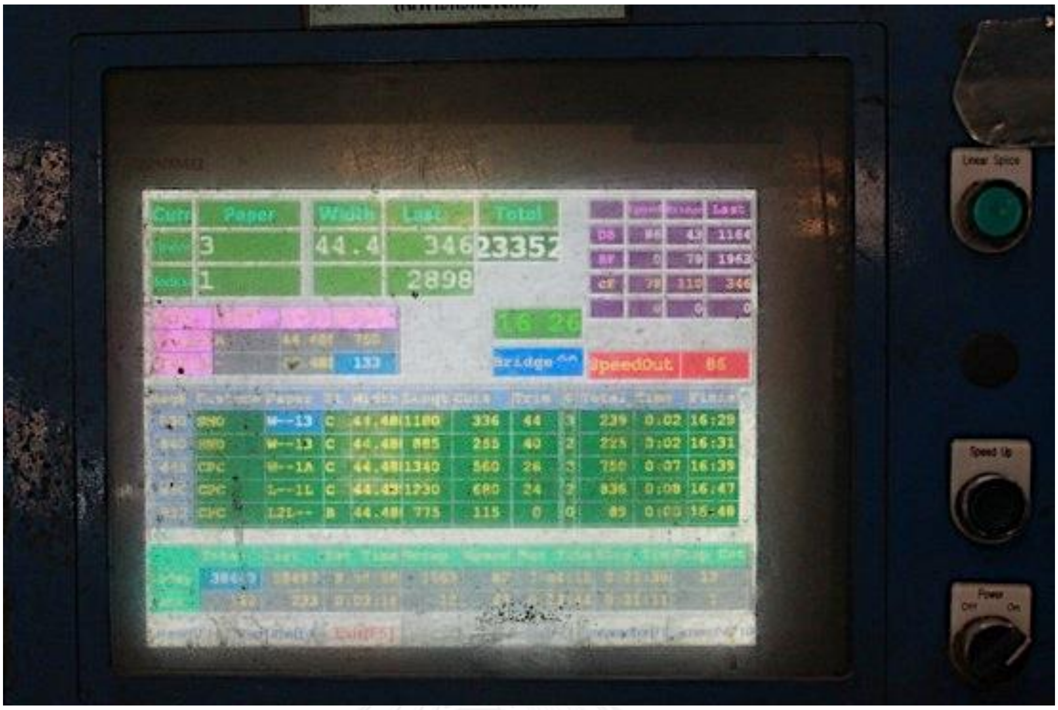


Figure 5.49: Speed Control Monitor

<u>Steps of experimenting corrugating production process for different speeds of belt</u>

1. Prepare paper roll with the same type follow by the division of paper into two groups, 1,000 kilograms each.
2. Run the experiment under the same machine, the same environment, and the same team of employees for both two groups of testing.
3. Set the corrugating belt speed at 120 meters per minute as one group and 150 meters per minute as another group.
4. Start the experiment for two different speeds of corrugating belt.

5. Inspect the blister defect and record the result.

Assumption

$H_0 : P_1 = P_2$; There is no difference between the percentage of blister defect from different speed of belt

$H_1 : P_1 \neq P_2$; There is a difference between the percentage of blister defect from different speed of belt

Where P_1 = percent of blister defect from running belt speed at 120 meter per minute

P_2 = percent of blister defect from running belt speed at 150 meter per minute

Table 5.18: Result from Experimenting Different Speeds of Belt

Speed of belt (m/min)	Amount of sample (kg)	Amount of blister defect (kg)	Percent of blister defect
120	1000	18	1.8%
150	1000	37	3.7%

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       18  1000  0.018000
2       37  1000  0.037000


Difference = p (1) - p (2)
Estimate for difference:  -0.019
95% CI for difference:  (-0.0333100, -0.00468998)
Test for difference = 0 (vs not = 0):  Z = -2.60  P-Value = 0.009

Fisher's exact test: P-Value = 0.013
```

Figure 5.50: Statistical Result from Two Proportions Testing of Speed of Belt

Figure 5.50 shows that P-value of 0.013 is less than 0.05; hence, null hypothesis is rejected. The variation of belt's speed has significant effect on blister defect at 95 percent significant level.

5.2.3 Thickness of Adhesive

To strengthen the adhesion between liners and medium, thickness of the glue or adhesive is the prime factor that influences the outcome. Apart from controlling the speed the corrugator to keep an appropriate level of humidity, glue thickness also has to be controlled. High level of glue thickness may cause blister defect in form of crease, while low level of glue thickness may produce blister defect as a gap between the liners and the medium. Regularly, the company operates the thickness of adhesive varying around 2 to 3 micrometer where there are blister defect remain. Hence, the experiment will be tested at 1 micrometer as the minimum level and 4 micrometer as the maximum level in order to observe significant effect between these two levels.

The thickness of glue can be measured both automatically and manually. The manual checking can be done using adhesive-thickness-measuring device shown in **Figure 5.51.** However, both methods are reported in different units. Automatic measurement can be read and adjusted directly through setting console of the machine. Whereas, manually method need to be performed by contacting the small square scale to rotating glue roll shown in **Figure 5.52**. In this experiment, the thickness of adhesive will be measure manually as described.

Figure 5.51: Adhesive Thickness Measuring Device

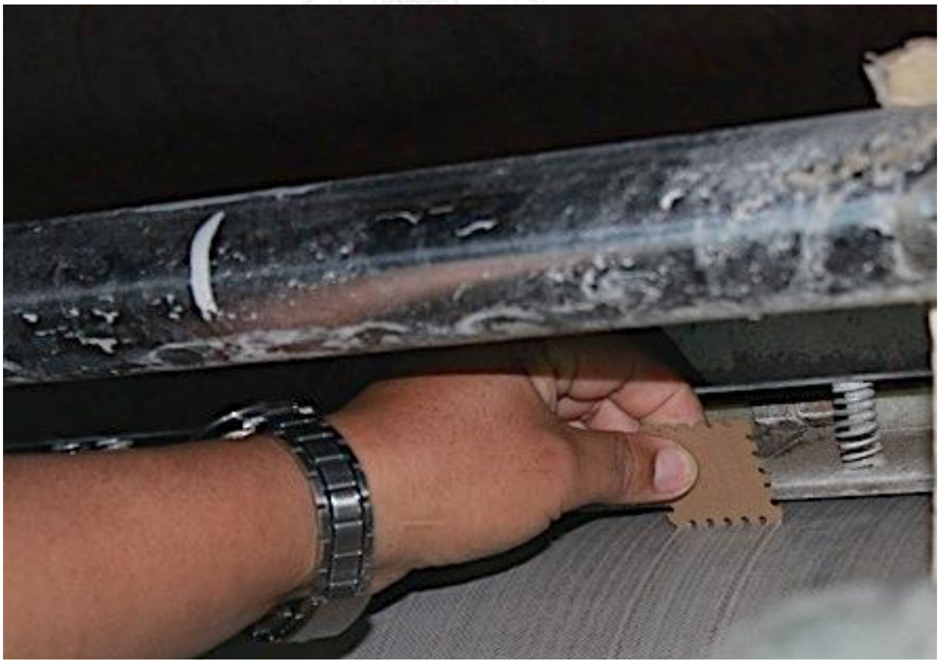


Figure 5.52: Method of Measuring Thickness of Adhesive

Steps of experimenting corrugating production process for different thicknesses of adhesive

1. Prepare paper roll of the same type follow by the division of paper into two groups, 1,000 kilograms each.
2. Run the experiment under the same machine, the same environment, and the same team of employees for both two groups.
3. Measure the thickness of adhesive at 1 micrometer for the first group and 4 micrometer for the second group.
4. Start the experiment at two different temperatures of hot plates.
5. Inspect the blister defect and record the result.

Assumption

$H_0 : P_1 = P_2$; There is no difference between the percentage of blister defect from different thickness of adhesive

$H_1 : P_1 \neq P_2$; There is a difference between the percentage of blister defect from different thickness of adhesive

Where P_1 = percent of blister defect from using 1 micrometer thickness of adhesive

P_2 = percent of blister defect from using 4 micrometer thickness of adhesive

Table 5.19: Result from Experimenting Adhesive in Different Thicknesses

Thickness of adhesive (μm)	Amount of sample (kg)	Amount of blister defect (kg)	Percent of blister defect
1	1000	20	2.0%
4	1000	39	3.9%

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       20  1000  0.020000
2       39  1000  0.039000


Difference = p (1) - p (2)
Estimate for difference:  -0.019
95% CI for difference:  (-0.0338077, -0.00419235)
Test for difference = 0 (vs not = 0):  Z = -2.51  P-Value = 0.012

Fisher's exact test: P-Value = 0.017
```

Figure 5.53: Statistical result from two proportions testing of thickness of adhesive

Figure 5.53 indicates that P-value is 0.017 which is less than 0.05; therefore, null hypothesis is rejected. Different thicknesses of adhesive have significant effect on blister defect at 95 percent significant level.

5.2.4 Temperature of Hot Plates

Hot plates are the last section of corrugating production process before performing slotting and scoring. Hot plate zone is located right after the assembly between liners and medium is finished. Hot plates are divided into three sections adjusted at different temperature in order to cool down the corrugated paperboard to normal or atmospheric temperature in orderly manner.

The testing temperature will be set firstly at the first section and slightly reduced automatically as the paperboard enters the next section. The temperature can be observed by the digital gauges shown in the **Figure 5.54**. Generally, temperature is controlled vary between 135 to 145 degree Celsius and the defect volume is no outstanding difference. Therefore, the experiment will be executed temperature of heat plate at 120 degree Celsius as the minimum level and 150 degree Celsius as the maximum level in order to observe the change in result between these two levels

Figure 5.54: Digital Gauge for Temperature of Hot Plates

<u>Steps of experimenting corrugating production process for different temperatures of hot plates</u>

1. Prepare paper roll of the same type follow by the division of paper into two groups, 1,000 kilograms each.
2. Run the experiment under the same machine, the same environment, and the same team of employees for both two groups.
3. Set the temperature of hot plates at 120 degree Celsius for one group and 150 degree Celsius for another group at the first station.

4. Start the experiment at two different temperatures of hot plates.
5. Inspect the blister defect and record the result.

Assumption

$H_0 : P_1 = P_2$; There is no difference between the percentage of blister defect from different temperatures of hot plates

$H_1 : P_1 \neq P_2$; There is a difference between the percentage of blister defect from different temperatures of hot plates

Where P_1 = percent of defected product from hot plates at 120 degree Celsius

P_2 = percent of defected product from hot plates at 150 degree Celsius

Table 5.20: Result from Experimenting Hot Plates in Different Temperatures

Temperature of hot plates (°C)	Amount of sample (kg)	Amount of blister defect (kg)	Percent of blister defect
120	1000	22	2.2%
150	1000	41	4.1%

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       22  1000  0.022000
2       41  1000  0.041000


Difference = p (1) - p (2)
Estimate for difference:  -0.019
95% CI for difference:  (-0.0342871, -0.00371291)
Test for difference = 0 (vs not = 0):  Z = -2.44  P-Value = 0.015

Fisher's exact test: P-Value = 0.021
```

Figure 5.55: Statistical Result from Two Proportions Testing of Temperature of Hot Plates

Figure 5.55 shows that P-value is 0.021, which is less than 0.05; thus, null hypothesis is rejected. Therefore, different temperatures of hot plates have significant effect on blister defect at 95 percent significant level.

5.2 Summary

In analyze phase, the factors defined the measure phase which include corrugating roll nip angle, speed of belt, thickness of adhesive, and temperature of hot plates were analyzed and verified to conclude the possibility of causing the blister effect at different conditions.

The factors were analyzed through hypothesis testing by two proportions method using Minitab. Each factor has different assumption in order to compare and analyze the data at two different levels. The result drawn from hypothesis testing is that all the four factors influence the blister defect in corrugating process at 95 percent significant level.

CHAPTER 6
IMPROVE PHASE

Since the analysis in analyze phase ensure that the factors including Angle of corrugating roll nip, Speed of belt, Thickness of adhesive, and Temperature of hot plates potentially affect the blister defect, which is the major problem in corrugating process. In this phase, improvement of corrugating system will be implemented in order to find out the best option on the factors creating the least portion of blister defect. The method is to create *Design of Experiment (DOE)*, analyze the data, and search for the optimum condition on each factor.

6.1 Input factors and levels

Input factors that will be used in DOE are the four factors that are analyzed and confirmed to significantly affect the blister defect occurrence, these factors are Angle of corrugating roll nip, Speed of belt, Thickness of adhesive, and Temperature of hot plates. All factors will be divided into two levels (low level and high level), which are the regular levels operated currently in the factory, shown in **Table 6.21**.

Table 6.21: Factors and Levels of Design of Experiment

Order	Factors affect Blister Defect	Low Level	High Level	Unit
1	Angle of corrugating roll nip	90	180	degree
2	Speed of belt	120	150	m/min
3	Thickness of adhesive	1	4	μm
4	Temperature of hot plates	120	150	℃

The input factors and the levels of the factors are created as notations and codes as shown in **Table 6.22** for running the experiment.

Table 6.22: Assume Factors Symbol and Coded Level of Factors

Order	Factors affect Blister Defect	Symbol	Low Level	High Level
1	Angle of corrugating roll nip	A	-1	1
2	Speed of belt	B	-1	1
3	Thickness of adhesive	C	-1	1
4	Temperature of hot plates	D	-1	1

6.2 Experimentation Method

In this Design of Experiment, Full Factorial Design will be used as to define the main effect of factors, interaction effect among factors, and to demonstrate how the factors may be presented graphically. With four-factor and two levels full factorial design, there will be 2^4 or 16 runs, with 2 replications; thus 32 runs are randomly shown in the **Table 6.23**. Employees who are experienced in setting machine and truly understand the objective of the experiment take the responsibility to execute the experiments. The same type of paper of 125 gram Kraft paper thickness for all top liner and bottom liner, and medium are used during the experiment, as these are the lowest grams of paper of each part that require accuracy of setting machine. Lack of awareness in setting and controlling the corrugator machine would easily cause the blister defect. Amount of blister defect is counted in a proportion from total running 1,000 kilograms of papers.

6.3 Result of Experiment

Since all 48 experiments were run respectively to “Run Order” through randomly full factorial experimental design, the proportions of response or blister defect were calculated showing in the rightmost column in **Table 6.23**.

Table 6.23: Random Full Factorial Design of Experiment

StdOrder	RunOrder	CenterPt	Blocks	A	B	C	D	Blister Defect
1	1	1	1	-1	-1	-1	-1	0.0105
16	2	1	1	1	1	1	1	0.0328
7	3	1	1	-1	1	1	-1	0.0180
26	4	1	1	1	-1	-1	1	0.0263
25	5	1	1	-1	-1	-1	1	0.0118
23	6	1	1	-1	1	1	-1	0.0166
20	7	1	1	1	1	-1	-1	0.0296
22	8	1	1	1	-1	1	-1	0.0290
2	9	1	1	1	-1	-1	-1	0.0254
9	10	1	1	-1	-1	-1	1	0.0113
29	11	1	1	-1	-1	1	1	0.0133
19	12	1	1	-1	1	-1	-1	0.0158
27	13	1	1	-1	1	-1	1	0.0169
18	14	1	1	1	-1	-1	-1	0.0247
32	15	1	1	1	1	1	1	0.0330
6	16	1	1	1	-1	1	-1	0.0277

StdOrder	RunOrder	CenterPt	Blocks	A	B	C	D	Blister Defect
3	17	1	1	-1	1	-1	-1	0.0155
12	18	1	1	1	1	-1	1	0.0294
28	19	1	1	1	1	-1	1	0.0309
14	20	1	1	1	-1	1	1	0.0274
4	21	1	1	1	1	-1	-1	0.0290
11	22	1	1	-1	1	-1	1	0.0167
10	23	1	1	1	-1	-1	1	0.0260
15	24	1	1	-1	1	1	1	0.0201
31	25	1	1	-1	1	1	1	0.0178
5	26	1	1	-1	-1	1	-1	0.0131
30	27	1	1	1	-1	1	1	0.0267
17	28	1	1	-1	-1	-1	-1	0.0106
13	29	1	1	-1	-1	1	1	0.0132
21	30	1	1	-1	-1	1	-1	0.0124
8	31	1	1	1	1	1	-1	0.0326
24	32	1	1	1	1	1	-1	0.0317

6.4 Checking Residuals

Firstly, before analyzing results from the experiment, the response needs to be checked for residuals in order to make sure that the assumptions of the experiment are not out of line with any conclusions. All Residual Plots are developed using Minitab through **Figure 6.56** to **Figure 6.58**.

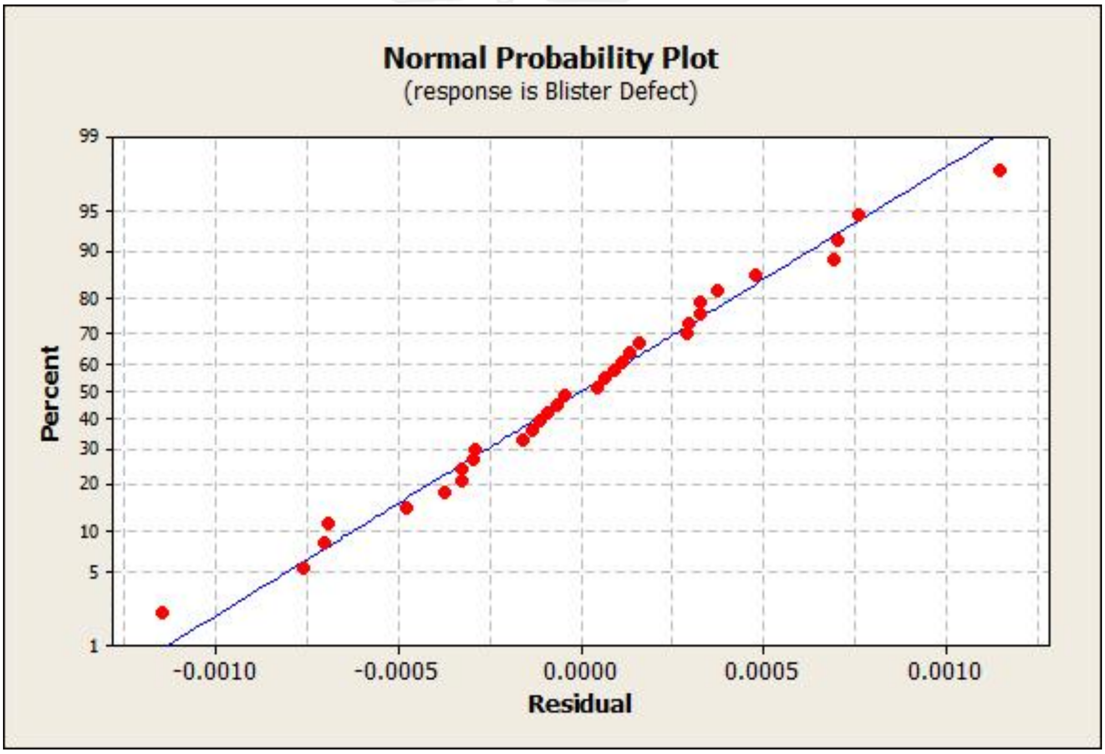


Figure 6.56: Normal Probability Plot of Blister Defect

Normal Probability Plot

To prove that the data has a normal distribution, the residual of the data must act accordingly. Normal Probability Plot shown in **Figure 6.56** verifies that residuals of blister defect have a normal distribution as represented as a location of a random data (red dots) along the blue line.

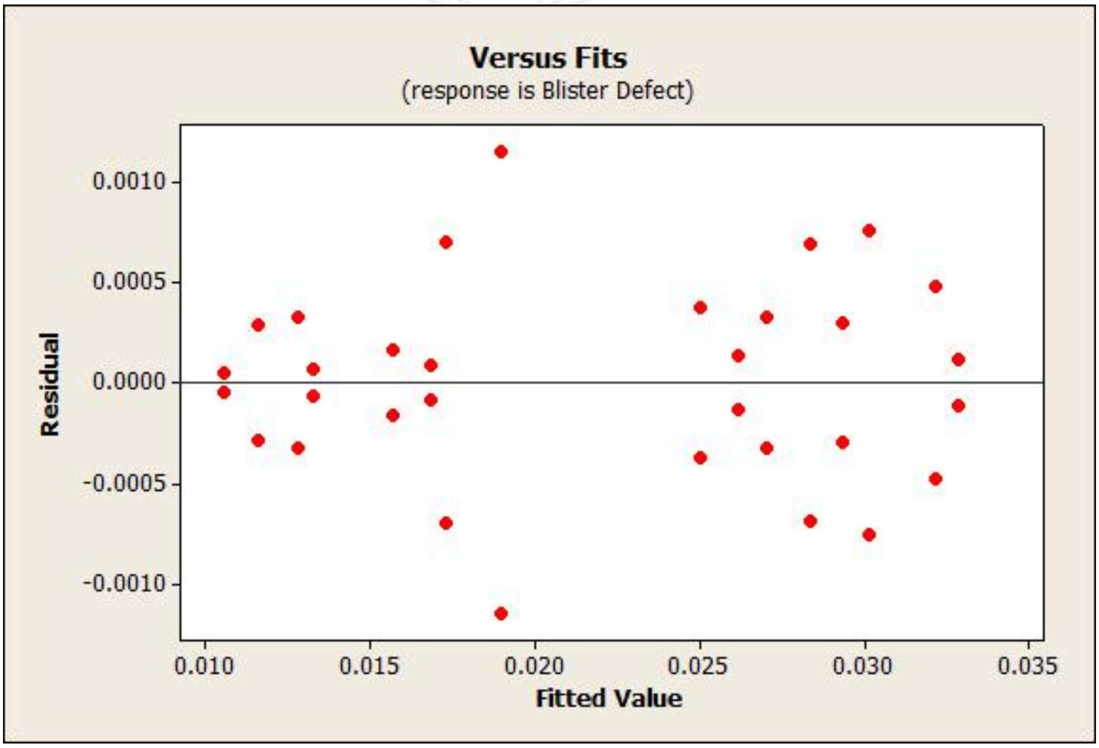


Figure 6.57: Residual Versus Fitted Value of Blister Defect

Variance Stability

Plot of the residuals versus fitted value of the experiment data shown in **Figure 6.57** illustrates that points on the graph are scattered randomly and symmetrically by the standardized residuals line at zero. No cluster on either side of graph and no pattern visible indicates that residuals of the blister defect value have stability in **variance.**

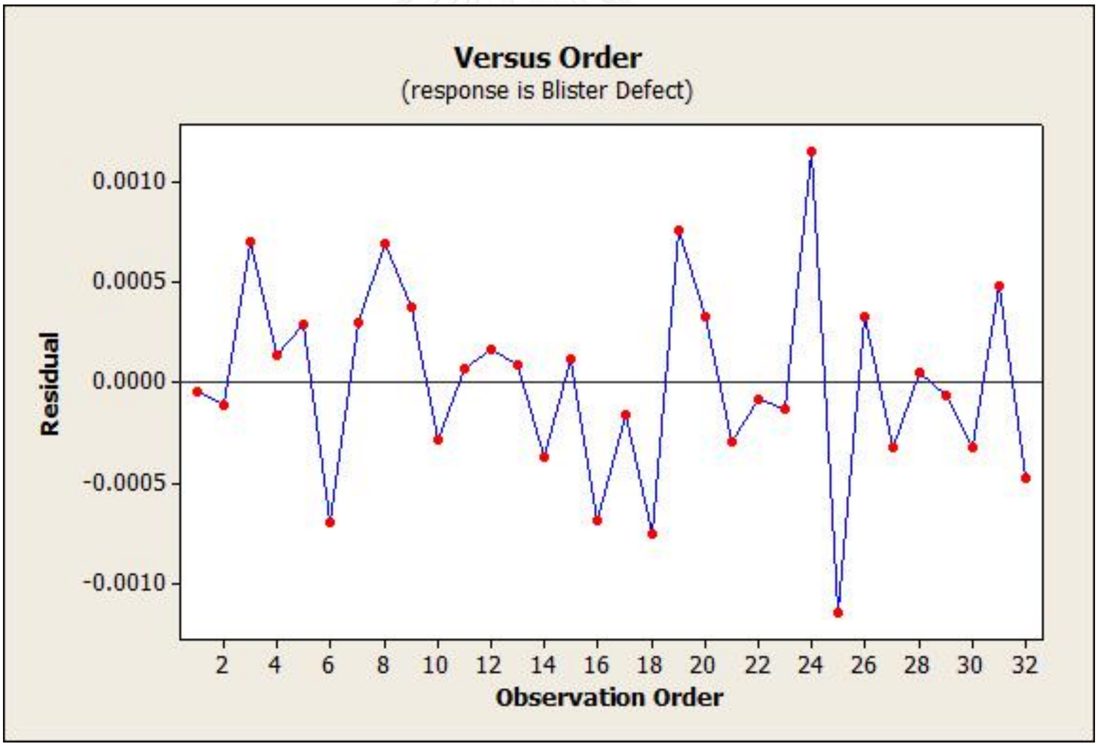


Figure 6.58: Residual Versus Observation Order of Blister Defect

Independent of Residuals

Plot of the residuals versus observation order of the experiment data shown in **Figure 6.58** demonstrates that residuals are randomly scattered over and under standardized residuals line at zero with an unpredictable trend. Non-pattern form of the plot seen as fluctuations, alternately located in positive side and negative side imply that the residuals of the blister defect data are independent.

The accuracy analysis of the experiment has found that residuals are normally distributed, stable in variance, and independent. Therefore, data of the designed experiment can be use for the further analysis.

6.5 Analysis of Response

Normal plot of the standardized effects is shown in **Figure 6.59**. The independent main factors that significantly affect blister defect are A, B, C, and D which represent Angle of the corrugating roll nip, Speed of belt, Thickness of adhesive, and Temperature of hot plates, respectively. While two-way and three-way interactions are not performed indicates that only the main factors independently cause the blister defect.

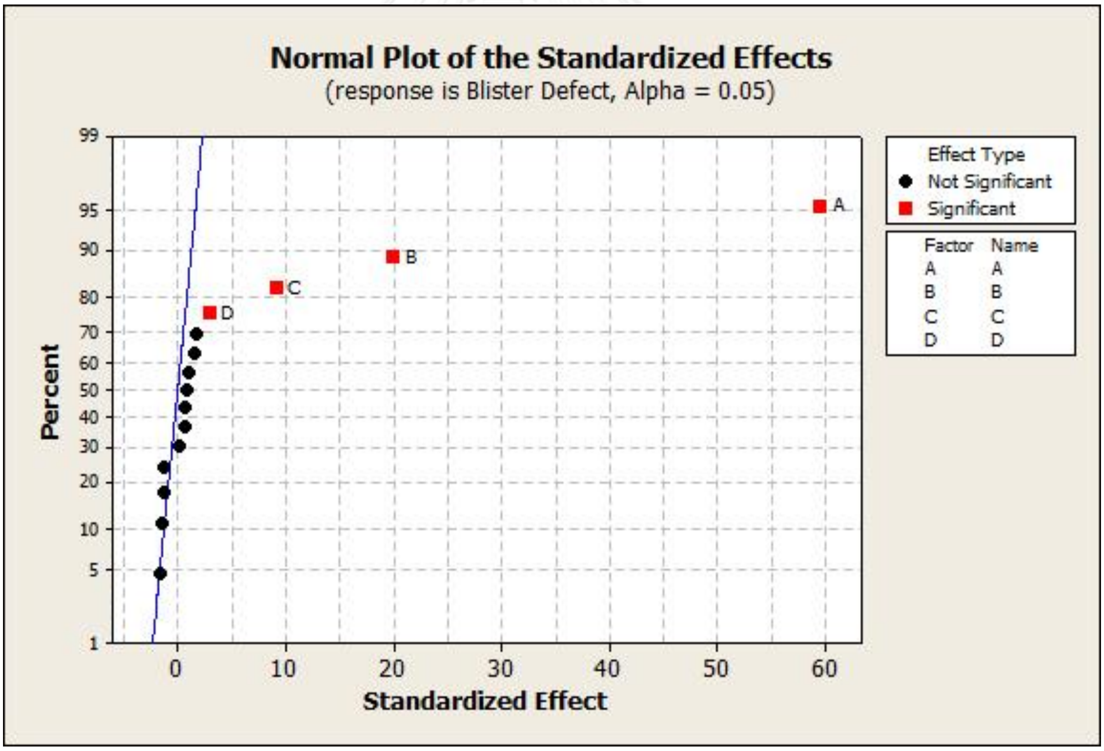


Figure 6.59: Normal Plot of the Standardized Effects

Pareto Plot shown in **Figure 6.60** demonstrates descending order of independent factors causing the blister defect at 0.05 confidence interval according to 80/20 rule of Pareto principle, which are A, B, C, and D, respectively.

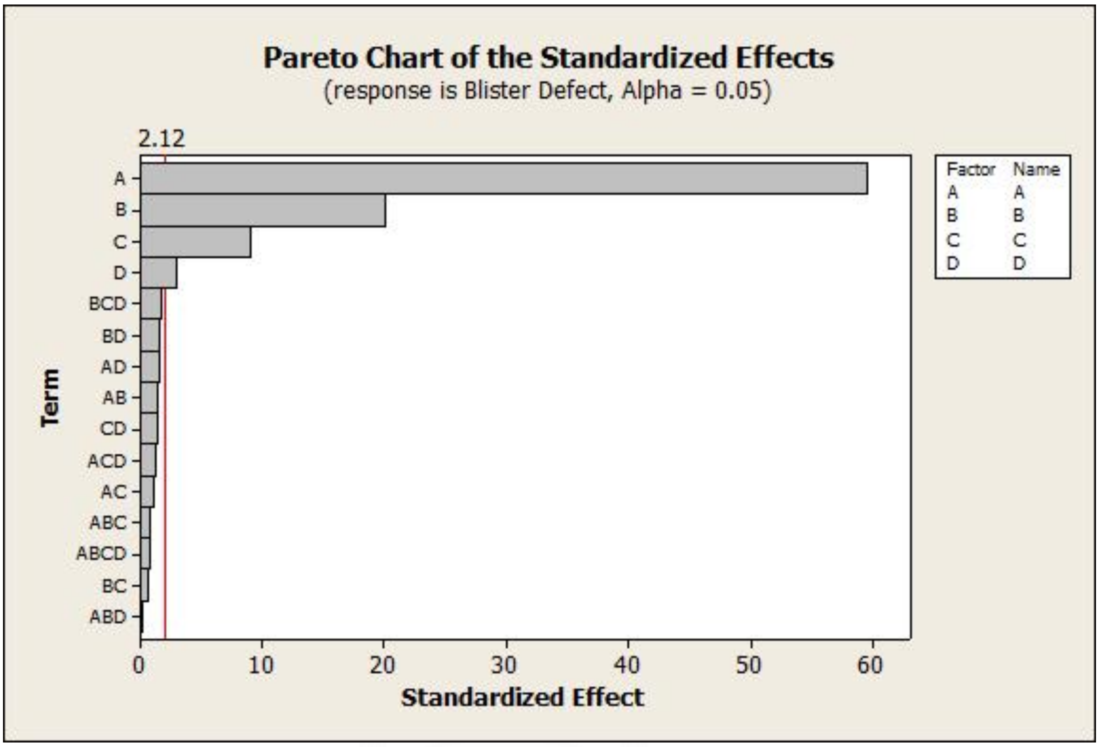


Figure 6.60: Pareto Chart of the Standardized Effects

To confirm the observed results from earlier Standardized Effects plots, **Figure 6.61** shows the analysis result of the designed factorial experiment with two replications using Minitab. The result is analyzed by determining P-value of the main effects and other interactions; P-value of less than 0.05 indicates that the factor causes the problem. The P-value of angle of corrugating roll nip, speed of belt, and thickness of adhesive are all show 0.000, and P-value of Temperature of hot plates is

0.010, which all results are apparently less than 0.05. As a result, the factors are all importantly affecting blister defect of corrugating production process.

For interactions between two factors as well as among three factors, P-values are totally over 0.05. Therefore, two-way and three-way interactions are not significantly affecting blister defect of corrugating production process at 95 percent confidence interval.

Analysis of the P-value conforms to the result observed by Pareto Chart. Descending sort of the P-value shows that A, B, C, and D are the main factors significant to the cause of blister defect respectively.

Analysis of Variance for Blister Defect (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	0.00185964	0.00185964	0.00046491	1009.55	0.000
A	1	0.00163290	0.00163290	0.00163290	3545.82	0.000
B	1	0.00018484	0.00018484	0.00018484	401.39	0.000
C	1	0.00003795	0.00003795	0.00003795	82.40	0.000
D	1	0.00000395	0.00000395	0.00000395	8.57	0.010
2-Way Interactions	6	0.00000468	0.00000468	0.00000078	1.69	0.187
A*B	1	0.00000090	0.00000090	0.00000090	1.95	0.182
A*C	1	0.00000053	0.00000053	0.00000053	1.15	0.299
A*D	1	0.00000110	0.00000110	0.00000110	2.38	0.143
B*C	1	0.00000019	0.00000019	0.00000019	0.41	0.529
B*D	1	0.00000113	0.00000113	0.00000113	2.46	0.136
C*D	1	0.00000083	0.00000083	0.00000083	1.80	0.199
3-Way Interactions	4	0.00000252	0.00000252	0.00000063	1.37	0.288
A*B*C	1	0.00000029	0.00000029	0.00000029	0.63	0.438
A*B*D	1	0.00000001	0.00000001	0.00000001	0.03	0.868
A*C*D	1	0.00000077	0.00000077	0.00000077	1.67	0.215
B*C*D	1	0.00000145	0.00000145	0.00000145	3.15	0.095
4-Way Interactions	1	0.00000023	0.00000023	0.00000023	0.51	0.487
A*B*C*D	1	0.00000023	0.00000023	0.00000023	0.51	0.487
Residual Error	16	0.00000737	0.00000737	0.00000046		
Pure Error	16	0.00000737	0.00000737	0.00000046		
Total	31	0.00187444				

Figure 6.61: Analysis of Variance for Blister Defect

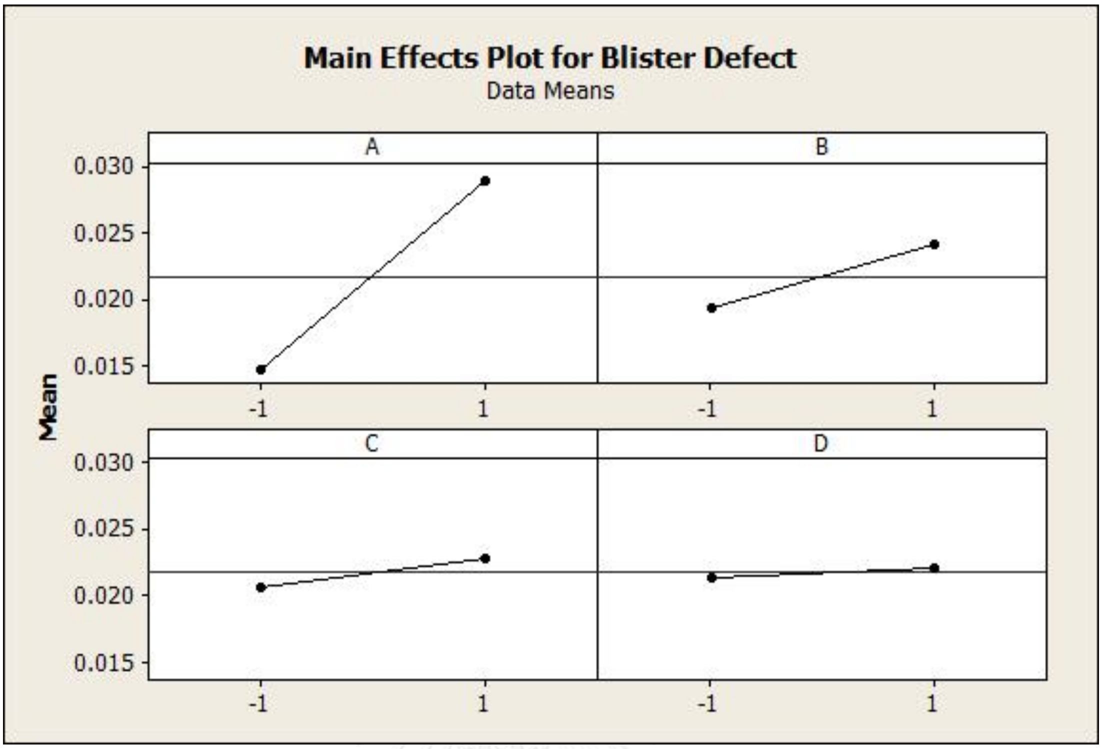


Figure 6.62: Main Effect Plot for Blister Defect

Minitab result shown in **Figure 6.62** presents the main factors that create the blister defect in corrugating production process in different setting condition. Comparing between low and high level of each factor, angle of corrugating roll nip (A), speed of belt (B), thickness of adhesive (C), and temperature of hot plates (D) are all satisfied at low level. Level of angle of corrugating roll nip at 90 degree achieves outstandingly lesser defects compared to angle at 180 degree, as well as, speed of belt at the lower rate of 120 meter per minute, adhesive at thickness of 1 micrometer, and temperature of hot plates of 120 degree Celsius are the optimal alternative as these conditions present less amount of defect. There is a slight difference between setting temperature of hot plates at 120 or 150 degree Celsius; however, 120 degree Celsius is the better option.

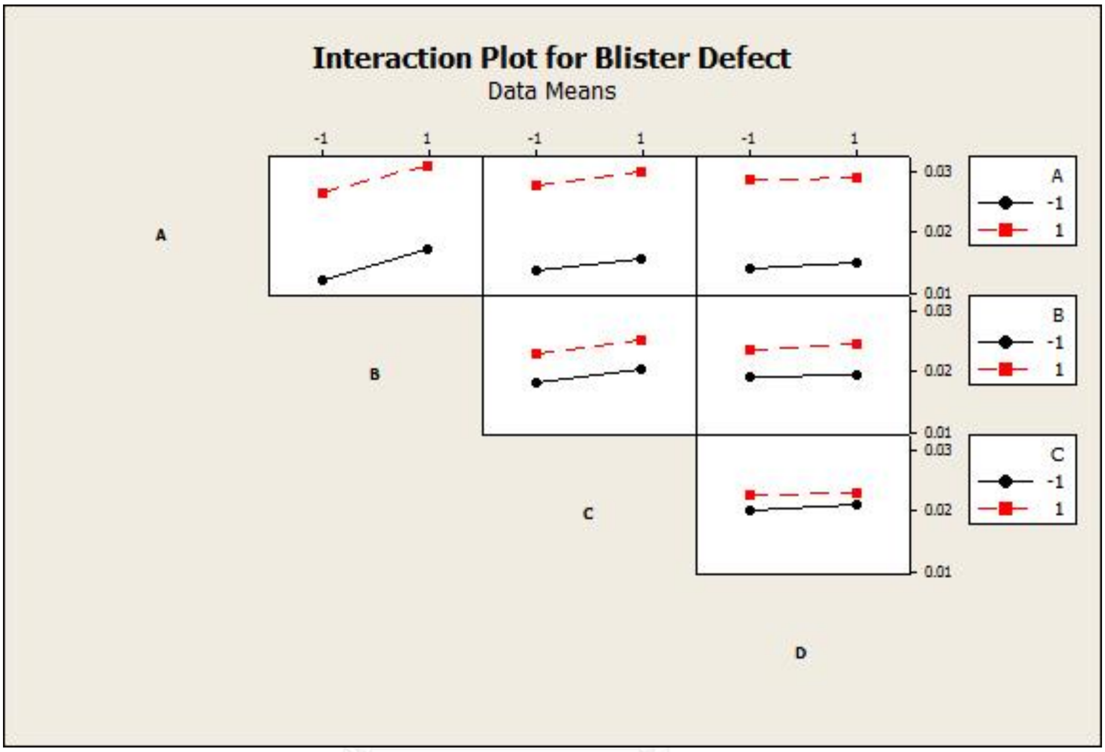


Figure 6.63: Interaction Plot for Blister Defect

Interaction plot shown in **Figure 6.63** illustrates that there are no interaction among the factors as there are no cross intersection of the lines.

From analyzing result of the response, blister defect, summary can be performed as shown in **Table 6.24** that optimum condition creating the least problem for angle of corrugating nip, speed of belt, thickness of adhesive, and temperature of hot plates is low level of 90 degree of corrugating roll nip's angle, 120 meter per minute of speed, 1 micrometer of adhesive thickness, and 120 degree Celsius respectively.

Table 6.24: Optimum Condition of Setting Corrugator

Factor	Optimum Coded Condition	Optimum Condition
Angle of corrugating roll nip	-1	90 degree
Speed of belt	-1	120 m/min
Thickness of adhesive	-1	1 μm
Temperature of hot plates	-1	120 °C

6.6 Test Confirmation

Since the result of DOE has demonstrated that the optimum combination condition for operation in achieving lower amount of blister defect done by setting all the four factors at low level. In order to confirm the outcome, the optimum combination condition of setting 90 degree of corrugating roll nip angle, 120 meter per minute of speed, 1 micrometer of thickness of adhesive, and 120 degree Celsius of hot plate's temperature, will be performed for 25 days with use of 125 gram Kraft paper thickness. Then record the volume of blister defect during the operation days and observe change. The data will be demonstrated as a control chart in the next chapter.

6.7 Summary

Since all four factors including angle of corrugating roll nip, speed of belt, thickness of adhesive, and temperature of hot plates were proved the true causes of blister defect, the full factorial design of experiment with two replications was implemented in order to search for the main factors and/or interaction among the factors based on the response, as well as find out the optimum option on each factor. 48 experiments were run; main four factors are significant to the problem. The optimum condition for the factors is 90 degree of corrugating roll nip, 120 meter per minute of belt’s speed, 1 micrometer of glue’s thickness, and 120 degree Celsius of hot plates.

CHAPTER 7
CONTROL PHASE

Operations from the define phase through the improve phase have indicated real main factors causing blister defect as well as optimum condition of each factor creating appropriate solution for improvement in the corrugating production process. Control phase is the last step in DMAIC Six Sigma Approach aims to apply a method to solve the problem, to implement, and to control in order to maintain improved result of the corrugating production process.

7.1 Control Plan

In order to control corrugating production process based on the optimize options as studied, all factors including angle of corrugating roll nip, speed of belt, thickness of adhesive, and temperature of hot plates have to be performed under the procedure as follow:

Angle of corrugating roll nip

Setting angle for corrugating roll nip can be done easily by hand, normally it is set by using two bars enclosing corrugating roll. To adjust the angle to 90 degree, one bar is fixed at the bottom left, thus another movable bar has to be set right above the corrugating roll perpendicular to the ground.

The angle of the corrugating nip might not always be set at 90 degree due to the variety of order. However, every time the corrugator runs an order using 125 gram Kraft paper thickness for liners and medium, the corrugating roll nip has to be set at 90 degree. In addition, temperature of papers has to be measured at 150 degree Celsius during the process. Therefore, to ensure the performance, first, control plan and work instruction must be established right at each station of corrugating roll nip (details shown in **Appendix B** and **Appendix C1**, respectively). Secondly, record on setting corrugating roll nip and temperature measurement need to be done by filling in the Check Sheet form (shown in **Appendix D**). The form includes signature of the inspector in order to track back in case any problem occurs. Finally, corrugating process manager has to repeatedly examine the setting and training of the employees regularly.

Speed of belt

Speed of belt helps monitor humidity and temperature within the paper during the operation. Speeds of belt feeding top liner, bottom liner, and the medium have to be set at the same speed. Since lower speed accelerates evaporation of paper moisture and faster speed makes level of paper's humidity uncontrollable, the optimum alternative is setting the speed at 120 degree Celsius at all time during the corrugating process as experimented earlier.

To guarantee that the speed at this rate will be performed throughout the corrugated paperboard manufacturing process, first, control plan has to be created at the control panel or speed setting console (details shown in **Appendix B**). Secondly, corrugating production manager has to inspect speed at each station during the operation. Inspectors responsible for setting speed need to fill the information in the form and take any note if needed. Finally, training is necessary and should be carried out regularly.

Thickness of adhesive

Thickness of adhesive is one of the important factors that affect attachment between top liner, medium, and bottom liner to form a completed single wall corrugated paperboard. Very thin glue layer may turn into a case of no glue and create incomplete attachment leaving a gap between liners and medium, whereas very thick glue layer may cause crumple, either way leads to the incidence of blister defect. Hence, the most appropriate thickness of adhesive is 1 micrometer as proved in the previous section.

Control plan and work instruction (details shown in **Appendix B** and **Appendix C2**, respectively) is truly important and needs to be constructed in order to control the standard of measuring thickness of adhesive of 1 micrometer throughout the corrugating process. In addition, inspection has to be done frequently using tiny square measure equipment as shown in the **Figure 5.51** (Chapter 5) and any adjustment can be done by setting automatically. Apart from following the control plan, every inspection of thickness of adhesive needs to be noted down in order to keep track in case of any change that may occur during the operation. Lastly, training is also important and needs to be arranged in order to ensure accuracy and precision of the adhesive's thickness measurement.

Temperature of hot plates

Hot plates is the station right after the top liner, medium, and bottom liner are all assembled. Temperature of hot plates has to be set appropriately and monitored accordingly while the heat within the corrugated paperboard cools down to normal temperature. Once at the normal temperature, the corrugated paper is prepared for slotting and scoring, then stacked for bundling.

The setting needs to follow the control plan and wok instruction (details shown in **Appendix B** and **Appendix C3**, respectively) in order to maintain the optimum condition of temperature throughout the hot plates stations as well as to conduct the dryness at appropriate level.

7.2 Control Chart

After the adjustment of blister defect corresponding to the setting of factors done by following DMAIC Six Sigma approach, from define phase, measure phase, analysis phase, improve phase, and control phase, respectively, the improvement of corrugating production process is successfully implemented. The operation needs to be controlled under regulation in order to keep blister defect at appropriate value.

Control chart are plotted as shown in **Figure 7.64** by collecting the amount of blister defect for 25 days. The data are measured in proportion with a batch size of 1,000 meter of corrugated paper. The control chart is in P chart type and presents average defect value at 0.01892 or 1.89% of blister defect. Proportion of the defect in each day is properly controlled between UCL (Upper Center Line) and LCL (Lower Center Line); not reaching higher than UCL and/or lowers than LCL.

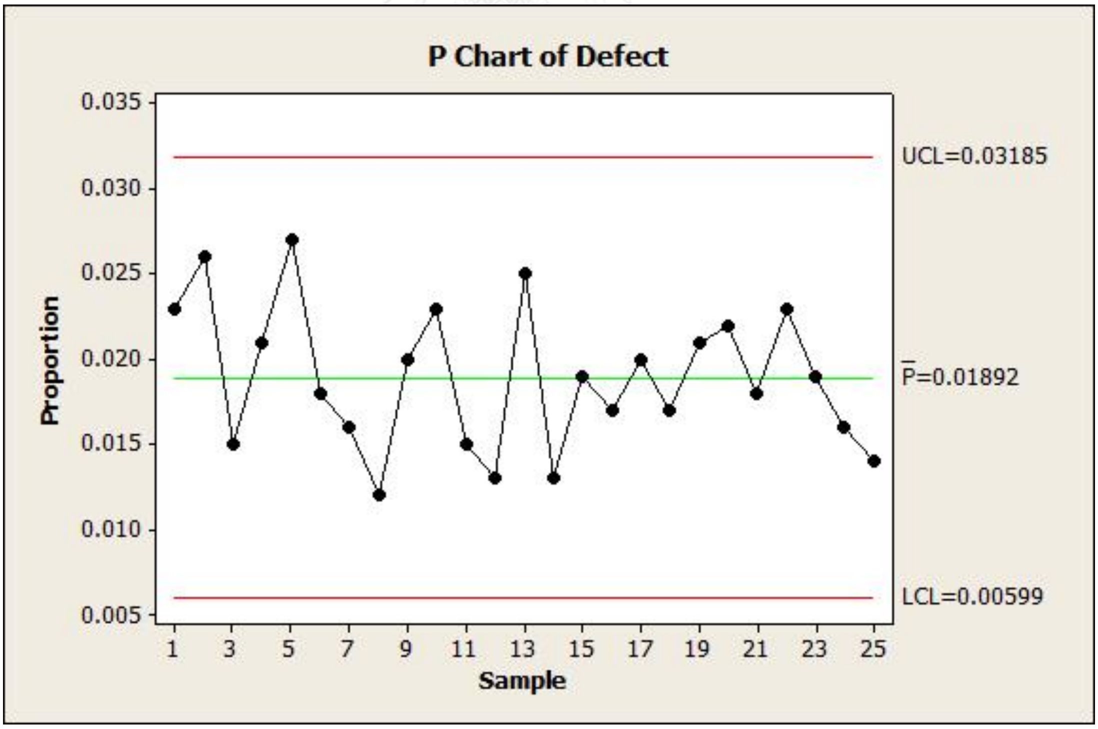


Figure 7.64: Control Chart of Blister Defect During 25 Days of Observation

Table 7.25: Comparison of Result Before and After Improvement

Factor Effects	Before Improvement	After Improvement
Angle of corrugating roll nip (degree)	Not specially identify	90
Speed of belt (m/min)	Not specially identify	120
Thickness of adhesive (μm)	Not specially identify	1
Temperature of hot plates (°C)	Not specially identify	120
Blister Defect (%)	2.87	1.89
Cost (million baht per month)	0.59	0.39

Improvement is clearly seen in **Table 7.25**, showing that blister defect has a significant decrease from 2.87% to 1.89%, which is 34.14% decrease. Moreover, cost of loss is also reduced from approximately 590,000 baht per month to 390,000 baht per month, which is a reduction of 200,000 baht per month or roughly 2.4 million baht per year.

7.3 Summary

The improvement operated in the improve phase achieved the optimum condition of each factor and successfully reduced the blister defect to low level. Control phase is the important step applied to manage and sustain the low percentage of blister defect. As a result, control plans were constructed for all four factors including angle of corrugating roll nip, speed of belt, thickness of adhesive, and temperature of hot plates.

Moreover, control chart was also updated to monitor stability of the blister defect and eliminate any special causes that may appear outside the control limits.

CHAPTER 8
CONCLUSIONS

This research proposes and applies DMAIC Six Sigma Approach including Define Phase, Measure Phase, Analyze Phase, Improve Phase, and Control Phase to solve the problem of blister defect in corrugating production process.

According to the result following the DMAIC Six Sigma method, there are four major factors that affect blister defect, which are Angle of corrugating roll nip, Speed of belt, Thickness of Adhesive, and Temperature of hot plates. Full Factorial Design of Experiment indicates that optimum condition for the angle of corrugating roll nip, speed of belt, thickness of adhesive, and temperature of hot plates is 90 degree, 120 meter per minute, 1 micrometer, and 120 degree Celsius, respectively. Implementation of all optimum condition of the factors creates a great improvement by reduction of blister defect from 2.87% to 1.89%. Conclusions in detail of each phase are performed as follow.

8.1 Conclusion of Define Phase

In define phase, studies on production process of the industry are done and weekly data of total defect during February to March 2014 are collected. Percentage of defect is used as the indicator in this research. All of the defects are categorized and sorted by Pareto Plot with an observation that the largest amount of defect in the corrugated production line is corrugating process. Among four types of defect, the greatest defect occurred is blister defect. Therefore, improvement will be focused on reducing amount of blister defect in corrugation production process.

8.2 Conclusion of Measure Phase

Measure phase is divided into three steps of operation. At the beginning, Gage Repeatability and Reproducibility is utilized by selecting three inspectors whom are the knowledgeable employees working directly in the corrugating production process. The testing is performed in order to clarify that measurement system in the studied process is standardize and reliable at 100 percent.

Secondly, brainstorming within the team and listing all possible factors causing the blister defect in corrugating production process using Cause-and-Effect Diagram. A total of 18 causes of defect are performed categorizing into six roots cause including Man, Machine, Material, Method, Measurement, and Environment. The causes are arranged in order based on weighted score in a team using Cause-and-Effect Matrix. Then, 9 factors are sorted out to find important affects that caused blister defect using Pareto Plot. Afterward, the selected 9 factors are analyzed in details following FMEA and ranked based on RPN score. Finally, there are merely four factors remained for analyzing in the next phase. The four factors are Angle of corrugating roll nip, Speed of belt, Thickness of Adhesive, and Temperature of hot plates.

8.3 Conclusion of Analyze Phase

In analyze phase, the factors selected through statistical tools in measure phase, Angle of corrugating roll nip, Speed of belt, Thickness of adhesive, and Temperature of hot plates, are further analyzed, tested and verified for their significance in the occurrence of blister defect.

The analysis is run through Minitab using Hypothesis Testing with two-proportion method, the result clearly proved that the four factors significantly affect the blister defect in corrugating production process in different level at 95 percent confidence interval.

8.4 Conclusion of Improve Phase

Since the factors of Angle of corrugating roll nip, Speed of belt, Thickness of adhesive, and Temperature of hot plates are the cause of blister defect, the four factors are later conducted in Full Factorial Design of Experiment with 2 replications; thus 48 experiments are performed to discover the appropriate level of each factor. The result reports that all the factors significantly affect the blister defect in the corrugating production process. The results show that by setting the conditions at 90 degree of corrugating roll nip, 120 meter per minute of belt, 1 micrometer of adhesive thickness, and 120 degree Celsius of hot plates give the optimum condition.

8.5 Conclusion of Control Phase

The implementation of setting machine in the previous section is successful at reducing blister defect in the corrugating production process. In order to maintain the blister defect at low level, the corrugating production process needs to be controlled by creating a control plan for monitoring the factors including angle of corrugating roll nip, speed of belt, thickness of adhesive, and temperature of hot plates.

Developing working instruction can be a method to control the factors. A form for employees to record data related to the factors as well as training would create consciousness and understanding among the employees. During a month of controlling corrugating production process through the control chart, proportion of the blister defect in each day did not exceed 0.02421 or 2.42% of UCL. This confirmed that by applying DMAIC Six Sigma Approach blister defect can be reduced in corrugating production process efficiently.

8.6 Limitations

This research only experimented on the corrugated paperboard manufacturing process with the use of 125 gram Kraft paper thickness for all top liner, bottom liner, and medium. Therefore, the result of optimum condition of setting the corrugator at 90 degree of corrugating nip, 120 meter per minute of speed, 1 micrometer of glue’s thickness, and 120 degree Celsius of hot plates’ temperature will be limited to the type of paper use, as well as the conditions within the working place.

Moreover, as the optimum condition acquired from performing DOE showing that the speed should be set at 120 meter per minute, which is the lower speed than company’s normal operation, thus cause the subsiding of production capacity. Even though the output is lower but the reduction of defect worth it.

8.7 Obstructions

Some equipment cannot be used during the experimentation. For example, control panel of auto-setting adhesive's thickness. Thus, device for manual measurement has to be use instead, which also caused slowdown in operation.

Some equipment was not kept in place, and required time to find. Hence, created a lose time during the experiment.

Change of climate causes the change of humidity in the paper, which leads to difficulties in experiment of setting temperature at corrugating roll.

8.8 Suggestions

As the company is a small-medium size company case study, readiness is not fully displayed in some parts such as highly experienced and knowledgeable employees, high-tech machine and equipment, and other concerns. Therefore, some of suggestions are shown as follow:

1. Hire more employees who are specialists to take responsibility for inspection and running the corrugating process in order to increase the operation performance and sustain the process improvement.
2. Arrange training more frequently in order to create awareness and encourage existing employees, as well as develop an understanding among the new employees.
3. Fix the nonfunctional machine and equipment to be ready to use, and regularly perform maintenance. Upgrade or purchase new machine or devices beneficial for production performance or improvement.
4. Testing more conditions apart from minimum and maximum levels that have done in this research since the experimented conditions are merely based on the company's history records.

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APPENDIX

Appendix A

Failure Mode and Effect Analysis Criteria

Appendix A1: Severity Evaluation Criteria (Nannikar, 2012)

Effect	Criteria: Severity of Effect on Product	Rank
None	No effect	1
Very Slight	Negligible effect on Performance. Some users may notice	2
Slight	Slight effect on performance; Non-vital faults will be noticed by many users	3
Minor	Minor effect on performance; User is slightly dissatisfied	4
Moderate	Reduced performance with gradual performance degradation; User dissatisfied	5
Severe	Degraded performance, but safe and usable; User dissatisfied	6
High Severity	Very poor performance; Very dissatisfied user	7
Very High Severity	Inoperable but safe	8
Extreme Severity	Probable failure with hazardous effects. Compliance with regulation is unlikely.	9
Maximum Severity	Unpredictable failure with hazardous effects almost certain. Non-compliant with regulations.	10

Appendix A2: Occurrence Evaluation Criteria (Nannikar, 2012)

Likelihood of Failure	Criteria: Occurrence of Cause	Rank
Extremely Unlikely	Less than 0.01 per thousand	1
Remote Likelihood	Approximately 0.1 per thousand rate of occurrence	2
Very Low Likelihood	Approximately 0.5 per thousand rate of occurrence	3
Low Likelihood	Approximately 1 per thousand rate of occurrence	4
Moderately Low Likelihood	Approximately 2 per thousand rate of occurrence	5
Medium Likelihood	Approximately 5 per thousand rate of occurrence	6
Moderately High Likelihood	Approximately 10 per thousand rate of occurrence	7
Very High Severity	Approximately 20 per thousand rate of occurrence	8
Extreme Severity	Approximately 50 per thousand rate of occurrence	9
Maximum Severity	Approximately 100 per thousand rate of occurrence	10

Appendix A3: Detection Evaluation Criteria (Nannikar, 2012)

Likelihood of Detection	Criteria: Likelihood of Detection by Design Control	Rank
Extremely Likely	Can be corrected prior to prototype/ Controls will almost certainly detect	1
Very High Likelihood	Can be corrected prior to design release/Very High probability of detection	2
High Likelihood	Likely to be corrected/High probability of detection	3
Moderately High Likelihood	Design controls are moderately effective	4
Medium Likelihood	Design controls have an even chance of working	5
Moderately Low Likelihood	Design controls may miss the problem	6
Low Likelihood	Design controls are likely to miss the problem	7
Very Low Likelihood	Design controls have a poor chance of detection	8
Very Low Likelihood	Unproven, unreliable design/poor chance for detection	9
Extremely Unlikely	No design technique available/Controls will not detect	10

Appendix B

Control Plan

CONTROL PLAN

Control Plan Number	Key Contact/Phone	Date(Orig)	Date (Rev.)
ABC 101-1	Jaidee K. - Production Engineer E2231	23/10/2013	11/08/2014
Part Number/Latest Change Level	Core Team	Customer Eng. Approval/Date	
N/A	Satorn N., Genggarn B., Patawaong M.	N/A	
Part Name/Description	Organization/Plant Approval/Date	Customer Quality Approval/Date (if Req'd)	
Corrugated Paperboard	07/07/2014	N/A	
Organization/Plant / Organization Code	Other Approval/Date (If Req'd)	Other Approval/Date (If Req'd)	
In-House / N/A	N/A	N/A	

Part/ Process Number	Process Name/ Operation Description	Machine, Device, Jig, Tools, for Mfg.	Characteristics			Special Char. Class	Methods					Reaction Plan
			No.	Product	Process		Product/Process Specification/ Tolerance	Evaluation/ Measurement Technique	Sample		Control Method	
									Size	Freq.		
1	Set the corrugating roll nip at 90 degree	Corrutting roll nip, Portable temperature measuring device		Single-faced Liners, Double-faced Liners	Corrugating process		Place movable nip arm right at on top of the corrugating roll perpendicular to the floor	Nip is completely locked and temperature of the paper is measured at 150 °C with the fixed area at 90 degree	1-3 cut	every 100 cuts	Work instruction	Reinspect and reset temperature or angle of corrugating roll nip if needed
2	Set belt's speed at 120 m/min	Corrugator' control panel			Corrugating process		Belt running at 120 m/s through out the operation	Automatically momitored	1-3 cut	every 100 cuts	Work instruction	Reinspect the speed since the last inspection if needed
3	Measure the glue's thickness at 1 μm	Adhesive thickness measuring device		Single-faced Liners, Double-faced Liners	Corrugating process			Ensure that thickness is applied at 1 μm during the operation	1-3 cut	every 100 cuts	Work instruction	Reinspect and readjust the thickness if needed
4	Control temperature of hot plates at 120 °C	Hot plates' contol panel		Finished corrugated paperboard	Corrugating process			Ensure that temperature is set automatically ahead process running at 120 °C	1-3 cut	every 100 cuts	Work instruction	Reinspect and reset the tempurature if needed

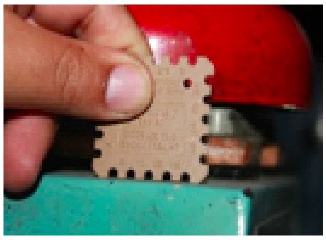
Appendix C

Work Instructions

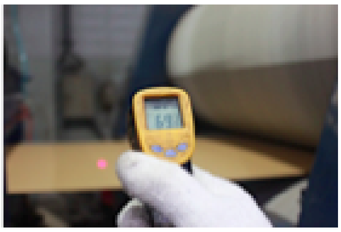
Appendix C1: Work Instruction for Setting Angle of Corrugating Roll Nip

Work Instruction				
Title	Setting angle of corrugating roll nip		**Process/station**	Corrugating roll nip
Last update	12/08/2014		**Responsibility**	Production manager
Step	**Equipment/ tools**	**Description**	**Picture**	
1	N/A	Inspect type of paper before use by checking the tag		
2	Portable humidity checking device	Measure humidity of paper before use		
3	N/A	Check the pressure to be controlled around 7 bar		
4	Folk lift	Place the paper reel in place		
5	N/A	Feed the paper though and lock with corrugating roll nip by move the controllable nip place right at the centre top of the corrugating roll, perpendicular to the floor		
6	Proatable measuring temperature	Meaure temperature of paper exactly at 150 °C		

Appendix C2: Work Instruction for Setting Thickness of Adhesive

Work Instruction				
Title	Setting thickness of adhesive		**Process/station**	Glue
Last update	15/08/2014		**Responsibility**	Production manager
Step	**Equipment/ tools**	**Description**	**Picture**	
1	Adhesive Thickness Measuring Device	Hand the measuring tool and leave the side of the measured unit		
2	Adhesive Thickness Measuring Device	Contact the side of scale to rotating glue roll and observe the thickness		
3	N/A	Adjust the glue amount automatically at the control panel if needed and recheck the thickness		

Appendix C3: Work Instruction for Setting Temperature of Hot Plate

Work Instruction				
Title	Setting temperature of hot plate		**Process/station**	Hot plate
Last update	15/08/2014		**Responsibility**	Production manager
Step	**Equipment/ tools**	**Description**	**Picture**	
1	N/A	Reduce pressure to around 6 bar to drop temperature of the hot plate		
2	Proatable measuring temperature	Measure temperature of paper at the first station of hot plate to confirm that the paper is heated at 120 degree Celsius		

Appendix D

Check Sheets

Appendix D1: Check Sheet for Corrugated Paperboard Process Control (Shift I)

Corrugated PaperBoard Process Control Report (Shift I)													
Duration	Job No.	Vapour Pressure	Paper Reel			Corrugating Roll Nip			Speed of Belt	Temperature of Hot Plates (°C)			Signature
		(7±1 Bar)	Humidity	Grade	Size	Flute B	Flute C	Liners	(m/min)	1	2	3	
						90 degree	90 degree	90 degree					
08.30-09.00													
09.00-09.30													
09.30-10.00													
10.00-10.30													
10.30-11.00													
11.00-11.30													
11.30-12.00													
12.00-12.30													
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13.00-13.30													
13.30-14.00													
14.00-14.30													
14.30-15.00													
15.00-15.30													
15.30-16.00													
16.00-16.30													
16.30-17.00													

Appendix D2: Check Sheet for Corrugated Paperboard Process Control (Shift II)

Corrugated PaperBoard Process Control Report (Shift II)

Duration	Job No.	Vapour Pressure	Paper Reel			Corrugating Roll Nip			Speed of Belt	Temperature of Hot Plates (°C)			Signature
		(7±1 Bar)	Humidity	Grade	Size	Flute B	Flute C	Liners	(m/min)	1	2	3	
						90 degree	90 degree	90 degree					
17.00-17.30													
17.30-18.00													
18.00-18.30													
18.30-19.00													
19.00-19.30													
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02.00-02.30													
02.30-03.00													

VITA

Miss Chanisa Grirasamee was born on 17th, August 1990 in Bangkok, Thailand. She earned her Bachelor of Engineering degree in Nano Engineering from International School of Engineering, Chulalongkorn University in 2012. In June 2012, she started her postgraduate dual-degree program in Engineering Management and Engineering Business Management cooperatively offered Regional Centre for Manufacturing System Engineering, Chulalongkorn University, and Warwick Manufacturing Group, University of Warwick, respectively.