Six Sigma Application for Reduction of the Defective Ratio in Consumer Products Manufacture

by

Ms. Jammaree Jongkautrakul

A Final Report of the Six-Credit Course
CE 6998 - CE 6999 Project

Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science
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Academic Year	November 2004

The Graduate School of Assumption University has approved this final report of the six-credit course, CE 6998 – CE 6999 PROJECT, submitted in partial fulfillment of the requirements for the degree of Master of Science in Computer and Engineering Management.

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ABSTRACT

This project concentrates on how to improve the defective rate of plastic material GPPS (General Purpose polystyrene) of Washing Machine and Refrigerator products in Toshiba Consumer Products (Thailand) Co.,Ltd. by using Six Sigma methodologies.

Six Sigma was recently introduced into Toshiba head office around 1997. In 2001, Toshiba Consumer Products (Thailand) Co.,Ltd. began to introduce Six Sigma within the company by adopting management basic from head office. We found that Six Sigma is extremely effective for quality and productivity innovation for our company.

The core objective of Six Sigma is to improve the performance of processes, by its attempts to achieve three things: the first is to reduce costs, the second is to improve customer satisfaction, and the third is to increase revenue, thereby, increasing profits.

After applying Six Sigma methodologies, the defect rate of GPPS (General Purpose Polystyrene) reduces from 5.77% (COPQ 2.02 MB) in term 03B (Oct'03 — Mar'04) to 2.24% (COPQ 0.99 MB) in term 04A (Apr'04 — Sep'04) less than our target at 4.0%. So we can keep the hard saving 1.02 MB/term in 04A.

Moreover we can improve the process capability after completing Six Sigma methodologies are C_pk additional from 0.48 to 1.22, Z-Bench (Sigma) additional from 1.51 to 3.86, and PPM reduction from 78,116.5 to 87.79.

There are some common industry tools that can give an insight to directions that can be considered a part of Six Sigma measurement and improvement strategy such as POKA-YOKE or Mistake-Proofing, Kaizen or Continuous Improvement, Total Quality Management (TQM), KANBAN, and Lean Manufacturing and Waste Prevention.

ACKNOWLEDGEMENTS

Several people have made contributions to this project. I would like to acknowledge their efforts and thank them for their contributions.

First of all, I would like to thank Dr. Chamnong Jungthirapanich, Dean of School of Computer and Engineering Management, my advisor who has always showed his support, assistance, guidance, and gave me the needed directions to accomplish this project.

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I would like to express my sincere thanks to every one of my classmates for the good time we had together, and who encouraged me in many ways.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

1.1 General Background of the Project

Today's business environment is tough. Consumer products manufactures or the other industries are more competitive. Consumer industry has come under ever increasing market pressures. The key to business success is doing the right thing faster and better and more efficiently than their competitors. They try to efficiently improve by reducing the manufacturing cost including reducing the number of defects in their products and services for their customers.

The sigma capability is a metric that indicates how well that process is performing. The higher the sigma valve the better. Sigma measures the capability of the process to perform defect-free work. A defect is anything that results in customer dissatisfaction. Therefore, to achieve a high Sigma capability, the goal should be to reduce the total number of opportunities for defect and concurrently increase the capability of each opportunity that remains. The Six Sigma approach aims to achieve this. Six Sigma is a methodology to enhance operational quality by improving all the processes using data and statistical methods, problem solving and problem prevention tools to improve customer satisfaction by removing and preventing defects from the process, products, services, documentation, and decisions to a 99.999% level of perfection. Six Sigma methodologies can be classified into 5 phases, which are: Define phase, Measurement phase, Analysis phase, Improvement phase and Control phase.

In early 1997, Toshiba began to introduce Six Sigma within the company. By innovating the operational quality and business processes in focusing customer satisfaction, we established new competitive advantages of Toshiba through the challenge for the destructive creation and the creation of a new corporate culture by all-

employee participation. We believe that Six Sigma is a new strategic paradigm of management innovation for company survival, which implies three things: statistical measurement, management strategy and quality culture. It tells us how good our products, services and processes really are through s tatistical m easurement o f quality level. It is a new management strategy under leadership of top-level management to create quality innovation and total customer satisfaction. It is also a quality culture.

In 2001, Toshiba Consumer Products (Thailand) Co., Ltd. began to introduce Six Sigma within the company by adopting management basics from the head office. The core objective of Six Sigma is to improve the performance of processes. By improving processes, it attempts to achieve three things: the first is to reduce costs, the second is to improve customer satisfaction, and the third is to increase revenue, thereby, increasing profits.

1.2 Significance of the Project

Washing Machines and Refrigerators are the products that are produced by Toshiba Consumer Products (Thailand) Co., Ltd. The aim of this project is to study and apply the Six Sigma concepts and tools to reduce defective ratio of plastic material that is the one of raw materials being used for produce parts. Many grade plastic materials are used for produce parts for example PP, ABS, PE, GPPS, POM, etc., but we found that GPPS (General Purpose Polystyrene) is the main material that caused the highest defective parts. This project will focus on reducing the defective ratio of GPPS materials by applying the Six Sigma methodologies. The reasons for improving the sigma rating of a process are for the product quality improvements, and the goal is to make fewer mistakes in everything you do from manufacturing products, so that the costs go down.

1.3 Objectives of the Project

The objectives of this project are as follows.

(1) To study Six Sigma, the systematic approach to problem solving.

(2) To apply Six Sigma methodologies to take steps necessary to improve the process by reducing the defective ratio.

(3) To learn how the key tools are blended and sequenced to form a scientific and repeatable process for solving critical manufacturing problems.

1.4 Scope of the Project

This project focuses on plastic material of Washing Machine and Refrigerator products in Consumer Manufacture (Toshiba consumer products (Thailand) Co., Ltd.).

1.5 Statement of the Problem

Plastic material is the one of raw materials being used for produced parts in Washing Machine and Refrigerator products. There were many materials to be subsequently used to create various parts. The main materials are PP, ABS, PE, GPPS, and POM.

We found that the highest defective parts are made from material GPPS (General Purpose Polystyrene) for example Cracking, Silver, Weld line, Miss color, etc. The problem statement of this project was defined as the defect ratio of GPPS (General Purpose Polystyrene) 5.77% (COPQ 2.02 MB). We set the objective and target to reduce the defective material GPPS (General Purpose Polystyrene) from 5.77% to 4.0%.

II. LITERATURE REVIEW

2.1 What is Six Sigma?

Sigma (a) is a letter in the Greek alphabet that has become the statistical symbol used to designate the distribution or spread about the mean (average) of any process or procedure. It is used to describe variability, where a classical measurement unit consideration of the program is defects per unit.

Sigma is a statistical unit of measure that reflects process capability. Sigma measures the capability of the process to perform defect-free work; the scale of measure is perfectly correlated to such characteristics as defects-per-unit, parts-per-million defective, and the probability of a failure or error.

For a business or manufacturing process, the **sigma capability** is a metric that indicates how well that process is performing. The sigma is to measure variation and is an indicator of the capability of the processes and quality of the products. The higher sigma quality level value is better. A sigma quality level offers an indicator of how often defects are likely to occur, where a higher sigma quality level indicates a process that is less likely to create defects.

Six Sigma is a methodology to enhance management/operational quality by improving all the processes using data and statistical methods based on customer focusing. A Six Sigma quality level is said to equate to a 3.4 parts per million outside specification limits.

Motorola launched Six Sigma in 1987. It was the result of a series of changes in the quality area starting in the late 1970s, with ambitious ten-fold improvement drives. The top-level management along with CEO Robert Galvin developed a concept called Six Sigma.

In the wake of successes at Motorola, some leading electronic companies such as IBM, DEC, and Texas Instruments launched Six Sigma initiatives in early 1990s.

2.2 Why is Six Sigma Fascinating?

Six Sigma has become very popular throughout the whole world. There are several reasons for this popularity. First, it is regarded as a fresh quality management strategy that can replace TQC, TQM and others. In a sense, we can view the development process of Six Sigma as shown in Figure 2.1.

Six Sigma is viewed as a systematic, scientific, statistical and smarter (4S) approach for management innovation, which is quite suitable for use in a knowledge-based information society. The essence of Six Sigma is the integration of four elements (customer, process, manpower, and strategy) to provide management innovation as shown in Figure 2.2.

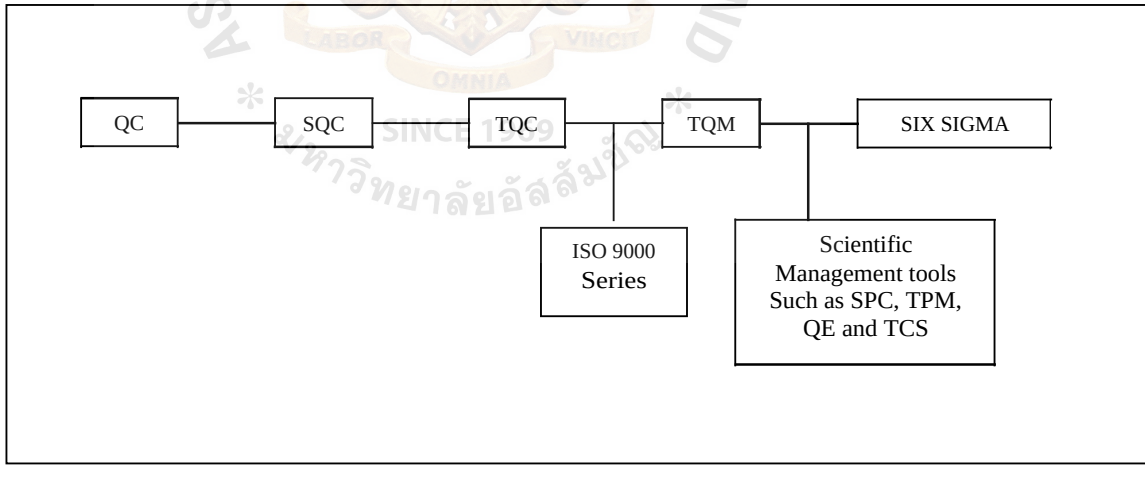


Figure 2.1. Development process of Six Sigma in quality management.

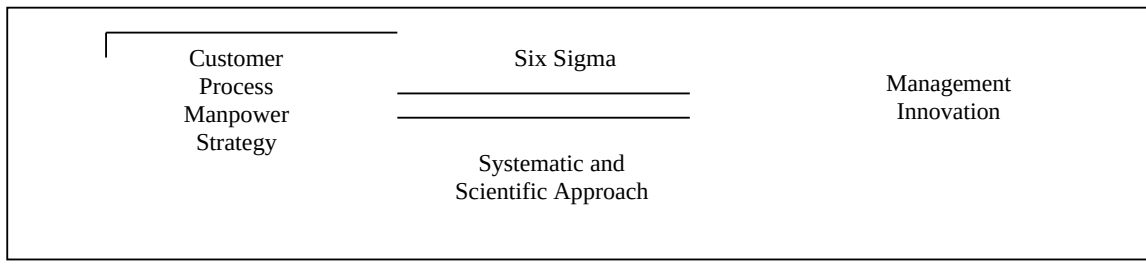


Figure 2.2. Essence of Six Sigma.

2.3 Key Concepts of Management

The core objective of Six Sigma is to improve the performance of processes. By improving processes, it attempts to achieve three things: the first is to reduce costs, the second is to improve customer satisfaction, and the third is to increase revenues, thereby, increasing profits.

2.4 Seven Steps for Six Sigma Introduction

When a company intends to introduce Six Sigma for its new management strategy, we would like to recommend the following seven-step procedures:

(1) Top-level management commitment for Six Sigma is first and foremost. The CEO of the corporation or business unit should genuinely accept Six Sigma as the management strategy. Then organize a Six Sigma team and set up the long-term Six Sigma vision for the company.

(2) Start Six Sigma education for Champions first. If Champions do not understand the real meaning of Six Sigma, there is no way for Six Sigma to proceed further in the company.

(3) Choose the area in which Six Sigma will be first introduced. We can divide Six Sigma into three parts according to its characteristics. They are R&D Six Sigma, manufacturing Six Sigma, and Six Sigma for non-manufacturing

areas. It is usually not wise to introduce Six Sigma to all areas at the same time. The CEO should decide the order of introduction to these three areas. However, the order really depends on the current circumstances of the company.

(4) Deploy CTQs for all processes concerned. The most important is the company's deployment of big CTQs from the standpoint of customer satisfaction.

(5) Strengthen the infrastructure for Six Sigma, including measurement systems, statistical process control (SPC), knowledge management (KM), database management system (DBMS) and so on. In particular, efficient data acquisition, data storage, data analysis and information dissemination are necessary.

(6) Designate a Six Sigma day each month, and have the progress of Six Sigma reviewed by top-level management. All types of presentation of Six Sigma results can be given, and awards can be presented to persons who performed excellently i n fulfilling S ix S igma t asks. I f necessary, s eminars r elating to Six Sigma can be held on this day.

(7) Evaluate the company's Six Sigma performance from the customers' viewpoint, benchmark the best company in the world, revise the Six Sigma roadmap if necessary, and repeat again the innovation process.

2.5 DMAIC

The most important methodology in Six Sigma management is perhaps the formalized improvement methodology characterized by DMAIC (define-measure-analyze-improve-control) process. This DMAIC process works well as a breakthrough strategy. Six Sigma companies everywhere apply this methodology as it enables real

improvements and real results. The methodology works equally well on variation, cycle time, yield, design, and others. Breakthrough Strategy can be classified into two types and divided into five phases as shown in Figure 2.3.

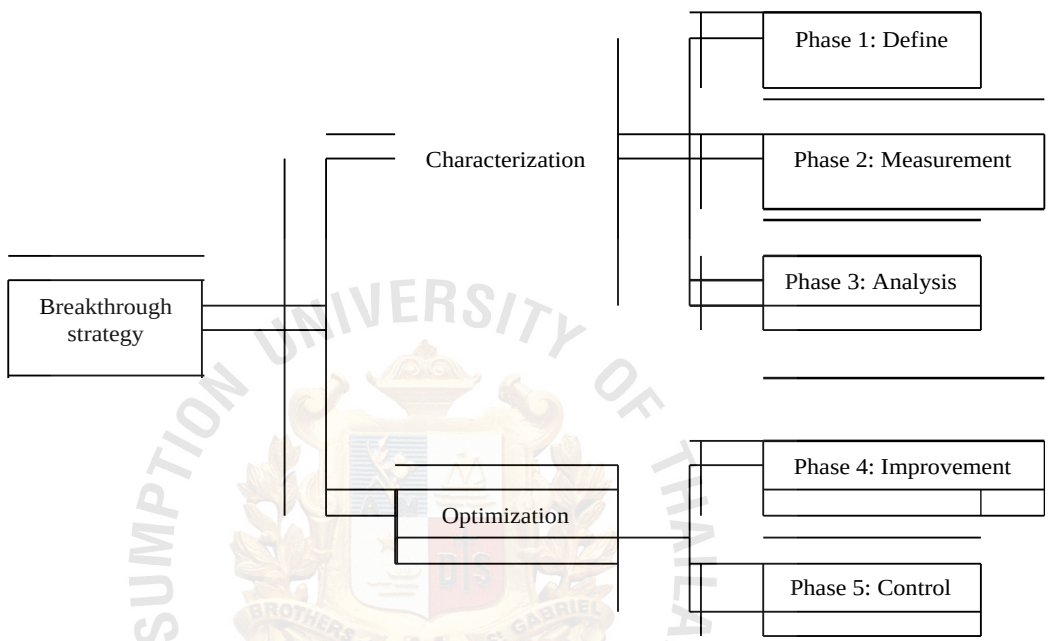


Figure 2.3. Breakthrough Strategy.

The components of breakthrough can be classified into 2 types:

(1) Product Characterization

Product Characterization is concerned with the identification and benchmarking of key product characteristics. By way of a gap analysis, common success factors are identified.

(2) Process Optimization

Process Optimization is aimed at the identification and containment of those process variables which exert undue influence over the key product characteristics.

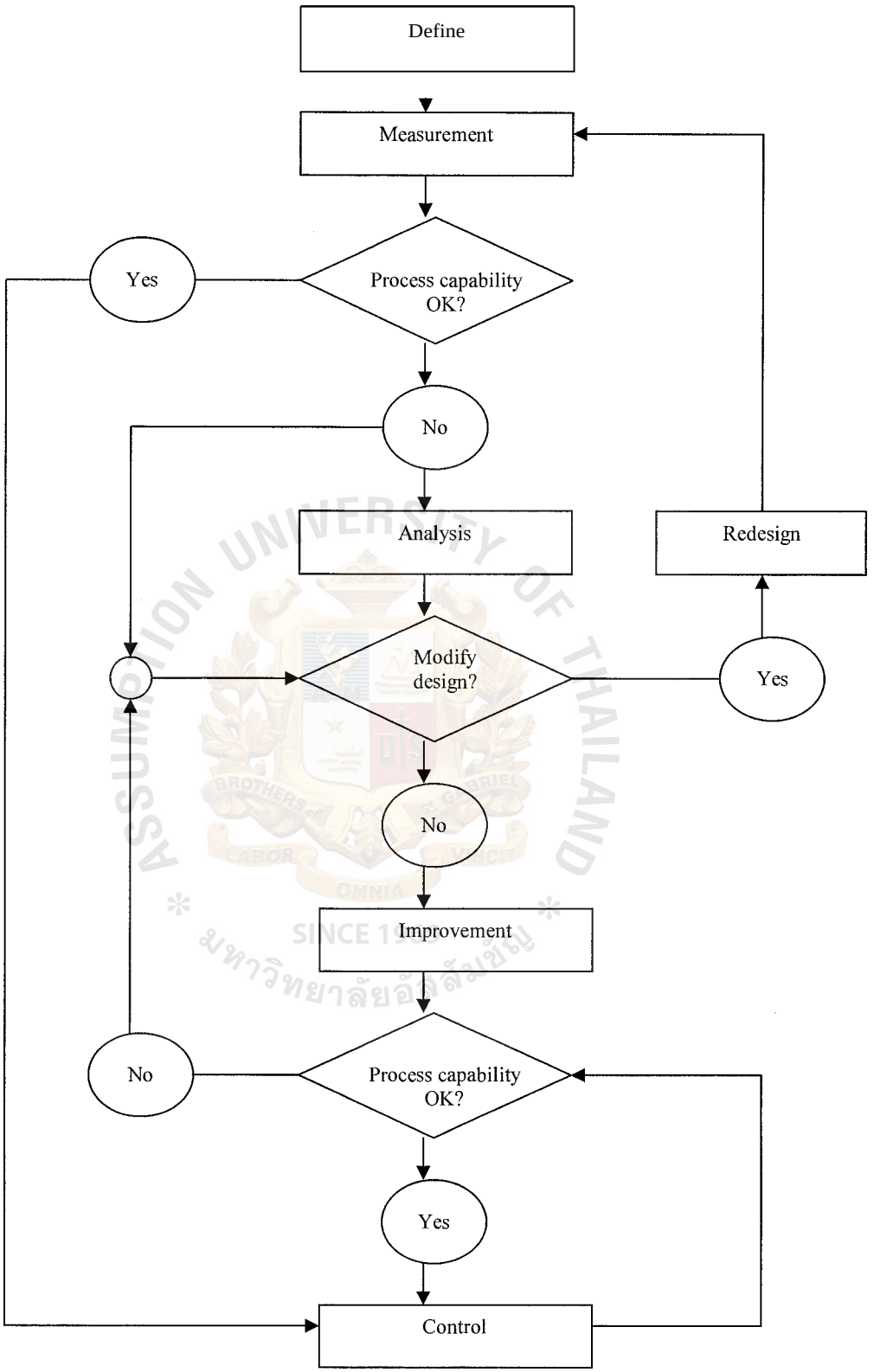


Figure 2.4. Flowchart of DMAIC process.

In each phase the major activities are as follows:

Phase 1: Define Phase

This phase is concerned with identification of the process or product that needs improvement. It is also concerned with benchmarking of key product or process characteristics of other world-class companies.

Phase 2: Measurement Phase

This phase is for studying the measurement items for identifying the characteristics of a product; i.e., dependent variables, mapping the respective processes, making the necessary measurement, recording the results and estimating the short-term and long-term process capabilities.

Phase 3: Analysis Phase

This phase is concerned with analyzing and benchmarking the key product/process performance metrics. Following this, a gap analysis is often undertaken to identify the common factors of successful performance; i.e., what factors explain best-in-class performance. In some cases, it is necessary to redefine the performance goal. In analyzing the product/process performance, various statistical and basic QC tools are used.

Phase 4: Improvement Phase

This phase is related to selecting those product performance characteristics which must b e improved t o achieve the g oal. I t a ddresses the use o f Design of Experiment (DOE) to gain process knowledge by structurally changing the operating levels of several factors simultaneously within a process. This information can help identify the setting of key variables for process optimization and change opportunities.

Phase 5: Control Phase

This phase addresses process control along with pre-control and error-proofing (poka-yoke).

The flowchart for DMAIC quality improvement process is sketched in Figure 2.4.

2.6 The Statistical Definition of Six Sigma

To define Six Sigma statistically, we will work with two concepts, specification limits and the normal distribution.

2.6.1 Specification limits

Specification limits are the tolerances or performance ranges that customers demand of the products or processes they are purchasing. Figure 2.5 illustrates specification limits as the two major vertical lines in the figure. The important thing to realize is about the range between the upper specification limit [USL] and lower specification limit [LSL].

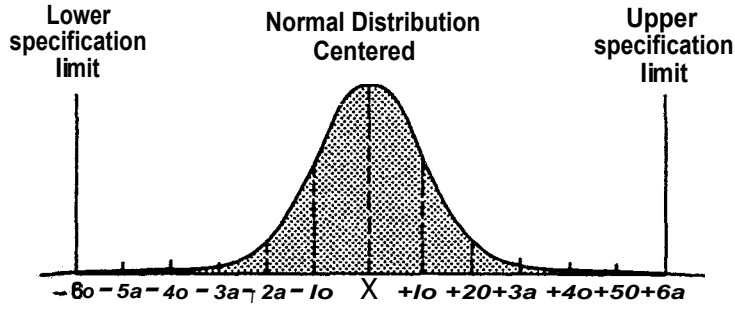
2.6.2 Normal Distribution

The bell-shaped curve in Figure 2.5 is called the normal distribution, also known as Gaussian curve. The curve is symmetrically shaped and extends from + to — infinity on the X-axis. This normal curve is totally independent of the LSL and USL. The dashed vertical lines on the curve in Figure 2.5 represent the number of standard variation units (a), a given hole diameter might be from the mean, which is shown as Tc on the x-axis.

2.6.3 Sigma Quality level

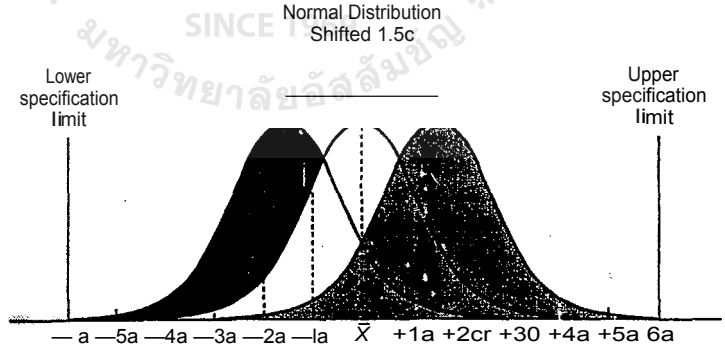
The sigma level, sometimes used as a measurement within a Six Sigma program, includes a +1.5a value to account for "typical" shifts and drifts of the mean. This shift of the mean is used when computing a process "sigma level" or sigma quality level," as shown in Figure 2.6. From the figure we note, for example, that a 3.4 ppm rate corresponds to a 6a quality level. Figure 2.7 illustrates how sigma quality levels would

equate to other defect rates and organizational performances. Figure 2.8 illustrates the impact of the +1.56 shift.



Spec. limit	Percent	Defective ppm
±1 sigma	68.27	317300
±2 sigma	95.45	45500
±3 sigma	99.73	2700
±4 sigma	99.9937	63
±5 sigma	99.999943	0.57
±6 sigma	99.9999998	.002

Figure 2.1 With a central normal distribution between Six Sigma Limits.



Spec. limit	Percent	Defective ppm
±1 a	30.23	697700
±.2 c	69.13	308700
±3 c	93.32	66810
±a a	99.3790	6210
±5 0	99.97670	233
±6 a	99.999660	3.4

Figure 2.6. Effects of a 1.56 shift where only 3.4 ppm fail to meet specifications.

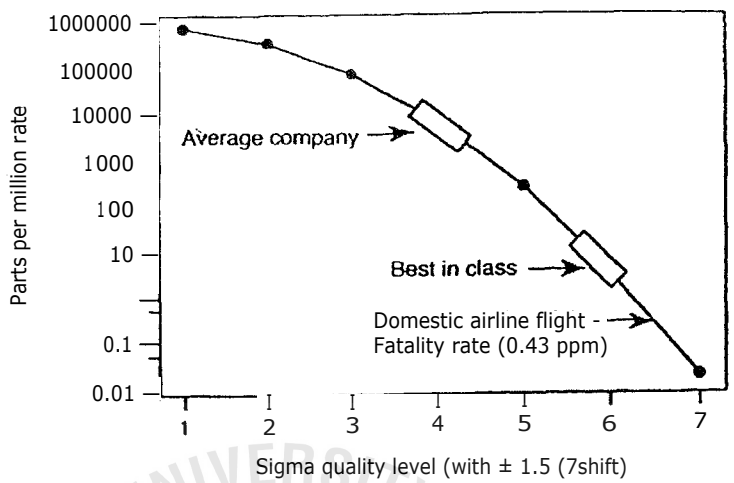


Figure 2.7. Implication of sigma quality level. Part per million (ppm) rate.

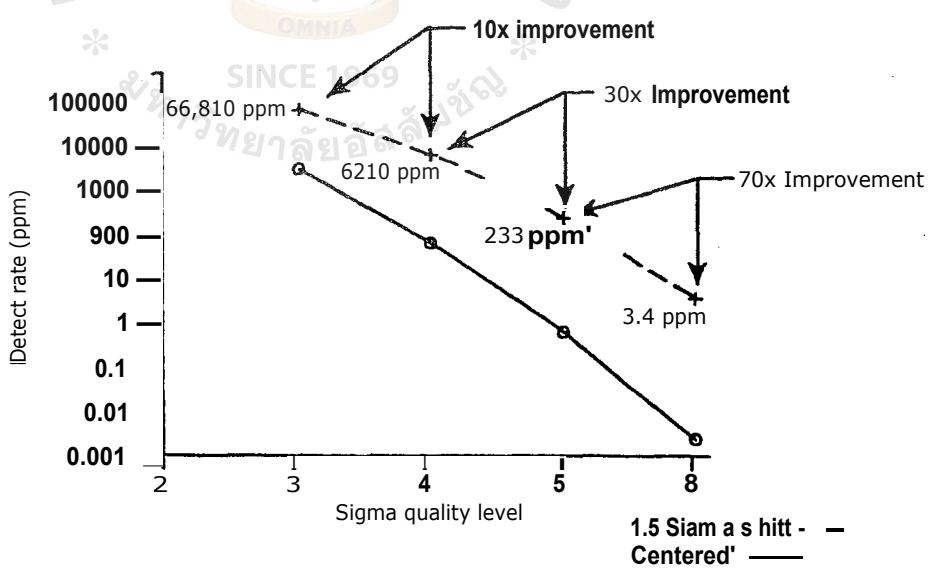


Figure 2.8. Defect rates (ppm) versus sigma quality level.

One point that should be emphasized is that sigma quality levels can be deceptive since they bear an inverse, nonlinear relationship to defect rates. Higher sigma quality levels mean fewer defects per million opportunities, but the relationship is not linear. Figure 2.8 illustrates that an improvement from a three to a four sigma quality level is not the same as an improvement from a five to a six sigma quality level. The first "unit" shift noted above corresponds to a 10x improvement in defect rate, and the latter "unit" shift to a 70x improvement, where these comparisons are based on a +1.56 shifted process. A unit change in sigma quality level does not correspond to a unit change in process improvement as measured by defect rates. A shift in sigma quality level from five to six sigma is a much more difficult improvement effort than a shift in sigma quality level from three to four sigma.

2.7 Basic QC and Six Sigma Tools

2.7.1 The 7 QC Tools

The Seven Quality Control tools (7QC tools) are graphical and statistical tools which are most often used in QC for continuous improvement. Since they are so widely utilized by almost every level of the company, they have been nicknamed the Magnificent Seven. They are applicable to improvements in all dimensions of the process performance triangle: variation of quality, cycle time and yield of productivity.

Each one of the 7QC tools had been used separately before 1960. However, in the early 1960s, they were gathered together by a small group of Japanese scientists lead by Kaoru Ishikawa, with the aim of providing the QC Circles with effective and easy-to-use tools. They are, in alphabetical order, Cause-and-Effect Diagram, Check sheet, Control chart, Histogram, Pareto chart, Scatter diagram and Stratification. In Six Sigma, they are extensively used in all phases of the improvement methodology — define, measure, analyze, improve and control.

2.7.2 Process Flowchart or Process Mapping

(1) Process Flowchart

For quality systems it is advantageous to represent system structure and relationships using flowcharts. A flowchart provides a picture of the steps that are needed to understand a process. Flowcharts are widely used in industry and have become a key tool in the development of information systems, quality management systems, and employee handbooks. The main valve of the flowchart resides in the identification and mapping of activities in processes, so that the main flows of products and information are visualized and made known to everyone.

In every Six Sigma improvement project, understanding the process is essential. The flowchart is therefore often used in the measure phase. It is also used in the analyze phase for identifying improvement potential compared to similar processes and in the control phase to institutionalize the changes made to the process.

Flowcharts can vary tremendously in terms of complexity, ranging from the most simple to very advanced charts. When improving variation, a very simple flowchart is often applied in the measure phase to map the Xs (input variables) and Y (result variable) of the process or products to be improved.

(2) Process Mapping

Process mapping is a graphical representation of the flow of a process. A details process map contains information that is beneficial to improving the process. Process mapping should identify the following.

(a) Value-Added Step: An operation which transforms the product in a way that is meaningful to the customer.

(b) Non-Value-Added Step: A rework activity or a delay in the process that does not add any new features to the product.

(c) Output (Y): Key process output variable (KPOV) or any item or feature on a product which is deemed critical by the "customer".

(d) Input (X): Key process input variable (KPIV) or any item which has an impact on Y.

(e) CTQ: Product, service, or information which is critical to customer and must be measured.

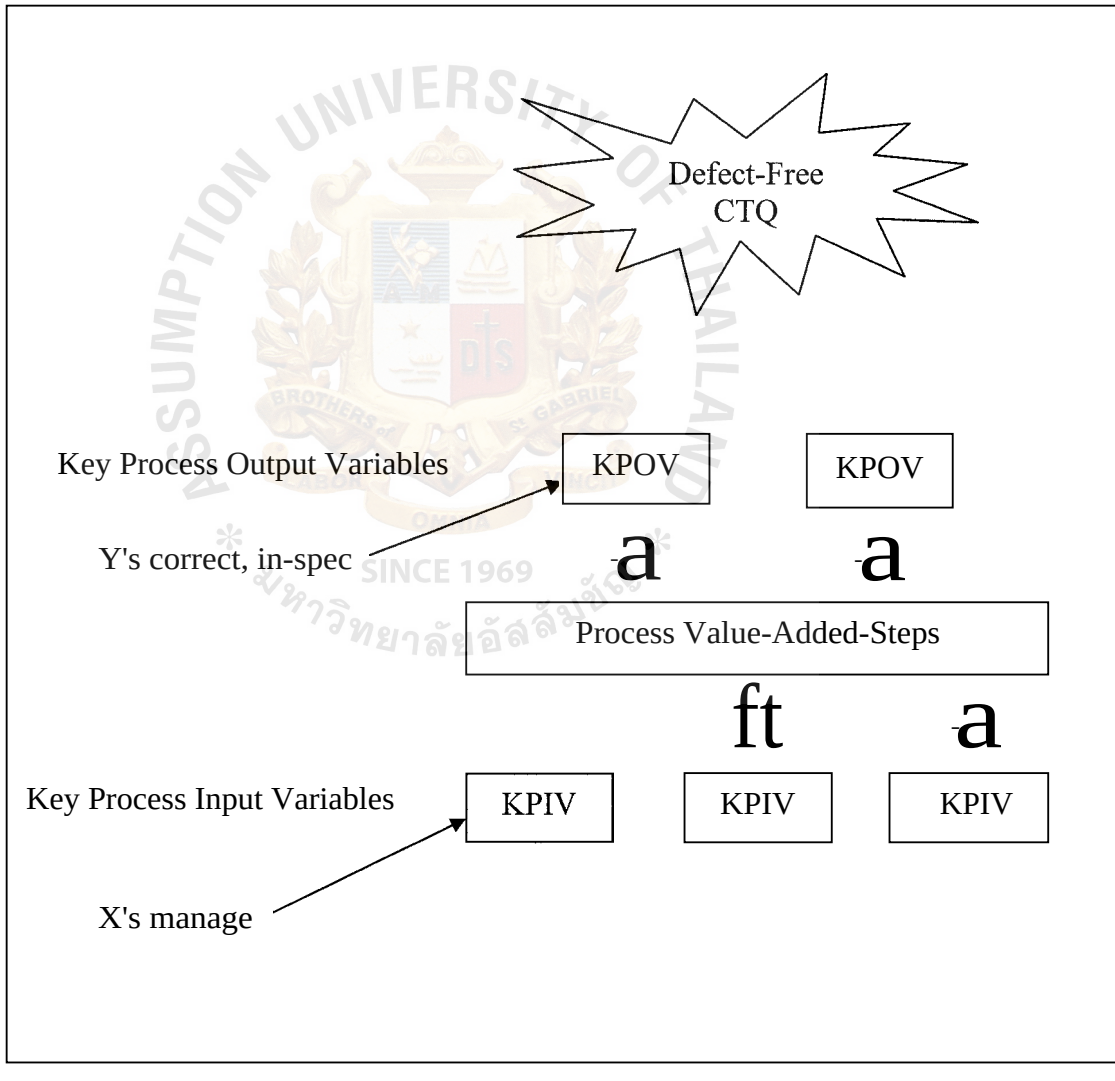


Figure 2.9. Overview of Process Mapping.

(3) Process Flow Symbols

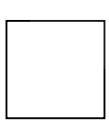
Figure 2.10 exemplifies the form of a process flowchart, frequently used symbols to describe the activity associated with a process map are as follows:

O Operation: All steps in the process where the object undergoes a change in form or condition.

Transportation: All steps in a process where the object moves from one location to another, outside the operation.

Storage: All steps in the process where the object remains at rest, in a semi-permanent or storage condition.

D Delay: All incidences where the object stops or waits on an operation, transportation, or inspection.

 Inspection: All steps in the process where the objects are checked for completeness, quality, and outside the operation.

An arrowhead on the line segments that connect symbols show the direction of the flow. The conventional overall flow direction of a flowchart is top to bottom or left to right. Usually the return loop flow is left and up. When a loop feeds into a box, the arrowhead may terminate at the top of the box, at side of the symbol, or at the line connecting the previous box.

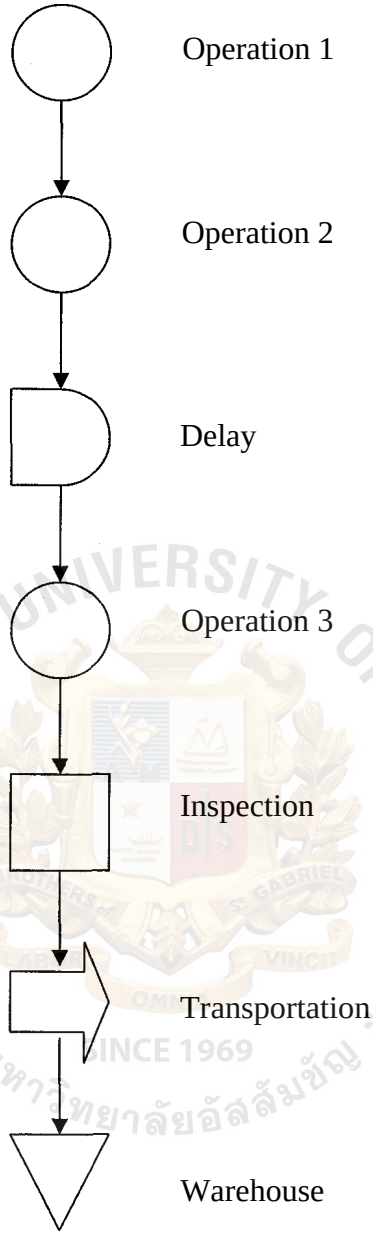


Figure 2.10. The Form of Process Flowchart.

A map which accurately and completely describes the process is important because it serves as input to the Cause and Effects Matrix, Capability Summary, Control Plan Summary, FMEA, and Multi-vari studies.

2.7.3 Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a structured technique to ensure that customer requirements are built into the design of products and processes. In Six Sigma, QFD is mainly applied in improvement projects on the design of products and processes. Hence, QFD is perhaps the most important tool for DFSS (design of Six Sigma). QFD enables the translation of customer requirements into product and process characteristics including target value. The tool is also applied in Six Sigma to identify the critical-to-customer characteristics which should be monitored and included in the measurement system.

Although QFD is primarily used to map and systematically transform c ustomer requirements, this is not its only use. Other possible applications concern the translation of market price into costs of products and processes, and company strategies into goals for departments and work areas.

Basically, QFD can be divided into four phases of transformation as shown in Figure 2.11. These four phases have been applied extensively, especially in the automobile industry.

Phase 1: Market analysis to establish knowledge about current customer requirements which are considered as critical for their satisfaction with the product, competitors' rating for the same requirements and the translation into product characteristics.

Phase 2: Translation of critical product characteristics into component characteristics, i.e., the product's parts.

Phase 3: Translation of critical component characteristics into process characteristics.

Phase 4: Translation of critical process characteristics into production characteristics, i.e., instructions and measurements.

The four phases embody five standard units of analysis always transformed in the following order: customer requirements, product characteristics, component characteristics, process characteristics, and production characteristics. The level of detail hence increases from general customer requirements to detailed production characteristics.

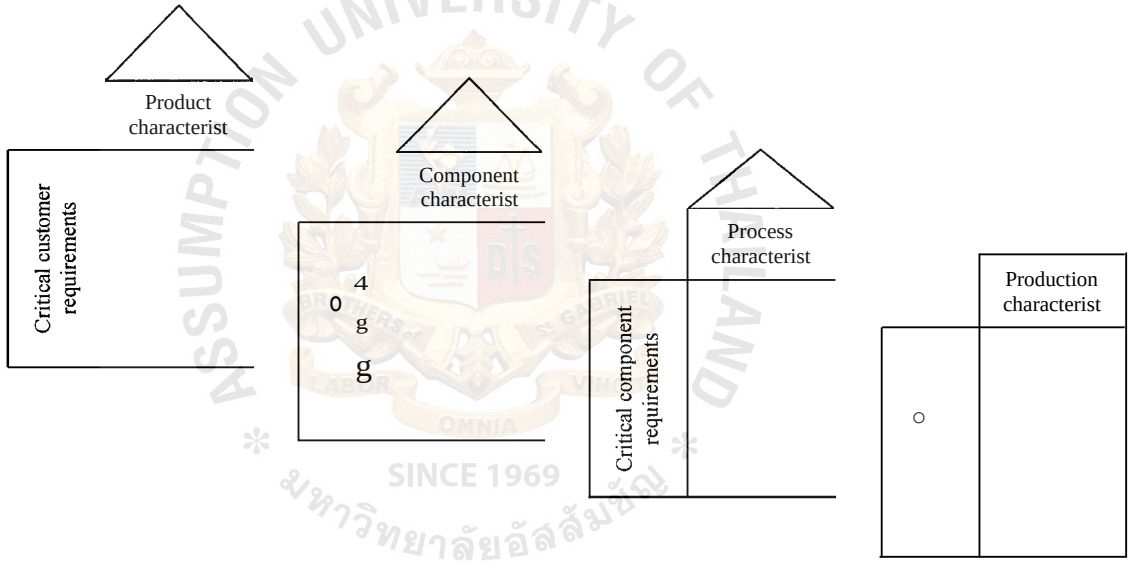


Figure 2.11. Four phases of transformation in QFD.

2.7.4 Cause and Effect Analysis

Cause-Effect is based on the idea that we can positively identify what we do not like about a situation and trace it back to some underlying cause and causes.

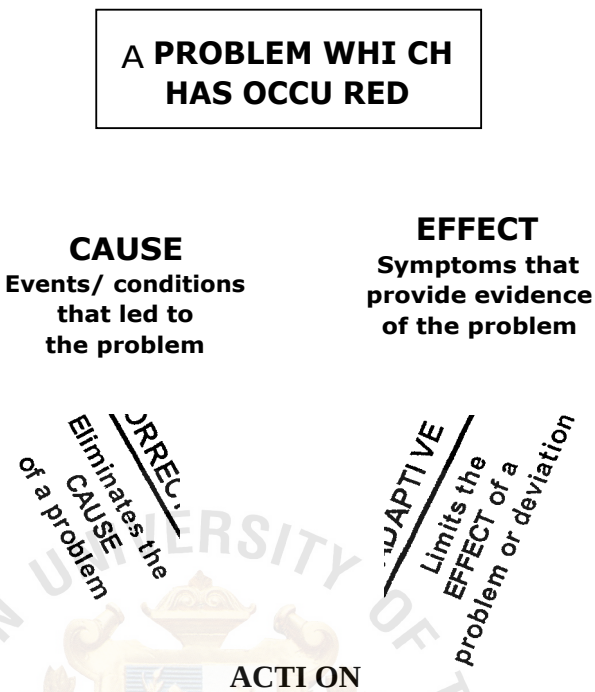


Figure 2.12. Cause-Effect Relationship (Dave 1998).

The 2 types of cause-effect analyses.

(1) Cause and Effect Diagram (Fishbone Diagram)

An effective tool as part of a problem-solving process is the cause-and—effect diagram, also known as an Ishikawa diagram (after its originator Karoru Ishikawa) or fishbone diagram. This technique is useful to trigger ideas and promote a balanced approach in group brainstorming sessions where individuals list the perceived sources (causes) of a problem (effect).

The effect being analyzed is drawn on the right side of the chart at the end of a large arrow. Main groups of probable causes are drawn as branches to the arrow. For each branch, all possible causes are identified.

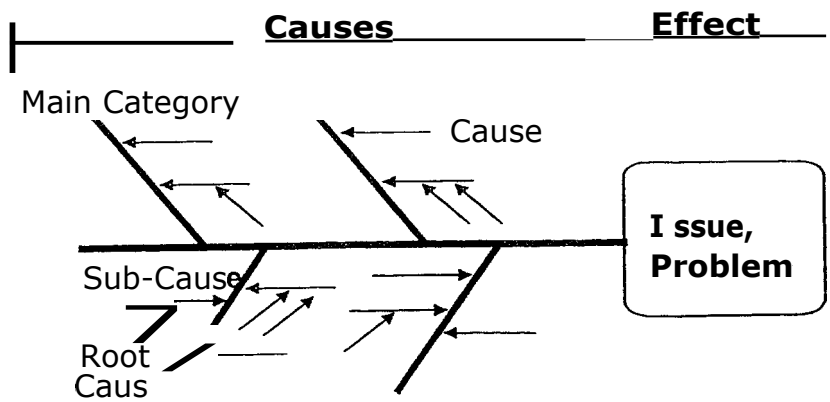


Figure 2.13. "Fishbone" or Cause and Effect Diagram.

When constructing a cause-and-effect diagram, it is often appropriate to consider six areas (causes) that can contribute to a characteristic response (effect): materials, machine, method, man (personnel), measurement, and environment. Each one of these characteristics is then investigated for sub-causes. Sub-causes are specific items or difficulties that are identified as a factual or potential cause to the problem (effect). Besides the identification of experimental factors within the cause-and-effect diagram, it can also be beneficial to identify noise factors and factors that can be controlled.

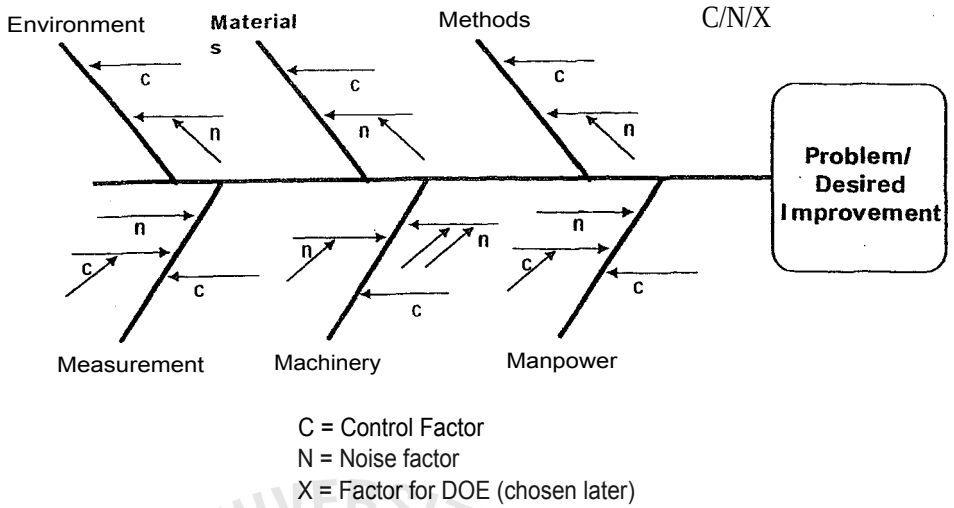


Figure 2.14. Construction of a Cause and Effect Diagram.

(2) Cause-Effect Matrix

A diagram in table form showing the direct relationships between outputs (Y's) and inputs (X's). The cause-and-effect matrix is a tool that can aid with the prioritization of importance of key process input variables. This prioritization by a team can help with the selection of what will be monitored to determine if there is a cause and effect relationship and whether key process input controls are necessary. The results of a cause-and-effect matrix can lead to other activities such as FMEA, multi-vari charts correlation analysis, and DOE.

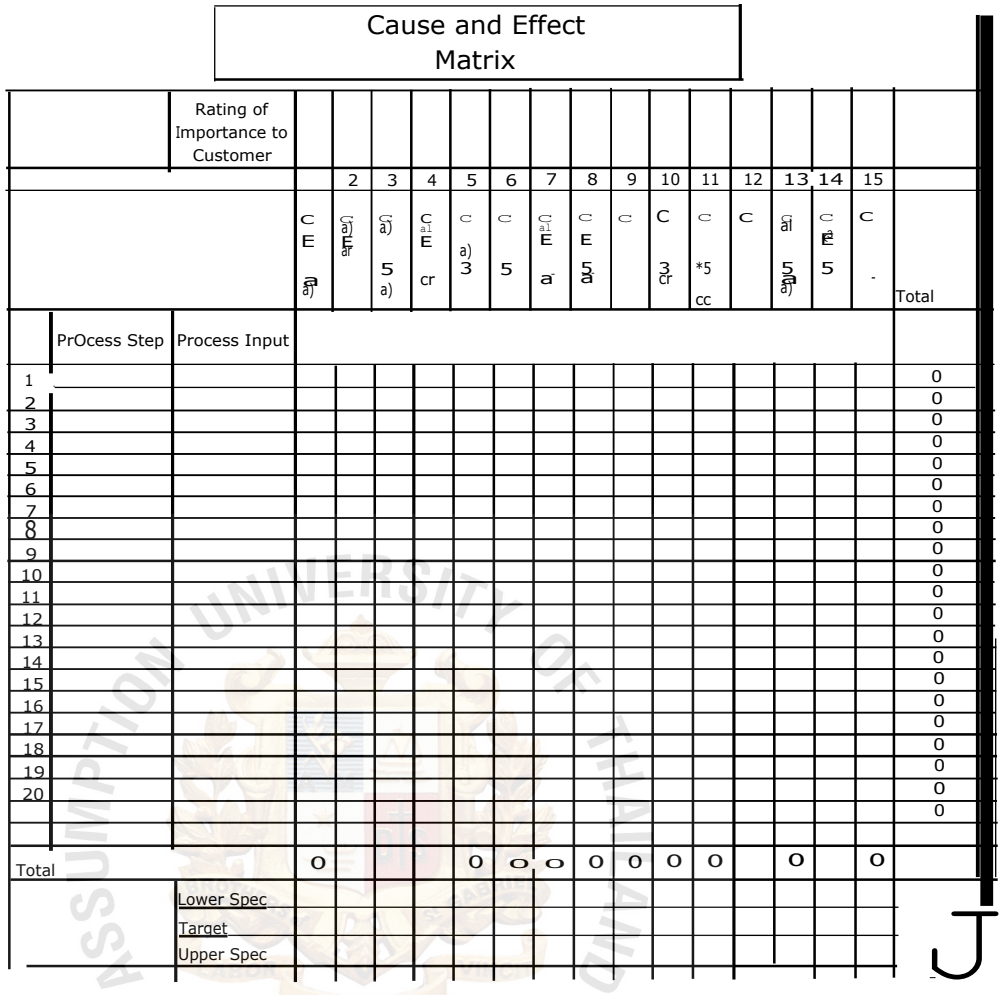


Figure 2.15. Cause and Effect Matrix.

To construct a cause-and-effect matrix, do the following:

(a) List the output variables (Y's) along the top section of the matrix. These are outputs which the team and/or the customer deems to be important. These may be a subset of the list of Y's identified on the process map.

(b) Rank each output numerically using an arbitrary scale (possibly 1-10). The most important output receives the highest number.

(c) Identify all potential inputs or causes (X's) that can impact the various Y's and list along left hand side of the matrix.

(d) Reach by consensus the amount of effect that each X has on each Y. Rather than use values from 1 to 10 (where 10 indicates the largest effect).

(e) Determine the result for each X by first multiplying the Y priority (step b) by the consensus of the effect for the X (step d) and then summing these products.

(f) The X can be prioritized by the results from step e and/or a percentage of total calculation.

The results from a cause-and-effect matrix can give direction for:

(a) The listing and evaluation of KPOV' s in a capability summary.

(b) The listing and evaluation of KPIV's in a control plan summary.

(c) The listing and exploration of KPIV's in a FMEA.

2.7.5 Process Capability and Process Performance

Process capability and process performance studies are to assess a process relative to specification criteria.

(1) Definitions

(a) Inherent Process Variation: That portion of process variation due to common causes only. This variation can be estimated from control chart by d_2, among other things.

(b) Total Process Variation: This is the variation due to both common and special causes. This variation may be estimated by s, the sample standard deviation, using all of the individual readings obtained from either a detailed control chart or a process study.

(c) Process Capability: The 6a range of a process's inherent variation, for statistically stable process only where a is usually estimated by R / d2.

(d) Process Performance: The 6a range of a process's total variation, where a is usually estimated by s, the sample standard deviation.

(e) C_p*:* This is the capability index which is defined as the tolerance width divided by the process capability, irrespective of process centering.

(f) C_{pk}*:* This is the capability index which accounts for process centering. It relates the scaled distance between the process mean and the closest specification limit to half the total process spread.

(g) P_p*:* This is the performance index which is defined as the tolerance width divided by the process performance, irrespective of process centering. Typically, this is expressed as the tolerance width divided by six times the sample standard deviation. (It should be used only to compare to or with C_p and C_{pk} and to measure and prioritize improvement over time.)

(h) P_pk*:* This is the performance index which accounts for process centering. (It should be used only to compare to or with C_p and C_pk and to measure and prioritize improvement over time.)

(2) Types of Capability Analysis

We have two types of capability analysis:

(a) Capability determination for a variable output (quantitative data) h as the method like the following:

(1) Verify the specification

(2) Pull a sample (short-term or long-term)

(3) Compute the Z-score

(4) Shift the Z-score by 1.56 if appropriate

(5) Convert Z-score into the desired index PPM or C_p, C_pk, Pp, P_pk.

(b) Capability determination for an attribute output (discrete qualitative events) has the method like the following:

(1) Verify the definition/description of a defect.

(2) Count the occurrence of defects (and track the total units processed). Historical data is typically used here and usually considered to be long-term.

(3) Compute the proportion of defects and the PPM.

(4) Compute the Z-score and shift by 1.56 if appropriate.

(5) Estimate traditional capability indices, change from Z to *cp*, *Pp*, *Ppk*.

2.7.6 Failure Modes and Effects Analysis (FMEA)

(1) Definitions

Failure modes and effects analysis (FMEA) is a set of guidelines, a process, and a form of identifying and prioritizing potential failures and problems in order to facilitate process improvement. By basing their activities on FMEA, a manager, improving team, or process owner can focus the energy and resources of prevention, monitoring, and response plans where they are most likely to pay off The FMEA method has many applications in a Six Sigma environment in terms of looking for problems not only in work processes and improvements but also in data-collection activities, Voice of the Customer efforts and procedures.

There are two types of FMEA; one is design FMEA and the other is process FMEA. Design FMEA applications mainly include component,

subsystem, and main system. Process FMEA applications include assembly machines, workstations, gauges, procurement, training of operators, and tests. Benefits of a properly executed FMEA include the following:

(a) Prevention of possible failures and reduced warranty costs

(b) Improved product functionality and robustness

(c) Reduced level of day-to-day manufacturing problems

(d) Improved safety of products and implementation processes

(e) Reduced business process problems

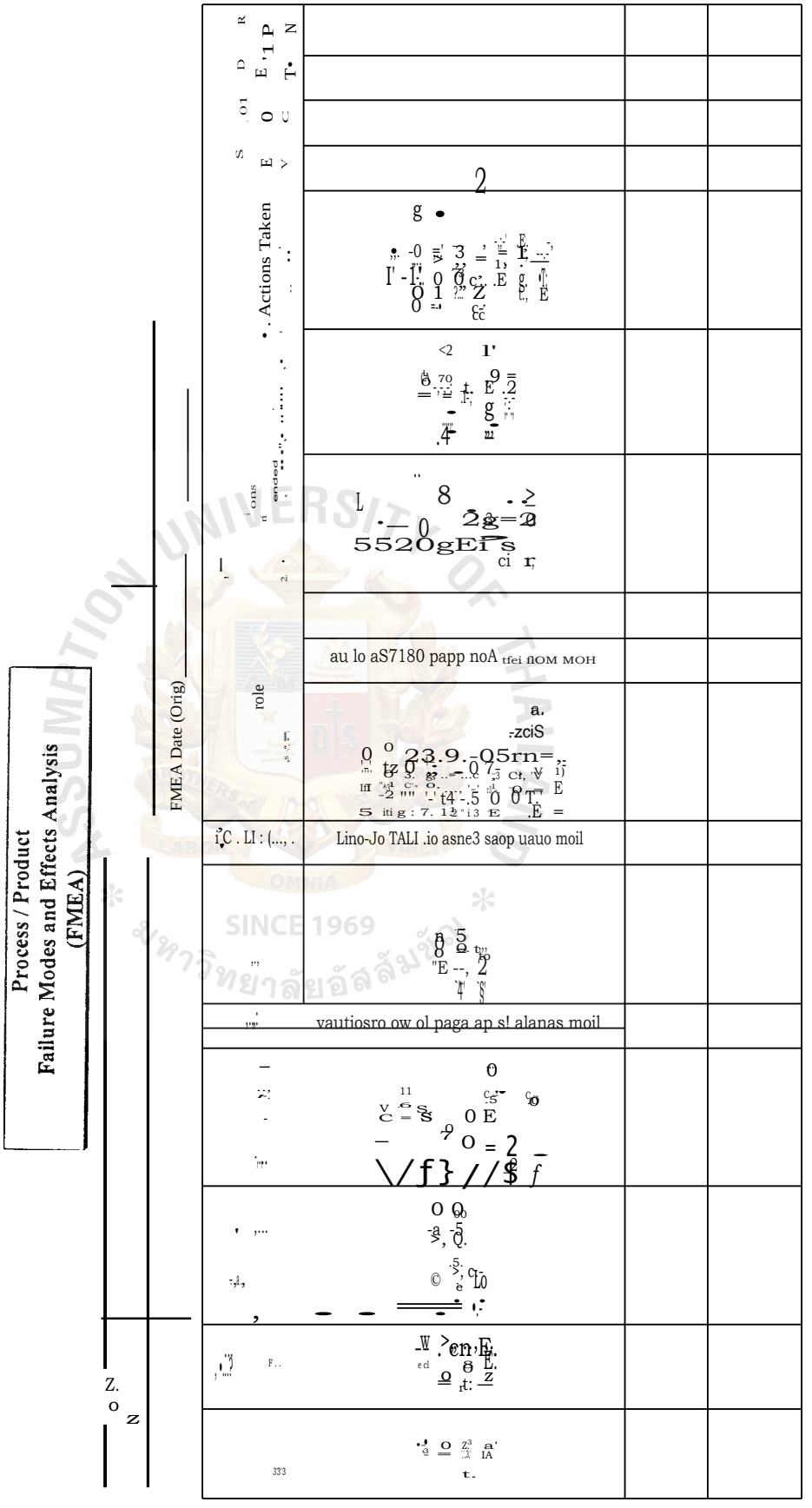
(2) Design FMEA

Within a design FMEA, manufacturing and/or process engineering input is important to ensure that the process will produce to design specifications. A term should consider including knowledgeable representation from design, test, reliability, materials, service, and manufacturing/process organizations. When beginning a design FMEA, the responsible design engineer compiles documents that provide insight into the design intent. Design intent is expressed as a list of what the design is expected to do.

(3) Process FMEA

For a process FMEA, design engineering input is important to ensure appropriate focus on important design needs. A team should consider including knowledgeable representation from design, manufacturing/process, quality, reliability, tooling, and operators.

Table 2.1 shows a blank FMEA form which can be simultaneously used for a design FMEA and for a process FMEA.



(a) Header Information: Documents the system/subsystem/component (under project name/description) and supplies other information about when and who created the FMEA.

(b) Item/Function: Contains the name and number of the analyzed item. Includes a concise, exact, and easy to understand explanation of function of the item task or response that is analyzed to meet the intent of the process. Includes information regarding the temperature, pressure, and other pertinent system operating conditions. When there is more than one function, it lists each function separately with different potential failure modes.

(c) Potential Failure Mode: Describes ways a process could fail to perform its intended function. May include the cause of a potential failure mode in a higher-level subsystem or process step. May also be the effect of one from a lower level component or process step. Contains for each item/function a list of each potential failure modes given the assumption that the failure could occur but may not necessarily occur. Items considered are previous problems and new issues from brainstorming sessions. Consideration is given to issues that could arise only under certain operation conditions such as high temperature and high humidity. D escriptions are i n physical t erms o r t echnical terms, not as a symptom. Includes failure modes such as fractured, electrical short-circuited, oxidized, and circuit logic failed.

(d) Potential Effect(s) of Failure: Contains an internal or external of customer point of view the effects of the failure mode on the function.

Highlights safety or noncompliance to regulation issues. Expressed in terms of the specific system, subsystem, or component hierarchical relationship that is analyzed. Includes failure effects such as intermittent operation, lost computer data, and poor performance.

(e) Severity: Assesses the seriousness of the effect of the potential failure mode to the next component, subsystem, or system, if it should occur. Reduction efforts for severity levels are through design change. Estimation is typically based on a 1 to 10 scale where the team agrees to a specific evaluation criteria for each ranking value.

(f) Classification: Includes optional information such as critical characteristics that may require additional process controls. An appropriate character or symbol in this, column indicates the need for an entry in the recommended action column and special process controls within the process FMEA.

(g) Potential Causes of Failure: Indicates a design weakness that causes the potential failure mode. Contains a concise and descriptive list that is as complete as possible to describe all root causes (not symptom) of failure. Includes causes such as incorrect algorithm, hardness, porosity, and incorrect material specified. Includes failure mechanisms such as fatigue, wear, and corrosion.

(h) Occurrence: Estimates the likelihood that a specific cause will occur. Consideration of historical data of similar components/subsystems and differences to the new design help determine the ranking value. Teams need to agree on evaluation criteria, where possible failure rates are anticipated values during design life.

(i) Current Design Controls: Lists activities (such as design verification tests, design reviews, DOEs, and tolerance analysis) that ensure adequacy of design control for the failure mode.

(j) Detection: Assessment of the ability of the current design control to detect the subsequent failure mode or potential cause of design weakness before releasing to production.

(k) Risk Priority Number (RPN): Product of severity, occurrence, and detection rankings. The ranking of RPN prioritizes design concerns; however, issues with a low RPN still deserve special attention if the severity ranking is high.

(1) Recommended Action(s): Intent of this entry is to institute actions that lower the occurrence, severity, and/or detection rankings of the highest RPN failure modes. Example actions include DOE, design revision, and test plan revision. "None" indicates there are no recommended actions.

(m) Responsibility for Recommended Action: Documents the organization and individual responsible for recommended action and target completion date.

(n) Action(s) Taken: Describes implementation action and effective date.

(o) Resulting RPN: Contains the recalculated RPN resulting from corrective actions that effected previous severity, occurrence, and detection rankings. Blanks indicate no action.

(4) Basic Steps of FMEA

(1) Develop a strategy

(2) Review the design/process

(3) List functions

(4) Brainstorm potential failure modes

(5) Organize potential failure modes

(6) Analyze potential failure modes

(7) Establish risk priority

(8) Take action to reduce risk

(9) Calculate resulting of RPN

(10) Follow up

The design or process must be improved based on the results of the FMEA study.

2.7.7 Measurement System Analysis

(1) Attribute Gage R&R Methodology

Step 1: Select a minimum of 30 parts from the process.

Step 2: Identify the inspector, who should be qualified and experienced.

Step 3: Have each inspector, independently and in random order, assess these parts and determine whether or not they pass.

Step 4: Enter the data into the Attribute R &R.xls spreadsheet t o report the effectiveness of the attributed measurement system.

Step 5: Document the results. Implement appropriate actions to fix the inspection process if necessary.

Step 6: Re-run the study to verify the fix.

Note: A 30 piece samples will yield an estimate of inspector efficiency and capability which has a fair amount of uncertainty. Typically a larger sample is not needed because the inspection process is obviously ineffective. The spreadsheet can handle up to 100 samples.

(2) Variable Gage R&R Methodology

Step 1: Collect 10 samples that represent the full range of long-term process variation. In addition, identify the operators who use this instrument daily.

Step 2: Calibrate the gage or verify when the last calibration date is valid.

Step 3: Set up the Minitab data collection sheet for R&R study.

(a) Column headings: Part ID, Operator, Trial, Measurement(s)

(b) Calc > Make Patterned Date < Simple Set of Numbers (for each input)

Step 4: Ask the first operator to measure all the samples once in random order. Blind sampling, in which the operator does not know the identification of each part should be used to reduce human bias.

Step 5: Have the second operator measure all the samples once in random order and continue until all operators have measured the samples once (this is trial 1).

Step 6: Repeat steps 4 and 5 for the required number of trials.

Step 7: Enter the data and tolerance information into Minitab.

(a) Stat > Quality Tools > Gage R&R Study

(b) Stat > Quality Tools > Gage Run Chart

Step 8: Analyze the results by assessing the quality of the measurement system based on the following guidelines.

2.7.8 Hypothesis Testing

In industrial situations we frequently want to decide whether the parameters of a distribution have particular values or relationships. That is, we may wish to test a hypothesis that the mean or standard deviation of a distribution has a certain value or

that the difference between two means is zero. Hypothesis testing procedures are used for these tests.

A statistical hypothesis is usually done by the following process.

(1) Set up a null hypothesis (Ho) that describes the value or relationship being tested.

(2) Set up an alternative hypothesis (Ha).

(3) Determine a test statistic, or rule, used to decide whether to reject the null hypothesis.

A specified probability value, denoted as cy, that defines the maximum allowable probability that the null hypothesis will be rejected when it is true.

(4) Collect a sample of observations to be used for testing the hypothesis, and then find the value of the test statistic.

(5) Find the critical value of the test statistic using cy and a proper probability distribution table.

(6) Compare the critical value and the value of the test statistic and decide whether the null hypothesis is rejected or not.

The result of the hypothesis test is a decision to either reject or not reject the null hypothesis; that is, the hypothesis is either rejected or we r eserve j udgment o n i t. In practice, we may act as though the null hypothesis is accepted if it is not rejected. Since we do not know the truth, we can make one of the following two possible errors when running a hypothesis test:

(1) We can reject a null hypothesis that is in fact true.

(2) We can fail to reject a null hypothesis that is false.

The first error is called a type I error, a, and the second is called a type II error, p. This relationship is shown in Figure 2.16. Hypothesis tests are designed to control the

probabilities of making either of these errors; we do not know that the result is correct, but we can be assured that the probability of making an error is within acceptable limits. The probability of making a type I error is controlled by establishing a maximum allowable value of the probability, called the level of significance of the test, which is usually denoted by the letter a.

		True state of nature	
		Ho	Ha
Conclusion made	Ho	Correct conclusion	Type II error 0(3)
	Ha	Type I error (a)	Correct conclusion

Figure 2.16. Hypothesis testing error types.

2.7.9 Correlation and Regression

A method to perform correlation has been developed by Lyle Dockendrof (Seagate) based on a paper by John Mandel in Journel of Quality Technology that takes into account the error in both variables. This method has been nicknamed "Mandel's Method".

Regression can conclude multiple inputs: $Y = f(X_1, X2, X3,...)$ while correlation focuses on one input: $Y = bX + a$. They are based on different assumptions. Regression assumes no measurement error in X variable while correlation usually involves measurement error in X variable. Historical practice has usually (incorrectly) used regression for correction studies. In the past, the only analysis tool available was

regression. However, regression provides correlation capability only when one value is considered the master.

Regression should only be used for correlation for the following two situations.

(1) The R^2 value exceeds 0.95. Then the error in slope is limited to being less than 2.5%.

(2) One of the systems represents the gold standard, that is, all other systems are tied directly and primarily to that standard.

2.7.10Design of Experiments (DOE)

(1) Framework of design of experiments

Experiments are carried out by researchers or engineers in all fields of study to compare the effects of several conditions or to discover something new. If an experiment is to be performed most efficiently, then a scientific approach to planning it must be considered. The design of experiments (DOE) is the process of planning experiments so that appropriate data will be collected, the minimum number of experiments will be performed to acquire the necessary technical information, and suitable statistical methods will be used to analyze the collected data.

The statistical approach to experimental design is necessary if we wish to draw meaningful conclusions from the data. Thus, there are two aspects to any experimental design: the design of experiment and the statistical analysis of the collected data. They are closely related, since the method of statistical analysis depends on the design employed.

An outline of the recommended procedure for an experimental design is shown in Figure 2.17. A simple, but very meaningful, model in Six Sigma is that "y is a function of x," i.e., y = f(x), where y represents the response

variable of importance for the customers and x represents input variables which are c ailed factors in DOE. The question is which of the factors are important to reach good values on the response variable and how to determine the levels of the factors.

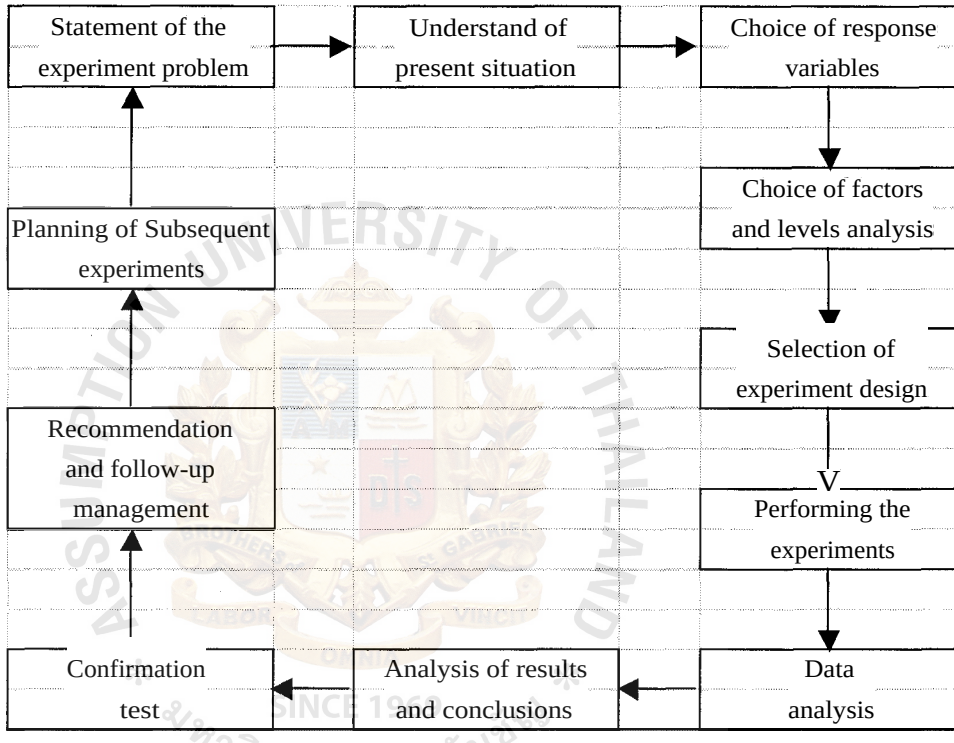


Figure 2.17. Outline of experimental design procedure.

The design of experiments plays a major role in many engineering activities. For instance, DOE is used for

(1) Improving the performance of a manufacturing process. The optimal values of process variables can be economically determined by application of DOE.

(2) The development of new processes. The early application of DOE methods in process development can result in reduced development time, reduced variability of target requirements, and enhanced process yields.

(3) Screening important factors.

(4) Engineering design activities such as evaluation of material alternations, comparison of basic design configurations, and selection of design parameters so that the product is robust to a wide variety of field conditions.

(5) Empirical model building to determine the functional relationship between x and y.

The tool, DOE, was developed in the 1920s by the British scientist Sir Ronald A. Fisher (1890 — 1962) as a tool in agricultural research. The first industrial application was performed in order to examine factors leading to improved barley growth for the Dublin Brewery. After its original introduction to the brewery industry, factorial design, a class of design in DOE began to be applied in industries such as agriculture, cotton, wool and chemistry. George E.P. Box (1919 -), an American scientist, and Genichi Taguchi (1924 -), a Japanese scientist have contributed significantly to the usage of DOE where variation and design are the central considerations.

Large manufacturing industries in Japan, Europe and the US have applied DOE from the 1970s. However, DOE remained a specialist tool and it was first with Six Sigma that DOE was brought to the attention o f t op management as a powerful tool to achieve cost savings and income growth through improvements in variation, cycle time, yield, and design. DOE was

also moved from the office of specialists to the corporate masses through the Six Sigma training scheme.

(2) Classification of design of experiments

There are many different types of DOE. They may be classified as follows according to the allocation of factor combinations and the degree of randomization of experiments.

(1) Factorial design

This is a design for investigating all possible treatment combinations which are formed from the factors under consideration. The order in which possible treatment combinations are selected is completely random. Single-factors, two-factor and three-factor factorial designs belong to this class, as do 2^k (k factors at two levels) and 3^k (k factors at three levels) factorial designs.

(2) Fractional factorial design

This is a design for investigating a fraction of all possible treatment combinations which are formed from the factors under investigation. Designs using tables of orthogonal arrays, Plackett-Burman designs and Latin square designs are fractional factorial designs. This type of design is used when the cost of the experiment is high and the experiment is time-consuming.

(3) Randomized complete block design, split-plot design and nested design

All possible treatment combinations are tested in these designs, but some form of restriction is imposed on randomization. For instance, a design in which each block contains all possible treatments,

and the only randomization of treatments is within the blocks, is called the randomized complete block design.

(4) Incomplete block design

If every treatment is not present in every block in a randomized complete block design, it is an incomplete block design. This design is used when we may not be able to run all the treatments in each block because of a shortage of experimental apparatus or inadequate facilities.

(5) Response surface design and mixture design

This is a design where the objective is to explore a regression model to find a functional relationship between the response variable and the factors involved, and to find the optimal conditions of the factors. Central composite designs, rotatable designs, simplex designs, mixture designs and evolutionary operation (EVOP) designs belong to this class. Mixture designs are used for experiments in which the various components are mixed in proportions to sum up unity.

(6) Robust design

Taguchi (1986) developed the foundations of robust design, which is often called parameter design or tolerance design. The concept of robust design is used to find a set of conditions for design variables which are robust to noise, and to achieve the smallest v ariation i n a product's function about a desired target value. Tables of orthogonal arrays are extensively used for robust design.

III. PROJECT METHODOLOGY

3.1 Project Criteria

There are two important criteria for a successful project: the *effect required* and the *probability of success.*

First, we must have a good understanding of the duration of the project in relation to the return on investment. In other words, it could take more than the project's duration before we see the money. We have to evaluate our effort in terms of the resources we deploy and the time it takes until those resources produce for us.

Second, we must consider the probability of success for a project. We need to consider the time, effort, and implementation factors to figure out if the project is desirable.

3.2 Project Problem Statements

Creating a good project statement is one of the hardest things to do in Six Sigma. Our statement must be quantifiable and specific; otherwise, we will not have a clue about what we are actually going to work on. Our statement attacks the business process at its core and looks at the business metrics around it.

There are two purposes to having a problem statement;

(1) To focus the team on the process deficiency or the actual defect.

(2) To communicate our project's purpose to "significant others."

Through our statement, everyone understands what the problem is and what the benefit will be once our team has fixed it.

3.3 Define Phase

3.3.1 Problem Statement

Plastic material is the one of the raw materials being used for produced parts in Washing Machine and Refrigerator products; there were many materials to be subsequently used to create various parts. The main materials are PP, ABS, PE, GPPS, and POM.

The good part and defects of the main material that is used for produce parts in term 03B (Oct'03-Mar'04) are shown in Table 3.1. We found that PP material is the best for making the good part while GPPS is the highest material that caused the defective part.

Table 3.1. Main material in term 03B (Oct'03-Mar'04), Kg.

Material		Month						Total
		Oct'03	Nov'03	Dec'03	Jan'04	Feb'04	Mar'04	
ABS	Good	33,188	22,373	50,189	55,759	4,426	23,743	189,678
	Defective	1,431	902	1,758	1,280	1,137	699	7,207
PE	Good	108	100	389	462	237	299	1,595
	Defective	1.2	2.6	3.8	0.5	1.3	5.3	15
PP	Good	109,100	76,097	157,749	202,522	148,735	94,184	788,387
	Defective	5,812	3,971	8,025	10,318	7,165	3,971	39,262
GPPS	Good	107,177	72,043	126,990	193,103	148,902	83,533	731,748
	Defective	6,837	5,554	7,678	10,041	8,668	6,014	44,792
POM	Good	51	100	54	149	297	91	742
	Defective	0.4	0.5	0.2	0.7	0.9	0.3	3

Figure 3.1 illustrates the graph of the main defective materials in the Injection shop in term 03B (Oct'03-Mar'04).

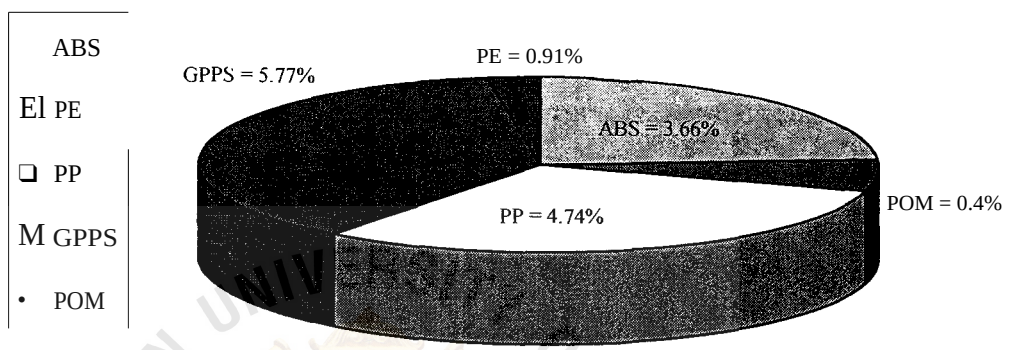


Figure 3.1. Defect ratio of main materials in the Injection shop.

The highest defective material is GPPS (General Purpose Polystyrene) 5.77%. The cost of GPPS is 45 TB/KG. The total of COPQ is 2.02 MB from term 03B (Oct'03-Mar' 04).

The defective parts which are made from GPPS material are caused by Crack mark, Silver mark, Weld line, Black dot, Purge, Flow mark, etc. as shown in Table 3.2. The total defective parts count on the GPPS materials was 20,492.

Figure 3.2 illustrates the Pareto chart that shows the causes of the defective part from GPPS material.

Table 3.2. Main defects from GPPS material.

DEFECT PART	Q'TY (Pc)
Crack mark	8,401
Silver mark	2,089
Weld line	2,004
Black dot	1,477
Purge	1,243
Flow Mark	654
Oil and dirty	733
Sink mark	737
Color tone	733
Bubble	618
Start NG	559
Short shot	549
Others	695
Total	20,492

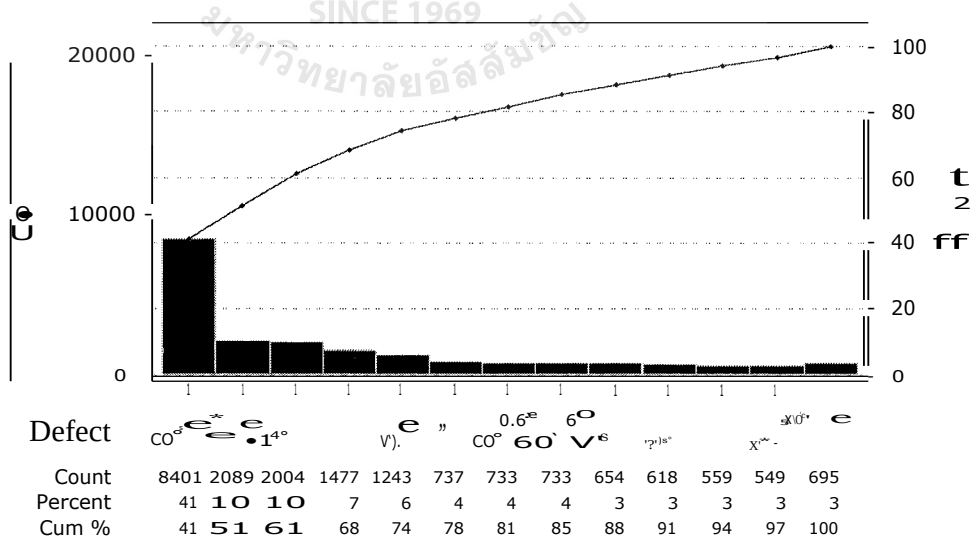


Figure 3.2. Pareto Chart showing the main defects of GPPS material.

The problem statement of this project was defined as the defective ratio of GPPS (General Purpose Polystyrene) 5.77% (COPQ 2.02 MB).

3.3.2 Objective and Target

To reduce defective material GPPS (General Purpose Polystyrene) from 5.77% to 4.0%.

3.3.3 Business Benefit

Hard saving : Approximately 1 MB/Term

Soft saving : Reduce process time for production

3.3.4 Metric

Metric of this project is defective ratio. Figure 3.3 illustrates the current defective ratio in term 03B (Oct'03-Mar'04) and target defective rate in term 04A (Apr'04-Sep ' 04).

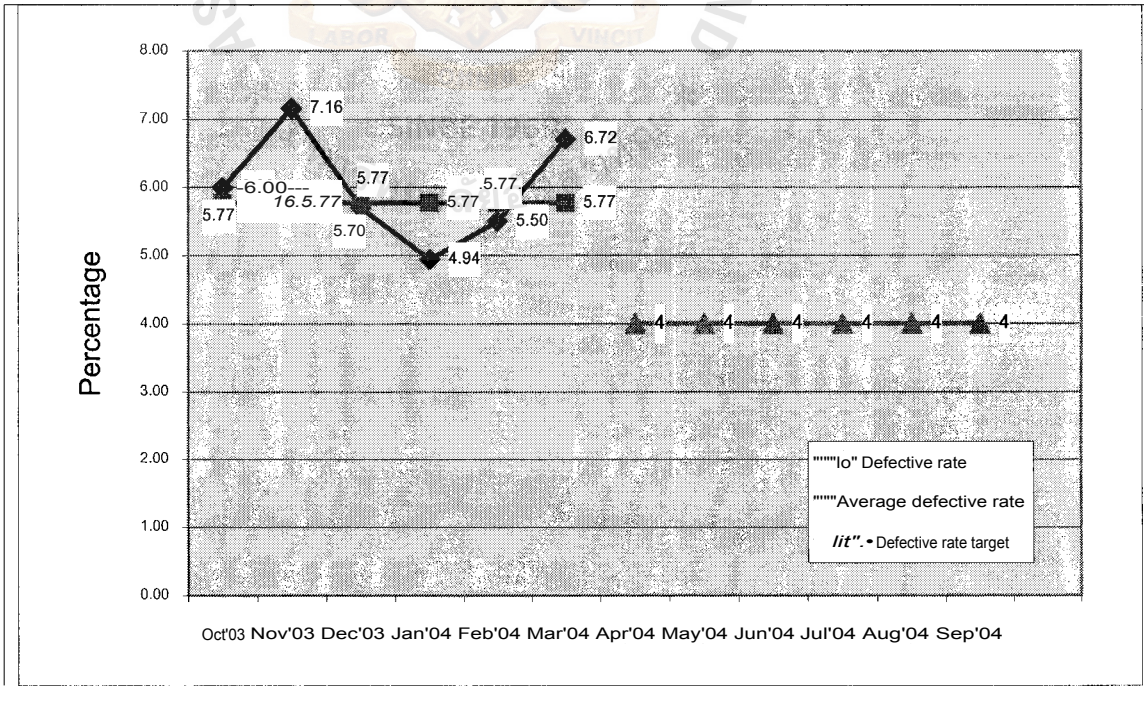


Figure 3.3. Current defective rate and target defective rate.

3.4 Measurement Phase

The methodology of measurement phase would address process flowchart, process mapping, cause-and-effect analysis, FMEA, and capability analysis.

3.4.1 Process Flowchart

The process flow chart is one of the techniques used to record a process sequence, a series of events or activities in the order in which they occur. Figure 3.4 illustrates Plastic Injection (GPPS) process flow chart. The process flow represents work operation by starting from material order to sending part to assembly line into Washing Machine and Refrigerator products.

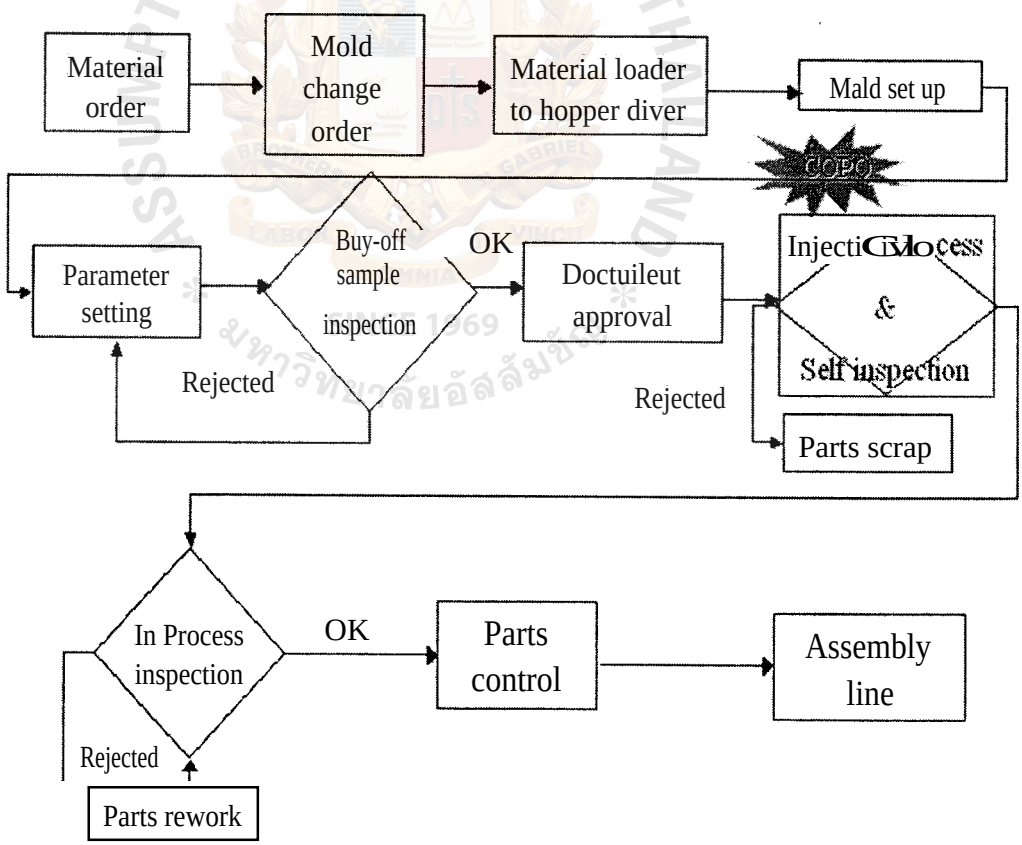


Figure 3.4. Plastic injection process flow of GPPS material.

3.4.2 Process Mapping

An alternative (or supplement) to a detailed process flow chart is a high-level process map that shows only a few major process steps as activity symbols. For each of these symbols key process input variables (KPIVs) to the activity are listed on one side of the symbols, while key process output variables (KPOVs) to the activity are listed on the other side of the symbol.

The steps of process mapping will be taken as follows.

(1) Define the scope of the process the team needs to map.

(2) Document all tasks or operations needed in the production of a "good" product or service.

(3) Document each task or operation above as value added or non-value added.

(4) List both internal and external Y's at each process step.

(5) List both internal and external X's at each process step.

(6) Classify all X's as one or more of the following;

(1) Controllable (C): These are inputs t hat c an b e a djusted o r controlled while the process is running. (i.e., speed, feed rate, temperature, pressure, etc). The variable or an input that can be readily changed to measure the effect on an output (Y).

(2) Noise (N): Things that cannot be controlled due to cost or difficulty in controlling (ambient temperature or humidity, operator training).

(3) Standard Operating Procedures (SOP): A clearly defined and implemented work instructions used at each process steps (i.e., cleaning, safety, loading of components, setup, etc).

(7) Clearly identify all data collection points.

3.4.3 Cause and Effect Analysis

Cause and Effect Analysis is a visual tool to identify, explore and graphically display, in increasing detail, all the possible causes related to a problem or condition to discover its root causes. It is based on the idea that we can positively identify what we do not like about a situation and trace it back to some underlying causes.

The project used Cause-and-effect matrix for analysis. Cause-and-effect matrix is in t able form showing the direct relationships b etween c ause (key p rocess input, Xs) and effect (key process output, Y). The cause-and-effect matrix is a tool that can aid the prioritization of importance of key process input variables. The steps of cause-and-effect matrix will be taken as follows.

Step 1: List the output variables (effect, Y's) along the top section of the matrix. These are outputs that the team or the customer deems to be important. There may be a subset of the list of Y's identified in the process map. Defect ratio will affect the Crack mark, Silver mark and Weld line that were defined as output variables in this project.

Step 2: Rank each output or effect numerically by using an arbitrary scale (possibly 1-10). The most important output (effect) receives the highest number. Crack mark, Silver mark and Weld line are output of this project that will be ranked. The given score of Crack mark is 9, Silver mark is 8 and Weld line is 7.

Step 3: Identify all potential inputs or causes (X's) that can impact the various Y's and list along the left hand side of the matrix. 15X's from process mapping bring to C&E Matrix.

Step 4: Numerically rate (correlate) the effect of each X on Y within the boundary of the matrix. This is based on experience. Rather than use

values from 1 t o 10 (where 10 indicates the largest e ffect), c onsider a scale using 1,4,7, and 9.

Step 5: Determine the result for each X by multiplying the Y priority (Step 2) by the consensus of the effect for the X (Step 4) and then summing these products.

Step 6: Use the total column to analyze and prioritize where to focus our effort when creating the preliminary FMEA.

3.4.4 Failure Modes and Effect Analysis (FMEA)

FMEA is a systematic approach used t o examine p otential failures and prevent their occurrence. Brainstorming is used to determine potential failure modes, their causes, severity, and their 1 ikelihood o f occurring. In Six Sigma, we apply FMEA to know failure modes. Our main interests are the cause and likelihood of occurrence, for which we have actual data and do not need to reply to brainstorming.

Below are the steps to fill up information into the FMEA form.

(1) Function: list functions that the component or system is supposed to perform.

(2) Potential Failure Mode: Brainstorm to get potential failure modes.

(3) Potential Effect of Failure: describe the effects for each of the level in term of what that subsequent user or customer would see.

(4) Severity of the Effect: rank the seriousness of the effect listed in the previous column of potential failure mode.

(5) Potential Cause of Failure: list every conceivable failure cause assigned to each potential failure mode.

(6) Occurrence: rank the number of a specific cause which will actually occur and result in the specific failure mode described.

(7) Current Control: list the activities which take place that either prevent the cause, detect the cause, detect the failure mode, or reduce the impact.

(8) Effectiveness: rank the ability of the current control activities (item 7) to detect the failure mode prior to occurring.

(9) Risk Priority Number (RPN): establish risk priority by multiplying severity, occurrence, and effectiveness.

We consider RPN to make the importance of the critical individual factor by performing the followings step by step.

(1) For each Process input, determine the ways in which the input can go wrong (These are Failure Modes).

(2) For each Failure Mode associated with the inputs, determine Effects.

(3) Identify potential causes of each Failure Mode.

(4) List the Current Controls for each Cause

(5) Assign Severity, Occurrence and Detection ratings to each Cause.

(6) Calculate RPN

(7) Determine Recommended Actions to reduce High RPN's.

(8) Take appropriate Actions and Document

(9) Recalculate RPN's

3.4.5 Capability Analysis

(1) Process Capability/Performance Indices

The purpose of process capability/performance indices is to quantify how well process is executing relative to the needs of the customer. These indices give insight into whether defects are the result of a mean shift in the process or excessive variability. Examples of process capability/performance indices are C_p, C_pk, Pp, P_pk.

(2) Process capability of Project

We will use Minitab program to calculate Process Benchmarks (Z-Bench and PPM) and Process Capability. Minitab provides procedures that allow us to employ the concepts of Six Sigma quality. The concept of Six sigma is based on the idea that there are relationships between product nonconformities and various aspects of product quality (such as yield, reliability, performance and cost).

Steps in Process capability are as follows.

(1) Calculate the defective rate of GPPS material and fill the defective rate data in Minitab program.

(2) Choose Six Sigma > Process Report

Six Sigma Process Report produces six process capability reports for a single quality characteristic of a product. A companion to this report is the Six Sigma Product Report which c ombines measures from m any characteristics into a product capability, or many products' capabilities into a "business capability."

(3) Minitab program will show Six Sigma Process Report as shown in Figure 3.5.

Choose Subgroups across rows of:.

(4) Input the Upper spec and Lower spec in column.

From the current defective rate, Upper spec defective rate is 7.16% and Lower spec defective rate is 0%.

(5) Find the report: "The Executive Summary Report" and "The Process Capability Report"

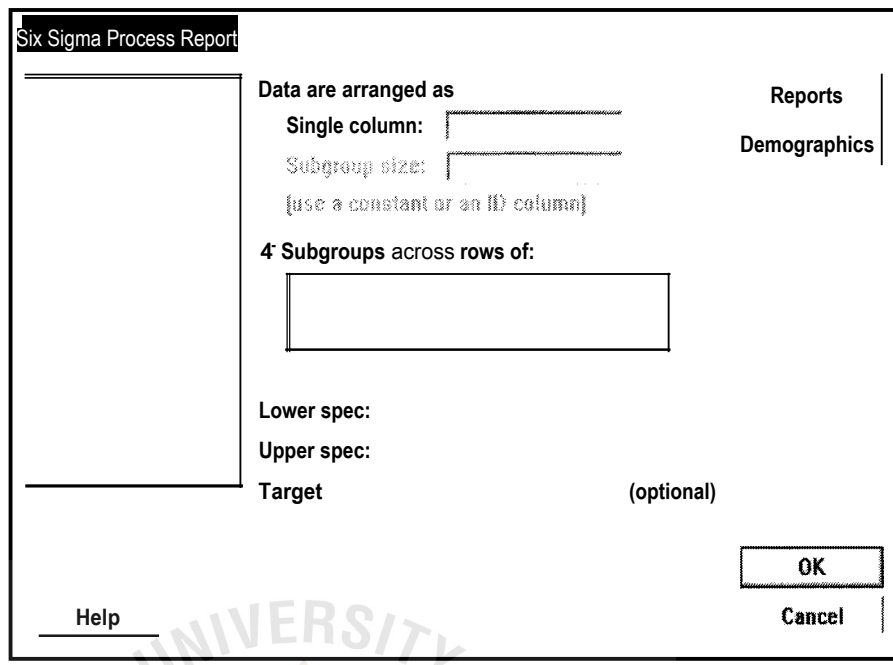


Figure 3.5. Six Sigma Process Report from Minitab program.

The Executive Summary Report displays estimates of both actual and potential process performance. It consists of three basic parts: the Process Performance, Process Demographics, and Process Benchmarks The Process Performance portion is on the left hand side. The top chart shows a normal curve for the actual long-term performance and the process potential short-term performance. The short-term potential tells how capable the process can be if we can control it and shift the mean on target. The second chart demographics table shows process information on the data set and the report itself. The last block, the Process Benchmarks block, reports the sigma level and PPM count for the long and short-term."

The Process Capability Report summarizes both long-term and short-term capability of your process, using X bar/R charts to establish that the

process is in control, graphical depictions of the process performance relative to the specification limits, and a table of capability statistics.

3.5 Analysis Phase

In the analysis phase of this project, we will use hypothesis testing and correlation study to analyze the data for the purpose of gaining.

3.5.1 Hypothesis Testing

Hypothesis testing answers the practical question "Is there a real difference between and ?". A practical process problem is translated into a statistical hypothesis in order to answer this question. P-value is the smallest level of significance that would lead to rejection of the null hypothesis Ho.

Steps in hypothesis testing are as follows.

(1) Define the problem.

(2) State the objectives.

(3) Establish the hypotheses.

(a) State the Null Hypothesis (Ho).

(b) State the Alternative Hypothesis (Ha).

(4) Decide on appropriate statistical test.

(5) Conduct test and collect data.

(6) Calculate the test statistics from the data.

(7) Determine the probability of that calculated test statistics occurring by chance = P-Value.

(8) If P-Value is less than a, reject Ho and accept Ha. If P-Value is greater than a, do not reject Ho.

(9) Replicate results and translate statistical conclusion to practical solution.

3.5.2 Normal Probability Plot

An Alternative to a histogram and dot plot, a normal probability plot can estimate the proportion of data beyond specification limits and can give a view of the "capability" of the process. This is an excellent tool when no specification limit exists for transactional/service processes. Normal probability plots also assess the validity of the normality assumptions.

3.5.3 Correlation and Regression

Correlation usually wants to measure or quantify the relationship or the degree of relationship. Characteristics are given below.

(1) Relationship is assumed linear.

(2) Relationship is defined as X2 = X1 b

(3) Degree of relationship is the correlation coefficient (R) or R^2.

3.5.4 Analysis Phase of Project

Evaluation method is as follows.

(1) State the objectives. We find the potential key inputs variable from FMEA analysis to analyze.

(2) Establish the hypotheses

Ho = Factor is not related to defect rate

Ha = Factor is related to defect rate

(3) Fill potential key inputs variable and yield data in Minitab program.

(4) Find the Normal Probability Plot by using Anderson-Darling in Minitab program to see the data follow a normal distribution.

Steps in Normality test are as follows.

(1) Choose Stat > Basic Statistics > Normality Test.

(2) Minitab program will show Normality Test as shown in Figure 3.6.

Choose Tests for Normality: Anderson-Darling

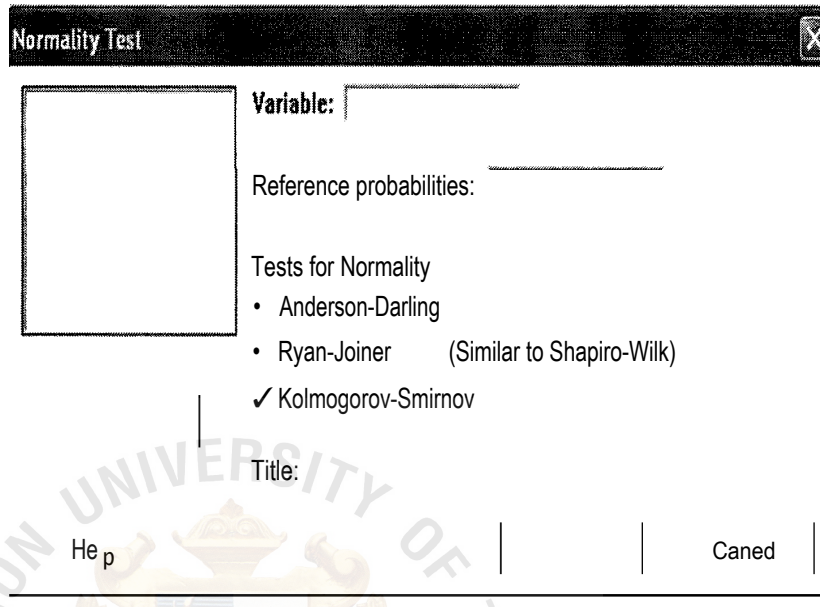


Figure 3.6. Normality Test from Minitab program.

(3) Fill "Yield" in Variable and fill "potential key inputs variable" in Reference probabilities.

(4) Find the report.

(5) Find the Regression Plot by using Minitab program.

Steps in Regression Plot are as follows.

(1) Choose Stat > Regression > Fitted Line Plot.

(2) Minitab program will show Fitted Line Plot as shown in Figure 3.7.

Choose Type of Regression Model: Linear

(3) Fill "Yield" in Response (Y) and fill "potential key inputs variable" in Predictor (X).

(4) Find the report.

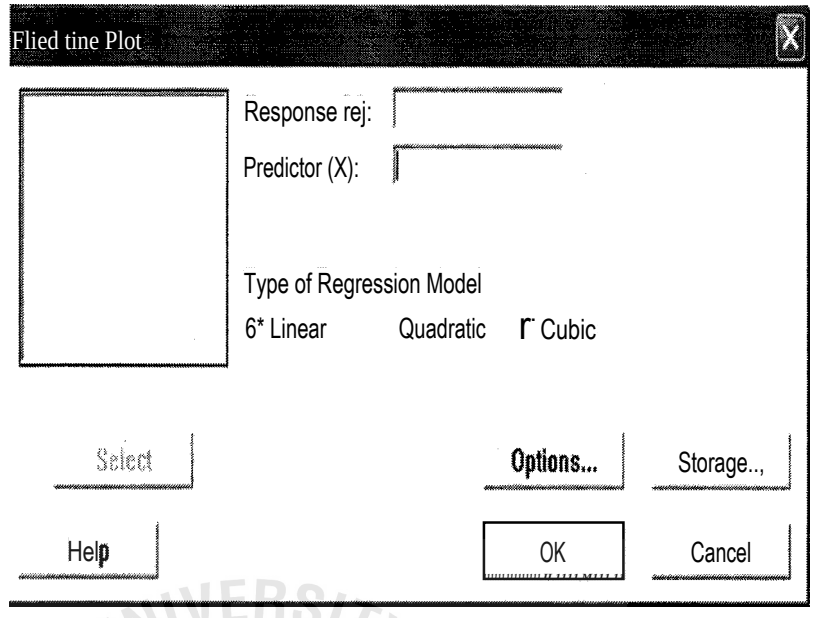


Figure 3.7. Fitted Line Plot from Minitab program.

(6) Analyze the hypothesis test result. If P-value is less than 0.05, it means accept Ha (Factor related to defect rate). While P-value is more than 0.05, it means accept Ho (Factor not related to defect rate).

(7) Analyze the correlation (R^2) about factor and defect rate.

3.6 Improvement Phase

In the improvement phase of this project, we will use Factorial design that is one kind of DOE for improving the performance of a manufacturing process. This is a design for investigating all possible treatment combinations that are formed from the factors under considerations.

Steps in DOE testing are as follows.

(1) Create the Factorial Design

Choose Stat > DOE > Create Factorial Design

Minitab program will show Factorial designs as shown in Figure 3.8.

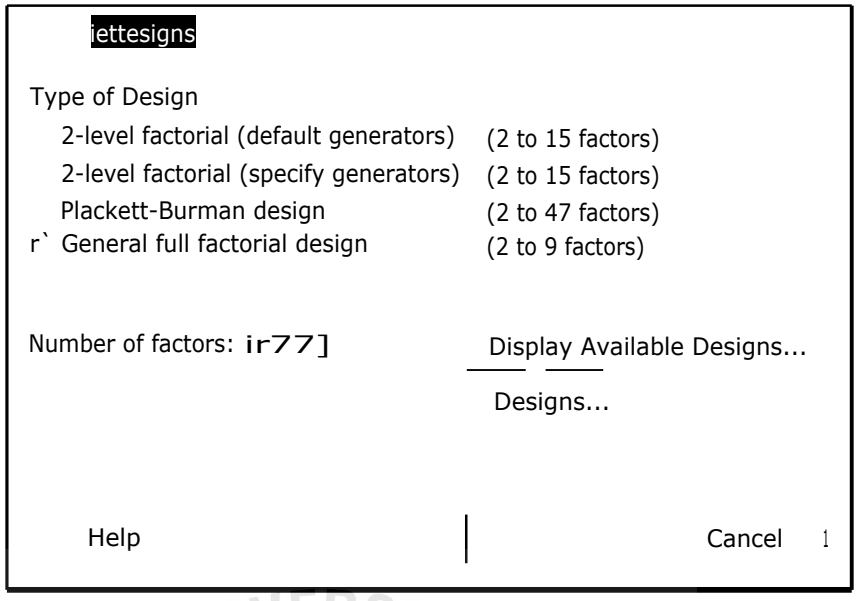


Figure 3.8. Factorial Designs from Minitab program.

(2) Fill Number of factors. Use data KPIVs that are finished analyzing from hypothesis testing and correlation (R^2) in analysis phase.

(3) Choose Display Available Designs... To find number of factors

Minitab program will show "Factorial design — Available Designs"

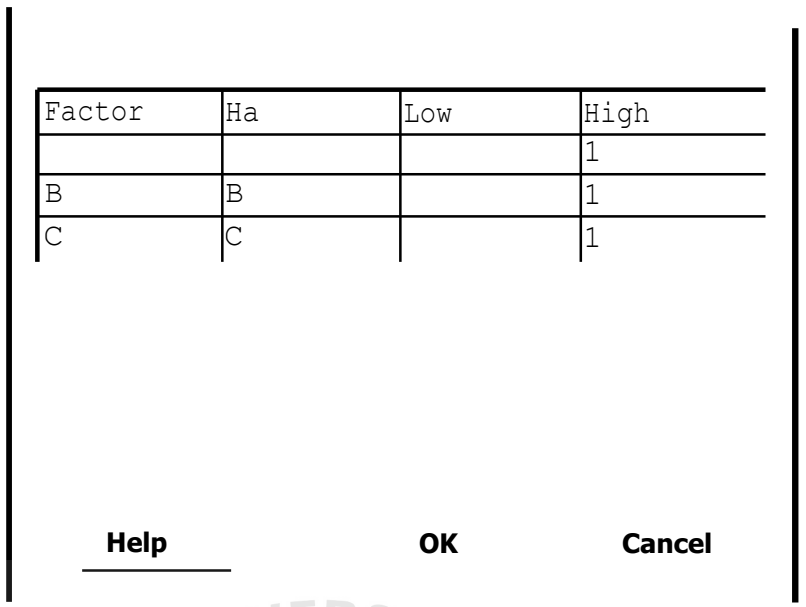
(4) Choose Design

Minitab program will show "Factorial design — Design"

Select Full factorial... To find number of runs

(5) Choose Factors

Minitab program will show "Factorial design — Factors" as shown in Figure 3.9. Input KPIVs from analysis phase in "Name".



Factor	Ha	Low	High
			1
B	B		1
C	C		1

Help OK Cancel

Figure 3.9. Factorial Design - Factors from Minitab program.

(6) State low value and high value

(7) Find the report

Minitab program will show Factorial design.

(8) Start to try-out the experiment followed by Standard Order to find the yield from Injection machine by using the difference factors.

(9) Create the Factorial Plots

Choose Stat > DOE > Factorial Plots

Minitab program will show Factorial Plots as shown in Figure 3.10.

(10) Choose type of Factorial Plots

In this project we select at "Cube (response versus levels of 2 to 8 factors)

Choose Setup...

(11) Minitab program will show Factorial Plots - Cube

Fill Response (optional): "Yield"

Factors to Include in Plots: Selected all factors

(12) Find the report

Minitab program will show Cute Plot.

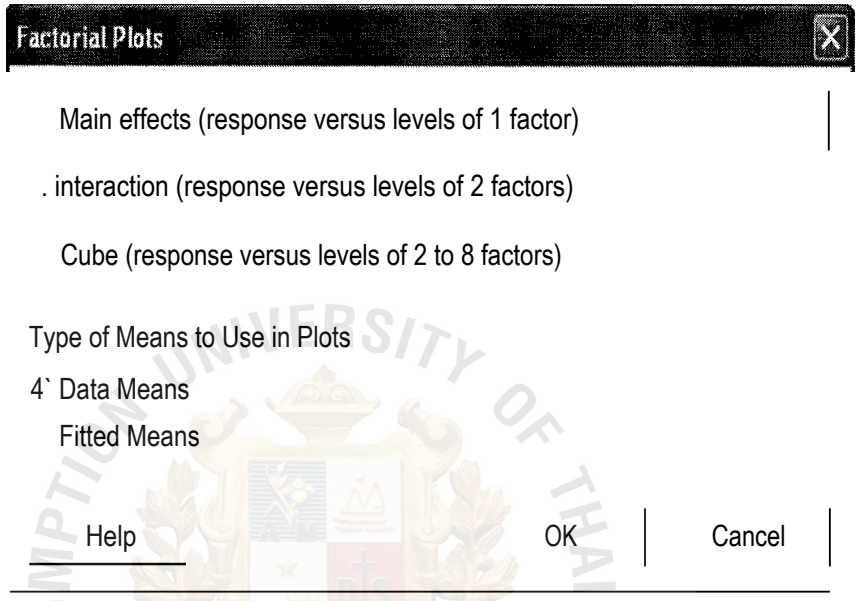


Figure 3.10. Factorial Plots from Minitab program.

After the design and plot of the factorial, the optimize parameter must be found. The data will show the optimize parameter that effect the yield; we can bring this data to improve the process in Injection machine and find the process capability again after improvement.

IV. RESULTS AND DISCUSSIONS

4.1 Measurement Phase

The results on measurement phase are process mapping, cause-and-effect analysis, FMEA, and capability analysis.

4.1.1 Process Mapping

Figure 4.1 illustrates Plastic Injection process mapping. Activity symbols of this project are Injection process. There are 18X of KPIV in this project that are the inputs in the left of the table and all Xs can be classified like this;

(1) Operator : Control

(2) Machine size : Control

(3) Material grade : Control

(4) Material color : Control

(5) Material humidity : Noise

(6) Material dirty : Noise

(7) Injection speed : Control

(8) Injection pressure : Control

(9) Ejector speed : Control

(10) Cooling time : Control

(11) Mold temperature : Control

(12) Mold clamping : Control

(13) Nozzle temperature : Control

(14) Operation instruction : SOP

(15) Injection time : Control

(16) Ambience temperature : Noise

(17) Limit sample : Control

(18) Inspection method : SOP

Only 15 X's bring to Cause and Effect Matrix except Material humidity, Material dirty and Ambience temperature which are noise and they could not be controlled. The KPOV in this project is plastic part that separate into accept or reject (crack mark, silver mark and weld line).

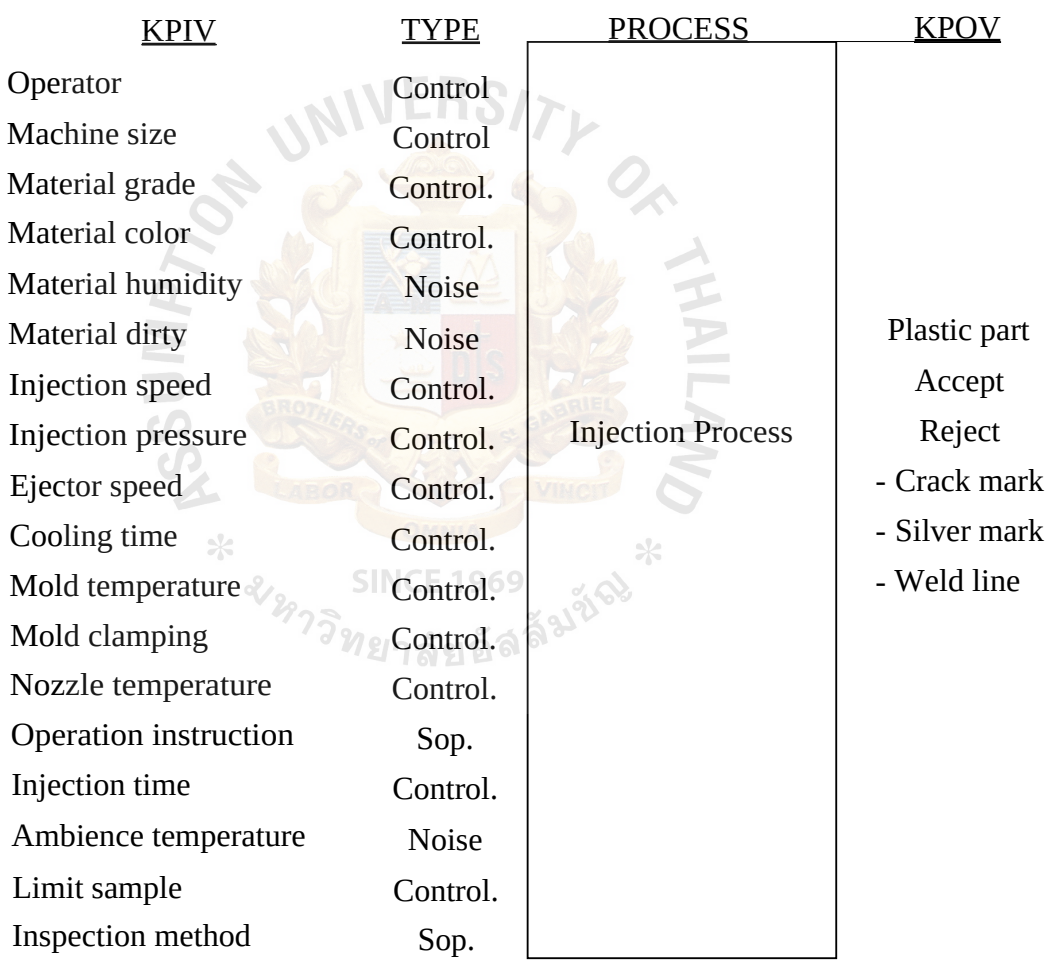


Figure 4.1. Process mapping of Injection Process.

4.1.2 Cause and Effect Matrix

Figure 4.2 illustrates a cause-and-effect matrix of this project got after following the steps in the Project Methodology chapter. The cause-and-effect matrix indicates that the major problems are 8X's significant KPIV identified in which they have scored more than 100 points; there are Machine size, Machine grade, Injection speed, Injection pressure, Ejector speed, Cooling time, Mold temperature and Injection time.

		Rating of Importance to Customer	**9**	**8**	**7**	
			1	**2**	**3**	
			Cracking	**rSilver**	**Weld line**	**Total**
	Process Step	**Process Input**				
1	Injection Process	Operator	1	1	1	24
2		Machine size	4	4	7	117
3		Material grade	4	4	7	117
4		Material color	1	1	1	24
5		Injection speed	7	7	7	168
6		injection pressure	7	7	9	182
7		Ejector speed	9	4	4	141
8		Cooling time	7	4	4	123
9		Mold temperature	9	7	7	186
10		Mold clamping	1	1	1	24
11		Nozzle temperature	1	1	4	45
12		Operation instruction	1	1	1	24
13		Injection time	4	4	7	117
14		Limit sample	4	4	4	96
15		Inspection method	1	1	1	24
Total						

Figure 4.2. Cause and Effect Matrix.

4.1.3 Failure Modes and Effect Analysis (FMEA)

All causes from Cause and Effect Matrix were put into FMEA form to examine potential failures and prevent their occurrence. There are 8X's significant KPIV as Machine size, Machine grade, Injection speed, Injection pressure, Ejector speed, Cooling time, Mold temperature and Injection time put into the FMEA table.

Table 4.1 illustrates FMEA of KPIV. After measuring we found that 4X's has the score of more than 100 points; there are Injection speed, Ejector speed, Cooling time and Mold temperature.

4.1.4 Process Capability

(1) Calculate the defective rate of GPPS material (use data from Table 3.1.)

Table 4.2. Defective rate of GPPS material in term 03B (Oct'03-Mar'04).

Month	Material		
	Good (Kg)	Defect (Kg)	Defect rate
Oct'03	107,177	6,837	6.00
Nov'03	72,043	5,554	7.16
Dec'03	126,990	7,678	5.70
Jan'04	193,103	10,041	4.94
Feb'04	148,902	8,668	5.50
Mar'04	83,533	6,014	6.72

(2) Fill the defect rate data in the Minitab program to find the report.

(3) After input of the data, the Minitab program will show the report as shown in Figure 4.3 Executive summary before improvement and Figure 4.4 Process Capability before improvement.

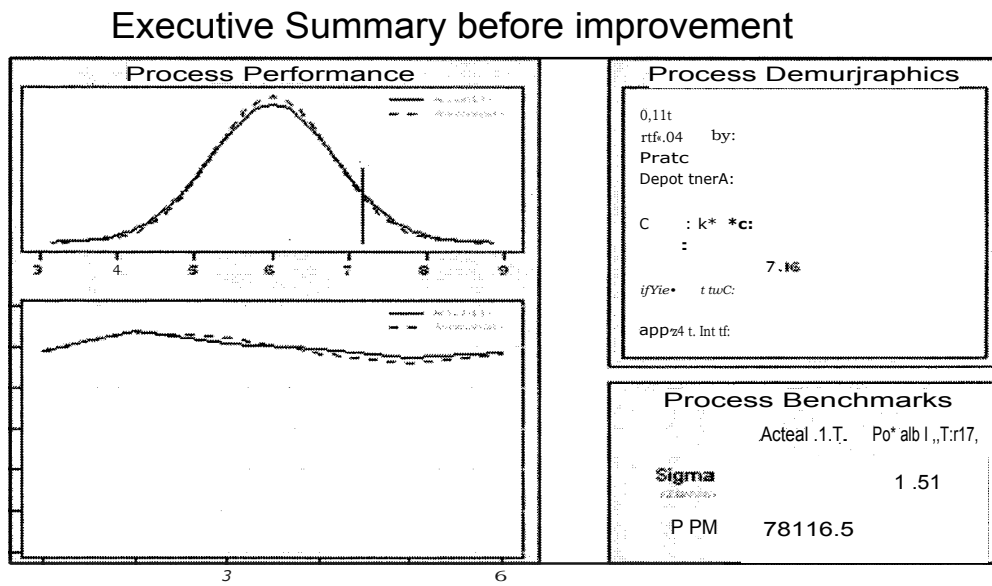


Figure 4.3. Executive Summary before improvement.

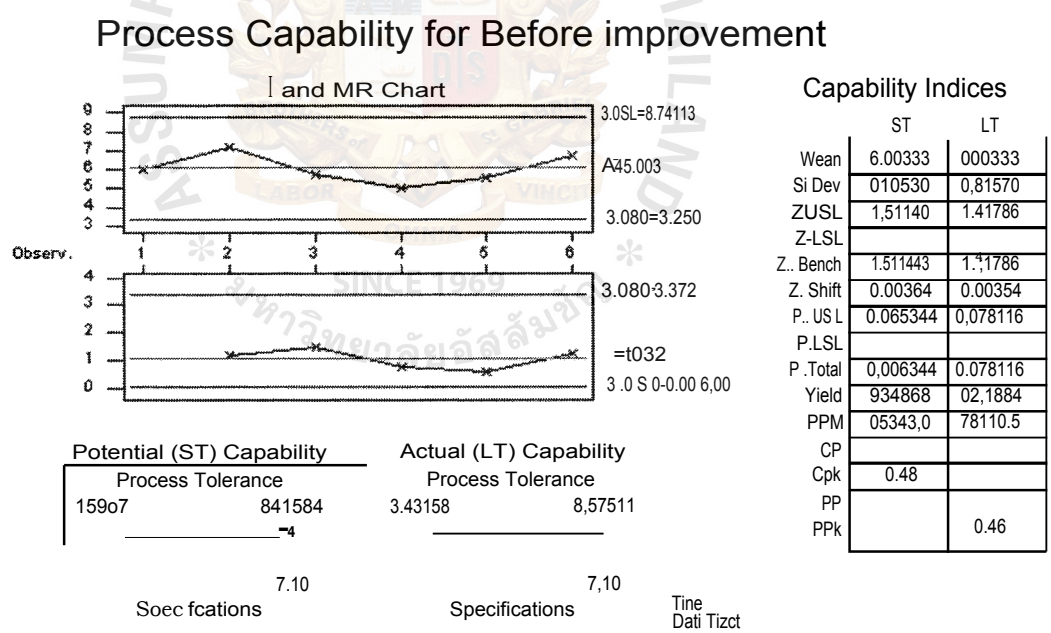


Figure 4.4. Process Capability before improvement.

From the report we found that Z-Bench is 1.51, PPM is 78,116.5 and C_pk is 0.48.

Table 4.1. Failure Mode and Effect Analysis (FMEA) of Injection process.

Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	S E V	Potential Causes	O C C	Current Controls	D E T	R P N
Injection Process	Machine size	Diference machine size.	Plastic parts will have silver .	7	Wrong selected machine size.	3	There are approved manual operation instruction or std. Parameter beside the machine.	2	42
	Material grade	Wrong grade material.	Plastic parts will have cracking	7	Material incoming problem.	2	SOP	2	28
	Injection speed	Set up injection speed too high and too low.	Plastic parts will have cracking and silver.	9	No proper setting.	7	There are approved manual operation instruction or std. Parameter beside the machine.	2	126
	Injection pressure	Set up injection pressure too high and too low.	Plastic parts will have cracking,silver .	7	No proper setting.	6	There are approved manual operation instruction or std. Parameter beside the machine.	2	84
	Ejector speed	Set up ejector speed too high.	Plastic parts will have cracking	9	No proper setting.	7	There are approved manual operation instruction or std. Parameter beside the machine.	2	126
	Cooling time	Set up cooling time long time.	Plastic parts will have cracking,silver ,	7	No proper setting.	7	None	8	392
	Mold temperature	Set up mold temperature too low.	Plastic parts will have cracking,silver .	9	No standard parameter.	8	None	8	576
	Injection time	Set up injection time too low.	Plastic parts will have cracking,silver.	7	No proper setting.	3	There are approved manual operation instruction or std. Parameter beside the machine.	2	42

4.2 Analysis Phase

There are 4X's significant KPIV as Injection speed, Ejector speed, Cooling time and Mold temperature brought from the FMEA analysis. In this project, we have been reviewing all test parameters to see a chance of reducing the defect rate.

Table 4.3. Analyze factor of X's and Y.

X	Y	Tool
Injection speed	Defect rate	Simple Regression
Ejector speed	Defect rate	Simple Regression
Cooling time	Defect rate	Simple Regression
Mold temperature	Defect rate	Simple Regression

From Table 4.3, we will analyze the hypothesis test result and correlation (R^2) of each KPIV and defect rate by using Normality Test and Regression Test report.

(1) Injection speed and Defect rate

Injection speed is one parameter that will be set in the tester. This setting is to define the relation of Injection speed and Defect rate. Injection speed to do significance difference analysis of test defect rate is based on the hypothesis statements given below:

(1) Establish the hypothesis

Ho = Injection speed is not related to defect rate

Ha = Injection speed is related to defect rate

(2) Use Injection Speed and Yield data (Table 4.4.) that we recorded in term 03B to fill in the Minitab program to find the report.

Table 4.4. History of Injection speed and Yield in term 03B.

Injection speed	Yield
30	94
32	96
35	95
40	96
41	93
45	95
46	95
48	93
50	94

(3) After input o f the data, the Minitab program will show the report as shown in Figure 4.5 Normality Probability Plot and Figure 4.6 Regression Plot.

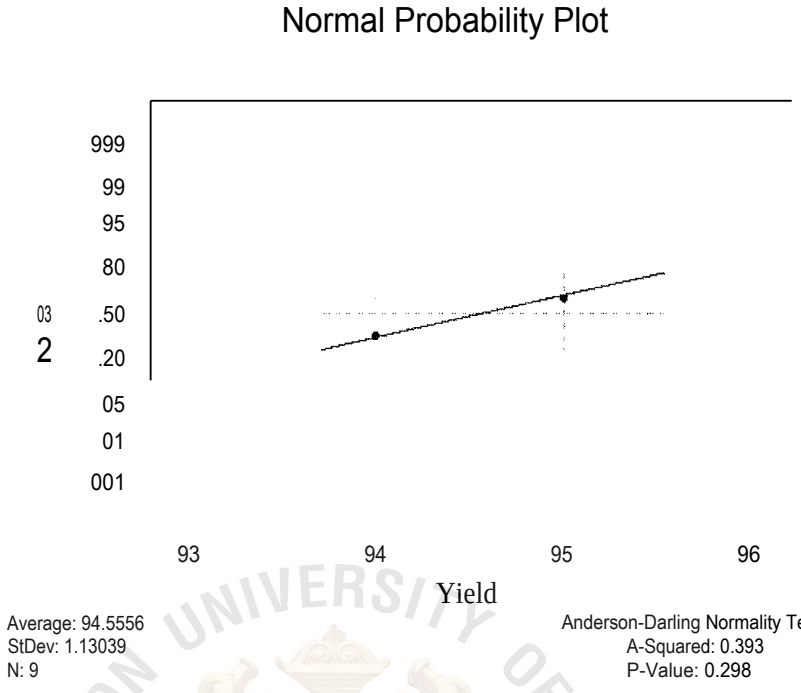
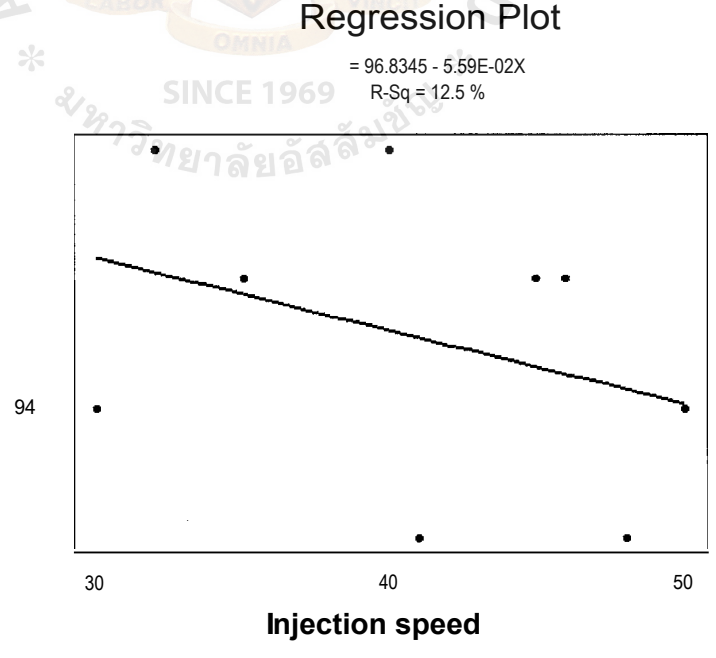


Figure 4.5. Normal Probability Plot of Injection speed and Yield.



Regression

```
The regression equation is
y = 96.8 - 0.0559 x

Predictor        Coef       StDev          T        P
Constant       96.835       2.308      41.95    0.000
x            -0.05589     0.05585      -1.00    0.350

S = 1.130       R-Sq = 12.5%     R-Sq(adj) = 0.0%

Analysis of Variance

Source            DF          SS          MS          F        P
Regression         1       1.279       1.279       1.00    0.350
Residual Error     7       8.943       1.278
Total              8      10.222
```

Figure 4.6. Regression Plot of Injection speed and Yield.

Figure 4.6 illustrates Regression Plot result of Injection speed, P-value is 0.350 (more than 0.05) that means we accept Ho. Therefore Injection speed is not related to defect rate, and R^2 i s 12.50% that means there is no correlation.

(2) Ejector speed and Defect rate

Ejector speed is one parameter that will be set in the tester. This setting is to define the relation of Ejector speed and Defect rate. Ejector speed to do significance difference analysis of test defect rate is based on the hypothesis statements given below:

(1) Establish the hypothesis

Ho = Ejector speed is not related to defect rate

Ha = Ejector speed is related to defect rate

(2) Use Ejector Speed and Yield data (Table 4.5.) that we recorded in term 03B to fill in the Minitab program to find the report.

Table 4.5. History of Ejector speed and Yield in term 03B.

Ejector speed	Yield
4	96
6	96
7	95
7	96
8	93
8	94
9	95
10	93
10	94

(3) After input o f the data, the Minitab program will show the report as shown in Figure 4.7 Normality Probability Plot and Figure 4.8 Regression Plot.

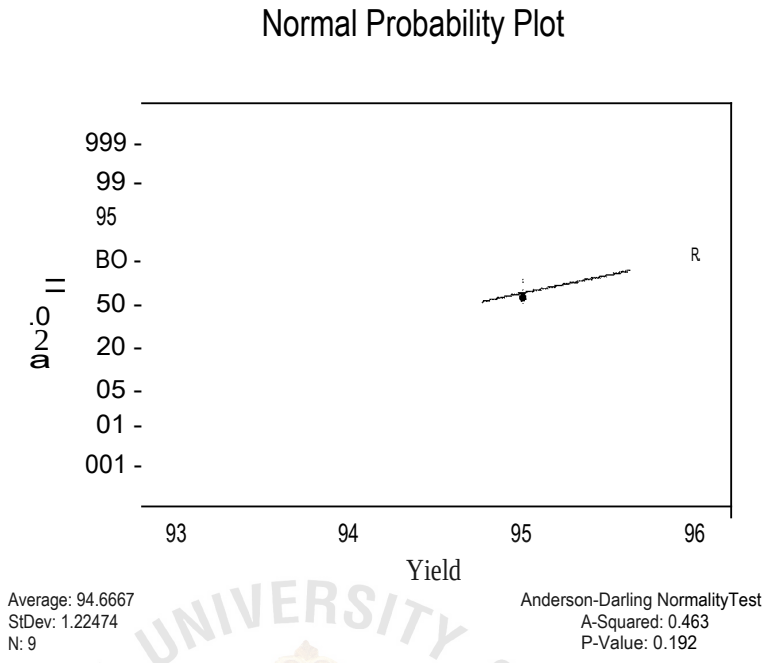
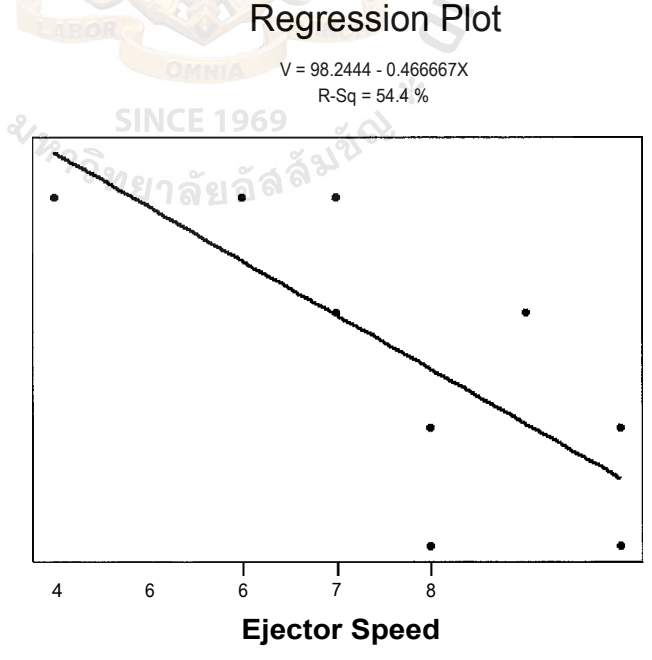


Figure 4.7. Normal Probability Plot of Ejector speed and Yield.



Regression

```
The regression equation is
y = 98.2 - 0.467 x

Predictor        Coef       StDev          T        P
Constant       98.244       1.272      77.26    0.000
x             -0.4667      0.1613      -2.89    0.023

S = 0.8837      R-Sq = 54.4%     R-Sq(adj) = 47.9%

Analysis of Variance

Source            DF          SS          MS         F        P
Regression         1      6.5333      6.5333      8.37    0.023
Residual Error     7      5.4667      0.7810
Total              8     12.0000
```

Figure 4.8. Regression Plot of Ejector speed and Yield.

Figure 4.8 illustrates the hypothesis test result of Ejector speed, P-value is 0.023 (less than 0.05) that means we accept Ha that the Ejector speed is related to defect rate. And R^2 is 54.40% that means there is correlation.

(3) Cooling time and Defect rate

Cooling time is one parameter that will be set in the tester. This setting is to define the relation of Cooling time and Defect rate. Cooling time to do significance difference analysis of test defect rate is based on the hypothesis statements given below:

(1) Establish the hypothesis

Ho = Cooling time is not related to defect rate

Ha = Cooling time is related to defect rate

(2) Use Cooling time and Yield data (Table 4.6.) that we recorded in term 03B to fill in the Minitab program to find the report.

Table 4.6. History of Cooling time and Yield in term 03B.

Cooling time	Yield
34	93
35	94
40	94
42	93
42	96
45	95
46	95
50	95
53	96
56	96

(3) After i nput o f the data, the Minitab program will show the report as shown in Figure 4.9 Normality Probability Plot and Figure 4.10 Regression Plot.

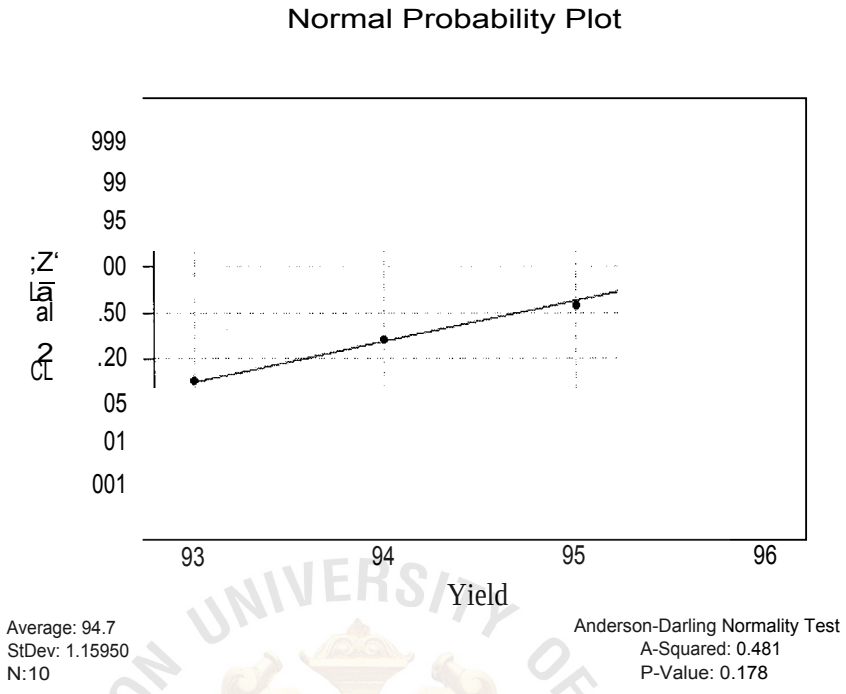
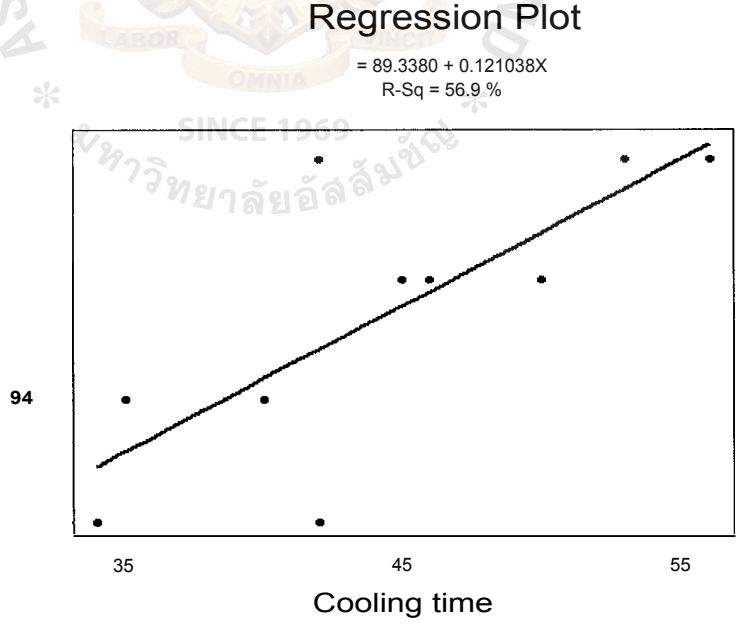


Figure 4.9. Normal Probability Plot of Cooling time and Yield.



Regression

```
The regression equation is
y = 89.3 + 0.121 x

Predictor        Coef       StDev          T        P
Constant       89.338       1.669      53.53    0.000
x             0.12104     0.03723       3.25    0.012

S = 0.8072      R-Sq = 56.9%     R-Sq(adj) = 51.5%

Analysis of Variance

Source            DF          SS          MS         F        P
Regression         1      6.8871      6.8871     10.57    0.012
Residual Error     8      5.2129      0.6516
Total              9     12.1000
```

Figure 4.10. Regression Plot of Cooling time and Yield.

Figure 4.10 illustrates the hypothesis test result of Cooling time, P-value is 0.012 (less than 0.05) that means we accept Ha that Cooling time is related to defect rate. And R^2 is 56.90% that means there is correlation.

(4) Mold temperature and Defect rate

Mold temperature is one parameter that will be set in the tester. This setting is to define the relation of Mold temperature and Defect rate. Mold temperature to do significance difference analysis of test defect rate is based on the hypothesis statements given below:

(1) Establish the hypothesis

Ho = Mold temperature is not related to defect rate

Ha = Mold temperature is related to defect rate

(2) Use Mold temperature and Yield data (Table 4.7.) that we recorded in term 03B to fill in Minitab program to find the report.

Table 4.7. History of Mold temperature and Yield in term 03B.

Mold temperature	Yield
31	93
31	95
33	93
34	94
34	95
37	95
40	96
45	96

(3) After input o f the data, the Minitab program will show the report as shown in Figure 4.11 Normality Probability Plot and Figure 4.12 Regression Plot.

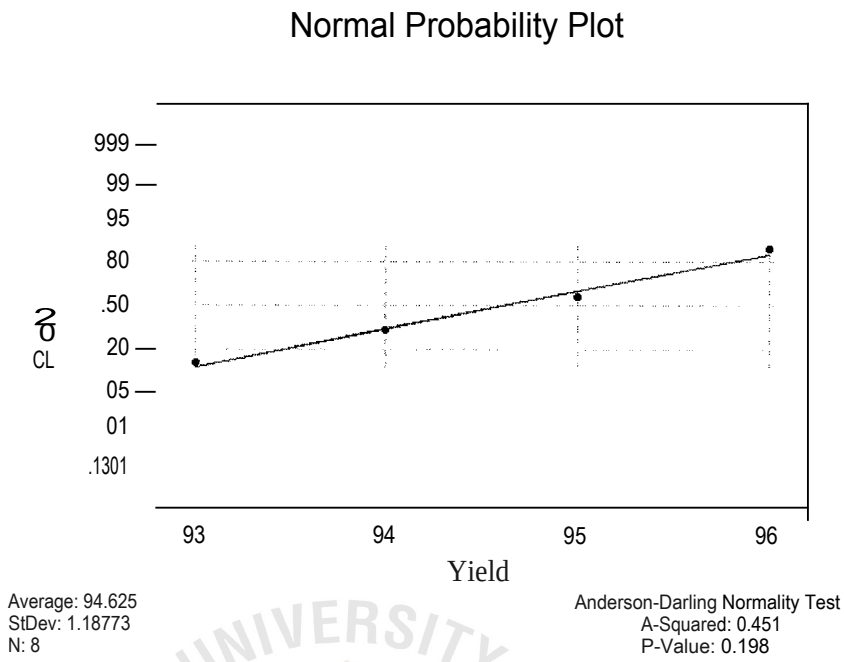
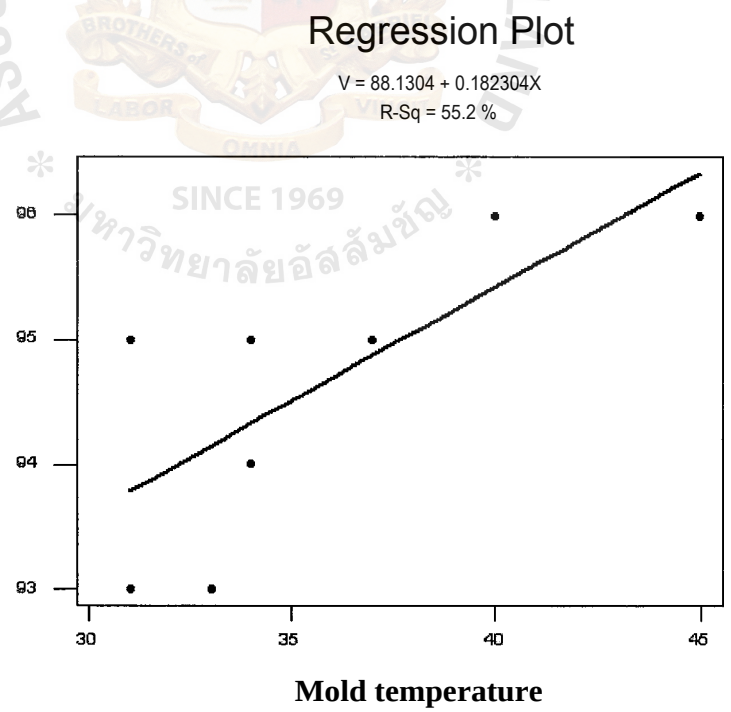


Figure 4.11. Normal Probability Plot of Mold temperature and Yield.



Regression

```
The regression equation is
y = 88.1 + 0.182 x

Predictor        Coef       StDev          T        P
Constant       88.130       2.410      36.57    0.000
x             0.18230     0.06711       2.72    0.035

S = 0.8591      R-Sq = 55.2%     R-Sq(adj) = 47.7%

Analysis of Variance

Source            DF          SS          MS          F        P
Regression         1      5.4463      5.4463       7.38    0.035
Residual Error     6      4.4287      0.7381
Total              7      9.8750
```

Figure 4.12. Regression Plot of Mold temperature and Yield.

Figure 4.12 illustrates the hypothesis test result of Mold temperature, P-value is 0.035 (less than 0.05) that means we accept Ha that the Mold temperature is related to defect rate. And R^2 is 55.20% that means there is correlation.

From the report analysis of the four factors with defect, we found that the three inputs variable, Ejector speed, Cooling time, and Mold temperature are significant to defective parts. While one input variable Injection speed is not significant to defect parts. Therefore the three input variables shall be studied to set up the suitable improvement.

4.3 Improvement Phase

4.3.1 DOE testing

(1) Create the Factorial Design

The Number of factors is 3. We use the three input variables from the analysis phase: Ejector speed, Cooling time, and Mold temperature.

(2) Choose Display Available Designs... To find number of factors

Minitab program will show "Factorial design — Available Designs" as shown in Figure 4.13.

We have to use 8 runs for full available factorial designs.

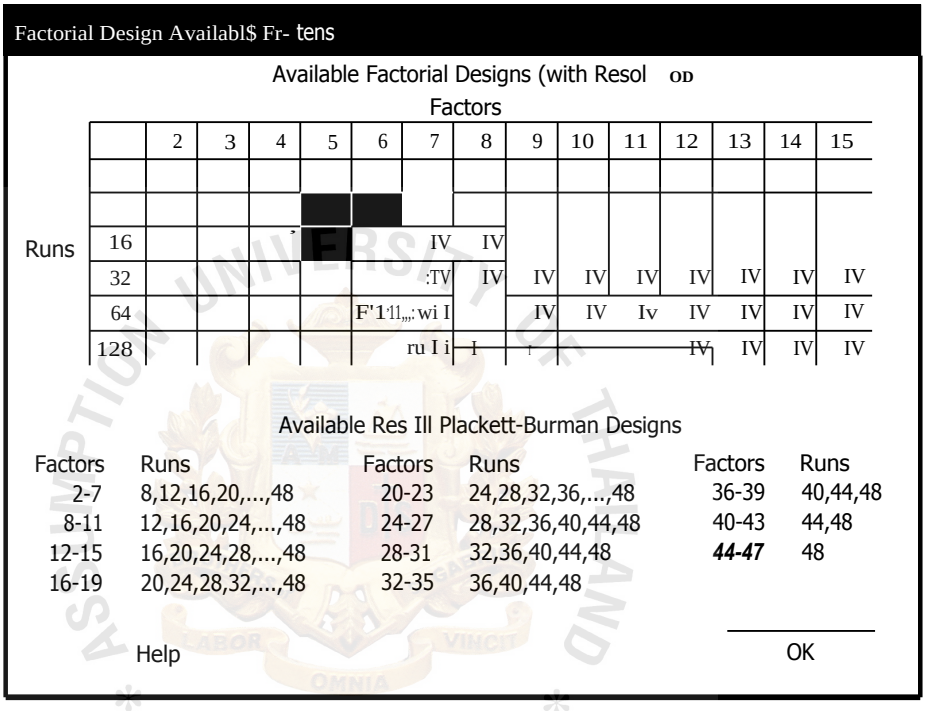


Figure 4.13. Factorial Design — Available Designs in Minitab program.

(3) Choose Design

Minitab program will show "Factorial design — Design" as shown in Figure 4.14. Select Full factorial...

We have to use 8 runs for full Resolution.

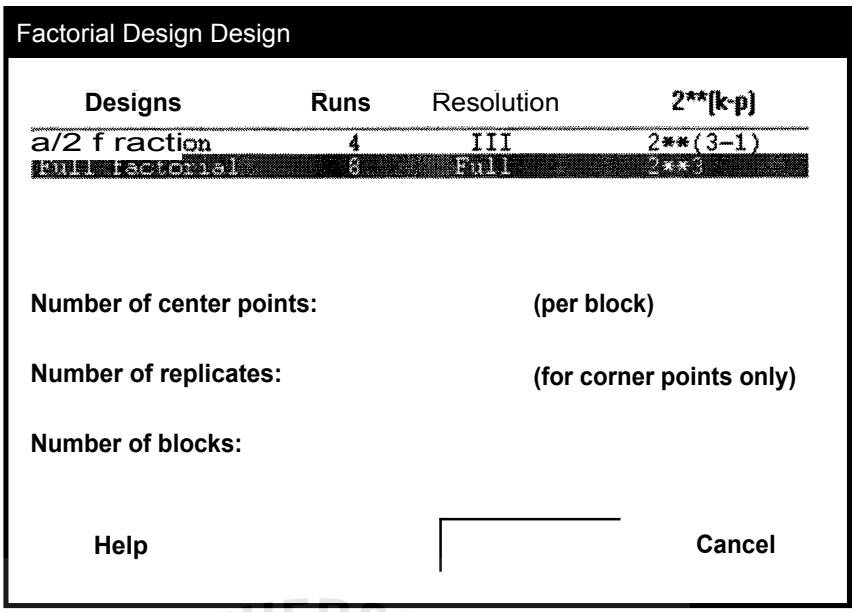


Figure 4.14. Factorial Design — Designs in Minitab program.

(4) Choose Factors

Minitab program will show "Factorial design — Factors"

Input Factor A is Ejector speed

Input Factor B is Cooling time

Input Factor C is Mold temperature

(5) State low value and high value

	Factorial Design	
	High(1)	Low (-1)
Ejector speed	10 mm/sec	5 mm/sec
Cooling time	50 sec	40 sec
Mold temperature	40°C	30°C

(6) Find the report

(7) Start to try-out the experiment following the Standard Order in Injection machine to find the yield value, after that fill the yield value in C8 as shown in Figure 4.15.

Factorial Design

```
Full Factorial Design

Factors:         3   Base Design:           3, 8
Runs:            8 Replicates:                1
Blocks:       none   Center pts (total):       0

All terms are free from aliasing
```

C1	C2	C3	C4	C5	C6	C7	C8
StdOrder	RunOrder	CenterPt	Blocks	Ejector speed	Cooling time	Mold temperature	Yield
6	1	1	1	1	-1	1	92.6
4	2	1	1	1	1	4	90.9
2	3	1	1	1	-1	-1	94.2
5	4	1	1	-1	-1	1	90.5
7	5	1	1	-1	1	1	95.6
8	6	1	1	1	1	1	93.6
3	7	1	1	-1	1	-1	97.8
1	8	1	1	-1	-1	-1	92.2

Figure 4.15. Factorial Design Report after experiment to find Yield value.

(8) Create the Factorial Plots as shown in Figure 4.16.

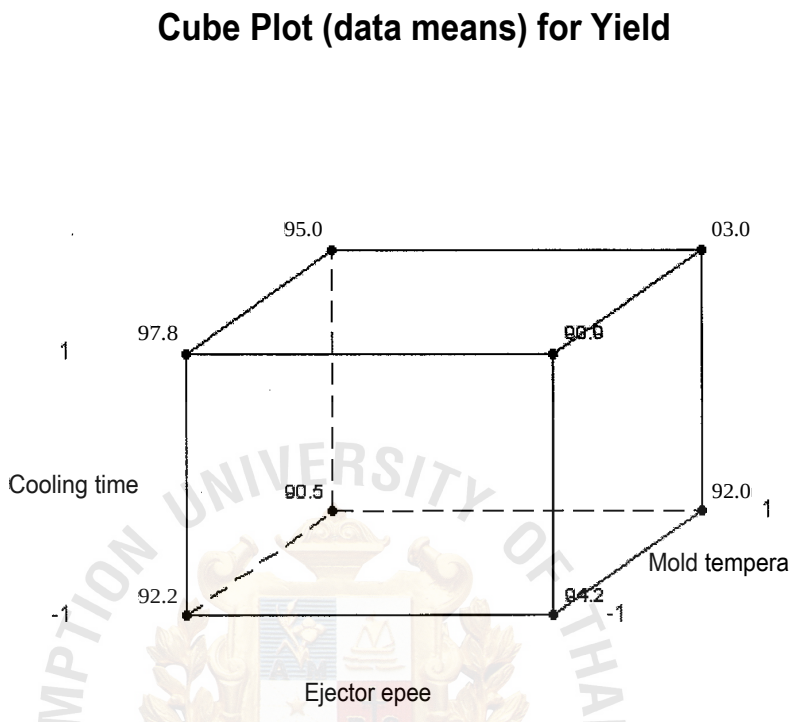


Figure 4.16. Cube Plot for Yield from Minitab program.

The three input variables, Ejector speed, Cooling time and Mold temperature are to try out DOE testing by designing and plotting the factorial to find the optimize parameter. At Standard Order 3 that means Ejector speed —1, Cooling time 1, and Mold temperature —1, we found yield value is maximum 97.8.

The optimize parameter is Ejector speed 5 mm/sec, Cooling time 50 sec, and Mold temperature 30°C.

4.3.2 Process Capability after improvement

(1) Calculate the defective rate o f G PPS material after u sing the optimization parameter. Table 4.8 shows the defective rate after improvement.

(2) Fill the defect rate data in the Minitab program to find the report.

(3) After input of the data, the Minitab program will show the report as shown in Figure 4.17 Executive summary after improvement and Figure 4.18 Process Capability after improvement.

From the report we found that Z-Bench is 3.86, PPM is 87.7906 and C_pk is 1.22.

Table 4.8. Defective rate of GPPS material after improvement.

Month	Material		
	Good (Kg)	Defect (Kg)	Defect rate
Apr'04	186,043	3,626	1.91
May'04	199,801	3,312	1.63
Jun'04	141,795	3,888	2.67
Jul'04	122,995	2,640	2.10
Aug'04	192,301	5,495	2.78
Sep'04	123,013	3,210	2.54

Executive Summary after improvement

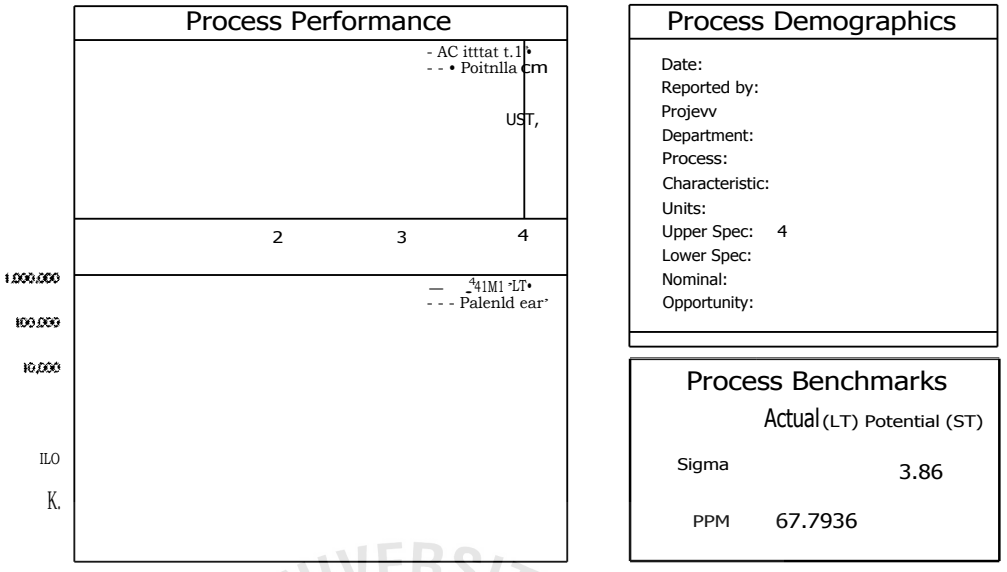


Figure 4.17. Executive Summary after improvement.

Report 2: Process Capability for Cl

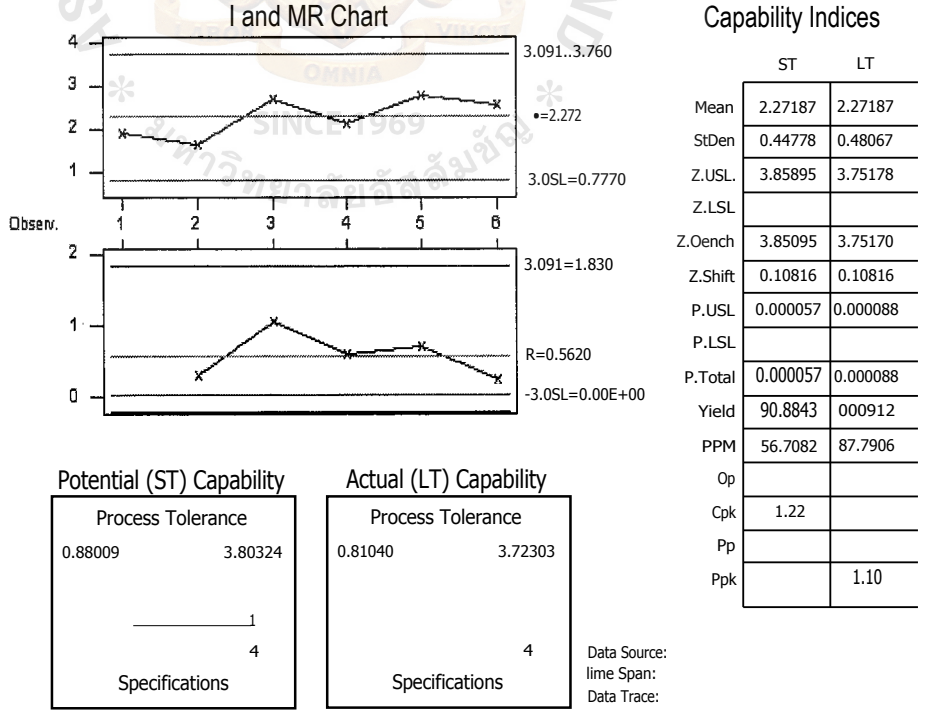


Figure 4.18. Process capability after improvement.

4.4 Control Phase

The followings are control plan for improvement actions.

(1) Issue Parameter Standard for control of the defective rate in the future.

(2) Issue Document to control working standard for example Working Instruction and Engineering Instruction.

(3) Check abnormal data everyday from the Daily report.

4.5 Project after improvement

4.5.1 Project Cost Saving

Table 4.9. shows COPQ before improvement and after improvement. We calculated from the data of defect material in term 03B (Oct'03 — Mar'04) compared with data of defect material in term 04A (Apr'04 — Sep'04). Project saving is 1,017,945 Baht in six months after using the optimize parameter by Six Sigma methodologies. Therefore we can keep the hard saving 1.02 MB/term in 04A.

Table 4.9. COPQ before improvement and after improvement, Baht.

Month	Before Improvement		After Improvement	
	Defect	Cost	Defect	Cost
1	6,837	307,665	3,626	163,170
2	5,554	249,930	3,312	149,040
3	7,678	345,510	3,888	174,960
4	10,041	451,845	2,640	118,800
5	8,668	390,060	5,495	247,275
6	6,014	270,630	3,210	144,450
Total cost		2,015,640		997,695

Remark: Cost of GPPS is 45 TB/KG.

4.5.2 Metric after improvement

Figure 4.19 illustrates the defective ratio after improvement and target defective rate.

The defect ratio of GPPS (General Purpose Polystyrene) reduces from 5.77% (COPQ 2.02 MB) in term 03B (Oct'03 — Mar'04) to 2.24% (COPQ 0.99 MB) in term 04A (Apr'04 — Sep'04) less than our target at 4.0%.

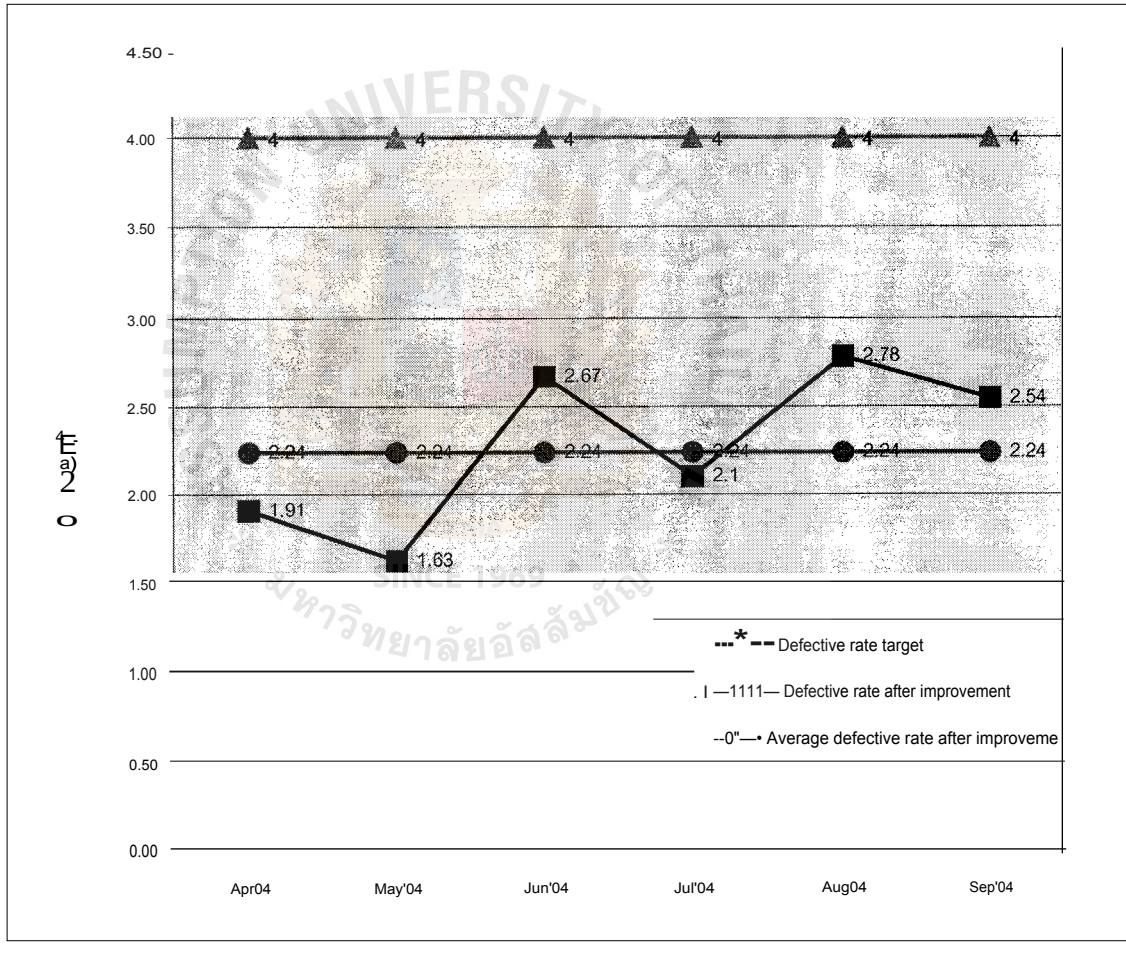


Figure 4.19. Defective rate after improvement and target defective rate.

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

GPPS (General Purpose Polystyrene) is the highest material cause of defective parts i n the Injection s hop. M any kinds o f c auses created the defective p arts such as Crack mark, Silver mark, Weld line, Black dot, Purge, Flow mark, etc. The average defect ratio is 5.77% when project started in the term 03B (October 2003 to March 2004) which caused a bottlenecked operation at Injection shop. The total of COPQ is 2.02 MB. The process capability before improvement is Z-Bench is 1.51, PPM is 78,116.5 and C_pk is 0.48.

To improve the defect rate of GPPS in Injection process, Six Sigma methodologies have been applied to eliminate the non-value added (NVA) tasks.

As presented in this project, Six Sigma can be classified into 5 phases:

(1) Define Phase

(2) Measurement Phase

(3) Analysis Phase

(4) Improvement Phase

(5) Control Phase

The findings and solutions after completing Six Sigma methodologies are as follows.

(1) The three input variables, Ejector speed, Cooling time, and Mold temperature are significant to defective parts. The optimize parameter at Ejector speed is 5 mm/sec, Cooling time is 50 sec, and Mold temperature is 30°C. Therefore we have to control this optimize parameter as the Parameter Standard.

(2) Improperly arranged Injection process that caused the defect part should be controlled. Solution is recommended to the Injection engineer to provide document to control working standard for example, Working Instruction and Engineering Instruction.

(3) Injection engineer should check abnormal data everyday from the Daily report especially when the project is started.

After applying Six Sigma methodologies, the defect rate of GPPS (General Purpose Polystyrene) reduces from 5.77% (COPQ 2.02 MB) in term 03B (Oct'03 — Mar'04) to 2.24% (COPQ 0.99 MB) in term 04A (Apr'04 — Sep'04) less than our target at 4.0%. So we can keep the hard saving 1.02 MB/term in 04A.

Moreover, we can improve the process capability after completing Six Sigma methodologies as follows.

(1) *Cpk* represents the potential (short-term) capability of the process. The greater the C_{pk} value means the more capable the process. In this project the C_{pk} addition is from 0.48 to 1.22.

(2) Z-Bench (Sigma) represents how well that process is performing. The sigma is to measure variation and is the indicator of the capability of the processes. The higher the sigma quality level the better the value is. In this project the Z-Bench (Sigma) addition is from 1.51 to 3.86.

(3) PPM (Part per million) means the quality of Sigma level. Higher sigma quality levels means fewer defects per million opportunities. In this project the PPM reduction is from 78,116.5 to 87.79.

5.2 Recommendations

There are some common industry tools that can give an insight to directions that can be considered a part of Six Sigma measurement and improvement strategy.

(1) POKA-YOKE or Mistake-Proofing

A poka-yoke device is a mechanism that either prevents a mistake from occurring or makes a mistake obvious at a glance. Poka-yoke can be much more effective than alternative demands of workers to be more careful.

(2) KAIZEN or Continuous Improvement

Kaizen is centered quantitative analysis. Kaizen provides the worker both the opportunity and means to find better ways to do his or her job. The Six Sigma involves good quantitative measurement the same as Kaizen. Moreover, Six Sigma also involves humanism.

(3) Total Quality Management (TQM)

TQM often has taken on the approach of dividing the system into processes and then optimizing the quality of each process. This approach is preferable to chasing symptoms, but it can create new problems if the role of individual processes i s not c onsidered a long with o ther process. H owever, new problems can be created if the individual process is not considered in concert with other process that it affects. TQM activities did not lead to a focus on the overall system and the bottom-line improvement metrics. Six Sigma activities need to be of a manageable size with consideration to the impact to the overall system and bottom-line improvements.

(4) KANBAN

The intent of Kanban is to signal to a former process that the next process needs parts/material. Because a bottle-neck is the slowest operation in a chain of operations, it will pace the output of the entire line. Buffers in high-volume manufacturing serves to affect line balance among bottlenecks and product specific operations. It is very important that bottleneck

operations be supplied with the necessary work-in process (WIP) at the appropriate time and that poorly sequenced work not interfere with the work that is to be accomplished at these operations.

(5) Lean Manufacturing and Waste Prevention

If we consider that waste is being generated anywhere work is accomplished, we can create a vehicle through which organizations can identify and reduce waste. The goal is total elimination of waste through the process of defining waste, identifying the source, planning for the elimination of waste, and establishing permanent control to prevent reoccurrence.

Six Sigma can improve the bottom line of an organization—if implemented wisely. An organization can get more with less using Six sigma; for example, it can use fewer runs and samples and obtain more information. However, if the organization does not apply Six Sigma techniques wisely, the methodology will fail. When this occurs, there is a tendency to believe that the statistical techniques are not useful, when in fact the real problem is how Six Sigma as a program was implemented or how individual techniques were effectively applied.

For the person interested in Six Sigma methodologies and who wants to apply to his manufacturing, there is a very important need to follow a step-by-step process for Six Sigma methodologies, D.M.A.I.C. tool. To get the most effective result from Six Sigma methodologies, one also should consider the following concerns:

(1) All sections or departments concerning the problem need to be the team members for brainstorming to get the best vision.

(2) Several times, the importance of conducting a measurement systems analysis is overlooked. When appraisers do not measure a part consistently, the

expense to a company can be very large when satisfactory parts are rejected and unsatisfactory ones are accepted. This can lead to lose sales and unnecessary expense while trying to fix a manufacturing process where the primary source of variability is from the measurement system. The careful consideration to measurement system before beginning experiment work is very important.

(3) In the measurement concern, the cost has to be controlled carefully. A lot of time and money for data collection that does not have added value, will cause waste of time and more cost when they question the effectiveness of their Six Sigma program and perhaps drop the effort.

Finally, one thing that should be a major focus of Six Sigma methodologies is the determination that the right measurements and actions are being taken relatively for bottom-line benefits.

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