DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

QUALITY FUNCTION DEPLOYMENT(QFD) AND USING QFD IN SIX SIGMA PROJECTS

by
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June, 2006
İZMİR

QUALITY FUNCTION DEPLOYMENT(QFD)
AND
USING QFD IN SIX SIGMA PROJECTS

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by

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"QUALITY FUNCTION DEPLOYMENT (QFD) AND USING QFD IN SIX SIGMA PROJECTS"** completed by **Eralp DOĞU** under supervision of **Asst. Prof. Dr. Ali Rıza FİRUZAN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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QUALITY FUNCTION DEPLOYMENT(QFD)
AND USING QFD IN SIX SIGMA PROJECTS

ABSTRACT

Quality Function Deployment (QFD) is a well-known quality improvement technique for customer focused design of the products, services or the processes. QFD simply focuses on "what" the customer wants and "how" the organization will achieve this aim.

QFD is a required method in many Six Sigma programs. Six Sigma is rich in statistical tools to provide the accuracy necessary to achieve 3.4 DPMO levels of quality.

In this study, vital role of QFD in improving the understanding of the voice of the customer, capturing customer priorities, and translating them into Six Sigma DMAIC directives are involved by statistical perspective. A case study is held in a plant in Turkey to determine the following Six Sigma projects for a switch and socket series by using the knowledge of provided by QFD process.

Key words: *Quality Function Deployment (QFD), Six Sigma, Customer Focus, Six Sigma Project Selection, DMAIC.*

KALİTE FONKSİYON GÖÇERİMİ(KFG)
VE KFG'NİN ALTI SİGMA PROJELERİNDE KULLANILMASI

ÖZ

Kalite Fonksiyon Göçerimi(KFG) müşteri odaklı ürün, hizmet ve süreç tasarımında kullanılan yaygın bir kalite geliştirme tekniğidir. KFG basitçe müşterilerin "ne" istediğine ve bu istekleri organizasyonun "nasıl" gerçekleştirebileceğine odaklanır.

Altı Sigma programlarında KFG'ye oldukça fazla ihtiyaç duyulur. Altı Sigma 3,4 DPMO seviyesine ulaşmayı sağlayacak pek çok istatistiksel araç kullanmaktadır.

Bu çalışmada istatistiksel bakış açısı yarımıyla müşterinin sesinin, önceliklerinin anlaşılması ve bulguların Altı Sigma DMAIC metodolojisini kullanan projelere dönüştürülmesi amaçlanmaktadır. İzmir Çiğli'de faaliyet gösteren ve anahtar priz serileri üreten bir fabrikada Altı Sigma Proje seçiminde KFG'den elde edilen bilginin kullanımı ile ilgili bir uygulama yapılmıştır.

Anahtar Kelimeler: *Kalite Fonksiyon Göçerimi(KFG), Altı Sigma, Müşteri Odaklılık, Altı Sigma Proje Seçimi, DMAIC.*

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CHAPTER ONE
INTRODUCTION

Quality Function Deployment (QFD) is a well-known quality improvement technique for customer focused design of the products, services or the processes. QFD simply focuses on "WHAT" the customer wants and "HOW" the organization will achieve this aim.

From the day it emerges, QFD has been a methodology gathers practitioners to understand the confound nature of the customers using survey designs, focus groups and statistical thinking. When the methodology evolves its links and contributions to other methodologies has been remarkable. For instance, to gain profound knowledge of customer requirements and needs Analytical Hierarchy Process (AHP), Fuzzy Sets and Survey Designs are used as it is called QFD Math.

On the other hand, the knowledge provided from QFD process is in great value for quality improvement. In the recent years, quality improvement techniques and methodologies all over the globe has been in great demand. One of the most popular quality improvement methodologies is Six Sigma which first used in Motorola and has many statistical tools in its body. Six Sigma philosophy needs a deep knowledge of customer needs and requirement to continually improve the process, product and service quality. It becomes obvious from this perspective that QFD basically contributes to Six Sigma Development initiatives.

This study consists of six parts;

First chapter is an introduction to the link between QFD and Six Sigma Development. The second chapter gives a basic knowledge about the QFD process. In this chapter, the meaning, history and components of QFD is explained. Moreover choice of the customer and analysis of the customer requirements are held.

The third chapter provides information about Six Sigma, its philosophy, history and importance. Meanwhile, statistical background of the methodology, a look on the frequently used statistical tools and role of these techniques are explained.

The fourth chapter is about the development model of Six Sigma called DMAIC. The contribution of QFD to Six Sigma development model is explained and the statistical tools are classified to the steps of DMAIC.

The application of the QFD process linked to Six Sigma projects in a switch and soket plant in Çiğli is in the fifth chapter. In this chapter, it is shown that the voice of the customer is deployed to Six Sigma projects to develop the product and production process. The conclusions are given in the last chapter.

CHAPTER TWO
QUALITY FUNCTION DEPLOYMENT (QFD)

2.1 Introduction

Over the last twenty years, companies in the world have moved toward new styles of doing business, based on competitive pressures, the needs of global economics, and the advances of technology.

Companies all over the globe have taken many steps to become more competitive. Among them has been the adoption of the Total Quality Management (TQM) approach or one of its aliases, *all of which have stressed customer driven planning*, continuous improvement, and employee empowerment.

ISO (The International Organization for Standardization) is the main address for companies to have been lightened their way beyond these obstacles. ISO 9000 series is very firm to conduct customer satisfaction. Its first management principle is "Customer Focus".

Customer Focus: Organizations depend on their customers and therefore should understand current and future customer needs, should meet customer requirements and *strive to exceed customer expectation.* (ISO 9000)

Also ISO has declared some definitions about Customer Focus.

Definition 3.3.5: Customer
Organization or person that provides a product
Examples: customer, client, end-user, retailer, beneficiary and purchaser,
Note: A customer can be internal or external to the organization (ISO 9000)

Definition 3.1.4: Customer satisfaction

Customer's perception of the degree to which the customer requirements have been fulfilled

Note 1: Customer complaints are a common indicator of low customer satisfaction but their absence does not necessarily imply high customer satisfaction.

Note 2: Even when customer requirements have been agreed with the customer and fulfilled, this does not necessarily ensure high customer satisfaction. (ISO 9000)

On the other hand, a process is defined in ISO 9001:2000 to understand profound knowledge of the customer behaviors.

Element 7.2.3: Customer Communication (ISO 9001:2000)

The organization shall determine and implement effective arrangements for communicating with customers in relation to

A product

Enquiries, contacts, or other handling, including amendments, and

Customer Feedback, including customer complaints

As it is seen, understanding and be aware of the customer is a vital activity on the way of success and sustainability.

Quality Function Deployment (QFD) is an adoption of some of the TQM tools. In Japan, in the sixties, QFD was invented to support the product design process (for designing large ships in fact). As QFD itself evolved, it become clear to QFD practitioners that it could be used to support service deployment as well.

Today, its applications goes considerably beyond product and service design, although those activities are quite commonly supported by QFD. QFD has been extended to apply to any planning process where a team has decided systematically to prioritize their possible responses to a given set of objectives. The objectives are called

“WHATS” and the responses called the “HOWS”. QFD provides a method of evaluating “How” a team should best accomplish the “WHATS”.

2.2 What is QFD?

Traditional quality activities focus on improving existing products and processes. For Instance; Statistical Process Control (SPC) examines the historical outputs of a process to identify the limits of stable process performance. When the outputs of the process go outside these limits, than an investigative action must be held on what has changed to cause this condition. Improvement is then made on the causes of the change.

Mazur (2003) stated that with new products, however, such outputs and processes may not yet be determined. Thus, to assure the quality of new products, Yoji Akao and Kiyotaka Oshiumi of Bridgestone Tire of Japan adapted the cause and effect diagram to instead identify the causes of positive quality, that is, those design elements which could assure Customer Satisfaction (1966). Applications to large, complex projects like shipbuilding used spreadsheets which were later nicknamed the “House of Quality” due to its many rooms.

Customers have their own language for expressing their needs. Each development team has its own language for expressing its technology and its decisions. The development team must make a translation between the customer language and their technical language. QFD is a tool that helps teams systematically map out the relationships between the two languages.

Cohen (1995) describes QFD as a method for structured product planning and deployment that enables a development team to specify clearly the customer’s wants and needs, and then to evaluate each proposed product or service capability systematically in terms of its impact on meeting those needs.

The nickname of the technique is from Japanese. The meanings of the components are explained by Yenginol (2000). The Japanese characters for QFD are, phonetically,

- Hinshitsu, meaning “quality”, “features”, “attributes”, or “qualities”
- Kino, meaning “function” or “mechanization”
- Tenkai, meaning “deployment”, “diffusion”, “development”, or “evolution”

Any of the English words could have been chosen by early translators of Japanese articles. It’s little more than a matter of chance that QFD is not called Feature Mechanization Diffusion today.

The QFD process involves constructing one or more matrices (sometimes called quality tables). The first of these matrices called the “House of Quality” (HOQ). It displays the customer’s wants and needs along the top. The matrices consist of several sections or sub matrices joined together in various ways, each of them containing information related to the others.

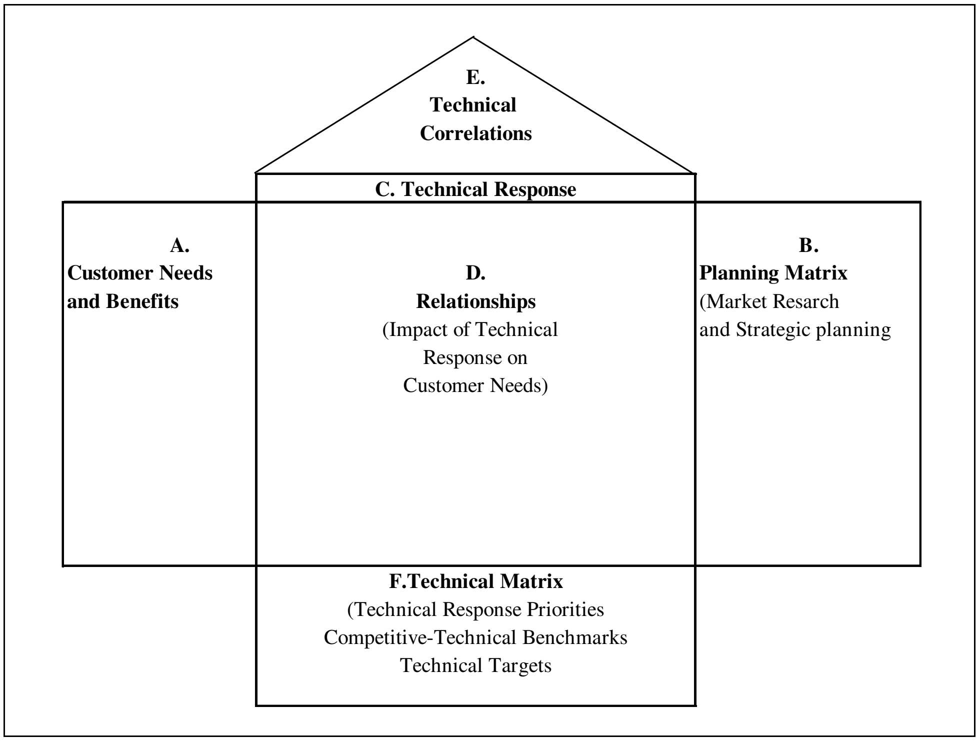


Figure 2.1 House of Quality.

Each of the labeled sections, A through F, is a structured, systematic expression of a product or process development team's understanding of an aspect of the overall planning process for a new product, service, or process. The lettering sequence suggests one logical sequence for filling in the matrix.

SECTION A: Costumer needs and benefits

SECTION B: Planning matrix

SECTION C: Technical response

SECTION D: Contributions

SECTION E: Technical correlations

SECTION F: Technical matrix

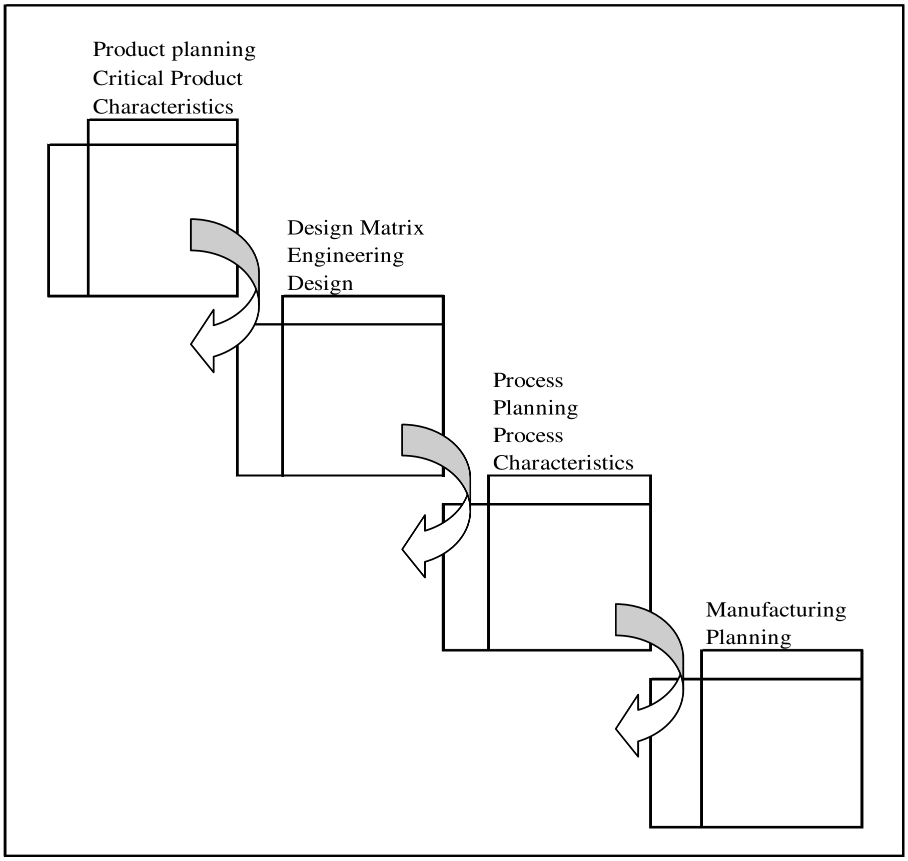


Figure 2.2 Four matrix approach to QFD.

Beyond the House of Quality, QFD optionally involves constructing additional matrices. The basic QFD methodology involves four basic phases that occur over the course of the product development process. During each phase one or more matrices are prepared to help plan and communicate critical product and process planning and design information. The number of translation matrices is determined by the properties and complexity of the product, as well as by level of detail required (Day 1997).

2.3 History of QFD

QFD began thirty years ago in Japan as a quality system focused on delivering products and services that satisfy customers. To efficiently deliver value to customers, it is necessary to listen to the “voice” of the customer throughout the product or service development process.

Dr. Shigeru Mizuno, Dr. Yoji Akao, Dr. Tadashi Yoshizawa and other quality experts in Japan developed the tools and techniques of QFD and organized them into a comprehensive system to assure quality and customer satisfaction in new products and services (Mazur, 1996).

Mazur (1996) also gives information on how the method deployed in North America and became well-known all over the globe. Since 1983, a number of leading North American firms have discovered this powerful approach and are using it with cross-functional teams and concurrent engineering to improve their products and services, as well as the design and development process itself. QFD was an integral part of Florida Power & Light’s successful bid to become the first non- Japanese Deming Prize recipient in 1990. It has been successfully applied in the U.S. healthcare industry since 1991 at the University of Michigan Medical Center.

Dr. Akao introduced QFD into North America in 1983 with his article in Quality Progress and workshop sponsored by Masaaki Imai's Cambridge Corporation (now called Kaizen Institute). In 1984, GOAL/QPC and American Supplier Institute (then Ford Supplier Institute) are two leads for the rapid rise in the use of QFD and adoption by numerous industries (Mazur, 2005).

Mazur and Akao (2003) states the benefits of Toyota Auto body as 40 % reduction in the development cost for a new model and 50 % reduction in development time.

Turkey has been quick to pick up QFD for its emerging consumer products industry. Two public QFD Green Belts courses have been held there, and in 2002 they hosted their first QFD Symposium under the auspices of Dokuz Eylül University.

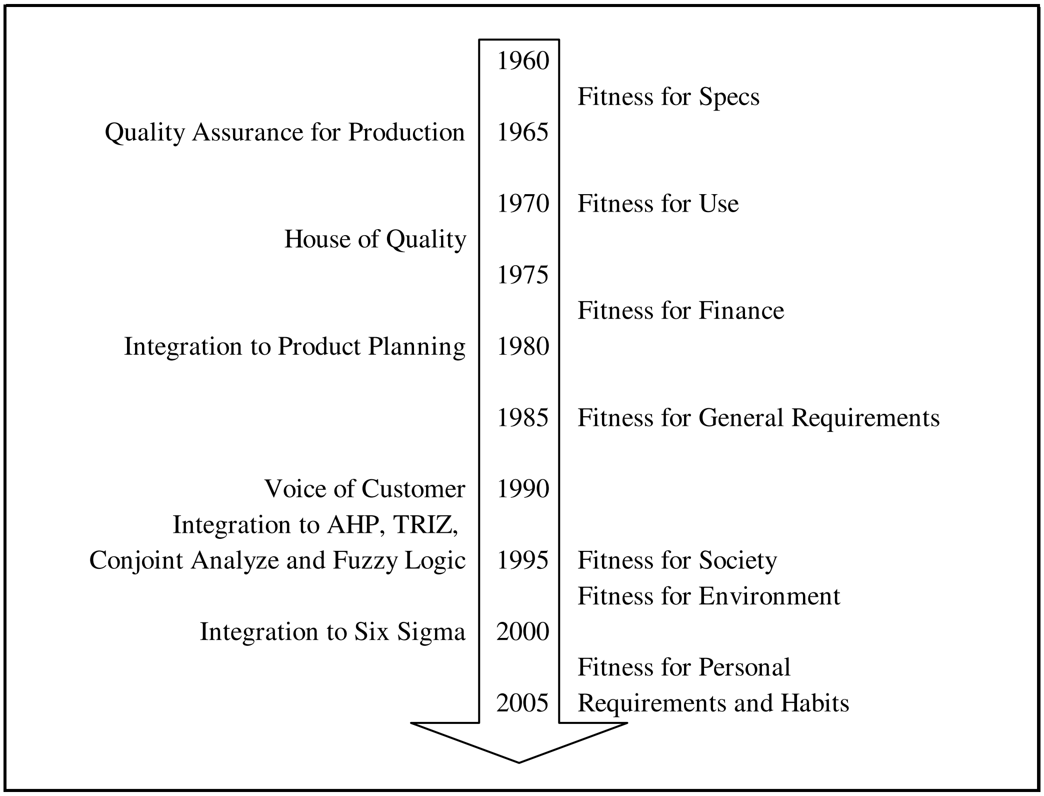


Figure 2.3 Historical development of QFD and quality.

Today QFD has evolved with its necessities. It is an important part of Six Sigma, Design for Six Sigma, FMEA and Conjoint Analysis, Analytic Hierarchy Process (AHP) and Fuzzy Logic are its horizons. The evolution of QFD with Quality is given above.

2.4 Kano Model

"The more I learn about customer satisfaction, the less I know." The CEO of a Fortune 500 company recently lamented. Many CEOs empathize – for even the most customer-centered companies fall short on truly understanding their customer's needs and often do not realize it until it's too late.

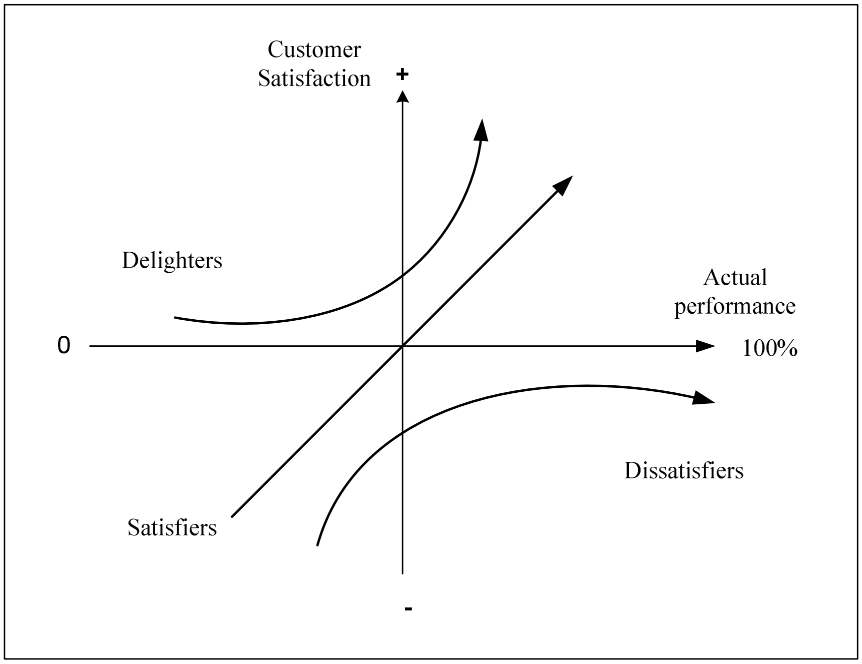


Figure 2.4 Kano's diagram.

The Kano Model is a powerful tool that enables a team to properly identifies the few critical items customers are saying have the highest impact. The main categories of the model are mentioned by Cohen (1995) as;

- Must Be's (Dissatisfiers)
- One- Dimensional(Satisfiers)
- Delighters

2.4.1 Must Be's (Dissatisfiers)

Must be's are those needs and wants that have to be met for a customer to even begin to have a positive relationship with your company. Many customers believe their must be needs are so basic they do not even think of discussing these unless they have been disappointed (Krupar, 2005).

Must Be's for a bank customer are accurate statement, short lines at branches, functional ATM's. A dissatisfier is a product characteristic that the customer takes for granted when it is present, but that causes dissatisfaction when it is missing. Dissatisfiers are the absence of "expected quality", in the sense that customers are dissatisfied.

Table 2.1 Dissatisfiers and related customer needs

Expected Quality	**Dissatisfiers**
Smooth surface	Scratches, blemishes
All parts work	Broken parts
Product comes with instructions	Missing instruction book
Product of this type normally perform function X	Function X not provided
Product is safe to use	Product is unsafe
Product conforms to local standards	Product is non conformant

Although customers won't ask for expected quality, they will be dissatisfied if they don't get it, and they will tell us by complaining. Thus, customer complaints are primary source of information on existing Dissatisfiers in our current products.

2.4.2 One Dimensional Needs (Satisfiers)

Cohen (1995) defines a satisfier as "something that customers want in their products, and usually ask for. Satisfiers are sometimes called "desired quality" because they represent the aspects of the product that define it for customer." Examples of satisfiers are increased capacity, lower cost, higher reliability, greater speed, and easier use.

To Jrupar (2005) one-dimensional Needs are the needs a customer will discuss and are typified by a "win-lose" negotiation.

Table 2.2: Examples of desired quality

Desired Quality	Performance Measurement	Direction of Goodness
Capacity	Cubic feet of storage	Larger the better
Price	Dollars	Smaller the better
Reliability	Mean time between failure	Larger the better
Speed	Transactions per second	Larger the better

One-dimensional needs for a bank customer are; low fees/free checking, higher passbook savings interest rates, more ATM locations.

2.4.3 Delighters

Jrupar (2005) explained that delighters are the properties when wants or needs are met when a customer is not expecting it. Delighters for a bank customer are; real time online banking, 5-munite credit card approval, pre-approved mortgages. Delighters are product attributes or features that are pleasant surprises to customers when they first encounter them. However, if Delighters are not present, customers will not be dissatisfied, since they will be unaware of what they are missing. Delighters are sometimes called “exciting quality” or “unexpected quality”.

Examples of delighters are not as instructive as examples of Satisfiers and Dissatisfiers. One very famous delighter is Sony Walkman. The 3M Post it Note is another example of a delighter. These delighters created new brands and temporary competitive advantages.

2.5 The Elements of the House Of Quality (HOQ)

2.5.1 Section A: Customer Needs And Benefits (Whats)

The Customer Needs section of the House of Quality contains a structured list of needs customers have for product or service being planned. The structure is usually determined by qualitative market research. The data is in the form of a tree diagram.

This is a very important step in QFD for obvious reason the Voice of Customer (VOC) is the main inputs to the QFD process. This section usually derives from the "Voice of Customer"- literally, statements or fragments of statements made by customers or potential customers.

Customer needs (WHATs) are statement, in the customer's words, of a benefit that a customer gets, or could get, or might get, from a product or service.

The usual steps in creating the Customer Needs Section are:

1. Gather the Voice of the Customer:
   - Interview customers.
   - Gather customer complaints.
2. Sort the Voice of the Customer into major categories, including.
3. Structure the Needs in an affinity diagram.
4. Arrange the Needs in Customer Needs Section.

2.5.1.1 Who Is The Customer?

During the QFD process, the team will be making many judgments. They will be estimating the relationships between product or service capabilities and customer needs, for instance. In order to make these judgments meaningfully, the team will need to make clear and consistent definitions.

The team's most important underlying assumptions will be those about the customer. From the experiences, it is surprisingly difficult for product development teams to agree on who their customer is.

The first step in defining the key customer is to make a list of all possible candidates. The affinity diagram is a useful tool for managing this list of customers. To identify several customer groups, start by brainstorming all possible customers of the product or service you are planning.

After identifying several customer groups, the second step is to focus on the key customers. Once the customer groups have been identified, deciding on the key customers is sometimes easy. Everyone glances at the list of customer groups and with little or no disagreement; they decide who the key customers are.

If everyone cannot quickly agree on the key customer group, one of the other methods for selecting the key customer group may be useful. Prioritization Matrix and Analytical Hierarchy Process can be given as examples of these methods.

2.5.1.2 How To Gather The Voice Of Customer?

The QFD process requires that customer data be represented as a list of product or service attributes that are important to the customer. Each attribute in the list is to have some numerical data associated with it: relative importance of the attribute to the customer, and the customer's satisfaction performance level of similar products with respect to that attribute.

The attributes are called "qualitative" customer data, and every numerical information about each attribute is called "quantitative" data.

It is possible to classify customer needs into categories that help development teams make decisions. There are several methods to gather qualitative data;

- Focus Group Interviews: The focus group process involves assembling a group of customers together in a room, and facilitating a discussion in which each respondent state his/her views to the group and can hear and respond the other group member's comments. The number of respondents in a focus group is generally between five and fifteen. The larger the group, the more skillful must be the facilitator in order to keep the discussion on the desired topic.
- One-on-One Interviews and Contextual Inquiry: An approach is to identify customer needs by interviews developed around open-ended questions.
- Unbiased Surveys: Breyfogle (1999) explained this type of gathering information in his book as the steps given below:
  1. Conduct brainstorming session(s) where a wish list of features, problem resolutions, and so forth are identified.
  2. If there are many different brainstorming sessions that contain too many ideas to consider collectively in a single survey, it may be necessarily to rank the individual brainstorming session items. A secret ballot rating for each topic by the attendees could be done during or after the sessions. The items that have the highest rankings from each brainstorming session are then considered as a survey question consideration.
  3. A set of questions is then determined and worded from a positive point of view. Obviously, care needs to be exercised with the wording of these questions so as not to interject bias. Because the action of the customer may not accurately reflect their perceived importance. For example, a customer may purchase a product more because of packing

than because of characteristics of the product within the package. The respondent to the question is asked to give an importance statement and a satisfaction relative to the question. The question can be formed as shown in Table 2.3

4. The information from this type of survey can be plotted in a perceptual map format.

Table 2.3 Example questionnaire format that can give a perceptual map response (Breyfogle, 1999)

The products produced by our company are reliable. (Please comments on any specific changes that you believe are needed.)	
What is the importance of this requirement to you?	What is your level of satisfaction that this requirement is met?
5 Very important	5 Very satisfied
4 Important	4 Satisfied
3 Neither important nor unimportant	3 neither satisfied nor unsatisfied
2 Unimportant	2 Unsatisfied
1 Very unimportant	1 Very satisfied
Response:	Response:
Comments:	

- <u>Proactive Databases-Customer Complaints</u>: most organizations have special organizations and processes for handling complaints. Typically, companies will maintain databases of customer complaints. These databases can be quite large, and their organization will not normally be convenient for merging into a customer needs affinity diagram.

After gathering customer needs with the most proper method, it is necessary to classify the raw needs into appropriate categories. A list of customer requirements (WHATS) is made in primary, secondary, and tertiary sequence. Applicable government regulation items should also be contained within this list (Breyfogle, 1999). An affinity diagram can be an useful tool to categorized the customer needs in to proper categories.

2.5.1.3 Importance To The Customer

The Importance to Customer column is the place to record how important each need or benefit is to the customer. Three types of data are commonly used in this column: Absolute Weight, Relative Weight, and Ordinal Importance.

- Absolute Importance: The Absolute importance entries are usually chosen from a scaled selection of importance. The number of points on such a scale has been known to range from three to ten. Mostly used scale of importance is given below:

Table 2.4 Common absolute importance values

Value	**Meaning**
1	Not at all important to the customer
2	Of Minor importance to the customer
3	Of moderate importance to the customer
4	Very important to the customer
5	Of highest importance to the customer

Absolute importance values are usually obtained by a survey designed by the development team.

- Relative Importance: Cohen (1995) states the Relative Importance as "if one need is twice as important as another to the customer, then the importance score of more important need would be twice the score of the less important need".

Relative importance values are typically placed on a 100-point scale or on a percentage scale. The number 100 indicates the highest possible importance. Typical ranges of relative importance scores are from about 40 to 85.

- Ordinal Importance: Ordinal Importance, like relative Importance, is an indication of order importance. Unlike Relative Importance, which indicate how much more or less important one attribute is compared to another attribute, Ordinal Importance indicates only that one attribute is more or less important than another. Typical methods for measuring Ordinal Importance involve surveying customers and asking them to rank-order the customer attributes, or to assign importance numbers to the attributes as with Absolute Importance.

There are many discussions on the importance of the needs. These three techniques are sometimes are not adequate to analyze the psychological nature of the customer. To a profound understanding of the customer's fuzzy nature Analytical Hierarchy Process and Fuzzy Logic Analysis are suggested by Mazur and Akao (2005) named the process QFD Math.

2.5.2 Section B: Planning Matrix

Section B contains three main types of information:

- Quantitative market data, indicating the relative importance of the wants and needs to the customer, and the customer's satisfaction levels with the organization's and its competition's current offerings
- Strategic goal setting for the new product or service computations for rank ordering the customer wants and needs

The Planning Matrix helps a team to do strategic planning for their project. The planning Matrix in fact is a market research data and benchmarking. This matrix is needed to see where the company is based on the given customer needs.

2.5.2.1 Customer Satisfaction Ratio (CSR)

The Customer Satisfaction Ratio is the customer's perception of how well the current product or service is meeting the customer's needs. Current product means that the product or service currently being offered or delivered that most closely resembles the product or service planned to develop.

The usual method for estimating this numerical data is by asking the customer, via survey, how well he or she feels the company' product or service has met each Customer Need. This satisfaction level is usually expressed as a "grade" or a performance level. Cohen (1995) suggests grades given on a four-, five-, or six-point scale, although sometimes scales up to ten points are used.

2.5.2.2 Benchmarking

In order to be competitive, the development team must understand the competition. It is usually much harder to reach the competition's customers than their own customers, development teams often operate in the dark with regard to their competition's strengths and weaknesses.

QFD provides a method by which the development team can record the competition's strengths and weaknesses alongside its own. In classical studies the comparison can be shown at two important levels: first, in terms of Customer needs, and second, in terms of Technical Response. In the Planning Matrix, the development team has the opportunity to compare, side-by-side, how well their current product and the competition's are meeting customer needs.

2.5.2.3 Goal And Improvement Ratio (IR)

In the Goal column of the Planning Matrix, the team decides what level of customer performance they want to aim for in meeting each customer need-the Goal. The performance goals are normally expressed in the same numerical scale as performance levels. The Goal, combined with Customer Satisfaction Ratio, is used to set the Improvement Ratio. The Improvement Ratio is one of the most important multipliers of Importance to Customer; thus, setting the Goal is a crucial strategic step in QFD.

From the point of view of limited resources, it is a strategic necessity to choose which aspects of a product or service will excel, and which won't. Thus, goal setting in QFD involves comparing ourselves to the competition, and noticing which customer needs are most important. Setting performance goals in the planning matrix of the House of Quality generally has far-reaching effects on priorities throughout the development project.

Improvement Ratio column, a measure of effort required to alter customer satisfaction performance for a customer attribute.

$$IR_i = \frac{Goal_i}{CSP_i} \qquad (2.1)$$

$$ID_i = 1 + (Goal_i - CSP_i)) \qquad (2.2)$$

CSR=CSP

CSP: Current Satisfaction Performance

IR: Improvement Ratio

ID: Improvement Difference

i: number of customer needs

This formula has the characteristic that all improvement increments- whether starting from a low or high level of customer performance- have the same impact on overall importance of a customer attribute. The formula has a disadvantage; its assumption is that goal is always greater than current satisfaction performance.

2.5.2.4 Sales Point (SP)

The Sales Point column contains information characterizing the ability to sell the product or service, based on how well each customer need is met. For example, for an automobile, a customer need might be for fuel efficiency. If the automobile could be designed to meet this need well, efforts to sell the product could capitalize on this capability.

Table 2.5 Common values assigned for Sales Points

Value	**Meaning**
1	No sales point
1,2	Medium sales point
1.5	Strong sales point

Sales Points do not carry as much weight as other factors in the, Planning Matrix, such as Importance to Satisfaction Performance Goal.

Not all customers needs represent sales opportunities. For example, fulfilling a need for safety or for compliance with long-established regulatory standards would not likely create customer interest that would justify a sales campaign.

2.5.2.5 Raw Weight (RW)

The Raw Weight column contains a computed value from the data and decisions made in Planning Matrix columns to the left. It models the *overall importance to the* *development team* of each Customer Need, based on its importance to the Customer, the Improvement Ratio set by the development team, and the Sales Point value determined by the development team. The value of the Raw Weight for each Customer Need is;

$$\mathrm{RW_i} = (I_i)\times(IR_i)\times(SP_i) \quad (2.3)$$

RW: Raw Weight
I: Importance to Customer
IR: Improvement Ratio
SP: Sales Point

The higher the Raw Weight is, the more important the corresponding Customer Need is to the development team. The Raw Weight is a single number embodying customer satisfaction performance, implementation effort, and sales potential. Hence it provides an overall strategic business perspective on the importance of the Customer Needs to the Success of the product or service being planned.

2.5.2.6 Normalized Raw Weight

The Normalized Raw Weight column contains the Raw Weight values, scaled to the range from 0 to 1 or expressed as a percentage.

To calculate the Normalized Raw Weight, first sum the Raw Eights to compute the Raw Weight Total, then divided each Raw Weight by the Raw Weight Total.

$$\mathrm{NRW_i} = \frac{RW_i}{\sum_i RW_i} \quad (2.4)$$

2.5.3 Section C: Technical Response

Just as the Voice of the Customer had a qualitative and quantitative component, so does the translation of the Voice of the Customer into the Voice of the Developer. The translation will be placed in qualitative form on the top of the Relationships Matrix, and in quantitative form at the bottom (Target Values and Competitive Benchmarks).

Cohen (1995) defined technical characteristics as the term used for the internal, technical language an organization uses to describe its product or service. The aim of Section C is to translate the characteristics from the “Customer’s Language” into the “Organization’s Technical Language”.

The QFD team must choose which of its possibly many technical formulations provide the team with more breakthrough opportunities at the expense of more QFD steps to bridge the gap between customer needs and action. While the development team decides the technical characteristics, they should define the metrics as the numerical knowledge input of these characteristics.

2.5.4 Section D: Contributions (Relationships)

Section D contains the development team’s judgments of the strength of the relationships between each element of their technical response and each customer want and need.

This section indicates how the relationship between the Technical Characteristics and Customer Needs are modeled in QFD. Each relationship cell represents a judgment made by the development team, of the strength of the linkage between one technical Characteristic and one Customer Need. These cells are called as the impacts of the Technical Characteristics on the Customer Needs. The Contributions section of the

House of Quality contains cells for storing these impacts about each Technical Characteristic/Customer Need pair.

There are four possible results of these relationships:

1. Costumer satisfaction performance with respect to the need is *not linked* to the Technical Characteristic.
2. Costumer satisfaction performance with respect to the need is *possibly linked* to the Technical Characteristic.
3. Costumer satisfaction performance with respect to the need is *moderately linked* to the Technical Characteristic.
4. Costumer satisfaction performance with respect to the need is *strongly linked* to the Technical Characteristic.

Global symbols are usually used in House of Quality to show these four results. The symbols, their meanings, and their numerical equivalents are as shown in Table 2.6.

Table 2.6 Global impact symbols

Symbol	Meaning	Numerical Contribution	Other Values
	No Relation/Contribution	0	
△	Weak Relation/Contribution	1	
○	Moderate Relation/Contribution	3	
⊙	High Relation/Contribution	9	10, 7, 5

2.5.5 Section E: Technical Correlations

Technical correlations, is half of a square matrix, split along its diagonal and rotated 45º. Mazur (2003) defines the technical correlations as the “roof” since it resembles the “**roof**” of a house, the term “House of Quality” has been applied to the entire matrix structure. Section E contains the development team’s assessment of the implementation interrelationships between elements of the technical response.

This section of the House of Quality is probably the least used in today's practice of QFD.

The roof of the House of Quality shows the impact of work on one Technical Characteristic on the status of other Technical Characteristics. The roof can show the existence and nature of design bottlenecks (Day, 1997).

The global symbols of the correlations are shown below:

Table 2.7 Global correlation symbols

Symbol	**Meaning**
✓✓ or ++	Strong Positive Impact
✓ or +	Moderate Positive Impact
Blank	No Impact
× or -	Moderate Negative Impact
×× or **--**	Strong Negative Impact

2.5.6 Section F: Technical Matrix

Section F contains three types of information:

- The computed rank ordering of the technical responses, based on the rank ordering of customer wants and needs from Section B and the relationships in Section D
- Comparative information on the competition's technical performance
- Technical performance targets

Once the development team has determined all the impacts or linkages, some simple arithmetic provides one of the key results of QFD: the relative contributions of the Technical Characteristics to overall customer satisfaction (Day, 1997).

For each column; a rank can be calculated as a combination of the customers' importance and the strength of the relationships.

For instance; the impact of the technical response X to Need A is "moderate". The multiplier of Need A is 3. The rank is calculated as the sum of the numerical values of the impacts of the technical responses to Need A multiplied by the Normalized Raw Weights.

$$\text{RANK} = \sum_{i=1}^{k} NRW_i \times \text{Impact Multiplier} \qquad (2.5)$$

After calculating the ranks competitive benchmarks should be conducted. No organizations would invest in the development of a product or service without knowing enough about the competition to be sure that their design is competitive.

If the Technical Characteristics were defined as performance measures, the benchmarking process becomes one of measuring the competitor's performance and one's own performance. To the extent that the performance measures were defined independently of the design of the product or service, the benchmarking process provides ideal "apple-to-apple" comparative data between the competitor's and development team's product or service (Cohen, 1995).

An example House of Quality is given below. The example is from the book written by William J. Kolarik "Creating Quality Concepts, Systems, Strategies, and Tools". If the matrices are examined carefully it is obviously seen that the most desired needs are clean and good looking clothes and fast service. To achieve this goal the technical matrix is formed and benchmarking studies are held. In the ranking and normalized ranking sessions, the greatest needs for an action are brightness, spot removal, and customer greetings. When these technical characteristics or processes are improved, customers are optimally being satisfied for most of their requirements. There seen no correlations between these characteristics, there is no way to effect each other processing the improvements.

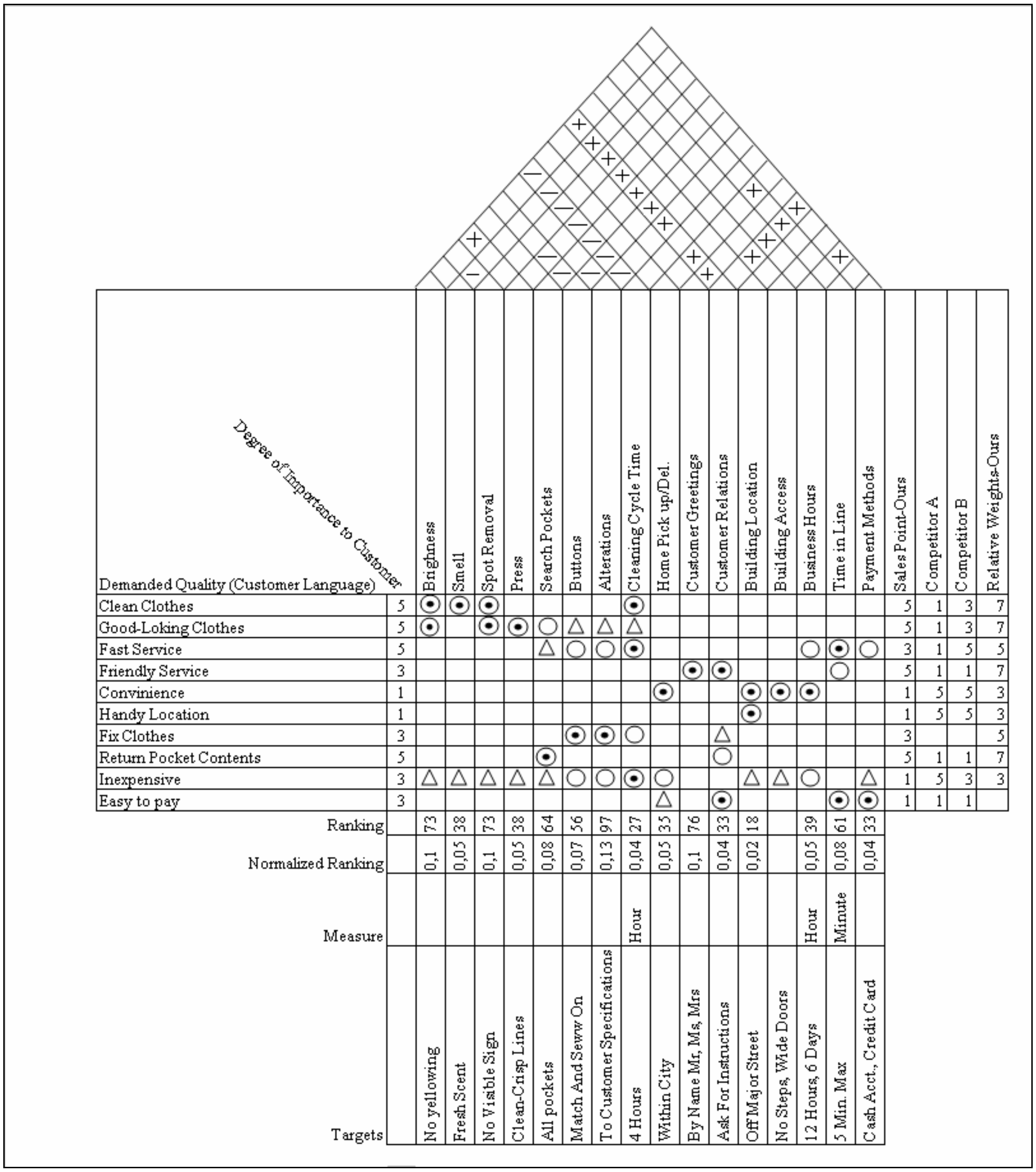


Figure 2.5: Demanded quality deployment chart illustration for a laundry service.

CHAPTER THREE
SIX SIGMA METHODOLOGY

"Statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write." H.G. Wells, National Science Board, Overview, Science and Engineering Indicators.

3.1 Introduction

For many years, the Greek letter sigma (σ) has been the universally accepted symbol for standard deviation.

Standard deviation is, of course, a measure of dispersion, variation or spread. To anyone with an elementary knowledge of the normal distribution, six sigma is the spread about the mean that includes 99.74% of the population.

However, to many employees of Motorola, General Electric, Allied Signal (now part of Honeywell), Bombardier, Black and Decker, ABB and Polaroid, Six Sigma is much more. To these people it is a company-wide transformation that has helped them to become very successful.

The companies listed above have publicized their success and have publicly emphasized the part played by Six Sigma in the achievement of this success. Here are some examples of them from their annual reports;

From the General Electric (GE) Annual Report 1998:

"… we plunged into Six Sigma with a company-consuming vengeance just over three years ago. We have invested more than a billion dollars in the effort, and the financial returns have now entered the exponential phase— more than three quarters of a billion dollars saving beyond our investment in 1998, with a billion and a half in sight for 1999" (Caulcutt, 2001).

From The Black and Decker Annual Report 1999:

"Having begun, in late 1998, to coordinate Six Sigma strategies and measurements on a worldwide basis, our experience clearly shows that the potential benefits are enormous in terms of productivity improvement, product quality, customer satisfaction, more efficient capital spending, and overall corporate profitability … Savings attributable to Six Sigma were more than $30 million in 1999, and we expect to generate twice that amount in 2000 as we intensify our efforts" (Caulcutt, 2001).

3.2 What Is Six Sigma?

There are many different perspectives on what "Six Sigma" is. The most well-known description is that "Six Sigma is a highly technical method used by engineers and statisticians to fine-tune products and processes." Measures and statistics are a key ingredient of Six Sigma improvement- but other perspectives can not be omitted.

Some other definitions are about its goal of near-perfection in meeting customer requirements based on the normality assumptions . "Six Sigma" itself refers to a statistically derived performance target of operating with only 3.4 defects for every *million* activities or "opportunities." It's a goal few companies or processes can claim to have achieved. Motorola- one of the world leaders in the world- is still striving to reach the target.

On the other hand, another definition can be made on its stunning cultural change affect. Considering the companywide commitment to Six Sigma at places like General Electric or Motorola, "culture change" is certainly a valid way to describe Six Sigma.

All these perspectives can be gathered in one definition for six sigma. Pande, Neumann and Cavanagh (2000) defined six sigma as "a comprehensive and flexible *system* for achieving, sustaining and maximizing business success". Six Sigma is uniquely driven by close understanding of customer needs, disciplined use of facts, data, and statistical analysis, and diligent attention to managing, improving, and reinventing business processes.

The term *sigma* is a Greek alphabet letter (σ) used to describe variability, where a classical measurement unit consideration of the program is defects per unit. George (2002) stated in his book on Lean Six Sigma that a sigma quality level offers an indicator of how often defects are likely to occur, where a higher sigma level indicates a process that is less likely to create defects.

In Six Sigma, standard deviation measures two things: how much one thing varies from a specific point or target and how much one thing varies from another. In business terms it measures the capability of any given process to perform defect free work.

Sigma—or standard deviation—is used to quantify how good or bad a process is performing their ideal functions. In other words, how many mistakes a company makes, doing whatever it does, from manufacturing steel to delivering the newspaper. Six is the Sigma level of perfection the companies are shooting for.

Six Sigma is not just an "improvement methodology." It is ...

- A *system* of management to achieve lasting business leadership and top performance applied to benefit the business and its customers, associates, and shareholders.
- A *measure* to define the capability of any process.
- A *goal* for improvement that reaches near-perfection (George, 2002).

Pyzdek (2003) defined the system using its tools and affects, “Six Sigma is a rigorous, focused and highly effective implementation of proven quality principles and techniques. Incorporating elements from the work of many quality pioneers, Six Sigma aims for virtually error free business performance”.

The concept of Six Sigma is wholly a matter of discussion. TQM mentality is not completely different from Six Sigma Philosophy. Pande, Neumann and Cavanagh (2000) defined Six Sigma as TQM with steroids that bumpers the TQM activities in a short time with its characteristics properties; Use of Statistics and Data Analysis, Teamwork Support and also Commitment of the Members.

3.3 Why Six Sigma?

Great expansion has been occurring in the field of communication, both in the speed and the availability of the Internet. Today in an access to Google one can reach at least 20,000,000 interrelated links about Six Sigma.

In quality, similar improvements have been made. These improvements have led to an increase in customer expectations of quality. Companies have responded to this increase by continuously measuring themselves and their competition in several areas of capabilities and performance. This concept, also known as benchmarking, is a favorite tool of managers to set goals for the enterprise. They can also gauge the progress of enterprises toward achieving their goals in quality, as well as cost, responsiveness, flexibility, and inventory turn over.

Six sigma is an excellent tool to achieve world class status as well as best in class results in quality, especially given the increased complexity of designs and products. At the same time, the requirements for developing new products in high-technology industries have followed these increases in complexity and improvements in quality, necessitating faster product development processes and shorter product lifecycles.

Many of the leading technology companies have created “virtual enterprises,” aligning themselves with design and manufacturing outsourcing partners to carry out services that can be performed more efficiently outside the boundaries of the organization.

Several industries, especially the auto industry, have worked to standardize their relationship with their suppliers. They created the Advance Product Quality Planning (APQP) Task Force. Its purpose was to standardize the manuals, procedures, reporting format, and technical nomenclature used by Daimler-Chrysler, Ford, and General Motors in their respective supplier quality systems for their design and manufacturing. The APQP also issued a reference manual developed by the Measurement Systems Analysis (MSA) Group for insuring supplier compliance with their standards, especially TS ISO 16949 (Shina, 2003, p 34).

Ford suggests its suppliers to have been guided from Ford Specific Requirements in their manufacturing processes. “Ford Specific Requirements” emphasizes on statistical techniques to achieve six sigma performance. These standards contain many of the principles of Six Sigma and associated quality tools, such as C_{pk} requirements. These manuals were published in the mid-1990s and are available from the Automotive Industry Action Group (AIAG) in Southfield Michigan.

Six sigma can be used as a standard for design and manufacturing, as well as a communication method between design and manufacturing groups, especially when part of the design or manufacturing is outsourced. This is important for companies in meeting shorter product lifecycles and speeding up product development through faster access to design and manufacturing information and the use of global supply chains.

3.4 The Six Sigma Philosophy

Eckes (2001) gave the basic idea in his study about managing the facts and data with Six Sigma. "Six Sigma is for most organizations a major change from how they typically manage their business. Movement toward managing with fact and data and aggressively pursuing greater efficiencies and effectiveness is a dramatic change. Change, even the positive change associated with Six Sigma, will be resisted."

Six Sigma is the application of the scientific method to the design and operation of management systems and business processes which enable employees to deliver the greatest value to customers and owners. As it is desired by the international standards of doing business and the leading companies all over the globe. Pyzdek (2003) explained the scientific approach of Six Sigma as follows:

1. Observe some important aspect of the marketplace or the business.
2. Develop a tentative explanation, or hypothesis, consistent with your observations.
3. Based on your hypothesis make predictions.
4. Test your predictions by conducting experiments or making further careful observations. Record your observations. Modify your hypothesis based on the new facts. If variation exists, use statistical tools to help you seperate signal from noise.
5. Repeat steps 3 and 4 until there are no discrepancies between the hypothesis and the results from experiments or observations.

This scientific approach enables the companies to struggle with the effects of deviation. The Six Sigma philosophy focuses the attention of everyone on the stakeholders for whom the enterprise exists. It is a cause-and-effect mentality. Six Sigma gives an idea on the relationships in the chain of employees to the end users. Well-designed management systems and business processes operated by happy employees cause customers and owners to be satisfied or delighted.

Six Sigma activities focus on the few things that matter most to three key constituencies: customer, shareholders, and employees. The primary focus is on customers, but shareholder interests are not far behind. The requirements of these two groups are determined using scientific methods.

Focus comes from two perspectives: down from the top-level goals and up from problems and opportunities. The opportunities meet the goals at the Six Sigma project. Six Sigma projects link the activities of the enterprise to its improvement goals. Six Sigma also has an indirect benefit on an enterprise, and one that is seldom measured. That benefit is its impact on the day-to-day way of doing things. When people observe Six Sigma getting dramatic results, they naturally modify the way they approach their work.

To Pyzdek (2003) Six Sigma enterprise proactively embraces change by explicitly incorporating change into their management systems. Full- and part time change agent positions are created and a complete infrastructure is created. New techniques are used to monitor changing customer, shareholder, and employee inputs, and to rapidly integrate the new information by changing business processes.

Chowdhury (2002) emphasis on the meaning of the philosophy; "Six Sigma is not a motivational trick that simply bumps up employee efforts for a month or two. Instead, it establishes a measurable status to strive for...It teaches the employees how to improve the way they do business, scientifically and fundamentally, and maintain their new performance level for years to come."

Like any popular approach to improving productivity, Six Sigma improvement tools and techniques are sound, principled, and effective. Eckes (2001) focuses on the implementation against the popularity of Six Sigma. "Implementation of any change effort within an organization is difficult. However, compounding the difficulty with Six Sigma is the level of associated comprehensive tools and techniques."

Six Sigma is a management method that has customer satisfaction as its overriding philosophy, but the strategy of Six Sigma is exclusively the domain of executive management to create the infrastructure for improvement to occur. The Six Sigma strategy involves the use of statistical tools within a structured methodology for gaining the knowledge needed to achieve better, faster and less expensive products and services than the competition.

The nature of Six Sigma has some components different from the other methodologies. Six Sigma gives change to the employees to be the actual parts of improvement by responding them with some roles. These roles are basically in two classes; black belts and green belts. Black belts are the employees who are responsible for especially guiding the others with the advanced statistical techniques. Different from black belts, green belts are basically responsible for collecting and summarizing the data. These roles lead the companies to be more project focused and improves the business performance.

3.5 History of Six Sigma

The roots of Six Sigma as a measurement standard can be traced back to Carl Frederick Gauss (1777-1855) who introduced the concept of the normal curve. Six Sigma as a measurement standard in product variation can be traced back to the 1920's when Walter Shewhart showed that three sigma from the mean is the point where a process requires correction. Barney and McCarty (2003) of Motorola University identifies the name in their book “The New Six Sigma”; “Many measurement standards (C_{pk}, Zero Defects, etc.) later came on the scene but credit for coining the term "Six Sigma" goes to a Motorola engineer named Bill Smith. (Incidentally, "Six Sigma" is a federally registered trademark of Motorola)”.

Six Sigma is a business initiative first espoused by Motorola in early 1990s. Recent Six Sigma success stories, primarily from the likes of General Electric, Sony, AlliedSignal, and Motorola, have captured the attention of Wall Street and propagated the use of this business strategy (George, 2002).

By the early 1970s, Motorola had established itself as the world leader in wireless communications products. Soon after Japanese manufacturers were on the stage to compete in the fierce conditions of the market. These difficulties were prefigured in 1973, when Motorola found itself not to be able to compete. In 1979, under the leadership of CEO Bob Galvin, a renewal and growth enterprise was begun. The words of the vice-president were clear to explain the situation: “Our quality stinks.”

The 10X quality improvement goal was driven by the selected senior executives in each of the business unit. However, focusing only on the manufacturing function was not convenient to find out the major sources of the problems.

Based on the history written in the web of Motorola University, in 1984 Motorola Manufacturing Institute (MMI) was established and the institute started the education programs. The rapid satisfaction of the top management, “Design for Manufacturability”(DFM) and “Six Steps to Six Sigma” training programs were used for all technical personnel worldwide. Another Motorola engineer, Craig Fullerton, developed and taught “Six Sigma Design Methodology” (SSDM-today called Design for Six Sigma, or DFSS, by most other companies).

Six Sigma’s success led Motorola’s managers to set an even more aggressive goal, from 10X to 100X improvement. A one-day course entitled “Understanding Six Sigma” was then developed for all nontechnical employees worldwide and Motorolans began to use Six Sigma on everything from measuring training defects to financial effectiveness (Breyfogle, 1999).

The efforts resulted in Motorola receiving the first Malcolm Baldrige National Quality Award in 1988. By 1990 Motorola was struggling to reach Six Sigma in everything it did, yet it seemed to be stuck at 5.4 sigma (Barney & McCarty, 2003).

Six Sigma has evolved over time. It's more than just a quality system like TQM or ISO. It's a way of doing business. As Geoff Tennant describes in his book “Six Sigma: SPC and TQM in Manufacturing and Services”; “Six Sigma is many things, and it would perhaps be easier to list all the things that Six Sigma quality is not. Six Sigma can be seen as: a vision; a philosophy; a symbol; a metric; a goal; a methodology”.

3.5.1 Some Six Sigma Success Stories

“Six Sigma has forever changed GE. Everyone- from the Six Sigma zealots emerging from their Black Belt tours, to the engineers, the auditors, and the scientists, to the senior leadership that will take this Company into the new millennium-is a true believer in Six Sigma, the way this Company now works.”- GE Chairman John F. Welch

At General Electric that passion and drive behind Six Sigma have produced some very positive results. From an initial year or so of break-even efforts, the pay-off has accelerated: $750 million by the end of 1998, a forecasted $1.5 billion by the end of 1999.

The financial “big picture,” though, is just a reflection of the many individual successes GE has achieved through its Six Sigma initiative. Some of which based on GE 1998 Annual Report to Shareholders are below;

- A Six Sigma team at GE’s Lighting unit repaired problems in its billing to one of its top customers-Wal-Mart- cutting invoice defects and disputes by 98 percent, speeding payment, and creating better productivity for both companies.

- The Medical Systems business-GEMS-used Six Sigma design techniques to create a breakthrough in medical scanning technology. Patients can now get a full-body scan in half a minute, versus increase their usage of the equipment and achieve a lower cost per scan.
- A group led by a staff attorney-a Six Sigma team leader- at one of GE Capital's service business streamlined the contract review process, leading to faster completion of deals-in other words, more responsive service to customers-and an annual saving of $1 million (Pande, 2000).
- GE reported capacity improvements of 12%-18%, a rise in operating margin to 16,7%, and 750 million in savings.
- GE Plastics Singapore team, starting in July 1996, reduced color variation in plastic products. The team raised quality from two Sigma to 4,9 Sigma over four months $400.000 a year for one plant.
- In 1996, their first year of Six Sigma deployment, GE Plastics achieved benefits of $20 million. This is quite impressive given that first year training costs substantially exceed subsequent year costs (Keller, 2001).

AlliedSignal/Honeywell began its own quality improvement activities in the early 1990s, and by 1999 was saving more than $600 million a year, thanks to the widespread employee training and application of Six Sigma principles. The company credits Six Sigma with a 6 percent productivity increase in 1998 and with its record profit margin of 13 percent. Since the Six Sigma effort began, the firm's market value had- through fiscal year 1998-climbed to a compounded 27 percent per year (Pande, 2000, p 76).

George (2002) gave a USA Today article (1998) presented differences of opinions about the value of Six Sigma in "Firms Air for Six Sigma Efficiency" in his book. Some of the quotes from the article are as follows:

- "Six Sigma is expensive to implement. That's why it has been a large-company trend. About 30 companies have embraced Six Sigma including Bombardier, ABB(Asea Brown Boveri) and Lockheed Martin."
- "Raytheon figures it spends 25% of each sales dollar fixing problems when it operates at four sigma, a lower level of efficiency. But if it raises its quality and efficiency to Six Sigma, it would reduce spending on fixes to 1%."
- "Lockheed Martin used to spend an average of 200 work-hours trying to get a part that covers the landing gear to fit. For years, employees had brainstorming sessions, which resulted in seemingly logical solutions. None worked. The statistical discipline of Six Sigma discovered a part that deviated by one thousandth of an inch. The company saves $14.000 a jet after correction.
- "Lockheed Martin took a stab at Six Sigma in the early 1990s, but the attempt so foundered that it now calls its trainees "program managers." Instead of black belts to prevent in-house jokes of skepticism...Six Sigma is a success this time around. The company has saved $64 million with its first 40 projects.

Keller (2001) gave the list below of companies benefiting from Six Sigma; IBM, Bombardier, Asea Brown Boveri, DuPont, Kodak, Boeing, Compaq and Texas Instruments. As with GE, Motorola, and Allied Signal, other examples of service-based deployments include GMAC Mortgage, Citibank, JP Morgan and Cendant Mortgage.

3.6 Background of Six Sigma

Six sigma is not a management philosophy that decisions are made emotionally or based on some ideas in the organization. As it is written in the ISO 9000 standard, a company should make its strategic decisions on facts and real data. On this perspective, its is not surprising that six sigma has profound statistical bases.

3.6.1 The Six Sigma Metric

The Normal Distribution gives us a quick understanding of the source for the Six Sigma Metric. First, the level of quality that is needed is considered. From Breyfogle (2001) the "goodness level" of 99% equates to;

- 20.000 lost articles of mail per hour
- Unsafe drinking water almost 15 minutes per day
- 5000 incorrect surgical operations per week
- 2 short or long landing at most major airports each day
- 200.000 wrong drug prescriptions each year
- No electricity for almost 7 hours per month

It is obviously agreed that this level of "goodness" is not close to being satisfactory for most of the processes. A Six Sigma program can offer a measurement for "goodness" across various products, processes, and services.

The sigma level (i.e., sigma quality level), sometimes used as a measurement within a Six Sigma program, includes a $\pm 1.5\sigma$ value to account for "typical" shifts and drifts of the mean. This sigma quality level relationship is not linear. In other words, a percentage unit improvement in parts-per-million (ppm) defect rate does not equate to the same percentage unit improvement in the sigma quality level (Breyfogle, 2001).

Figure 3.1 shows the sigma quality level associated with various service (considering the 1.5σ shift of the mean). From this figure it is noted that the sigma quality level of most services is about four, while world class is considered six. A goal of a Six Sigma implementation is to continually improve processes and become world class.

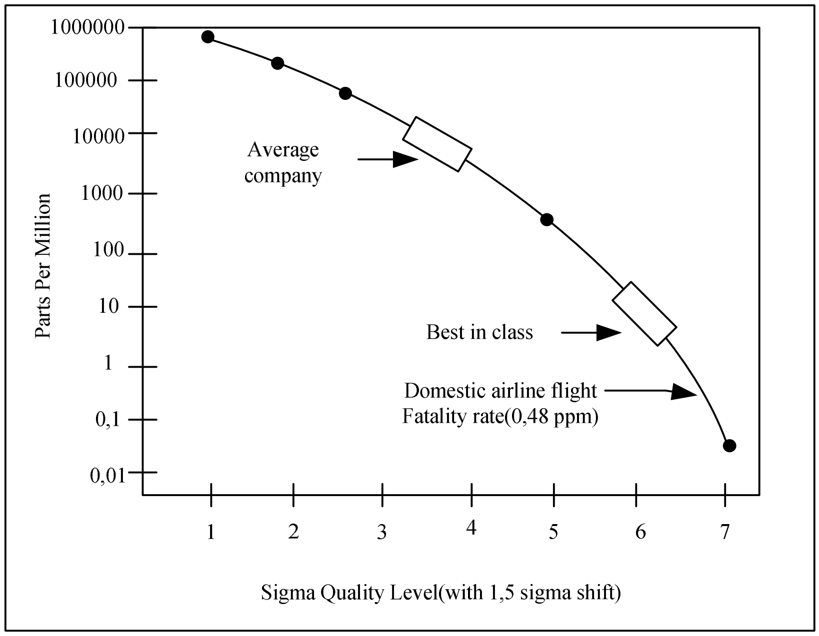
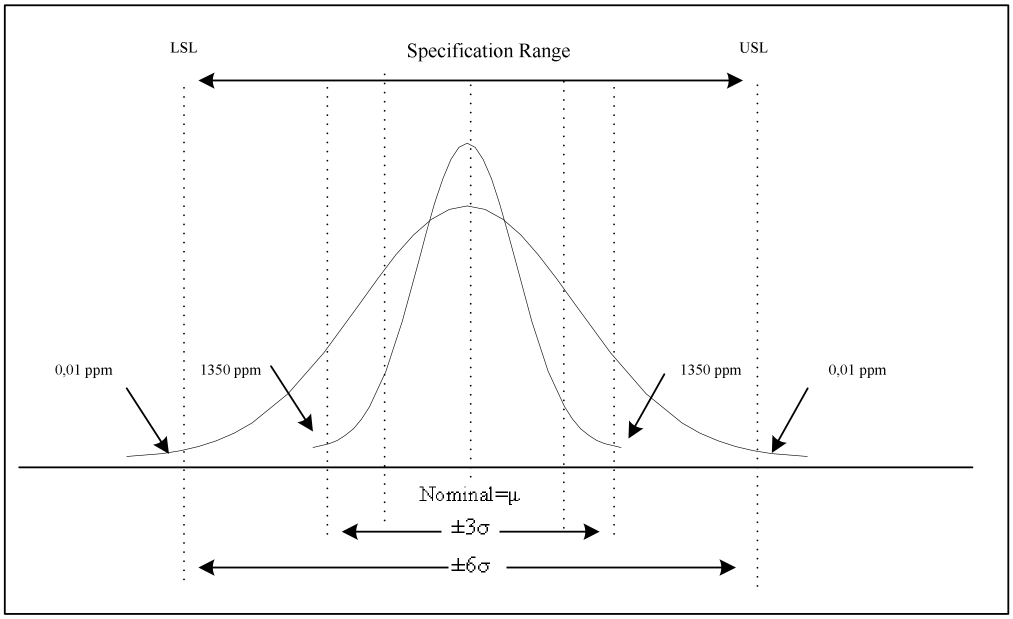


Figure 3.1 Implication of sigma quality level from Breyfogle (2001). Part per million (ppm)rate for part or process step.

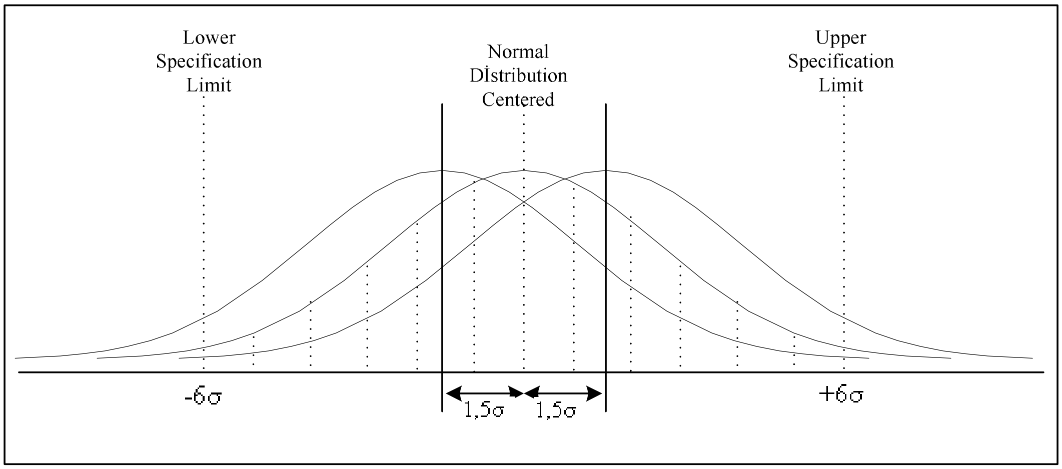
Figure 3.2 and 3.3 illustrates various aspects of a normal distribution as it applies to Six Sigma program measures and the implication of the 1.5σ shift. Figure 3.2 illustrates the basic measurement concept of Six Sigma where parts are to be manufactured consistently and well within their specification range. Figure 3.3 extends Figure 3.2 to noncentral data relative to specification limits, where the mean of the data shifted by 1.5σ.

Figure 3.2 with a centered normal distribution between Six Sigma limits, only two devices per billion fail to meet the specification target. Normal distribution curve illustrates to Three Sigma and Six Sigma parametric conformance.



Spec. limit	Percent	DPMO
±1 σ	68.27	317,300
±2 σ	95.45	45,500
±3 σ	99.73	2,700
±4 σ	99.9937	63
±5 σ	99.999943	0.57
±6 σ	99.9999998	0.002

Figure 3.2 Six sigma metric for centered data.



Spec. Limit	Percent	DPMO
±1 σ	30.23	697,700
±2 σ	69.13	308,700
±3 σ	93.32	66,810
±4 σ	99.3790	6,210
±5 σ	99.97670	233
±6 σ	99.999660	3.4

Figure 3.3 Six sigma metric for noncenteral data.

Using the tables for sigma levels one can easily find that 6 sigma actually translates to about 2 defects per billion opportunities, and 3.4 defects per million opportunities, which is normally define as six sigma, really corresponds to a sigma value of 4.5. Motorola has determined, through years of process and data collection, that processes vary and drift over time - what they call the "Long-Term Dynamic Mean Variation". This variation typically falls between 1.4 and 1.6. Also it is obvious that for many situations controlling the process the target is less expensive than reducing the process variability. It is important here to say that a quality level of 3.4 defects per million can be achieved in several ways, or instance:

- With centered data and 4.5 sigma level of quality
- With 1.00 sigma shift and 5.5 sigma level of quality
- With 1.50 sigma shift and 6.0 sigma level of quality

Table 3.1 Numbers of defectives (parts per million) for specified off-centering of the process and quality levels (one tail only) (Evans J. R. & Lindsay W.M, 2005)

	Quality Level						
Off Centering	3 sigma	3.5 sigma	4 sigma	4.5 sigma	5 sigma	5.5 sigma	6 sigma
0.00 sigma	1350	233	32	3.4	0.29	0.017	0.001
0.25 sigma	3577	666	99	12.8	1.02	0.1056	0.0063
0.50 sigma	6440	1382	236	32	3.4	0.71	0.019
0.75 sigma	12288	3011	665	88.5	11	1.02	0.1
1.00 sigma	22832	6433	1350	233	32	3.4	0.39
1.25 sigma	40111	12201	3000	577	88.5	10.7	1
1.50 sigma	66803	22800	6200	1350	233	32	3.4
1.75 sigma	105601	40100	12200	3000	577	88.4	11
2.00 sigma	158700	66800	22800	6200	1300	233	32

The difference between a 4 and 6 sigma quality level can be surprising. To put it in practical terms, If your cell phone system operated at a 4 sigma level, it is expected that te customers will be out of service for more than 4 hours each month, on the other hand, a six sigma level of quality means in this process that the customers will be out of service at about 9 seconds a month. Figure 4 indicates the surprising nature of improvement gained from six sigma.

Otherwise from its stunning results it is not be considered that it is easy target to reach Motorola in its 1990 results as stucked in 5.4 sigma level of quality over all and decided to establish the Six Sigma Research Institute to achieve “Six Sigma and Beyond” (Barney & McCarty, 2003).

Six Sigma uses a different metric to measure the defects and performance as its seen above. Six sigma timeline is very aggressive for the targets, companies looking for a great improvement in their quality measures their mistakes and errors using defects per million opportunities (DPMO). DPMO can be thought as the overall performance of the organization as observed by customers. An example of DPMO is given below for a technical support call center.

$$\text{DPMO} = \frac{\text{Total Defects}}{\text{Total Opportunities}} * 1{,}000{,}000 \qquad (3.1)$$

$$\text{Yield}(\%) = 100 - (\text{Defects Percentage}) \qquad (3.2)$$

$$\text{Process Sigma} = \frac{\text{NORMSINV}(1 - ((\text{Total Defects})}{(\text{Total Opportunities})} + 1{,}5 \qquad (3.3)$$

Table 3.2: Example process defect rates (Pyzdek, 2003, p.22)

Process Element	Calls Handled	Calls Meeting Requirements	DPMO	Sigma Level
Hold Time<5 minutes	120,000	110,000	83,333	2.9
SE Rating>5	119,000	118,000	8,403	3.9
Problem Solved	125,000	115,000	80,000	2.9
Total	364,000	343,000	57,692	3.1

DPMO calculation is based on the opportunities of making mistake in a process or on a product. The proportion of total defects done to total opportunities gives the process or product DPMO.

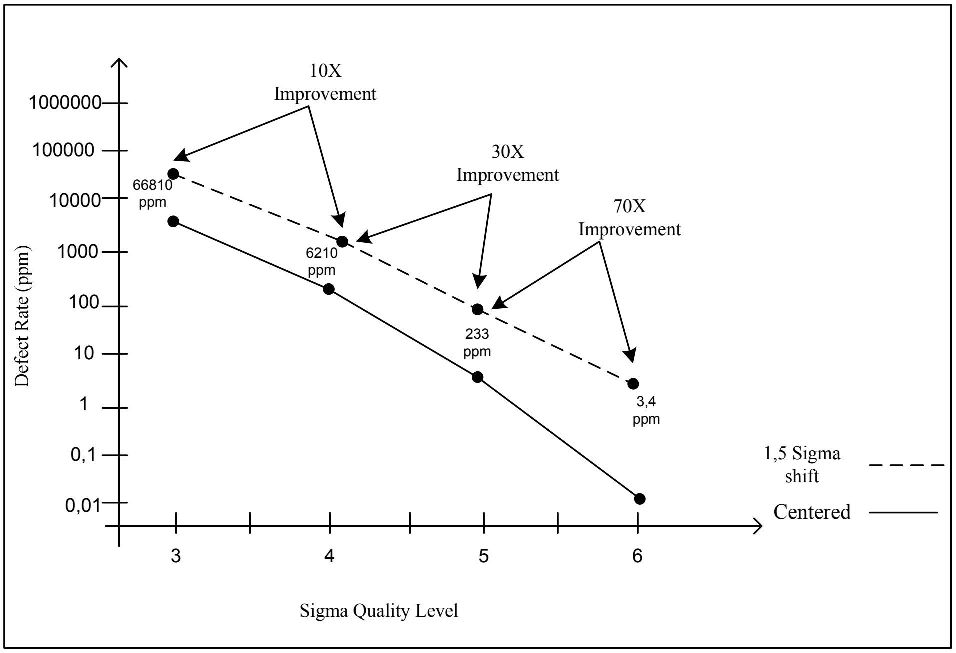


Figure 3.4 Defect rates (ppm) versus sigma quality level from Breyfogle (2001).

A metric that describes how well a process meets requirements is process capability. A Six Sigma quality level is said to translate to process capability index values for C_p and C_{pk} requirement of 2.0 and 1.5, respectively. To achieve this basic goal of a Six Sigma program might then be to produce at least 99.99966% “quality” at the “process step” and part level within an assembly.

Process capability, called Cp, is defined as:

$$C_p = \frac{USL - LSL}{6\sigma} \tag{3.4}$$

$$C_{pk} = \min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right) \tag{3.5}$$

C_p is process capability, corrected for a noncentering of the process average, $\overline{X}$, relative to the design center (or target value). Until the 1970s, C_{pk} of 0.67 was considered adequate enough. In the 1980s, process widths were targeted to equal specification widths, with both at $\overline{X} \pm 3\sigma$. This resulted in a lower defect level of 0.27 percent or 2,700 parts per million (ppm) and was considered a “reach out” quality level, with a C_{pk} of 1.0. In the 1990s, with global competition driving quality toward zero defects, process limits at $\overline{X} \pm 3\sigma$, and specification limits at $\overline{X} \pm 4\sigma$ (i.e., a C_{pk} of 1.33), the defect level is further reduced to 63 ppm. As an example, QS-9000, the quality system of the automotive industry, requires a minimum C_{pk} of 1.33 for key parameters from its suppliers.

Table 3.3 Quantitative relationship between sigma, DPMO, and C_{pk} (for process limits at $\overline{X} \pm 3\sigma$)

	Amount Defective Outside Sigma Limit (Centered Data)		
Specification Limits	%	DPMO	C_{pk}
$\overline{X} \pm 1\sigma$	31.74	317,400	0.33
$\overline{X} \pm 2\sigma$	4.56	45,600	0.67
$\overline{X} \pm 2{,}5\sigma$	1.24	12,400	0.83
$\overline{X} \pm 3\sigma$	0.27	2,700	1.00
$\overline{X} \pm 3{,}3\sigma$	0.096	960	1.10
$\overline{X} \pm 4\sigma$	0.0063	63	1.33
$\overline{X} \pm 5\sigma$	0.000057	0.057	1.67
$\overline{X} \pm 6\sigma$	0.0000002	0.0002	2.00

In the 2000s, world-class companies are striving for process widths reduced to $\overline{X} \pm 3\sigma$, relative to specification limits of $\overline{X} \pm 5\sigma$, resulting in defect levels as low as 0.57 ppm (i.e., a C_{pk} of 1.67).

The full impact of Motorola's famous Six Sigma launch is a process width reduced to $\overline{X} \pm 3\sigma$, relative to a specification width of $\overline{X} \pm 5\sigma$, lowering the defect level to a microscopic two parts per billion (ppb)— or a C_{pk} of 2.0. For all practical purposes, that is zero defects. This is the statistical meaning of Six Sigma (Bhote, 2003, p. 33).

3.7 Defending Six Sigma

Six sigma, like many new trends or initiatives, is not without its critics and detractors. Shina (2002, p.34) explained some of the most frequent critiques of six sigma are listed below:

a) *The confusion of the numerical targets and indicators*. Such as 3.4 ppm, and $\pm 1.5\sigma$ shift. These are reasonable assumptions that were made to implement six sigma. There are other comparable systems, such as C_{pk} targets used in the auto industry that could substitute for some of these assumptions.

b) *The cost of achieving six sigma*. Six sigma advocates the identification of the costs during the design stage, prior to the manufacturing release of the product, so that these costs are well understood. In addition, it has been demonstrated in six sigma programs that the cost of changing the product in the design stage to achieve higher quality, whether through design changes, different specifications, better manufacturing methods, or alternate suppliers, are much lower than subsequent testing and inspection in manufacturing.

c) *The feeling that the six sigma programs only work well for large-volume, well-established, and consumer-oriented companies such as Motorola and GE*. There are many statistical methods that can be used to supplant the sampling and analysis required for six sigma, allowing smaller companies the full benefits of six sigma in product design and manufacturing. The only problem for small-volume companies to compensate the costs of Six Sigma.

d) *The thought of Six Sigma is for manufacturing only.* There are many applications on different areas like service and design. One can use the proper statistical technique to where it is necessitate.

3.8 Role of Statistical Methods

Each step of the improvement process requires generation of the new knowledge through iterative cycles of data collection, data analysis, and decision making. This task is made difficult because all processes have variability, and variability causes uncertainty.

Joglecar (2003) suggests considering the case of frozen pizza currently in production. Through consumer testing, it has been established that each pizza should have a minimum of 30 g of pepper to achieve desired consumer preference.

Table 3.4: An example on the role of statistical methods

Steps of Improvement	Statistical Methods
Understanding the customers preference	*Quality Function Deployment(QFD)*
Evaluation of the pizzas for pepper weight	*Control Charts*
Number of pizzas to be evaluate	*Sample-size formulae*
The capability of the production process	*Capability indices*
Economic meaning of variability in weight of pepper	*Economic loss functions*
Understanding the causes of variability	*Control charts, Variance components analysis, and Measurement system analysis(MSA)*

Improving the pepper deposition process	*Comparative experiments(also designed experiments), Confidence intervals, Regression analysis, and Variance transmission analysis*
Validation experiment	*Control charts, Tolerance intervals, and Capability analysis*
Control of the improvement	*Real-time control charts*

The current situation may be that due to large variability in pepper weight; the mean pepper weight has to be targeted at 50 g to ensure that a very small proportion of pizzas will have less than 30 g of pepperoni. However, this causes an average of 20 g of pepperoni per pizza to be given away for free. The table indicates the improvement strategy and the methods may be used for the case. The way for the improvement is a typical approach of Six Sigma problem solving mentality called DMAIC.

CHAPTER FOUR
DMAIC: A SIX SIGMA IMPROVEMENT MODEL AND QFD

4.1 Six Sigma Improvement Model

"Process Improvement" refers to a strategy of finding solutions to eliminate the root causes of performance problems in processes that already exist in the companies. Process Improvement efforts seek to fix problems by eliminating the causes of variation in the process while leaving the basic process intact. In Six Sigma terms, Process Improvement teams find the critical Xs (causes) that create the Ys (defects) that the companies do not prefer to face of produced by the process.

Pande, Neuman and Cavanagh (2002) defined Process Improvement Model as it is given below:

Define the problem and what the customers require.
Measure the defects and process operation.
Analyze the data and discover causes of the problem.
Improve the process to remove causes of defects.
Control the process to make sure defects don't recur.

This process—often called DMAIC. The steps are explained below.

D (Define) the goals of the improvement activity. The most important goals are obtained from customers. At the top level the goals will be the strategic objectives of the organization, such as greater customer loyalty, or increased market share, or greater employee satisfaction. At the operations level, a goal might be to increase the throughput of a production department. At the project level goals might be to reduce the defect level and increase throughput for a particular process. The development team obtains goals from direct communication with customers, shareholders, and employees.

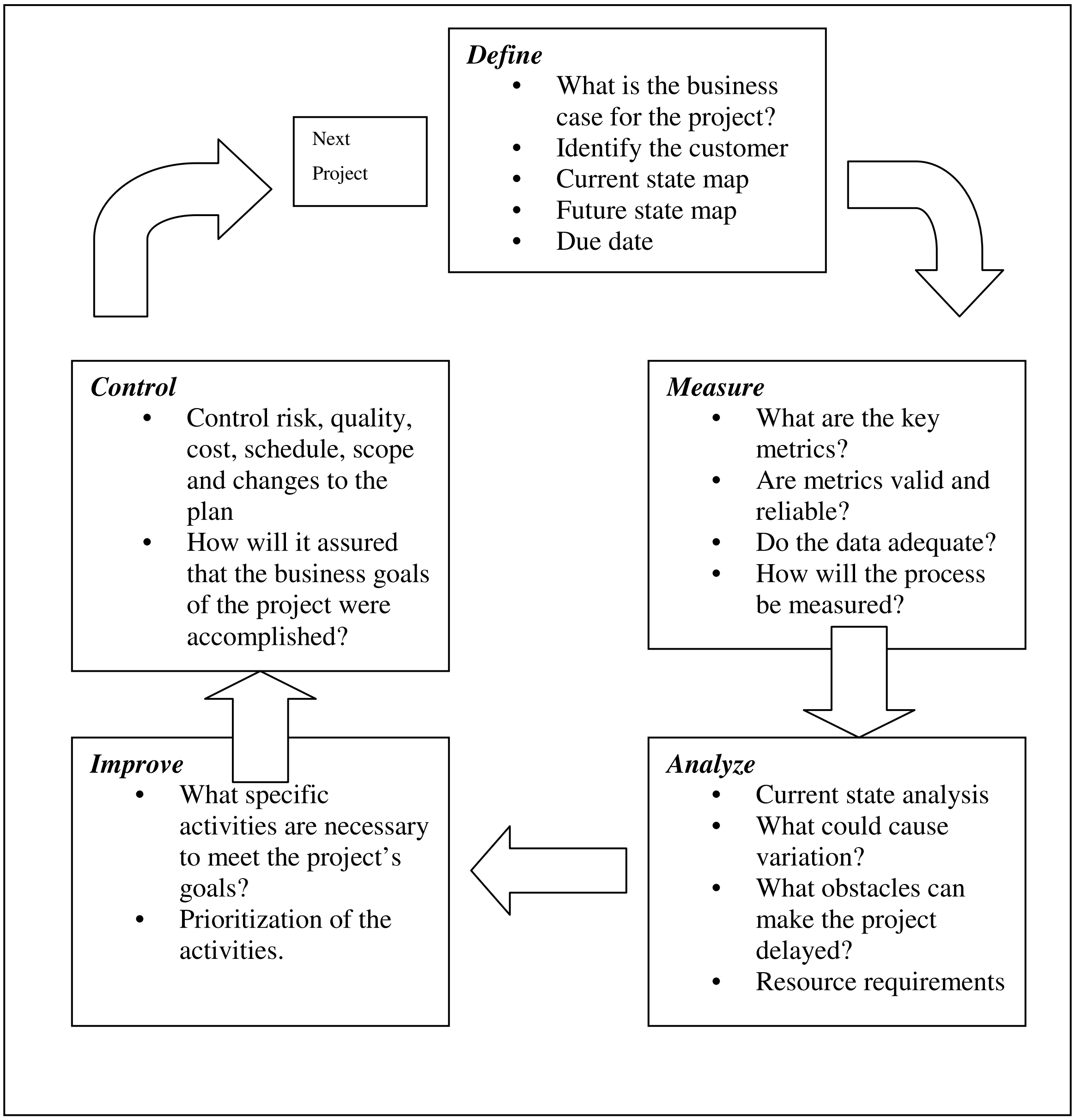


Figure 4.1 Using DMAIC on a six sigma project (Pyzdek, 2003, p.239).

M (Measure) the existing system. The development team establishes valid and reliable metrics to help monitor progress towards the goal(s) defined at the previous step.

A (Analyze) the system to identify ways to eliminate the gap between the current performance of the system or process and the desired goal. Analyze begins by determining the current baseline. Here exploratory and descriptive data analyses are used to help the development team to understand the data.

I (Improve) the system. The development team should be creative in finding new ways to do things better, cheaper, or faster. Project management and other planning and management tools are used to implement the new approach. Statistical methods are used to validate the improvement.

C (Control) the new system. The development team should institutionalize the improved system by modifying compensation and incentive systems, policies, procedures, budgets, operating instructions and other management systems. Standardization such as ISO 9000 is used to assure that documentation. Statistical tools are used to monitor stability of the new systems.

DMAIC is such an integral part of Six Sigma that it is used to organize the tools for the team. It provides a useful framework for conducting Six Sigma projects. DMAIC is sometimes even used to create a "gated process" for project control. That is, criteria for completing a particular phase are defined and projects reviewed to determine if all of the criteria have been met. If so, then the gate (e.g., Define) is "closed."

Table 4.1. Six Sigma tools commonly used in each phase of a project

	Meaning of the Phase	Commonly Used Tools
Project Phase		Candidate Six Sigma Tools
Define	Identify the Problem Define Requirements Set Goals	• Project charter • VOC tools (surveys, focus groups, letters, comment cards) • Through process map • **QFD**, SIPOC • Benchmarking • Process Map
Measure	Validate Problem/Process Refine Problem/Goal Measure Key Steps/Inputs	• Measurement systems analysis • Exploratory data analysis • Descriptive statistics • Data mining • Run charts • Pareto analysis
Analyze	Develop Causal Hypotheses Identify Root Causes Validate Hypothesis	• Cause-and-effect diagrams • Tree diagrams • Brainstorming • Process behavior charts (SPC) • Process maps

		• Design of experiments • Enumerative statistics (hypothesis tests) • Inferential statistics (Xs and Ys) • FMEA • Simulation
Improve	Develop Ideas to Remove Root Causes Test Solutions Standardize Solutions Measure Results	• Force field diagrams • 7M tools • Project planning and management tools • Prototype and pilot studies
Control	Establish Standard Measures to Maintain Performance Correct Problems as Needed	• SPC • FMEA • Documentation • Change budgets, bid models, cost estimating models • Reporting system

4.2 Examples on DMAIC Tolls and "Where to Use Them?"

DMAIC improvement model uses many of statistical and management tools to improve the performance of the processes and their outputs. The aim of Six Sigma applications is to reduce deviation of the performance of a process or output. The statistical tools are crucial to understand the behavior of a data set.

DMAIC uses a list of statistical tools (for instance; descriptive statistics, inferential statistics, hypothesis testing, statistical process control, exploratory data analysis, measurement system analysis, failure modes and effects analysis and project planning etc.) to examine the nature of the processes and eliminate variation sources.

With these and beyond statistical tools, Six Sigma Development teams use numerous management tools. These management tools are vital to manage the process of development, planning the time line and setting the team members.

In this part of the study, some of these tools and their usage in the steps of a DMAIC model are introduced.

Table 4.2 Examples for DMAIC tools and their usage

Tool	Phase	Questions to be answered
Team/Project Charter	Define	• What is the focus of the team's efforts? • What are the boundaries of the effort? • What is the expected outcome?

Process Map	Define	• What is the problem? • Does the development team have any data and information on the problem? • What processes are being considered?
Flow Chart	Define	• What is the starting point of the process? • What is the end point of the process? • What are the major steps in the process?
DPMO and Sigma Level	Measure	• What is the output volume of the process? • What are the opportunities for error? • How many defects are produced?
Descriptive Statistics	Measure	• Is the data normally distributed? • What are the confidence intervals? • Can the data be used for further analysis?
Control Charts	Measure	• What are the performance trends? • Is variation within the normal range? • Is the process stable? • Is the process capable?

Detailed Process Map	Measure	• Who are the suppliers and customers? • What are the inputs and outputs? • Which inputs are controllable? • Where does the company have issues? • What impacts cycle time?
Problem List	Measure	• What goes wrong at each step in the process? • Where are the majority of the problems? • What functional areas are most affected?
Cause and Effect Matrix	Analyze	• What are the most important customer requirements? • What is the relationship of major process steps and inputs to customer requirements? • Where should the development team focus the improvement efforts?
Cause and Effect Diagram	Analyze	• Which of the process inputs are likely to contribute to the problem? • What are the categories of root causes? • What are the most likely root causes within each category?

Pareto Analysis	Analyze	• What is the frequency of occurrence of each potential root cause? • Which root causes are likely to contribute most to our defects? • Which root causes should we focus on first?
Failure Modes And Effects Analysis	Analyze Control	• How can the product, service or process fail? • What are the consequences of failure? • How likely is the failure to occur? • How likely is the customer to be affected?
Variance Components	Analyze	• Where are the major sources of variation? • How much variation is present at each level of the hierarchy? • Where should the development team focus their efforts to reduce the variation?
Measurement System Analysis	Measure Improve	• How real is the variation that the development team observes in the

		process? • Does the measurement system contribute to the variation? • Is the measurement system adequate?
Control Charts	Control	• What are the performance trends? • Is the development team holding the gains from the process improvements? • Is any further action required?
Business Impact Analysis	Control	• What is the business impact of the process improvement? • How should the savings be reflected in the current plan or forecast? • Does the improvement free up capacity to satisfy new demand?

4.3 The Essential Role of QFD for Six Sigma

"Customer Focus" became the crucial element of the quality management systems in the recent decade. With the wave of this spirit, dozens of techniques have been applied to the problems of the companies. ISO comities have stressed the vitality of "Customer Focus" in its early standards and principles. Also, the committee has proposed to the companies to create a process to understand the customer, including profound understanding of customer needs, and, explained the increments as given below:

Applying the principle of customer-focused organization leads to the following actions:

- Understanding the whole range of customer needs and expectations for products, delivery, price, dependability, etc.
- Ensuring a balanced approach among customers and other stakeholders (owners, people, suppliers, local communities and society at large) needs and expectations.
- Communicating these needs and expectations throughout the organization,
- Measuring customer satisfaction and acting on results, and
- Managing customer relationships.

As it is mentioned earlier, dozens of techniques have the same claim, “being the best tool to understand the customer needs and requirements”. None of them have been stunning as QFD have been. QFD is the proven technique to analyze the customer preference and helps to reflect it to the body of design process and involving other processes.

At the same time, the companies have to be more careful to their production processes to eliminate the variation sources affecting them in the cost and customer satisfaction. Defects and variation have the same meaning; “devil”. The programs for decreasing defects always have the attention for this reason, but a few of them were successful. For instance “Zero Defect” programs have failed soon after their appearance. In our competitive globe, the most proven system for the problems of variation is “Six Sigma”. Six Sigma is a methodology which is combined to the statistical thinking and statistical tools. The basic principle of Six Sigma is “to understand what the customer wants” as the same principle of QFD.

Executive Director, QFD Institute Mazur declared in the 11th International Symposium on Quality Function Deployment that “QFD is a required method in many

Six Sigma programs. Six Sigma is rich in statistical tools to provide the accuracy necessary to achieve 3.4 DPMO levels of quality". At the same meeting, some of the professionals on QFD pay special attention on the contribution of QFD to Six Sigma programs.

Six Sigma may be described as a Management based philosophy with a Customer focused, measurement based strategy that focuses on Process improvement and variation reduction. At the heart of the Six Sigma philosophy is an improvement process, working within an existing process, that Defines, Measures. Analyses, Improves, and Controls – DMAIC (Ferguson, 2005).

Six Sigma and QFD are closely interwoven, since QFD is a system for delivering deployed integrated measurements that delight the Consumer/Customer. One can see how QFD can provide the mechanism for achieving the many of the key precepts and principles precepts of Six Sigma.

Some of the key principles of Six Sigma:

- Six Sigma is a Management Philosophy affecting all areas of a business.
- Six Sigma has a Customer focus of satisfying their Needs and eliminating Problems.
- Measurement gives understanding of Current Performance and required improved performance.
- Six Sigma prioritizes improvement activity to eliminate Customer dissatisfaction and enhance profitability.

Ferguson (2005) explained some of the ways in which QFD can help achieve the aims of Six Sigma:

- QFD is an Integrated Philosophy by deploying Consumer Needs through Systems, Product and Process Design, and Manufacture.
- QFD listens to the Voice of the Customer and interprets their needs, problems

deploy the needs to the technical characteristics of the current or future design.

- QFD Benchmarks identified ideal target values against the competition, the present design and its customer satisfaction level.
- QFD derives improved, measurement features over existing designs, focused on **minimum variation** around identified targets.

QFD is a proven technique for the Define phase of Six Sigma. The focus of Six Sigma on customer satisfaction can be held with QFD. Six Sigma and Design for Six Sigma (DFSS) are growing in use around the world. To the tools and methods of Total Quality Management has been added financial accountability for better cost/ benefit analyses of measurement and quality control. Stronger, also, is the systemization of the quality processes and tools into a more logical flow that is easier to teach, test, and certify.

QFD will play a vital role in improving the understanding of the voice of the customer, capturing customer priorities, and translating them into Six Sigma directives (Akao & Mazur, 2003).

In the process of complex natures of the problems, the Define stage of a DMAIC process takes on extra import. Writing down a few customer requirement statements simply will not help the development team. The development team has to be more rigorous in their investigation of customers and their needs, and in defining specific requirements. QFD is an advanced Define tool and can easily solve this complex structure of the customer requirements.

QFD is a commonly used technique to deploying the Six Sigma strategies to the Six Sigma projects. Choosing the best fitted project to the strategies can be done with using QFD. Pyzdek studied on this problem and gave some examples in his Six Sigma Handbook.

CHAPTER FIVE
APPLICATION

5.1 Introduction

After introducing the techniques and the methodology in this part of the study, it is shown that how these techniques and methodology (DMAIC) are combined together and how QFD customer knowledge turn into DMAIC directives in a Six Sigma Organization.

5.2 ABC Electric

ABC is the third top switch and socket seller company in İzmir since 1983 and in 2003 an cooperation with a world class company is a worldwide specialist in Electrical Distribution, Automation and Control, with 3 main international brands is achieved. ABC produces following products in İzmir Çiğli plant with 15 000 m^2 closed area.

- Flush mounting electric & electronic installation materials
- Industrial plugs & Sockets
- Luminaries

The company has been holding ISO 9001:2000 Quality System Certificate, and is manufacturing the products with TSE, TSEK, BS, DIN, VDE, CB and GOST-R quality certificate.

The study is conducted in their latest switch-socket series. The product has been released in 2005 and the study focuses on how the customers can be more satisfied using Quality Function Deployment and using the knowledge in Six Sigma Development Methodology.

5.3 Application

Application takes form of two main parts;

- *QFD Application*: The goal of this part of the study is to observe and gather the customer complaints, needs and requirements, and choose a way of deploying an “important” technical characteristic to boost the customer satisfaction.
- *Six Sigma Project Selection:* The goal of this part is to reflect the customer needs and requirements in a chosen process using the Six Sigma development model DMAIC. When using QFD initiatives, the selection of Six Sigma projects is in this part.

However; QFD application has a problem solving methodology, this study aimed to indicate how to use QFD and its results in a Six Sigma project using DMAIC. The application formed to use QFD knowledge to define and select Six Sigma projects based on customer requirements applied in the plant.

5.3.1 House of Quality (HoQ)

QFD is a popular and proven technique used in many areas nowadays to enhance the customer satisfaction. In this study, it is researched that how QFD can contribute to a customer based system like Six Sigma.

QFD Application will be ended with “constructing” the House of Quality, but before constructing it, many other steps have to be examined as the components of the House of Quality. The steps are given below:

Before the start of the project a series of meeting held in the company to form the development team and some meetings are focused on the introduction of the methodologies planned to be used.

5.3.1.1 Gathering the Voice of the Customer

The first step for QFD is to gather the Voice of the Customer. The real data of the customers can show the development team where to improve. There can be many approaches to gather the Voice of the Customer. The most preferred ways are to form focus groups and survey designs. In this study, survey design is preferred but combining with focus groups.

Survey forms are prepared for the customers to be answered and than the forms are analyzed. Survey procedure and customer selection is the most important parts of these studies, because the more powerful data is, the more the researchers are accurate.

The development team’s first decision was about “who the customer is”. A brainstorming session is made to make a decision. After the session, in spite of different thoughts, the team has drawn a conclusion on that gathering the customer needs from the technicians who are responsible to assembly the product to the end using place. There are many characteristics involving this decision. These are; technicians are professionals of assembling the products, so they are the most experienced source, and most of the times they behave like the guides for the end users to purchase the product. On the other hand, when they suggest the products, they usually have an eye on the price, appearance, and the marketing strategies.

The next decision was to determine what to ask to the customers and how many customers are contained in the survey. The first problem has bridged with brainstorming the most available two focus groups. The basic problems are held in this way and discussed in the team’s next meeting. Then the survey form is prepared (see Appendix).

From the database of The Society of The Electric Technicians, it is estimated that there are approximately 1000 of their registered members in İzmir. The survey is determined to be applied the technicians both have knowledge about ABC and two competitors because of the benchmarking study. As a constraint, there was approximately no knowledge about the electric technicians' addresses in the database so ABC helped the team with directing the surveys to its dealers.

Survey design is based on the Simple Random Sampling Procedure. The sample size is computed from the equations below with the estimated proportion of general satisfaction of the customers (p).

For $\alpha=0.05$ $t\approx2$ and the estimate can be in % 1 bound, when $p=0.50$ and $q=0.50$. The sample size is 100.

Approximately 100 survey forms are filled using the quota sampling in İzmir and analyzed. The estimated distribution of the technicians' is given below:

Table 5.1 The estimated distribution of market share of the dealers in İzmir

Market Share	Estimated Proportion	Estimated Size
ABC	0.15	150
Competitor X	0.40	400
Competitor Y	0.30	300
Others	0.15	150

After the survey, the customer needs are classified in an affinity diagram and attached to the Customer Needs session in the House of Quality. The results of the survey helped the development team to construct the planning matrix. The Weights and the benchmarking columns are filled after the survey. The "modes" are used to explain the numerical meanings because of the scale's characteristic.

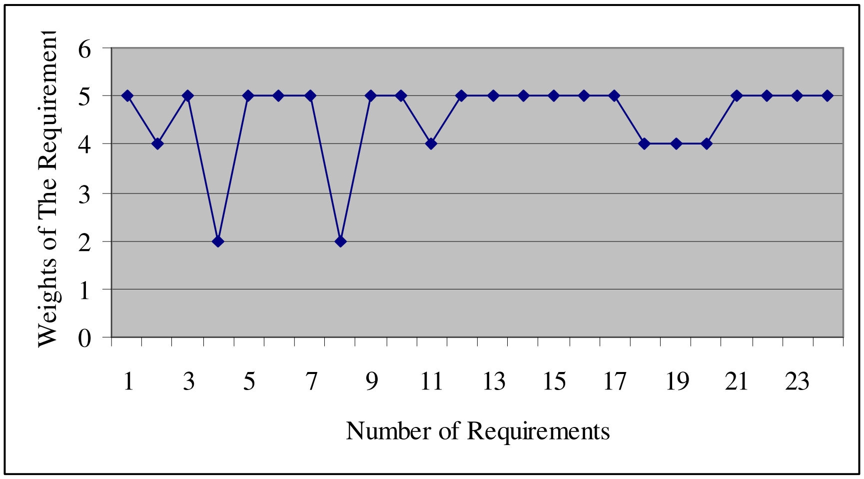


Figure 5.1: Plot of the weights of the customer requirements.

	Customer Requirements	Weight
Appearance	Enough color alternatives	4
	No packaging problems	3
Price	Adequate price	5
Marketing	Timely delivery	5
	Customer support	2
	Brand image	5
	Enough visit by the sales person	3
	Enough promotion for marketing	5
Assembly	Switch series functionality	3
	Easy installation with claws or screws	5
	Enough angle with the clawns	5
	No time consume when installation-uninstallation	5

Figure 5.2: Customer requirements session of HoQ.

5.3.1.2 Constructing Planning Matrix

One of the most important components of the planning matrix is the weighting column of the requirements. Basic aim of this column is to understand how much important a requirement. The customers are either asked that how they mark ABC, Competitor X and Competitor Y for the same requirements. The charts for ABC, Competitor X and Competitor Y for their evaluations by the customers for the same requirements are shown as follow:

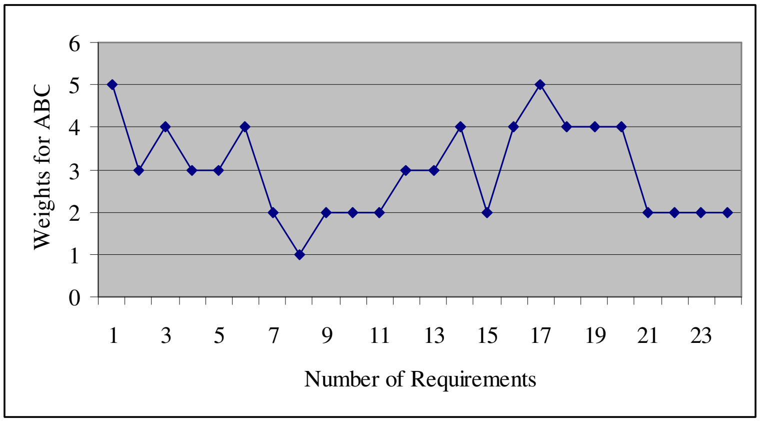


Figure 5.3 Plot of the weights of the customer requirements for ABC.

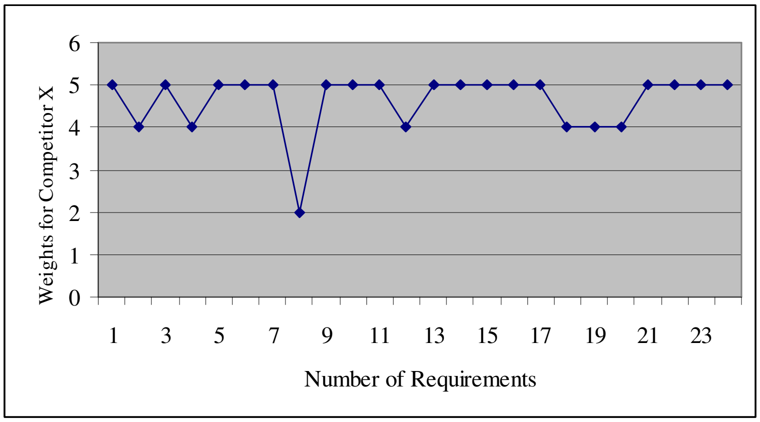


Figure 5.4 Plot of the weights of the customer requirements for Competitor X.

For many different evaluators there is a remarkable difference between the three companies. As it is seen Competitor X has high results approximately for all the requirements and ABC has many results under 3. The improvement route starts to be drawn with this benchmarking study.

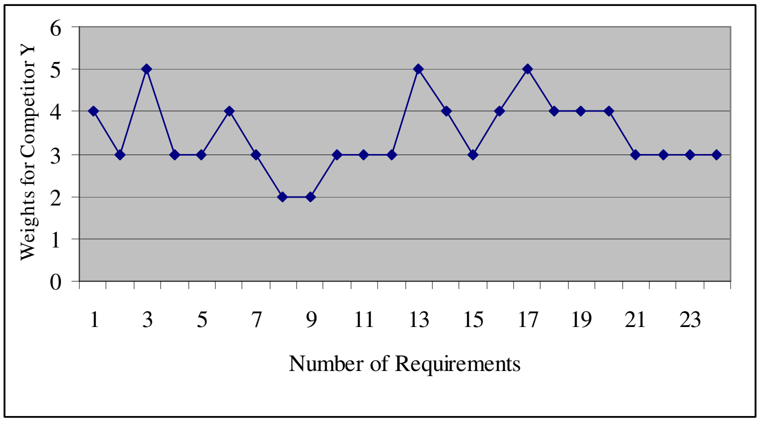


Figure 5.5 Plot of the weights of the customer requirements for Competitor Y.

The other items of the Planning Matrix are held in a series of meetings and the team gave those numerical values to explain what ABC targets to make real customer needs and how each customer need affects the sales. Targets have to be realistic for all the requirements but the team's baseline for targets is to reach the most powerful competitors results. Anyway some of the requirements are difficult to succeed. For instance "No time consume when installation/uninstallation" requirement is about the design process of the product and it is not easy to improve this requirement before changing the design activities have been procedured by the cooperative company. So the team decided to stand this target as the same of the evaluation result.

On the other hand, it is very important to understand the contribution of a requirement for the sales. The global scale of HoQ is used to analyze the requirements in the Sales Point column. For example for a switch and socket series "Brand Image" and "Customer Support" are in high concern even though, "Visiting Activities" are not. The column of Sales Points is formed in the HoQ.

Another important component of the planning matrix is the "Improvement Ratio Column". The logic underlying this study is to analyze the needs for the improvements of the needs. The ratios are calculated from targets divided to the weights given for the company. Thus if a requirement is evaluated by the customer as low results and the company has a high target, the improvement ration should be grater than the others vise versa. With these analyses the customer needs and planning matrix sessions are finished.

	Customer Requirements	Weight	ABC	Competitor X	Competitor Y	Target	Improvement Ratio	Sales Point
Appearance	Enough color alternatives	4	3	3	3	5	1,7	1,2
	No packaging problems	3	2	5	4	4	2	1,2
Price	Adequate price	5	3	5	5	5	1,7	1,5
Marketing	Timely delivery	5	4	4	4	5	1,3	1,5
	Customer support	2	1	2	2	5	5	1,5
	Brand image	5	2	5	3	5	2,5	1,5
	Enough visit by the sales person	3	2	5	2	5	2,5	1
	Enough promotion for marketing	5	2	5	3	5	2,5	1,5
Assembly	Switch series functionality	3	4	5	4	4	1	1,2
	Easy installation with claws or screws	5	2	5	3	5	2,5	1,5
	Enough angle with the clawns	5	2	5	3	5	2,5	1,5
	No time consume when installation-uninstallation	5	2	5	3	2	1	1,5

Figure 5.6 Planning matrix of HoQ.

5.3.1.3 Constructing the Technical Characteristics

The next step is to construct the "Technical Characteristics" session, the team had some other meetings to determine which of the technical characteristic(s) is the best explanatory of the customer needs are, and decide 15 technical characteristics. For every customer need at least one technical characteristic is decided that best explains the need. Examples for the characteristics and the customer needs they explain are given below:

Technical characteristics are examined with the customer needs then. In the middle part of the House of Quality the contributions of the technical characteristics to the customer needs are searched in a brainstorming session for every possible combination. The relationships are scaled with global weights (1: weak, 3: moderate, 9: strong).

Table 5.2 Examples on technical characteristics

#Tech. Char.	Technical Characteristic	Customer Need
1	Customer Service Level (CSL)	Delivery on Time
2	Packaging Cost	No Packaging Problems
3	Overturn Angle	Enough angle with the claws
4	Average Installation Time	No time consume when installation-uninstallation

House of Quality suggests a benchmarking study for the technical characteristics either. The development team had a research on the competitors to understand where they are for the same technical characteristics. Although, it is difficult to find out all of characteristics, the ones available are recorded. On the other hand, the relationships between the technical characteristics are examined and recorded. This study allows the company to evaluate itself for technical characteristics and targets on these technical characteristics.

Table 5.3 Benchmarking study for the technical characteristics

	Measurement Scale	ABC	Competitor X	Competitor Y	Target
Number of Colors		10	10		10
Sales Price	YTL	1,3	1,3	1	1,25
Customer Service Level					96
Packaging Cost	YTL				
BT Survey Proportion	%				
EZ Response Number	%				
Number of Monthly Visits	Mountly Periods	80	0		100
Annual Promotion Budget	YTL				
Switch on/off Score	Item*1000	120			120
Overturn Angle	Degree	7,5			7,5
Number of Components	Item	5	4	4	5
The Lenght of Claws	mm				
Distance Between Claws	mm				
Average Installation Time	Minute				
Avarege Uninstallation Time	Minute				

5.3.1.4 Constructing the Roof of HOQ

The roof of HoQ is a special part of the study. After determining the technical characteristics, it is vital to analyze that if there is any possible correlation between the technical characteristics. For example, a candle manufacturer can gather the voice of its customers, and find that the customers want a beautiful smelling and solid candle. Smell can be obtained by adding more fragrance, but what is the effect of fragrance to the solidity. More fragrance can make the candle less solid vise versa.

Starting with this basic philosophy, all the logical technical characteristic combinations are analyzed. And correlations are added to the roof of the house. Some technical characteristics are easy to analyze the correlations by statistical methods. For instance, switch on/off scores historical mean is 120 itemX1000 and standard deviation is approximately 3, and overturn angle's parameters are (7.5, 0.001). And Pearson correlation coefficient is –0.103 means a negative weak correlation between the variables shown in the scatter plot.

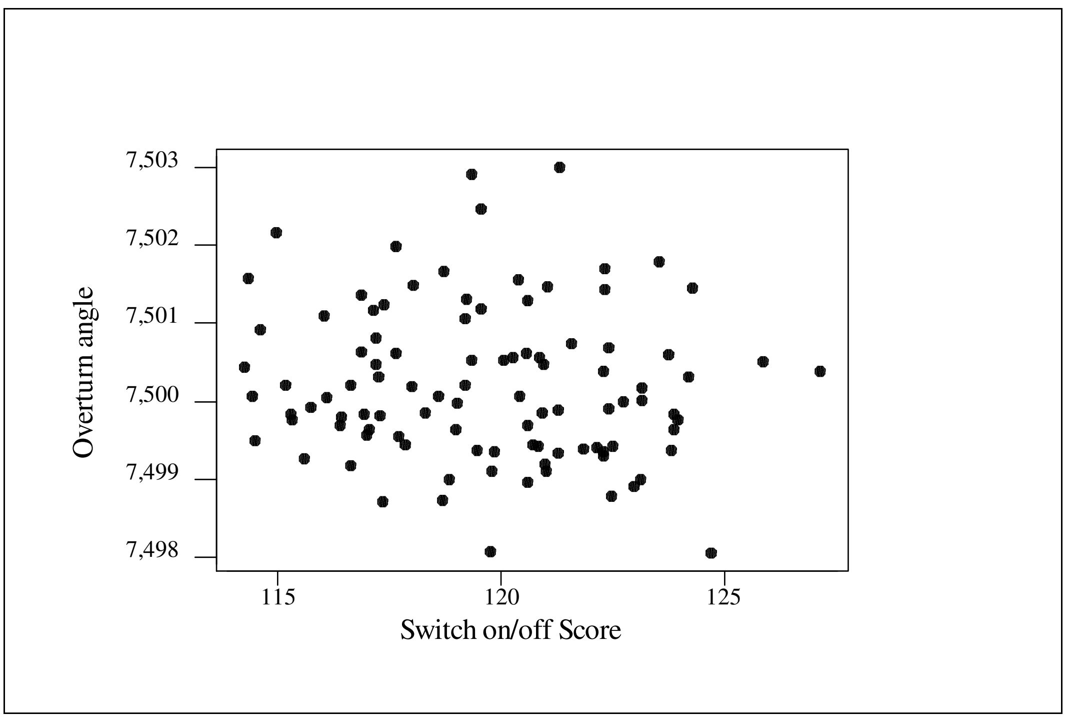


Figure 5.7 Scatter plot of overturn angle and switch on/off scores.

The correlations can not be computed with statistical methods are determined by the team using their experience. Given the symbols to the correlations (negative weak, negative strong, no correlation, positive weak and positive strong) the roof is formed.

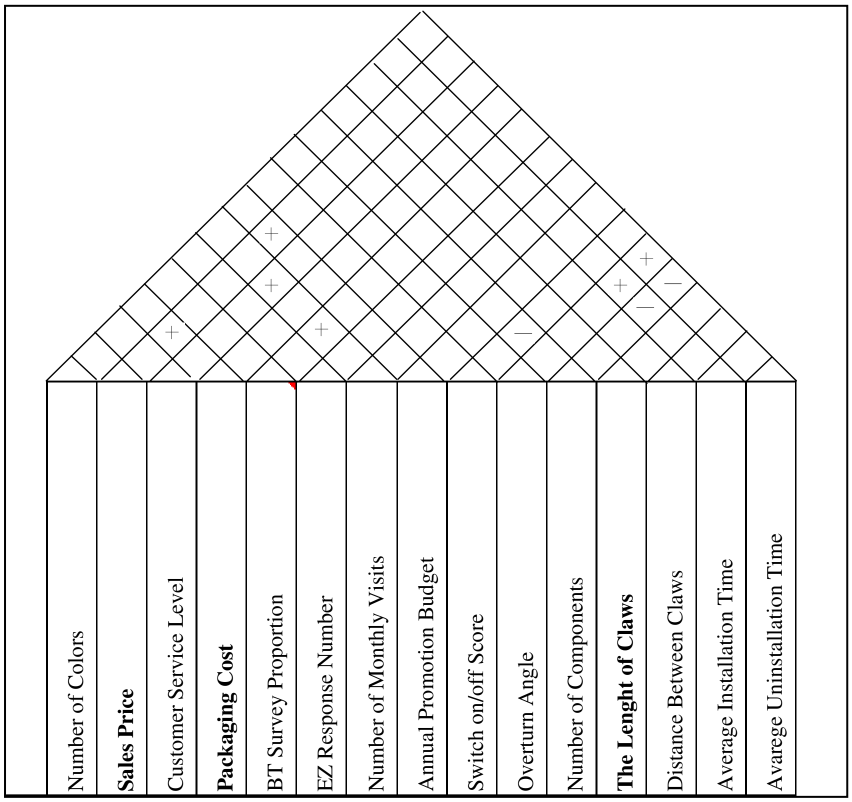


Figure 5.8 The roof of house of quality.

5.3.1.5 Ranking of the Technical Characteristics

The last part of the QFD study is to find the best technical characteristic to be improved with the best contribution to the customer needs. The team decided on the rule to deal with the top three computed results of technical characteristics. These are:

Table 5.4 Top four results of the technical characteristics

#Tech Char.	Technical Characteristic	Ranking	Normalized Ranking (%)
1	The Length of Claws	221	12
2	Sales Price	193	11
3	BT Survey Proportion	153	8,6
4	Packaging Cost	147	8,3

The team started the study with gathering the Voice of the Customer, and discovered some improvement addresses dealing with the customers. The whole House of Quality for ABC in plugs is given in Figure 5.4. The “length of claws” technical characteristic was known before the study from the customer complaints. By the way, the packaging cost also was the weak side of the company and is related to the sales price directly. On the other side, Bt survey proportion is a very important technical characteristic for the brand image of ABC. The basic problem is the resource allocation to the following Six Sigma projects based on these three issues:

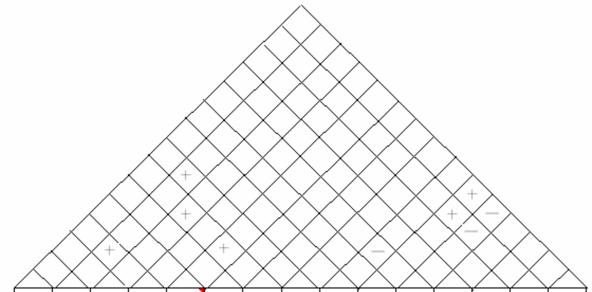
- Costs (Packaging, promotion etc)
- Brand Image
- The Size of Claws and the other engineering specifications

The different addresses to maximize customer satisfaction are deployed to Six Sigma projects. The Costs project firstly focused on packaging costs and turn over of costs in ABC’s packaging usage according to packaging groups and to reduce packaging costs. The project also aimed to reduce the sales price. The second project is focused on the improving the Brand Image followed by BT Survey Proportion. And the third focused on a experimental design study for the optimum length of claws and the effects of the other engineering specifications. The resource allocation problem led the team to use a prioritization matrix to find the first project to start. The matrix is given in Figure 5.9.

Table 5.5 Prioritization matrix for six sigma projects

Project Number		1	2	3
Project Selection Matrix		Costs Project	Brand Image Project	Lenghts of Claws Project
		X Correlation with Y (1 = weak, 3 = moderate, 9 = strong)		
Project Description/Potential Project Title (X)	Priority 1..........10			
1. Is it likely that the project can be completed within six months?	7	3	3	9
2. Does the project represent a significant improvement in quality?	10	3	3	9
3. Does the project justify the deployment of a Six Sigma team?	8	1	9	9
4. Does it appear a minimum of investment will be required to solve the problem?	8	3	3	9
5. Is the problem easily defined (the function, Y, the defect, Xs)?	9	1	1	3
6. Will success significantly improve customer satisfaction?	7	3	9	9
7. Is the process currently measured?	6	9	1	3
8. Is the process measurable?	4	9	3	9
9. Is it likely that the solution will be highly implicable?	7	3	1	9
10. Does it appear that Six Sigma DMAIC is the right problem-solving approach?	9	3	3	9
11. Is success likely?	8	9	9	9
Totals		323	193	393

The prioritization matrix has some important aspects on the DMAIC approach like measurability, team base and customer focus. The highest total is for "Lengths of Claws" project. This result showed that the first Six Sigma project to start is about the engineering specifications and design of the claws.



	Customer Requirements	Weight	Number of Colors	**Sales Price**	Customer Service Level	**Packaging Cost**	**BT Survey Proportion**	EZ Response Number	Number of Monthly Visits	Annual Promotion Budget	Switch on/off Score	Overturn Angle	Number of Components	**The Lenght of Claws**	Distance Between Claws	Average Installation Time	Avarege Uninstallation Time	ABC	Competitor X	Competitor Y	Target	Improvement Ratio	Sales Point	Relative Importance	Normalized Importance
Appearance	Enough color alternatives	4	9															3	3	3	5	1,67	1,2	8	5,49
	No packaging problems	3				9												2	5	4	4	2	1,2	7,2	4,94
Price	Adequate price	5		9		9												3	5	5	5	1,67	1,5	13	**8,58**
Marketing	Timely delivery	5			9	3												4	4	4	5	1,25	1,5	9,4	6,44
	Customer support	2						9										1	2	2	5	5	1,5	15	10,3
	Brand image	5		9	1	3	9		9	9						3	3	2	5	3	5	2,5	1,5	19	12,9
	Enough visit by the sales person	3			3			3	9									2	5	2	5	2,5	1	7,5	4,9
	Enough promotion for marketing	5					3			3								2	5	3	5	2,5	1,5	19	**12,3**
Assembly	Switch series functionality	3									9	9	3			9	9	4	5	4	4	1	1,2	3,6	2,35
	Easy installation with claws or screws	5										3	9	9	9			2	5	3	5	2,5	1,5	19	**12,3**
	Enough angle with the claws	5										1		9	9			2	5	3	5	2,5	1,5	19	**12,3**
	No time consume when installation-uninstallation	5										1				3	3	2	5	3	2	1	1,5	7,5	4,9
	Ranking		49	**193**	85	**147**	**153**	107	160	153	21	75	117	**221**	123	74	87	1766						146	97,5
	Normalized Ranking		2,8	**11**	4,8	**8,3**	**8,6**	6,1	9,06	8,6	1,2	4,3	6,6	**12**	6,9	4,2	4,9	100							
	Measurement Scale			YTL	%	YTL	%	%	Mountly Periods	YTL	Item*1000	Degree	Item	mm	mm	Minute	Minute								
	ABC		10	1,3					80		120	7,5	5												
	Competitor X		10	1,3					0				4												
	Competitor Y			1									4												
	Targets		10	1,25	96				100		120	7,5	5												

Figure 5.9: The House of quality for ABC switch and socket.

CHAPTER SIX
CONCLUSIONS

In this study a brief knowledge about the nature of Six Sigma and Quality Function Deployment (QFD) and statistical background of the methodologies is addressed. Vital role of QFD in improving the understanding of the voice of the customer in business processes, capturing customer priorities, and translating them into Six Sigma DMAIC directives are involved by statistical perspectives.

Six Sigma is being a popular icon of statistics and management, a trademark and being a fad all over the globe. The popularity brings some other claims and problems with its fame. Some of us even think of the meaning of “six” in the name of the methodology. Juran said that if you are able to achieve, name it seven or eight sigma when he is asked.

As it is clear in the development model (DMAIC) there is no new statistical method in any of the steps. Six Sigma is a methodology able to bring the known tools to analyze the variabil4ity. Six sigma is creative rather than innovative.

Six Sigma is popular with the other methodologies already. Six Sigma Fusion or Beyond Six Sigma is bodied first in design activities. GE suggested a new development model DMADV (Define, Measure, Analyze, Design and Verify) to reach Six Sigma target in design called DFSS(Design for Six Sigma) using QFD and TRIZ. An integration between Lean Thinking and Six Sigma anticipated called Lean Six Sigma.

Edgeman & Bigio (2004) suggested a new route to Six Sigma to other bottom-lines such as the **b**iophysical-environmental, **s**ocietal, and technological (built environment) called BEST principles and “BEST Six Sigma”.

A new development model is introduced called DMAIC with Six Sigma. In fact it is hard to say it is quite different from PDCA but suggestions of the statistical tools for all the steps and the flaw of monitoring the analysis on variation is more sophisticated.

Six Sigma is a style today; some black belts are preparing six sigma projects on diet and healthy life. Even Though, Six Sigma sometimes claimed to be the same of TQM for many aspects and found suspicious for the metrics it uses, Its support of teamwork, motivating power, strong data analysis background can not be ignored.

Over the fifty years of evolution today QFD is used in many different area of business from entertainment to medical, automotive to education. The simple philosophy to reflect the voice of customer to the business processes has made the technique popular all this time.

QFD is a required method in many Six Sigma programs. QFD is a proven technique to achieve the customer satisfaction. Based on this mentality, QFD is a useful tool to choose the best Six Sigma projects that maximize the customer satisfaction.

In ABC which is a well known Six Sigma Company in İzmir a QFD study is conducted to choose the six sigma projects that serves to customer requirements. First of all to reach the customer requirements two focus groups are formed to find the inputs of the designed survey and the survey is conducted to electric technicians. The customer requirements showed that the customers evaluate ABC weak for some of the intended requirements like packaging, price and customer support. The survey also let the company to a benchmarking study for the perception of customers with the competitors. The planning matrix is formed with this knowledge and benchmarking study added to this process. ABC became able to evaluate its own image and perception with this study. Constructing the customer requirements and planning matrix, the team decided the technical requirements that best fit to the customer requirements. A benchmarking study conducted for the technical knowledge either. ABC is in suitable conditions for some of these technical characteristics for instance; monthly visits, number of colors and switch on/off scores. The contributions of the technical characteristics are shown in the contributions session of House of Quality. When the ranks of the technical characteristics based on the contributions are the first top four results was involving with the costs of packaging and promotion, brand image and the engineering design of the claws. The QFD study, made the company to clarify the route to six sigma projects. Three six sigma projects are evaluated with a prioritization matrix with a series of six sigma objectives and the team gave the top grade to the "engineering design of claws" project and gave a report to the sponsors and top management with the results. Study issued in the monthly magazine of the company in intranet worldwide.

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APPENDIX

SURVEY FORM

Dokuz Eylül Üniversitesi
Fen Bilimleri Enstitüsü
İstatistik ABD

Elektrik Teknisyenlerinin Priz ve Anahtar Priz Serileri ve Üreticilerinden Beklentileri Araştırması

Anket için anahtar:

1. Aşağıdaki müşteri gereksinimleri yapılan odak grup çalışması sonucunda ortaya çıkmıştır. Sizden istediğimiz her bir müşteri gereksinimi için ilk kolonda kendi görüşlerinizi

1: önemsiz
2: az önemli
3: orta düzeyde önemli
4: önemli
5: çok önemli

anlamlarının karşılarındaki sayıları kullanarak değerlendirmeniz.

2. Kendi görüşlerinizi belirttikten sonra aynı özellikleri belirtilen ürünler içinde değerlendirmeniz gerekmektedir.

Örneğin;

Müşteri gereksinimleri MONTAJ	Kendi önem düzeyiniz	ABC	X	Y
Montaj kolaylılığı	5	3	4	2

gibi.

Teşekkür Ederim.

Eralp Doğu
Dokuz Eylül Üniversitesi
İstatistik ABD
Yüksek Lisans Öğrencisi

Müşteri gereksinimleri TASARIM/Görünüm	Sizin için önemi	ABC	X	Y
Tasarımının güzel olması				
Renk seçeneklerinin yeterli olması				
Ürün çeşitliliğinin yeterli olması				
Bağlantı şemalarının yeterince anlaşılır olması				

Müşteri gereksinimleri FİYAT		ABC	X	Y
Fiyat beklentinize cevap vermesi				

Müşteri gereksinimleri PAZARLAMA/Servis/Satış		ABC	X	Y
Teslimatların zamanında yapılması				
Marka bilinirliği				
Müşteri destek hattı bulunması				
Satış sorumlularının ziyaretlerinin yeterli olması				
Pazarlama için promosyon faaliyetlerinin yeterli olması				
Katalog fiyat listesinin elinize zamanında ulaşması				
Katalog fiyat listesinin yeterince açık olması				

Müşteri gereksinimleri TEKNİK ÖZELLİKLER		ABC	X	Y
Yeterli teknik özelliğe sahip olması				
Güvenilir olması				
Çoklu çerçevenin kullanışlılığı				
Anahtar grubunun kullanışlılığı				
Priz grubunun kullanışlılığı				
Data prizinin kullanışlılığı				
Tv-sat prizinin kullanışlılığı				
Işık ayarlayıcının kullanışlılığı				

Müşteri gereksinimleri MONTAJ		ABC	X	Y
Montaj kolaylılığı sağlaması				
Anahtar kasasına rahat oturması				
Montaj ayaklarının yeterli açıya sahip olması				
Montaj esnasında söküp takmada zaman kaybı yaratmaması				