KADIR HAS UNIVERSITY
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SIX SIGMA PROJECT EVALUATION UNDER FUZZINESS IN FOOD INDUSTRY

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"I, Özlenen Şentürk, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis."

ÖZLENEN ŞENTÜRK

ABSTRACT

SIX SIGMA PROJECT EVALUATION UNDER FUZZINESS

IN FOOD INDUSTRY

Özlenen Şentürk

Master of Science in Industrial Engineering

Advisor: Assoc. Prof. Zeki Ayağ

May, 2013

Modern-day business world is under constant development at production and service market. Common purpose is to return profit by optimizing costs and raise customer satisfaction to maintain acquired success. It is observed at processes that more service and production are provided by less work force. In food sector which is one of the best known service and production areas, if there will be a new production system "knowledge" should be used as base. On the other hand it is necessary to focus on food safety and customer satisfaction. It is obvious that Six Sigma approach is helpful to achieve this tradition. Statistically objective is to enhance performance at processes by reaching defect margin of 3,4 units at 1 million product or service. Six Sigma methodology provides cultural exchange on the way to improvement. Companies can do measurements by using quality control tools for topics like determining cost expenses. However these companies will have difficulties measuring customer satisfaction. Especially at food sector, performing measurements mostly brings along difficulties due to variable customer needs. In this connection it will be an important attempt to use "Fuzzy Logic". Fuzzy Logic is an artificial intelligence principle with variable outcomes which does not gives certain results like classic logic and datas are estimated. In this research, most suitable alternative and method is determined by Six Sigma project evaluation approach under Fuzzy Logic for 5 different selected food facilities in Turkey

Keywords: *Six Sigma, Six Sigma Methodology, Fuzzy Logic, Fuzziness, Food Industry*

ÖZET

GIDA SEKTÖRÜNDE BULANIKLIK ALTINDA
ALTI SİGMA PROJE DEĞERLENDİRMESİ

Özlenen Şentürk
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Günümüz iş dünyası, üretim ve hizmet sektöründe sürekli gelişim halindedir. Ortak amaçları; en yüksek kaliteyi yakalamak, maliyetleri optimize ederek kar sağlamak ve elde edilen başarının sürdürülebilmesi için müşteri memnuniyetini en yüksek seviyeye çıkarabilmektir. Süreçlerde daha az iş gücü ile daha çok üretim ve hizmet uygulaması görülmektedir. En yaygın üretim ve hizmet sektörlerinden biri olan gıda sektöründe, yeni bir üretim sistemi uygulanacak ise, "bilgi" temel alınmalıdır. Diğer yandan gıda güvenliği ve müşteri memnuniyetine odaklanmak gerekir. Altı Sigma yaklaşımının bu geleneği sağlamada yardımcı olabileceği aşikardır. İstatiksel olarak süreçlerdeki performansı iyileştirerek 1 milyon ürün veya serviste 3,4 birim hata oranına ulaşmayı amaçlar. Altı Sigma metodolojisi şirketlerde iyileştirme yolunda kültür değişimini sağlar. Firmalar maliyet giderlerinin belirlenmesi gibi konularda kalite kontrol araçlarını kullanarak ölçümleme yapabilmektedir. Lakin, ölçümlemekte zorlanacakları en önemli husus müşteri memnuniyetidir. Özellikle gıda sektöründe müşteri ihtiyaçları değişkenlik göstereceğinden çoğu zaman ölçümleme yapmak büyük zorlukları beraberinde getirir. Bu hususta, Bulanık Mantık'tan faydalanmak önemli bir girişim olacaktır. Bulanık mantık, klasik mantıkta olduğu gibi kesin sonuçlar vermeyen, verileri varsayımsal ve sonuçları değişkenlik gösteren bir yapay zeka prensibidir. Bu araştırmada, Türkiye'de 5 farklı seçili gıda tesisinde Six Sigma proje değerlendirmesi ile Bulanık Mantık altında en uygun alternative ve method belirlenmiştir.

Anahtar Kelimeler: *Altı Sigma, Altı Sigma Metodolojisi, Bulanık Mantık, Bulanıklık, Gıda Sektörü*

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My parents – For their love and support.

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Chapter 1

Introduction

In new millennium, the toughest question that business world leaders and managers will encounter is not "How can we be successful?" but "How will we preserve our success?". Even many, such as IBM, Apple, Ford and more corporate strongholds are going through dramatic cycles from the threshold of death to the revival. At first, Six Sigma may seem like a proper answer; but when you look closer you can realize the significant difference. Six Sigma is not a temporary excitement that is built over a single method or a strategy; it is a flexible system that aims to improve management ability and performance. (Isıgıcok, E., 2011)

Six sigma is not just a theory, it's an action. Another definition that would be broader is "to effective use of entire employees' knowledge and quantitative methods to evaluate client's needs, organization's basic processes, now and then." Six sigma is a statistically-based quality improvement program and business strategy that used to identify and reduce the variations and defects in the process. Goal is to achieve near-perfection. Most of the companies processes use three or four sigma level, that means the defects are between 6,210 to 66,807 out of one million opportunities; while, Six Sigma represents 3,4 dpmo (defects per million opportunities), which is near-perfection in the process. Six Sigma will be explained below these features;

- What is Six Sigma?
- How and when it appeared?
- How does the process work?
- What are the benefits?

Chapter 2

Literature Overview

The Six Sigma topic started to be practiced by Motorola in early 1980's. In time it had been a method spreading through production to sale, design to service with positive results. Studies of this section which are about Six Sigma are being analyzed. (Atmaca, E., Girenes, S.Ş., 2009)

The Six Sigma which have been used by many leader foundations around the world for the past ten years. Served them in making every process more productive and helped the companies to increase their profit and growth rates. The definition of quality in the terms of Six Sigma is: "Reaching the goals settled by the client and by the supplier in every step of the work". From the perspective of Six Sigma only fitting the clients demands or for another way to say being suitable to the specifications is not enough to make a trade or for making business. In addition specifications must be dealt with minimum outcome. The philosophy made the jump in Japanese industry was Deming's analyzing and minimizing the variations in production processes". And this is the main idea behind the Six Sigma. The miracle-like increase rate of Japanese industry had been the pre-setter of many quality methods in 1980's America. Statistical Process Control, Just-in-time Production and Kaizen are some of these methods. The weakness of these methods was that they couldn't make the bond between clients, process and employees. And they never had been accepted by all. (Atmaca, E., Girenes, S.Ş., 2009)

In those years an engineer of American "Motorola" company moved Mikel Harry was advising Deming's philosophy to the employees and Mikel Harry called his method "Six Sigma". Because that the term of variability is measured with standard deviation and it is shown with "Sigma (upper case Σ , lower case σ)" from Greek alphabet. The main reason of this was that he aimed the level of Six Sigma for every improvement in Motorola. (Blakeslee, J.A., 1999)

The world-wide fame of Six Sigma was provided by General Electric (GE) in second half of 1990's. Six Sigma had been started at General Electric by Jack Welch's (the head director at the time) calling Larry Bossidy (former General Electric director, CEO of Allied Signal) for a presentation and eventually adopting Six Sigma to General Electric. After that the increase on companies' shares referred that Six Sigma was accepted as a really result giving technique.

Six Sigma was first used by Motorola in 1985 and is now being used by General Electric, Allied Signal, Boeing, Sony and alike international foundations. Applications of Six Sigma in General Electric was started by Jack Welch and was integrated to the strategies and the goals of the company by himself. In the year 1997 four hundred million dollars was spent for the educational activities about Six Sigma and 600 million dollars of income was possessed after the Six Sigma projects. General Electric's Six Sigma rate was 3 sigma when they first started to apply these methods in 1995. Then it increased to 3.5 sigma in 22 months. The company's rate is 5.6 sigma for the recent. (Atmaca, E., Girenes, S.Ş., 2009)

Performance appraisements of the employees in General Electric is being done with Six Sigma applications since 1998. An employee cannot be promoted or ascended to administration level unless he or she is educated about Six Sigma. Besides %40 of the yearly premiums given to the administrators in consider of their success about Six Sigma.

Successes achieved with Six Sigma is not only limited with General Electric. Motorola which has been using Six Sigma from the year 1980 had an income of 11 billion dollars in 19 years. Motorola has tripled its world-wide activities. Allied Signal Inc. started to practice Six Sigma in 1991 with 14 billion dollars of capital. And have possessed over 800 million dollars of income in 8 years. This amount is about to be %6 of the total endorsement. (Stamatis, D.H., 2003)

As an example; to be increased from 2 sigma to 3 sigma error rates must 5 times be corrected. But to be increased from 3 sigma to 4 sigma the error rates must be corrected 11 times. Table 2.1 demonstrates the possessed incomes of some companies of which had earned great amounts of money by efficiently implementing Six Sigma.
(Gür, İ.İ., Ağustos 2003)

Company Name	Company Income (US$)	Years
Motorola	2.2 billion	2.6
Allied Signal	1.2 billion	2
GE	2.2 billion	4
Nokia	300 million	2
Sony	100 million	1

Table 2.1 Implementing Six Sigma in above companies and their incomes [2]

As can be regarded from table 2.1 great amounts of profit can be possessed in short terms with the applications of Six Sigma.

Chan and Spedding had used Experimental Design, Response Surface, Nerve Network metamodel approaches in their studies about on-line optimization of the quality level on a production system to reach the Six Sigma quality level. (Chan, K.K., Spedding, T.A., 2001)

D’angelo and Zarbo made a study on constant improvement of quality in service sector. The aim of the study is analyzing the failures and finding out the sources with ways of correction to reach a non-failure system. (D’angelo, R., Zarbo, R.J., 2007)

Linderman and his friends examined Six Sigma from target theory perspective. They examined two approaches together emphasizing that Six Sigma is usually using open targets to augment its performance. ‘Target Theory’ determines which targets could be reached easily or cannot be reached under which circumstances.

As an example; target theory states that clearly fixed and measured goals are giving better results than fuzzy or ‘do-best’ goals.
Furthermore target theory has been ranked ‘very well’ in comparison to other methods for its validity and for being useful. (Linderman, K., Schroeder, R.G., Zaheer, S., Choo, A.S., 2003)

The first company practiced Six Sigma in food sector is Dupont. In conclusion of the Six Sigma applications 1100 employees had been trained for Black Belt. 34 hundred improvement projects had been accomplished. As a result of all these projects the possessed profit was declared as 700 million dollars. (Standart Merkezi)

It can be noticed that different techniques have been applied by the researchers during the studies. In conclusion it can be said that, Six Sigma methodology is used both by the sectors and by the companies on an increasing rate.

Chapter 3

Six Sigma

3.1. History of Six Sigma

Lately 18th century in Europe, the roots of Six Sigma can be traced back to Carl Frederick Gauss who presented the concept of the normal curve, after then, the implementation of Six Sigma started in 1920’s to eliminate defects and to optimize the production in process when Walter Shewhart (who shares the leadership of this work with W. Edward Deming, Joseph Juran) demonstrated that 3 sigma from mean is the point where corrections appear in process. (Zhen, Y., 2011)

However, the real Six Sigma concept was introduced by engineer Bill Smith of the Motorola Corporation in 1986. It is a business strategy and Motorola was the first transnational corporation to put into effect this initiative. In early 1970s, Motorola was the leader of the wireless communications products, however raising of Japanese manufacturers technology obligate the conditions of the market, especially Motorola found itself not capable enough to compete. Under leadership of CEO Bob Galvin, a growth enterprise was begun. The words of deputy chairman were explain this situation: “Our quality stinks.” Therefore, in 1984 Motorola Manufacturing Institute (MMI) was set up and started the education programs. The priority satisfaction of that management was “Design for Manufacturability” (DFM). All technical personnel used for “Six Steps to Six Sigma” training programs worldwide. (Doğu, E., 2006)

Craig Fullerton, a Motorola engineer, developed and taught “Six Sigma Design Methodology” (SSDM - called Design for Six Sigma (DFSS) today)

First was only focusing on the manufacturing function which was not convenient to find out the major sources of the problem called 10X quality improvement; after training programs, 10X to 100X improvement was espoused which led Motorola's managers to set more aggressive goal in order to success with Six Sigma business strategy. In 1988, the efforts came up with result in Motorola accepting the first award which is Malcolm Bridge National Quality Award.

Motorola was striving to reach Six Sigma in every department of the organization, however, it seemed to be stuck at 5,4 sigma (Barney & McCarty, 2003) But then, Motorola implement Six Sigma successfully, moreover, Motorola takes this business strategy further. Motorola saved over $20 billion dollars since 1986 with implementing this management strategy which stated goal of reducing defects and cost of the production to a remarkable level that contributes reputational and financial benefits to the organization and the Return on Investment has been between 10:1 to 50:1 (Motorola University, 2008).

Thus, Six Sigma success story in Motorola inspired quite a few companies in several industrial sectors to espouse Six Sigma. General electric, AlliedSignal/Honeywell, Sony and Motorola have caused to notice of Wall Street and published the use of this business strategy (George, M.L., 2002)

Jack Welch who is the CEO of General Electric(GE) applied the techniques in GE in 1995. And within five years of the implementation, GE accomplished and returned profit of $10 billion (Six Sigma, 2011). But most companies today function at only 3 to 4 sigma and lose 10-15% of their total revenue due to defects. At 4 sigma (or 99% perfect), this still means 6,210 defects per million opportunities. (Innovation Consultancy Partnership Ltd.)

GE, also first began with a level of 3 Sigma, thereafter just in 22 months it is reached the level of 3,5 sigma. Today, GE implements 5,6 sigma. Allied Signal was handling Total Quality Management (TQM) system before 1994, then the organization switched to Six Sigma. Allied Signal had saved 500 million dollar in 1998, this amount raised to 600 million dollar Six sigma approach is more than TQM and it's a way of doing business. Six Sigma, "Statistical Programme Committee (SPC) and

TQM in Manufacturing and Services” which is Geoff Tennant’s book is described “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.” (Konak, M. M., Duman,E., Albayrak, F., 2004)

3.2. Six Sigma Philosophy and Methodology

The facts and the data can be managed with Six Sigma which idea is given in Eckes (2001)’s study. “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 implementation of the statistical method to the design and operation of the business processes and management systems while minimizing the sources and waste of cost and time, it provides the greatest value of the products or services to owners and customers and maximizes the profit of the organization. (Doğu, E., 2006)

Six Sigma leads to do less defects from production to delivery in every part of the organization. TQM systems aim to catch and correct the defects in commercial, industry and design sectors while Six Sigma typically has the aim of produce services or productions near-perfection, that is not even occur any defects to improve the specific method in process.

The Six Sigma philosophy focuses the attention of everyone on the partners for whom the enterprise exists. It is a cause-and-effect mentality. Well-designed business strategy and management program ran by happy employees and it causes satisfaction of customers and owners. Six Sigma improvement techniques and tools are effective, sound and principled. (Doğu, E., 2006)

Organizations provide training for the employees to take part of this improvement with certain roles and belts in Six Sigma application. Six Sigma philosophy requires strong leadership and foot soldiers to succeed the implementation.

A methodology is a leading system for solving a problem, with specific components such as phases, tasks, methods, techniques and tools. (Wikipedia)

The most common approach to Six Sigma methodology is DMAIC, which is universally known and defined as including these following five phases; Define, Measure, Analyze, Improve, Control.

DMAIC tools are used to remove problems or defects, as the causes of problems are found, begin a process which does not occur that situations further productions or services.

3.2.1. DMAIC Methodology

The DMAIC methodology specify as follows;

Define Phase: Define the problems in your business project. Then identify the goal of the project and the internal / external customers.

Measure Phase: Measure the size of the problem and determine the current efficiency by using statistical data.

Analyze Phase: Analyze and determine the causes of the problem or defects by using the collected data.

Improve Phase: Improve the process with advanced statistical techniques and eliminate the causes of the defects.

Control Phase: Control the further process to ensure it stays fixed. (Esposto, F., Master Black Belt)

The DMAIC's tools are as follows;

Define Phase Tools; Project Charter, Stakeholder Assessment, Pareto Charts, SIPOC, VOC/VOB & CTQ's, High Level Process Map

Measure Phase Tools; Any Appropriate Tool from Previous Phase, Process Maps, Value Stream Mapping, Failure Modes & Effects Analysis (FMEA), Cause & Effect Diagram, XY Matrix, Basic Control Charts, Six Sigma Statistics (Basic Statistics, Descriptive Statistics, Normal Distributions, Graphical Analysis), Measurement Systems Analysis, Process Capability (Cpk, Ppk) & Sigma, Data Collection Plan

Analyze Phase Tools; Any Appropriate Tool from Previous Phase, Hypothesis Testing, Simple Linear Regression, Multiple Regression

Improve Phase Tools; Any Appropriate Tool from Previous Phase, Design of Experiment (DOE), Implementation Plan, Change Plan, Communication Plan

Control Phase Tools: Control Plan, Training Plans, Poka-Yoke and/or Audit Plans, Translation Plan - How can this be translated to others
(Six Sigma Digest, 2011)

The Six Sigma methodology can be summarized by using a roadmap in below Table 3.1;

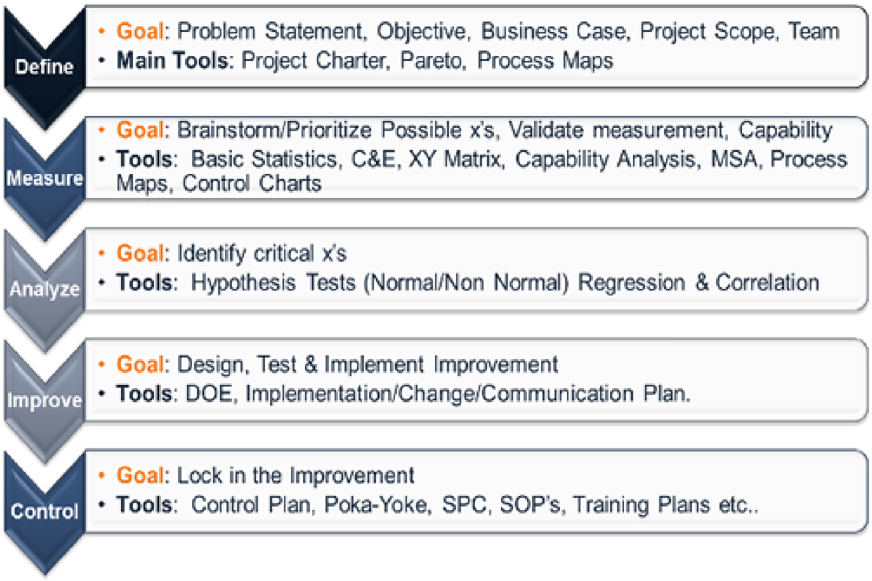

Table 3.1 Summary of the Six Sigma methodology [17]

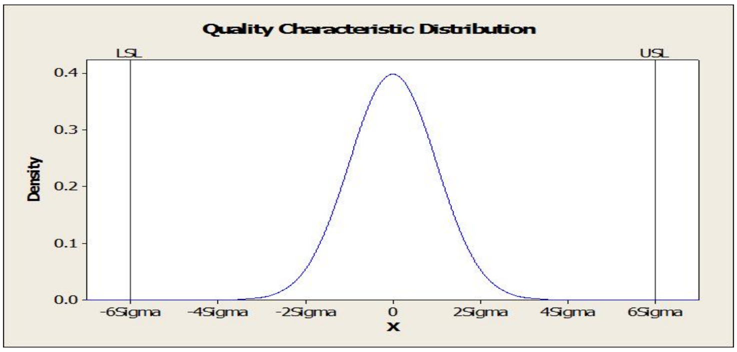

Chart 3.1 Quality Characteristic Distribution [19]

Organization must determine the requirements for project and use statistical tools for applications, such as SPC (Statistical Process Control), QFD (Quality Function Deployment) and many others to meet the customer expectations.

3.2.2. DFSS or DMADV Methodology

DFSS ("Design for Six Sigma") is another project methodology that is used to design or redesign a service or a product beginning to the end of the process which is also commonly known as The DMADV features five phases:

- Define; define the project goals that are met the customer deliverables.
- Measure; specify the customer expectations (CTQs (characteristics that are Critical To Quality)) and benchmark the other competing companies and industry also identify product capabilities, production process capability, and risks.
- Analyze; examine process alternatives, select the best design and meet the customer requirements.
- Design; detailed the process options, optimize the design to meet customer demands.
- Verify; design to ensure if it meets customer demands.

(Esposto, F., Master Black Belt)

3.2.3. Six Sigma Training Methods

The nature of Six Sigma has different components from the other methodologies.

There are 10 distinct roles to achieve Six Sigma in an organization which may overlap to employees.

The Six Sigma hierarchy is influenced from Japanese martial of karate which are as follows;

- Executive Management
- Senior Champion
- Deployment Champion
- Project Champion
- Deployment Master Black Belts
- Project Master Black Belts
- A Project Belt
- Process Owners
- Green Belts
- Team members (Yellow Belts)

Organization’s Roles and Belts can be defined item by item as follows;

Executive management;

- Has the highest level of technical and organizational skills.
- Responsibilities in strategic implementations
- Commits money and manpower to an improvement project.

Champion;

- Identifies resources and remove impediments.
- Translates the company’s vision, mission, goals and metrics to build an organizational system and deployment plan. (American Society for Quality)

Master Black Belt;

- Leads and trains Black Belts and Green Belts throughout Six Sigma projects.
- Has advanced statistical tools with brainstorming and teaching others.
- Work full-time experts who has specialized skills and experiences to deploy Six Sigma methodology.

Black Belt;

- Works full-time for the execution of Six Sigma projects.
- Leads problem-solving projects through from beginning to end.
- Trains Green Belts and Project Team members to achieve their goals.

Green Belt;

- Working on projects and using the Six Sigma methods in daily jobs.
- Learning how to use statistical analysis.
- Calculates formulas and gather data.
- Leads smaller scale of projects in its respective area.
- Generally, Green Belts exceed the number of Black Belts.

Yellow Belt;

- Takes part as a project team member.
- Supports the project through implementation of the Six Sigma concept.

White Belt;

- Works on local problem-solving teams that support overall projects. (generally understands the basic Six Sigma methodology and may not be part of a Six Sigma project team.) (Aveta Business Institute, Six Sigma Online)

3.3. What is Sigma?

Sigma is the 18th letter of Greek alphabet (upper case Σ , lower case σ) that imply the standard deviation from a statistical population or a sample. The higher sigma level, the less defects exist.

"What is Standard Deviation?"

Sigma is a measure of variation which takes place in statistical science literature that terms the standard deviation and so, the standard deviation is a measure of how spread out numbers are. The formulation is simple. It's the square root of Variance.

"What is Variance?"

Variance is defined as; the average of the squared differences from the Mean. Mean is the average of a population or a sample.

When your data is the whole population the formula is:

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \mu)^2}$$

When your data is a sample the formula is:

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - x)^2}$$

Formulas are given for short below;

$$\mu = \frac{\sum_{i=1}^{N} X_i}{N} \qquad X = \frac{\sum_{i=1}^{n} X_i}{N}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (X_i - \mu)^2}{N}} \qquad \sigma = s = \sqrt{\frac{\sum_{i=1}^{n} (X_i - X)^2}{N-1}}$$

(**N-1**: size of the sample data set, **N**: size of the population data set, **σ**: population standard deviation, **S**: sample standard deviation, $\boldsymbol{X_i}$: the population / the sample data set, **X**: mean value of the sample data set , **μ**: mean of the population data set)

3.3.1. Relation between Sigma and Six Sigma

Sigma (σ) is a measure of variability on the other hand, Six Sigma (6σ) is the targeted measure of variability. From average of process or from average of business results to 6σ left-side and to 6σ right-side gives the range of symmetric 12σ in short-term process level.

On the other hand, from average of process or from average of business results to 4,5σ left-side and to 6σ right-side or to 4,5σ right-side and to 6σ left-side express the range of the asymmetric 10,5σ in long-term sigma level.

3.3.1.1. Process Capability Analysis

"The Process Capability is a measurable property of a process to the specification, expressed as a process capability index (C_{pk})." (Wikipedia)

Companies have to provide the customer specification limits in production to win through the competitive business world. Hence, managements generate products which are supply the customer expectations in that specification limits for desired quality level. (Senvar, O., Tozan, H., 2010)

The level of the process specifications can be determined Normal and Non-normal distributions with process capability indexes. (Upper specification limits shown as 'USL' and lower specification limits shown as 'LSL'.)

The form of Process Capability for continuous data is known as C_p;

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

The P_p rate is as follows which is similar to the C_p calculation;
(s: standard deviation of all data.)

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

Solely, C_p analyze the spread of the process. The value of C_p required to be greater than 1; however, C_p is suggested to be greater and equal to 1.33 ($Cp \geq 1.33$), based on 99.73% of data points spread between ±3 standard deviations in any normally distributed data. Additionally, the sample number is proper at least 50 for reliable results.

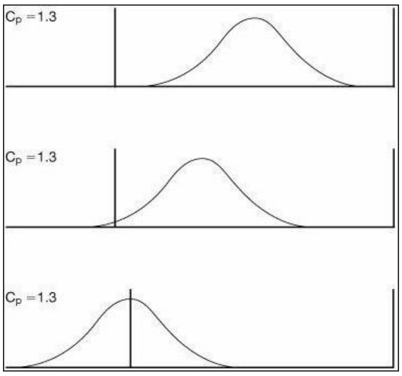

Chart 3.2 3 graphs with same C_p in different process centering [23]

In spite of that the process spread level is defined by C_p, it does not obtain any data about forming the targeted value level in process. In this case, C_{pk} is defined as the average value of the function.

The form of Process Capability Index is known as $C_{pk;}$

$$C_{pk} = \ Min \ \ \frac{X - \ LSL}{3s}, \frac{USL - X}{3s}$$

(P_{pk} is presented with the similar calculation of C_{pk}.)

C_{pk} is positive when the mean of the process is inside the specification limits. It drops to zero as the mean hits the USL or LSL.

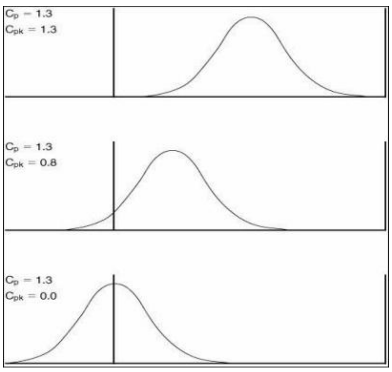

Chart 3.3 Specification Limits in 3 different way [23]

Six Sigma quality level can be explained with two perspectives of process capability; which are short-term process capability and long-term process capability.

Short-term process capability; an item or a part (denoted by X) is classified as defective if the targeted measurement is outside the lower specification limit (LSL) or the upper specification limit (USL). Additionally, specifying the LSL and USL, a customer would also indicate a target value, which is the midpoint between the LSL and USL. In various sigma levels, a six sigma process that generates the parts is normally distributed in short-term process capability. (see Table 3.2 and Chart 3.4)

Sigma Level	% Good	PPM/DPMO
2	95.45	45500
3	99.73	2700
4	99.9937	63
5	99.999943	0.57
6	99.9999998	0.002

Table 3.2 Short-Term Process Capability at Various Sigma Quality Levels [24]

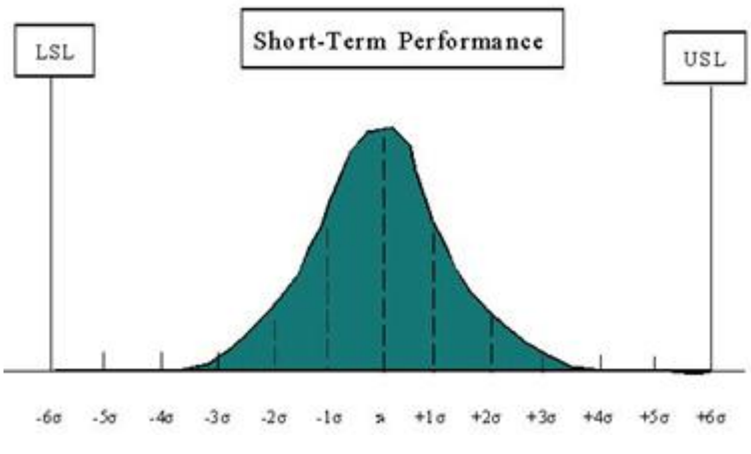

Chart 3.4 Short-Term Six Sigma Performance for a Single Process [24]

Long-term process capability: The capability of the process includes all over a period of time that is long enough to all probable sources of regular cause variation. SPC is used to collect and plot data through the long-term work and as in the short-term work, if special cause of variation existed the study is stopped and the source of variation is eliminated.

The long-term study is to determine if the process is able to meet internal or external customer requirements. ‘Internal customer requirements would be the requirements for the next process while external requirements would be those product characteristics that would affect the performance of the end item or customer use product.’ (Malphrus, J., 2010)

Long-term process capability in various sigma levels. (see Chart 3.5and Table 3.3)

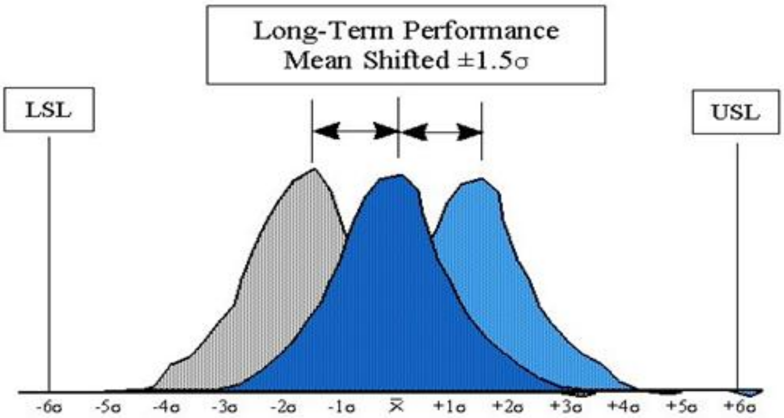

Chart 3.5 Long-Term Six Sigma Performance
for a Single Process (Shifted 1.5σ) [24]

Sigma Level	% Good	PPM/DPMO
2	69.15	308,537
3	93.32	66,807
4	99.379	6,210
5	99.9676	233
6	99.99966	3.4

Table 3.3 Long-Term Process Capability in Various sigma Levels [24]

3.4. What is Six Sigma?

The term six sigma is a business strategy which is a measure of defects level and statistical variations. Six sigma can be defined statistically as less than 3,4 defects per million products or services (pmo: per million opportunities=3,4) or it can be defined less than 34 defects per 10 million opportunities as well.

Plus or minus 6 standard deviations from the mean; said simply: near perfection. (DPMO: Defects per million opportunities = 3,4) Six Sigma approach uses ‘defects per unit (DPU) as a measurement tool. DPU is the best way of measure the quality of the process or product. Customer satisfaction increases and cost and cycle time decreases while Six Sigma level gets higher. ‘Most companies today function at only 3 to 4 sigma and lose 10-15% of their total revenue due to defects. At 4 sigma (or 99% correct), this still means 6,210 defects per million opportunities.’ (Konak, M.M., Duman, E., Albayrak, Fatma, 2004)

The table below shows effects of different Sigma Levels;

Sigma Level	Defects per million opportunities (DPMO/ppm)	Ratio of Efficiency/ Success Rate (%)	Defect Rate (%)	Cost of Quality (%)
1 σ	691.462	30,8538	69,1462	>40
2σ	308.538	66,1462	30,8538	30-40
3σ	66.807	93,3193	6,6807	20-30
4σ	6.210	99,3790	0,6210	15-20
5σ	233	99,9767	0,0233	10-15
6σ	3,4	99,99966	0,00034	<10

Table 3.4 Relation between ‘Defect rate or Success Rate’ and ‘Six Sigma Level’[1]

The figure below also shows the different variations of plus/minus Six Sigma;

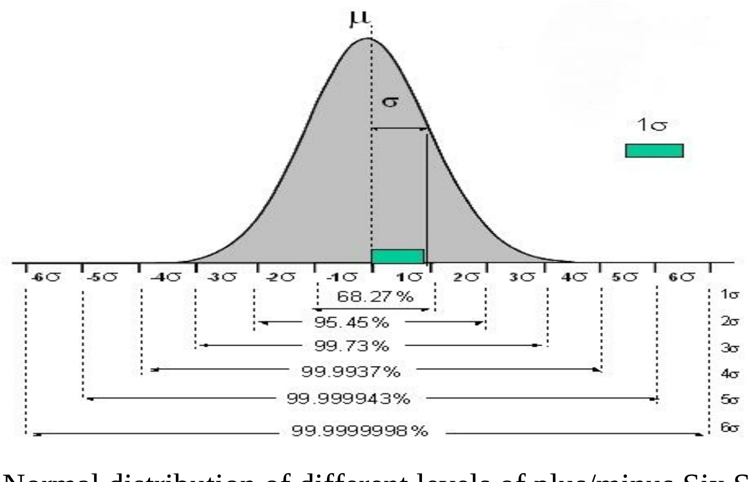

Chart 3.6 Normal distribution of different levels of plus/minus Six Sigma [14]

Six sigma is a result-oriented approach business that focuses on continual or non-stop improvement and the most effective tool to reach total quality management and the perfection model. It's an entirely evolution of the culture where is applied in an organization. Six sigma is a comprehensive and flexible system to catch, maintain and reach maximum level in business. Unique mechanism running Six Sigma consists of understanding customer needs deeply; using facts, datas and statistical analysis within a discipline; managing, enhancing and rediscovering work processes. (Pande, Peter S., Neuman, Robert P., Cavanagh, Roland R., 2000)

3.4.1. A brief comparison of 3,8 Sigma and 6 Sigma level

A conventional 3,8 sigma implemented company can't stand on other competitive companies due to less quality and that cannot meet customer demands. Quality problems can be solved with tests and searches. After all there can be seen decreasing of defects, however, the cost of process increases inherently. Thus, it affects the sales price as well as the quality. High sales price with variation quality decreases the customer satisfaction. As a result company's profit goes down. (Isıgıcok, E., 2011)

3,8 Sigma is used to determine the state of a process while 6 Sigma generates a methodology to achieve targets for quality outcomes. Table below demonstrate that '%99 good' actually not enough to define the products or services are good.

3,8 Sigma (%99 good)	**6 Sigma (% 99,99966 good)**
20.000 missing post per hour	7 missing post per hour
5.000 failed surgery per week	1,7 failed surgery per week
Each year 200000 prescription is written wrong	Each year 68 prescription is written wrong
Approximately 7 hour electricity-cut per month	Approximately 1 hour electricity-cut once every 34 years
2 failed landing to a major airport per day	1 failed landing to a major airport once every 5 years

Table 3.5 The effects of comparison 3,8 Sigma and 6 Sigma [1]

3.4.2. Advantages and Disadvantages of Six Sigma

Advantages of Six Sigma;

Six Sigma is a business strategy and a new culture in organizations, that is implemented successfully in all line of business such as production, design, sales marketing, services; can be defined with some major advantages such as below;

- Reduces waste steps related to poor quality,
- Reduces the cost of product and production to %10-25 and %10-40, respectively, (Motorola publishes it has "documented over $17 billion in savings" in over 20 years of using Six Sigma.)
- Specify the value of customer expectations,
- Improves the quality by reducing defects in goods produced that meet customer requirements which secure the customer driven strategy.
- Enlarges the market share and improves the quality of performance in distribution,
- Reducing the cycle time of production,
- Settling proactive approach rather than reactive.
- Improving production and settling the new business culture. (Pande, Peter S., Neuman, Robert P., Cavanagh, Roland R., 2000), (Konak, M.M., Duman, E., Albayrak, Fatma, 2004), (Hung, H.C., Sung, M.H., 2011)

Disadvantages of Six Sigma;

Below it is seen this management strategy includes few disadvantages as well;

Features; The method of analyzing and combining the data can be a disadvantage because of the complexity of Six Sigma's profitable features. Key people in the rating process must attain what the tools mean and how to make improvements with these tools and reduce defects in a product or service.

Time Frame; the time and attention necessary for the process can be a disadvantage. Gathering the data is involved time, key people needs training in the process. Number of products may have ordered for the deadline. Thence, the time and attention necessary for the process can be a disadvantage.

Personnel Considerations; Six Sigma uses the conception of martial arts to assign the level of training a person has with the system. "green belt" training which is one of the first levels of six sigma and then "black belts" or "master black belts." Unfortunately, Six Sigma training used for only just a few people in an organization.

Data Considerations; The company may have some data, such as a number of customers. However, the companies may not have data on customer satisfaction. Also the company may not have efficient information to know why it is losing customers. The Six Sigma process can provide the data; however, it might not be fast enough to help a company, especially if gathering the data has extra related costs.

Complexity Considerations; Six Sigma is not just complex for untrained people to understand, the system itself may be too complex for some improvements. The tools of Six Sigma to gather data on such things as how many times managers use the form in a month, or how many people handle the forms, may involve too much data gathering for the problem. Determining the proper projects for Six Sigma can be a disadvantage. (eHow, Demand Media Inc., 1999)

Chapter 4

Six Sigma Approach under Fuzziness

Six Sigma is a business strategy and management system which culture should be espoused as philosophy in a company in all levels of hierarchy. Otherwise, this management strategy will not be succeeded. According to this philosophy, priorities of Six Sigma must be considered. The most important application of this concept is to meet the customer requirements successfully. All employers must have extensive knowledge and employees must be trained about this methodology.

This cultural change should first of all meet customer needs and to reduce the cost of production with the purpose of maximizing the profit. Thus, this implementation carries company to brandization.

Also applying this method arranges the time management that increases the efficiency of employees.

Six Sigma methodologies can be applied in all fields of industry. However, very few companies use Six Sigma methodology because implementation takes time and causes high initial costs.

By any means, Six Sigma determined "near-perfection" in statistical science.

Fuzzy Logic is an artificial intelligence principle. Its purpose is to correcting inconsistencies during customer satisfaction measurement by using linguistic variables.

In this practice Six Sigma philosophy under Fuzzy Logic is used with triangular membership function.

4.1. Fuzzy Logic

The founder of the Fuzzy Logic, Lotfi Askar Zadeh was born in Bakü, in 1921 who better known as “Zadeh” discovered and published his revolutionary article “Fuzzy Sets” in “Information and Control” scientific journal while he was working at Berkeley University in “Electrical Engineering and Electronics Research Laboratory” in 1965. This revolution is not only going to be used in the field of application in technology but also it involved philosophic comments and bring a new perspective in logic and physic world. (Ural, S., 2004)

Regarding to Lotfi Askar Zadeh’s researches about the fuzzy logic, it comprise especially three features, as follows; (McNeill, D., Freiberger, P., 1994):

1) Fuzzy logic’s truth values are linguistic variables; not in numerological terms.

2) These linguistic variables are just as; too right, quite right, too wrong etc. Fuzzy logic’s truth tables do not include the certainty. Fuzziness is a multi-valued logic (0-1 oriented decisions)

3) Fuzzy Logic do not give validity of the implication rules.

(Ural, S., 2004)

4.1.1. Differences between Classical Logic And Fuzzy Logic

Classical and Fuzzy Logics can set a part in certain features which is briefly shown in tableau below;

Classical Logic	Fuzzy Logic
A or Not A	A and Not A
Certain	Partial
All or None	Varying degrees
0 or 1	Range from 0 and1 (in consistency)
Dual sets	Fuzzy sets

Table 4.1 Differences between Classical Logic and Fuzzy Logic [31]

4.1.2. Advantages and Disadvantages of Fuzzy Logic

Advantages of Fuzzy Logic;

- Fuzzy Logic brings simple solutions to uncertain, time-varying, complex, ill-defined systems in audits as in daily life. It analyses systems better than conventional logic as well, which is also economic.
- If the system is defined as a mathematical model than a conventional audit would be suited, but it's either difficult to apply or cost much in a conventional logic to complex system.
- In Fuzzy Logic fuzzy audit can be resulted sooner with a small program due to reduction of membership functions from extensive values.
- Results can be found faster just because of the few rules which is applied on a few values in a program.
- Fuzzy Logic audit also directly provides the users to take advantages of their inputs and experiences. (Yaralioglu, K., 2007)

Disadvantages of Fuzzy Logic;

Fuzzy logic quite depends on the rules that applied in audit.

- There is no certain method to choose the membership of functions.
- Optimum function can be found with several tests and it takes times.
- Consistency analysis cannot be performed for a system that is being audited and it cannot be determined in advance how system will respond. The only thing to do is performing simulation study. (Yaralioglu, K., 2007)

4.1.3. Fuzzy Sets and Membership Functions

Fuzzy Logic is built on Neighborhood of Numbers philosophy. During decision process if a status is defined by a number then acceptability of that status is fulfilled by realization of relevant number but numbers proximate to the desired one will not be perceived as a part of decision process. However in a confidence coefficient suggesting these numbers are members of different populations will be a statistical error. For example if temperature of a component that is being processed at a workbench reaching 39 ^{0}C leads to maintenance of the workbench, it is possible that temperature reaching 36 ^{0}C can also be accepted as a prerequisite for starting the same maintenance process. In this condition it is possible to mention proximity of numbers serving to same purposes. (Yaralioglu, K., 2007)

If A in $R \in (-\infty, +\infty)$, and the unit of the set is $\mu_A(x)$ then the membership function is set between;

$R \rightarrow [0,1]$.

In other words, A set is between $A = [a_1, a_3]$.

$\mu_A(x)$ membership function can be shown in Figure (1) as follows;

$$\mu_A(x) = \begin{cases} 0 & , \quad x < a_1 \\ 1 & , \quad a_1 \leq x \leq a_3 \\ 0 & , \quad x > a_3 \end{cases} \qquad (1)$$

Generally membership of functions can be analyzed, in 2 different under the same heading; (see chart 4.1)

1. Triangular-shaped membership function
2. Trapezoidal-shaped membership function

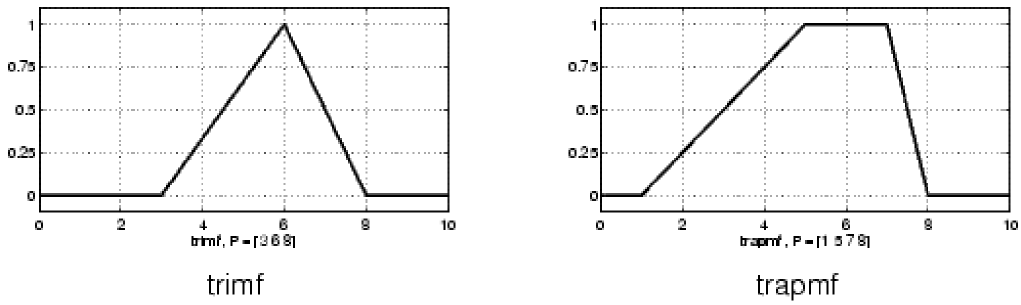

Chart 4.1 Triangular and Trapezoidal Membership Functions [32]

$\mu_A(x)$ Triangular-shaped membership function is shown in Figure (2) as follows;

$$\mu_A(x) = \begin{cases} 0 & , \quad x < a_1 \\ \frac{x - a_1}{a_2 - a_1} & , \quad a_1 \leq x \leq a_2 \\ \frac{a_3 - x}{a_3 - a_2} & , \quad a_2 \leq x \leq a_3 \\ 0 & , \quad x > a_3 \end{cases} \qquad (2)$$

With this formulation A set is defined, $A = (a_1, a_2, a_3)$.

a_2 can be defined membership of normal value.

At this point, Fuzzy Logic assumes that depending on coefficient of α , values close to a_2 will be represented by assigning a meaning to this value. In other words uncertainty at a_2 can be tolerated by coefficient of α which will be assumed or determined due to distribution.

Neighborhood which is shown as follows below chart 4.2; (Lootsma, 1997)

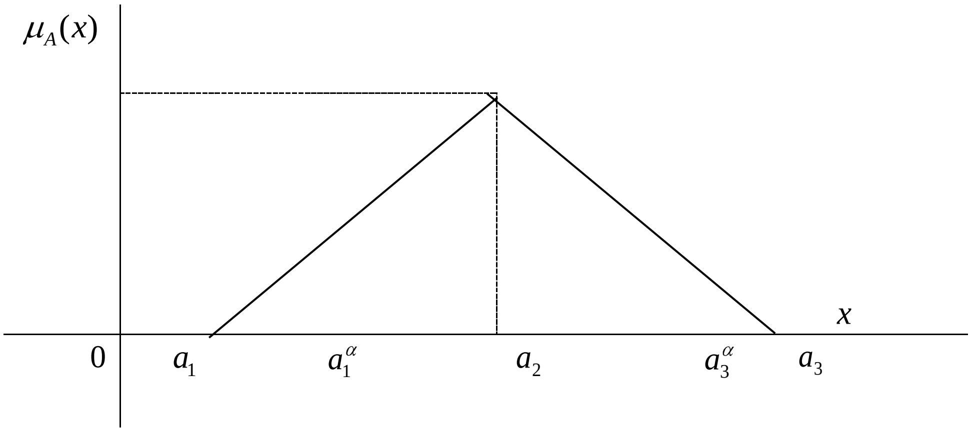

Chart 4.2 The Neighborhood diagram of the Membership Function [31]

α value is defined as shear coefficient in fuzzy logic terminology. a_1^α and a_3^α numbers are maximum and minimum threshold values of forming normal value neighborhood for a_2. In other words, all numbers between a_1^α and a_3^α range have the same meaning with normal value of a_2. Values of a_1^α and a_3^α can be determined by equations (3) and (4) (Terano, 1997), (Yaralioglu, K., 2007)

$$\frac{a_1^\alpha - a_1}{a_2 - a_1} = \alpha \qquad (3)$$

$$\frac{a_3 - a_3^\alpha}{a_3 - a_2} = \alpha \qquad (4)$$

From equations (3) and (4) for $\forall\, \alpha \in [0,1]$ $A\alpha = [a_1^\alpha, a_3^\alpha]$ range can be generated. a_1^α and a_3^α values are shown in equations (5) and (6)

$$a_1^\alpha = \alpha\,(a_2 - a_1) + a_1 \qquad (5)$$

$$a_3^\alpha = a_3 - (a_3 - a_2)\alpha \qquad (6)$$

For instance if number set regarding triangular fuzzy logic is A = (-5,-1, 1) then in this situation membership function can be found from equation (2),

$$\mu_A(x) = \begin{cases} 0, x < -5 \\ \frac{x+5}{4}, -5 \leq x \leq -1 \\ \frac{1-x}{2}, -1 \leq x \leq 1 \\ 0, \quad x > 1 \end{cases}$$

If decision maker determines α sector parameter as 0,5 neighbors of -1 nominal value can be obtained by equations (5) and (6) as $a_1^{0,5}$ = -3 and $a_3^{0,5}$ = 0 In other words number set range is [-3,0] on the same significance level with -1 normal value. Relevant relationship is presented at Chart 4.3. [31]

If there are two values present which is accepted as normal in the set regarding fuzzy logic numbers , in other words if set consists of 4 identifier values like A = (a_1, a_2, a_3, a_4) in this case membership function will be formed as irregular membership function. Irregular membership function is shown at equation (7)

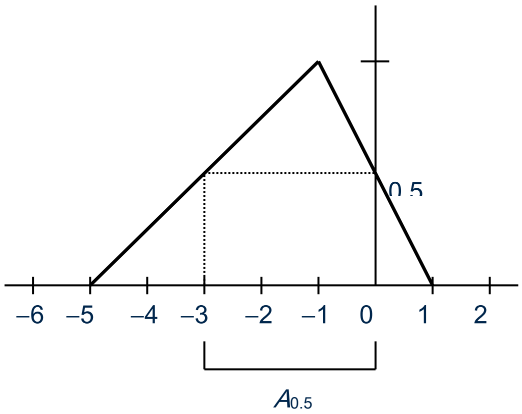

Chart 4.3 Neighborhoods of the example's A set in (-5,-1, 1)

$$\mu_A(x) = \begin{cases} 0, & x < a_1 \\ \frac{x-a_1}{a_2-a_1}, & a_1 \leq x \leq a_2 \\ 1, & a_2 \leq x \leq a_3 \\ \frac{a_4-x}{a_4-a_3}, & a_3 \leq x \leq a_4 \\ 0, & x > a_4 \end{cases} \quad (7)$$

Subjected neighborhood will be occurred as Chart 4.4

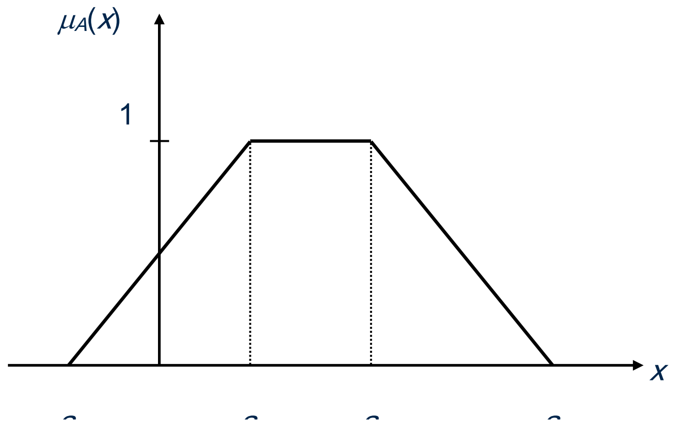

Chart 4.4 Irregular Number Neighbourhood [31]

4.1.4. Application Areas of Fuzzy Logic

Fuzzy logic can find application area at almost every scope, especially used commonly at industrial area. Japanese applied fuzzy logic especially to dish washers, washing machines, vacuum cleaners and video cameras.

Fuzzy logic applications are initially used at cement sector. In this sector limestone and clay react at temperature between 1000-1400 °C. Heat in oven and oxygen ratio directly affects quality of cement. Operators who are specialized in this subject can only produce products with in desired limits. But at a system working in shifts there are large numbers of operators and because each operator has different area of expertise, products are obtained at different qualities and efficiency.

Products at desired quality can only be supplied by experts who are working in this business for many years. Because cement production has fuzzy structure, process control is maintained by fuzzy rules. For instance it is not maintained by accurate rules like raise the temperature 10 ºC or lower by 5ºC instead fuzzy expressions like raise a little or lower it slightly are used. A Denmark company has produced a micro-controller with reference to 50-60 rules which expert operators using to control this process and as a result they achieved constant product quality and fuel savings.
(Yaralioglu, K., 2007)
There are some examples provided about practical use of fuzzy logic at Table 4.2.

PRODUCT	COMPANY	FUNCTION OF FUZZY LOGIC
Elevator Controlling	Fujitec –Toshiba Mitsubishi Hitachi	Reduces waiting time by analyzing passenger traffic.
SLR Camera	Sanyo –Fisher Canon Minolta	Determines the best focus and lightning if there are multiple objects on visor.
Video Record Camera	Panasonic	Removes the shake effect during recording caused by holding device at hand.
Washing Machine	Matsushita	Determines washing program by sensing contamination, load and fabric type of laundry.
Vacuum Cleaner	Matsushita	Adjusts optimum suction power by sensing dirt status and type of floor.
Water Heater	Matsushita	Adjusts heating in compliance with amount and desired temprature of water
Air Conditioner	Mitsubishi	Configures the optimum working settings by analyzing the environment conditions and enhances cooling if a person entres the room.
ABS (Anti-lock Brake System)	Nissan	Provides braking withoud locking the wheels.
Steel Industry	Nippon Steel	Replaces the traditional controllers.

Sendai Subway System	Hitachi	Provides comfortable transportation by configuring acceleration and deceleration, also makes power consumption by arranging the optimum position.
Cement Industry	Mitsubishi Chem	Performs heat and oxygen ratio control at mill.
Television	Sony	Configures screen brightness,contrast and color.
Handheld Computers	Sony	Enables command and data inputs by handwriting.

Table 4.2 Applications in Fuzzy Audit [31]

An Example;

A career placement exam is performed twice in a year that final grade is 65. Candidates have to succeed this exam to pass onto higher levels. There are 100 questions present in the exam and each question has value of 1, 25 points. Candidates have infinite chances to attend the exam.

However when exam commission evaluated former exam results, it is determined that below 65 points only results proximate to this are accumulated. Exam commission wants so design a new and flexible exam system which lowers this accumulation and provides fair exams. Exam commission decided that fuzzy logic can provide solution for the problem as result of preliminary research conducted about decision techniques. Because for exam commission there is not any statistical differences in meaning, between 65 points and points too close or below 65. Exam commission determined 65 points as normal value and in (0,65,100) fuzzy set below membership function is generated. (Yaralioglu, K., 2007)

$$\mu A\,(x) = \begin{cases} 0, & x < 0 \\ \frac{x-0}{65-0}, & 0 \leq x \leq 65 \\ \frac{100-x}{100-65}, & 65 \leq x \leq 100 \\ 0, & x > 100 \end{cases}$$

In this function a_1= 0, a_2= 65 and a_3= 100 values are presumed and below formulas are obtained for 65 normal value.

$$a_1^{\alpha} = 65.\alpha$$

$$a_3^{\alpha} = 100 - 35.\alpha$$

Exam commission obtained below table when neighborhoods of 65 normal value are calculated with the assist of these formulas for different α coefficients.

α	Neighborhood of Normal Value 65	Corrected Interval
0,99	64.350 – 65.350	63.750 – 66.250
0,97	63.050 – 66.050	62.500 – 66.250
0,95	61.750 – 66.750	61.250 – 67.500
0,94	61.100 – 67.100	61.250 – 67.500
0,93	60.450 – 67.450	60.000 – 67.500
0,90	58.500 – 68.500	58.750 – 68.750
0,88	57.200 – 69.200	57.500 – 70.000
0,85	55.250 – 70.250	56.250 – 70.000
0,80	52.000 – 72.000	52.500 – 72.500

Table 4.3 Calculations of the exam commission from an example of Fuzzy Logic [31]

In calculations, neighborhoods acquired for different α coefficients are shown in second column of the table, corrected intervals for situation increase in points are 1,25 are shown in third column of the table. (Yaralioglu, K.,2007)

Exam commission surmised that at examinations achieved using this table, proper α interval coefficient can be selected in accordance with accumulation area extent around 65 points and by this way accumulation can be prevented and exams will be fair.

4.1.5. Fuzzy Six Sigma Project Selection in Food Industry

Fuzzy Logic is an artificial intelligence principle. Its purpose is to correcting inconsistencies during customer satisfaction measurement by using linguistic variables.

In this case study Six Sigma philosophy under Fuzzy Logic is used with triangular membership function.

In this research, most suitable alternatives are determined by Six Sigma approach under Fuzzy Logic for 5 different selected food facilities in Turkey.

The steps of our methodology are as follows:

- Calculation of criteria weights
- Ranking Alternatives

4.1.5.1. Calculation of criteria weights

Triangular fuzzy number for criteria "i" that is reviewed by expert E_k is assigned as S_{ik}. Each triangular fuzzy number points out a choice which is supplied by an expert due to subjective criteria and available data. Concerning criteria "i", it can be accepted S_i^* , i = 1,2,...,n as the fuzzy aggregated score. S_i^* value is calculated with help of Eq. (8) where the fuzzy weighted triangular averaging operator is applied.

$$S_i^* = S_{i1} x\, c_1 + S_{i2}\ x\ c_2 + \ldots + S_{ik} + \ldots + S_{ip}\ \mathrm{x}\ c_p \qquad (8)$$

Calculated S_i^* value will be weight for criteria "i". As a general rule, the criteria weights are usually ranged between 0 and 1. In this manner, S_i^* is converted to Wi is presented by Eq. (9).

$$W\iota = S_i^* / u\ ,\ i = 1, 2, ..., n \qquad (9)$$

The fuzzy aggregated weights for project are calculated by multiplying the criteria weights and the project weights in accordance with each criteria. As the fuzzy aggregated weight of the jth project, Aj , j = 1, 2, ..., m is set and Aj can be calculated by Eq. (10) also the matrix form is shown at Eq. (11).

$$A_j = W_i \, x \, X_{ij} \quad , i = 1, 2, ..., n \tag{10}$$

$$\begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} = \begin{matrix} W_1 & \cdots & W_n \end{matrix} \quad x \quad \begin{matrix} X_{11} & \cdots & X_{n1} \\ \vdots & \ddots & \vdots \\ X_{1m} & \cdots & X_{nm} \end{matrix} =$$

$$\begin{matrix} W_1.X_{11} & + & W_2.X_{12} & + & \cdots & + & W_n.X_{1m} \\ & & \vdots & & & & \\ W_1.X_{n1} & + & W_2.X_{n2} & + & \cdots & + & W_n.X_{nm} \end{matrix} \tag{11}$$

Calculated fuzzy aggregated weight is assumed as $A_j = (a_1^j, a_2^j, a_3^j)$ and Aj , j = 1, 2, ..., m, is converted into a nonlinear value R(Aj) as shown by the following equation using the method named centroid-index defuzzification, presented by Yager (1980).

$$R(Aj) = \frac{a_1^j, a_2^j, a_3^j}{3} \quad , j = 1, 2, ..., m$$

Project priority and defuzzification values are linked, if defuzzification value is high so is the project priority. Integration processes and resource assignment of comprehensive improvement activities are determined correspondingly by Six-Sigma project selection priority which is connected with the project ranking. (Yang, T., Hsieh, C-H.,2009)

4.1.5.2. Ranking Alternatives (Methods)

To assess risk ranking 2 methods are determined, traditional numerical risk priority number (RPN) method and multi–ranking method as a result two methods are compared to decide the effectiveness of each of the method used. (P.Prodanovic, 2001)

a. Numerical Ranking

Ranking values are composed of numerical values between 1 to 10 due to detection, severity and occurrence. This kind of ranking method can be used at circumstances when experts are more than 90% certain regarding the ranking value for specific parameters.

For instance if severity(S) is determined as very high, than its rank value is 10 or if detection is defined as moderate than its rank value is 6. (P.Prodanovic, 2001)

b. Fuzzy Ranking

Fuzzy ranking method can be utilized in two alternatives; ranking by using fuzzy numbers and by linguistic variables.

As stated earlier numerical ranking method is used when experts are more than 90% certain and ranking values are between 1 to 10, in some cases certainty value is stated in a form of triangular fuzzy number (TFN) where certainty is less than 50%. In Chart 4.5, an example is presented for fuzzy ranking which used with linguistic variables and ranks are set as low, moderate and high.

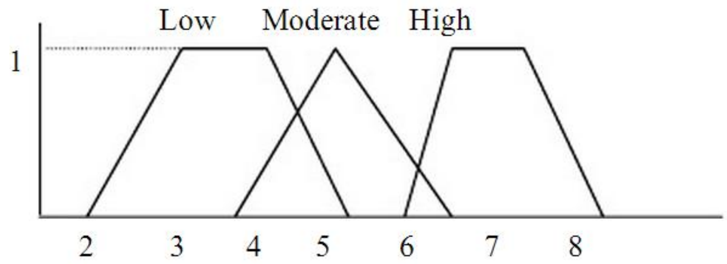

Chart 4.5 Linguistic Ranking [35]

c. Multi-Ranking Method

Multi-ranking method can be separated into two other methods as output risk ranking aggregation method and input ranking aggregation method. These methods are also divided into three sub methods known as; with common rule-base, with peer-ranking and different rule base. If multi ranking is performed with input ranking aggregation method then inputs from detection(D), occurrence(O) and severity(S) from several different experts are combined together by using numerical or linguistic values into a single fuzzy set due to relevant parameters before the data is processed by fuzzy interference system. (P.Prodanovic, 2001)

c.1. Input Ranking Aggregation

Aggregation process consists of two stages which are ranking stage and aggregation stage. In the first phase known as ranking stage, expert does the ranking linguistically for detection, occurrence, and severity which are in a fuzzy set and can be a numeric value, fuzzy number or linguistic variable.

In the second stage which is defined as aggregation stage numeric values and previously ranked fuzzy sets are combined together in a single fuzzy set.

For example, an expert defined as t ,ranks severity as *high* which can also be defined by a trapezoidal fuzzy number that can be generated by $M_s^t = (l_s^t, m_s^t, n_s^t, r_s^t)$.

For the calculation of aggregated trapezoidal fuzzy number equations (12), (13), (14) and (15) can be used, n is the number of experts involved and k is the fuzzy set currently being studied. (P.Prodanovic, 2001)

$$m_k = \frac{1}{n} \sum_{t=1}^{n}(m_k^t) \tag{12}$$

$$n_k = \frac{1}{n} \sum_{t=1}^{n}(n_k^t) \tag{13}$$

$$l_k = \text{Min } l_k^t \quad t=1,........n \tag{14}$$

$$r_k = Max \ r_k^t \quad t=1,........n \tag{15}$$

c.2. Output Risk Ranking Aggregation

This method can be performed in three different ways which are by using; “single common rule-base”, “common rule-base and peer ranking” and “different rule-base and peer ranking”. Third method makes it possible for each expert to use their own rule-base as groups or individually to get the risk outcome by defuzzing and combing the risk. It should be considered that all methods use the same fuzzy universe expressions for ranking. Another important part in multi-ranking method is that incoming data from experts are qualified separately and not combined like the way in input ranking aggregation. After individually assessing each data from experts, the final output risks are joined together in additive manner. For this reason aggregation is applied only to the output risk values. (P.Prodanovic, 2001)

c.3. Peer Ranking

Different types of data as numerical, linguistic or TFN from 3 experts are evaluated for each expert within the rules defined to produce a single risk zone all output risk data from each expert is combined during aggregation process. Output zone of the risk is first scale due to experts peer ranking prior to aggregation.

Scaling for the input data is performed with Eq. (16).

$$\mu_{si}\ x\ = \forall_{i=1}^{N}\mu_{si}(x) \text{ x } P_i \qquad (16)$$

(μ_s is risk membership function, N is maximum amount of defined fuzzy sets and P_i represents peer ranking that can take values between 0 to 1) (P.Prodanovic, 2001)

c.4. Output Aggregation

During aggregation process it is crucial to minimize or decrease loss of data from each expert so that the data is preserved properly. As a result to combine output risk, additive aggregation method is applied and later this output is defuzzified using Mean of Maxima method. Additive aggregation operator is displayed in Eq. (17).

$$\mu_{outi}[x] = \forall_{i=1}^{N}(\min(\mu_{outi}\ x\ +\ \mu_{si}[x]),1) \qquad (17)$$

(N, μ_{out} and μ_{si} are amount of experts involved. (P.Prodanovic, 2001)

4.1.6. Defuzzification Method

Defuzzification is the transaction of producing evaluable results in fuzzy logic which is expressed with fuzzy sets which is covered membership degrees. It is typically needed in fuzzy control systems. Number of rules transforms a number of variables into a fuzzy result. The membership terms in fuzzy sets defined as a result.

Today, the concept of fuzzy sets used in many different fields to applied in operation research and expert systems which applications are mentioned ranging from control applications, medical and biological sciences, speech and image processing etc.
Most of these applications can be referred as systems with numerical input (e.g. sensor data) and numerical output (e.g. voltages). These systems are effected with fuzzy values, which have to be mapped to non-fuzzy (crisp) values after processing. So that, this conversion is called defuzzification.

The common defuzzification methods are the mean of maxima method and the center of gravity method. These methods are computationally inexpensive and implementation is easier within fuzzy-logic microprocessors. Most of the defuzzification methods estimate fuzzy sets in an objective way.

The appropriate defuzzification method is difficult to select in some specific application problems. Many researchers attempted to seize the logic of the defuzzification process.(Watts, Michael J.)

Main Defuzzification Methods;

1. Centre of Gravity Defuzzification

$$y = \frac{{}_{i}^{K} \mu \ v_i \ v_i}{{}_{i}^{K} \mu \ v_i}$$

– y is the crisp value

– K is the number of items in the fuzzy set

An Example of Centre of Gravity Defuzzification as below Table 4.4:

Table 4.4 Applying the formula to the first combined set: [36]

v	0	1	2	3	4	5	6	7	8	9	10	11	12
$\mu(v)'$	0	0.16	0.32	0.48	0.64	0.8	0.64	0.48	0.32	0.24	0.36	0.48	0.6
$v\mu(v)'$	0	0.16	0.64	1.44	2.56	4	3.84	3.36	2.56	2.16	3.6	5.28	7.2
v	13	14	15	16	17	18	19	20	21	22	23	24	25
$\mu(v)'$	0.48	0.36	0.24	0.14	0.28	0.42	0.56	0.7	0.56	0.42	0.28	0.14	0
$v\mu(v)'$	6.24	5.04	3.6	2.24	4.76	7.56	10.64	14	11.76	9.24	6.44	3.36	0

${}_{i}^{K} \mu \ v_i \ v_i = 121.68$

${}_{i}^{K} \mu \ v_i \ = 10.1$

$\frac{121.68}{10.1} = 12.05 = 12.05$

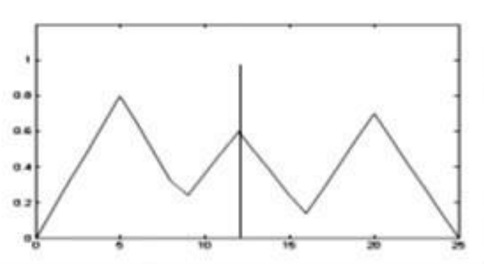

Chart 4.6 Center of Gravity Defuzzification [36]

2. Mean of Maxima Defuzzification

- Mean of Maxima finds the mean of the crisp values which is the equivalence of the maximum fuzzy values.
- If there is one maximum fuzzy value, fuzzy set will take the corresponding crisp value.

An Example of Mean of Maxima Defuzzification as below tableau 4.5:

- Maximum fuzzy value; 0.8
- Corresponding crisp value; 4

Table 4.5 Applying the values to the first combined set: [36]

v	0	1	2	3	4	5	6	7	8	9	10	11	12
$\mu(v)'$	0	0.2	0.4	0.6	0.8	0.8	0.8	0.6	0.4	0.4	0.6	0.6	0.6
v	13	14	15	16	17	18	19	20	21	22	23	24	25
$\mu(v)'$	0.6	0.6	0.4	0.2	0.4	0.6	0.7	0.7	0.7	0.6	0.4	0.2	0

If maximum fuzzy value; 0.8

Corresponding crisp values; 4, 5 and 6

$$y = \frac{4+5+6}{3} = 5$$

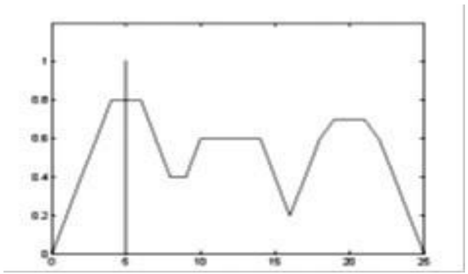

Chart 4.7 Mean of Maxima Defuzzification [36]

Therefore, this application will be displayed the role of defuzzication (numerical inputs and outputs) in Six Sigma under Fuzzy Logic. (Watts, Michael J.)

Defuzzification is applied to this project with Kaufmann and Gupta's ranking method. Kaufmann and Gupta have three ranking method and in this case study project’s results formulated with comparing the ordinary numbers as follows: $\frac{a+2b+c}{4}$ (Kahraman, C., Cebeci, U., Ruan, D.,2004)

4.1.7. Fuzzy Arithmetic

- Using the extension principle fuzzy addition is defined as:

$\mu_{A+B}(z) = \vee\ (\mu_A(x) \wedge\ \mu_B(y))\quad x,y\ \ x+y = z$

$A+B = (x_1 + y_1, x_2 + y_2, x_3 + y_3)$

- Using the extension principle fuzzy substraction is:

$\mu_{A-B}(z) = \vee\ \mu_A(x) \wedge\ \mu_B(y)\quad x,y\ \ x-y = z$

$A-B = (x_1 - y_3, x_2 + y_2, x_3 - y_1)$

- The principle fuzzy multiplication is:

$\mu_{A*B}(z) = \vee\ \mu_A(x) \wedge\ \mu_B(y)\quad x,y\ \ x*y = z$

$A.B = (x_1 y_1, x_2 y_2, x_3 y_3)$

- And the principle fuzzy division is:

$\mu_{A/B}(z) = \vee\ \mu_A(x) \wedge\ \mu_B(y)\quad x,y\ \ x/y = z$

$\frac{A}{B} = (\frac{x1}{y3}, \frac{x2}{y2}, \frac{y3}{x1})$

(Kahraman, C., ITU)

Chapter 5

Application of the Six Sigma Project Evaluation under Fuzziness in Food Industry

5.1 Determination of the Project

Agriculture is always essential and the base sector which provides humankind the nutritional needs. Agriculture, genarally includes both herbal and zoological production in its activities.

When agricultural structure is analized at developed countries it show that zoological productions is ahead of herbal productions. In our country, production of agricultural sector distibutes as 65% herbal, 25% zoological, 7% aquaculture and 3% sylviculture. Due to growing population, providing staple foods become crucial. (Hedef Food Gıda Maddeleri İhracat ve İthalat, 2013)

In this research, a hypothetical problem is handled; including 5 food investment alternatives that will be realized in different cities in Turkey and 10 criteria including Six Sigma goals. We also assumed that 8 experts evaluated the alternatives considering the Six Sigma criteria. Numerical variables have been determined with some selected criterias by Six Sigma approach under fuzziness. This application will present a study which includes chicken, meat, dairy, fish and fruit sector that have the most importance in Turkey. Some criterias can effect selection of Six Sigma Model can be defined by a financial value, some can not be digitised due to distinctive characteristic. Defuzzification methods should be used to gain numerical values.

Application is going as follows:

5.2. Determination of the criteria

The project selection criteria decision for food industry are adopted as the Six-Sigma project selection criteria for this study after a wide literature review the following criteria have been determined for selecting the best Six Sigma Project in food industry.

Criterias can be clarified as follows; Transportation of Products, Sufficient of Human Resources, Geographical Conditions, Quality of Man power, Land Cost, Adjustable Technology for Six Sigma, Proximity to Costumers, Six Sigma Educated People, Numbers of Competitors, Six Sigma Capability of Processes.

5.3. Determination of criteria weights

The scala used for weighting the criteria and alternatives are as follows:

Linguistic Variable	Membership Function
VH	(7.5, 10.0, 10.0)
H	(5.0, 7.5, 10.0)
M	(2.5, 5.0, 7.5)
L	(0.0, 2.5, 5.0)
VL	(0.0, 0.0, 2.5)

Table 5.1 Weighting Criteria and Alternatives [34]

(**VH:** Very High, **H:** High, **M:** Medium, **L:** Low, **VL:** Very Low)

8 experts evaluated the alternatives and the results are given in the following table and the scores average calculated assigned by the experts.

1.Criteria	E1	E2	E3	E4	E5	E6	E7	E8	Weighted Criteria
Transportation of Products	VH 7.5 10.0 10.0	H 5.0 7.5 10.0	L 0.0 2.5 5.0	M 2.5 5.0 7.5	L 0.0 2.5 5.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	M 2.5 5.0 7.5	(3.12, 5.62, 7.81) ∑=16.55 (3.12/16.55=0.19) (5.62/16.55=0.34) (7.81/16.55=0.47) ***X*=(0.19, 0.34, 0.47)**
Sufficient of Human Resources	H 5.0 7.5 10.0	M 2.5 5.0 7.5	L 0.0 2.5 5.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	L 0.0 2.5 5.0	VH 7.5 10.0 10.0	H 5.0 7.5 10.0	(3.44, 5.94, 8.12) ∑=17.50 **(0.20, 0.34, 0.46)**
Geographical Conditions	VL 0.0 0.0 2.5	M 2.5 5.0 7.5	L 0.0 2.5 5.0	VL 0.0 0.0 2.5	L 0.0 2.5 5.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	M 2.5 5.0 7.5	(1.56, 3.44, 5.94) ∑=10.94 **(0.14, 0.31, 0.55)**
Quality of Manpower	H 5.0 7.5 10.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	L 0.0 2.5 5.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	L 0.0 2.5 5.0	H 5.0 7.5 10.0	(3.12, 5.62, 8.12) ∑=16.86 **(0.18, 0.34, 0.48)**
Land Cost	L 0.0 2.5 5.0	M 2.5 5.0 7.5	VL 0.0 0.0 2.5	L 0.0 2.5 5.0	VL 0.0 0.0 2.5	M 2.5 5.0 7.5	H 5.0 7.5 10.0	M 2.5 5.0 7.5	(1.56, 3.44, 5.94) ∑=10.94 **(0.14, 0.31, 0.55)**
Adjustable Technology for Six Sigma	M 2.5 5.0 7.5	VH 7.5 10.0 10.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	L 0.0 2.5 5.0	H 5.0 7.5 10.0	(3.75, 6.25, 8.44) ∑=18.44 **(0.20, 0.34, 0.46)**
Proximity to Costumers	L 0.0 2.5 5.0	H 5.0 7.5 10.0	M 2.5 5.0 7.5	L 0.0 2.5 5.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	VH 7.5 10.0 10.0	H 5.0 7.5 10.0	(3.44, 5.94, 8.12) ∑=17.50 **(0.20, 0.34, 0.46)**

Six Sigma Educated People	M 2.5 5.0 7.5	VH 7.5 10.0 10.0	H 5.0 7.5 10.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	VH 7.5 10.0 10.0	(4.69, 7.19, 8.75) ∑=20.63 **(0.23, 0.35, 0.42)**
Numbers of Competitors	L 0.0 2.5 5.0	H 5.0 7.5 10.0	VH 7.5 10.0 10.0	L 0.0 2.5 5.0	M 2.5 5.0 7.5	L 0.0 2.5 5.0	VH 7.5 10.0 10.0	H 5.0 7.5 10.0	(3.44, 5.94, 7.81)∑=17.19 **(0.20, 0.34, 0.46)**
Six Sigma Capability of Processes	H 5.0 7.5 10.0	VH 7.5 10.0 10.0	H 5.0 7.5 10.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	M 2.5 5.0 7.5	H 5.0 7.5 10.0	VH 7.5 10.0 10.0	(5.00, 7.50, 9.37) ∑=21.87 **(0.23, 0.34, 0.43)**

Table 5.2 Experts Evaluations for the Alternatives and the averages of the scores for the Critera 3

Project 1		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
P1: Frozen Chicken Facility in Kastamonu	E1	5.00	2.50	2.50	5.00	7.50	2.50	5.00	0.00	5.00	2.50
		7.50	5.00	5.00	7.50	10.00	5.00	7.50	0.00	7.50	5.00
		10.00	7.50	7.50	10.00	10.00	7.50	10.00	2.50	10.00	7.50
	E2	7.50	2.50	0.00	7.50	2.50	2.50	7.50	7.50	7.50	0.00
		10.00	5.00	2.50	10.00	5.00	5.00	10.00	10.00	10.00	2.50
		10.00	7.50	5.00	10.00	7.50	7.50	10.00	10.00	10.00	5.00
	E3	2.50	0.00	0.00	0.00	2.50	5.00	2.50	5.00	2.50	0.00
		5.00	2.50	0.00	2.50	5.00	7.50	5.00	7.50	5.00	0.00
		7.50	5.00	2.50	5.00	7.50	10.00	7.50	10.00	7.50	2.50
	E4	2.50	0.00	2.50	0.00	5.00	0.00	2.50	5.00	2.50	5.00
		5.00	0.00	5.00	0.00	7.50	0.00	5.00	7.50	5.00	7.50
		7.50	2.50	7.50	2.50	10.00	2.50	7.50	10.00	7.50	10.00
	E5	0.00	7.50	2.50	7.50	0.00	5.00	0.00	0.00	5.00	0.00
		2.50	10.00	5.00	10.00	0.00	7.50	2.50	0.00	7.50	0.00
		5.00	10.00	7.50	10.00	2.50	10.00	5.00	2.50	10.00	2.50
	E6	0.00	5.00	5.00	5.00	5.00	0.00	0.00	5.00	0.00	0.00
		0.00	7.50	7.50	7.50	7.50	0.00	0.00	7.50	0.00	2.50
		2.50	10.00	10.00	10.00	10.00	2.50	2.50	10.00	2.50	5.00
	E7	7.50	0.00	0.00	0.00	5.00	2.50	2.50	0.00	2.50	0.00
		10.00	0.00	0.00	2.50	7.50	5.00	5.00	0.00	5.00	0.00
		10.00	2.50	2.50	5.00	10.00	7.50	7.50	2.50	7.50	2.50
	E8	5.00	5.00	2.50	0.00	0.00	0.00	5.00	2.50	5.00	2.50
		7.50	7.50	5.00	0.00	0.00	0.00	7.50	5.00	7.50	5.00
		10.00	10.00	7.50	2.50	2.50	2.50	10.00	7.50	10.00	7.50

Table 5.5 Experts Evaluations for Project 1: Alternatives with respect to Criteria

Project 2		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
P2: Frozen Tropical Fruit in Antalya	E1	5.00	7.50	2.50	5.00	0.00	2.50	2.50	5.00	0.00	7.50
		7.50	10.00	5.00	7.50	0.00	5.00	5.00	7.50	0.00	10.00
		10.00	10.00	7.50	10.00	2.50	7.50	7.50	10.00	2.50	10.00
	E2	7.50	2.50	0.00	7.50	7.50	0.00	5.00	7.50	7.50	2.50
		10.00	5.00	2.50	10.00	10.00	2.50	7.50	10.00	10.00	5.00
		10.00	7.50	5.00	10.00	10.00	5.00	10.00	10.00	10.00	7.50
	E3	0.00	2.50	0.00	0.00	5.00	0.00	0.00	0.00	5.00	2.50
		2.50	5.00	0.00	2.50	7.50	0.00	0.00	2.50	7.50	5.00
		5.00	7.50	2.50	5.00	10.00	2.50	2.50	5.00	10.00	7.50
	E4	0.00	5.00	5.00	0.00	5.00	5.00	2.50	0.00	5.00	5.00
		0.00	7.50	7.50	0.00	7.50	7.50	5.00	0.00	7.50	7.50
		2.50	10.00	10.00	2.50	10.00	10.00	7.50	2.50	10.00	10.00
	E5	7.50	0.00	0.00	7.50	0.00	0.00	0.00	7.50	0.00	0.00
		10.00	0.00	0.00	10.00	0.00	0.00	0.00	10.00	0.00	0.00
		10.00	2.50	2.50	10.00	2.50	2.50	2.50	10.00	2.50	2.50
	E6	5.00	5.00	0.00	5.00	5.00	0.00	7.50	5.00	5.00	5.00
		7.50	7.50	2.50	7.50	7.50	2.50	10.00	7.50	7.50	7.50
		10.00	10.00	5.00	10.00	10.00	5.00	10.00	10.00	10.00	10.00
	E7	0.00	5.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	5.00
		2.50	7.50	0.00	2.50	0.00	0.00	7.50	2.50	0.00	7.50
		5.00	10.00	2.50	5.00	2.50	2.50	10.00	5.00	2.50	10.00
	E8	0.00	0.00	2.50	0.00	2.50	2.50	7.50	0.00	2.50	0.00
		0.00	0.00	5.00	0.00	5.00	5.00	10.00	0.00	5.00	0.00
		2.50	2.50	7.50	2.50	7.50	7.50	10.00	2.50	7.50	2.50

Table 5.6 Experts Evaluations for Project 2: Alternatives with respect to Criteria

Project 3		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
P3: Frozen Fish in Muğla	E1	7.50	5.00	2.50	2.50	5.00	0.00	7.50	2.50	5.00	2.50
		10.00	7.50	5.00	5.00	7.50	0.00	10.00	5.00	7.50	5.00
		10.00	10.00	7.50	7.50	10.00	2.50	10.00	7.50	10.00	7.50
	E2	5.00	7.50	5.00	0.00	7.50	7.50	2.50	0.00	7.50	5.00
		7.50	10.00	7.50	2.50	10.00	10.00	5.00	2.50	10.00	7.50
		10.00	10.00	10.00	5.00	10.00	10.00	7.50	5.00	10.00	10.00
	E3	0.00	0.00	0.00	0.00	0.00	5.00	2.50	0.00	0.00	0.00
		2.50	2.50	0.00	0.00	2.50	7.50	5.00	0.00	2.50	0.00
		5.00	5.00	2.50	2.50	5.00	10.00	7.50	2.50	5.00	2.50
	E4	0.00	0.00	2.50	5.00	0.00	5.00	5.00	5.00	0.00	2.50
		0.00	0.00	5.00	7.50	0.00	7.50	7.50	7.50	0.00	5.00
		2.50	2.50	7.50	10.00	2.50	10.00	10.00	10.00	2.50	7.50
	E5	2.50	7.50	0.00	0.00	7.50	0.00	0.00	0.00	7.50	0.00
		5.00	10.00	0.00	0.00	10.00	0.00	0.00	0.00	10.00	0.00
		7.50	10.00	2.50	2.50	10.00	2.50	2.50	2.50	10.00	2.50
	E6	5.00	5.00	7.50	0.00	5.00	5.00	5.00	0.00	5.00	7.50
		7.50	7.50	10.00	2.50	7.50	7.50	7.50	2.50	7.50	10.00
		10.00	10.00	10.00	5.00	10.00	10.00	10.00	5.00	10.00	10.00
	E7	0.00	0.00	5.00	0.00	0.00	0.00	5.00	0.00	0.00	5.00
		0.00	2.50	7.50	0.00	2.50	0.00	7.50	0.00	2.50	7.50
		2.50	5.00	10.00	2.50	5.00	2.50	10.00	2.50	5.00	10.00
	E8	7.50	0.00	7.50	2.50	0.00	2.50	0.00	2.50	0.00	7.50
		10.00	0.00	10.00	5.00	0.00	5.00	0.00	5.00	0.00	10.00
		10.00	2.50	10.00	7.50	2.50	7.50	2.50	7.50	2.50	10.00

Table 5.7 Experts Evaluations for Project 3: Alternatives with respect to Criteria

Project 4		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
P4: Frozen Doner in Urfa	E1	5.00	0.00	7.50	5.00	2.50	2.50	5.00	0.00	2.50	2.50
		7.50	0.00	10.00	7.50	5.00	5.00	7.50	0.00	5.00	5.00
		10.00	2.50	10.00	10.00	7.50	7.50	10.00	2.50	7.50	7.50
	E2	7.50	7.50	2.50	7.50	0.00	5.00	7.50	7.50	5.00	0.00
		10.00	10.00	5.00	10.00	2.50	7.50	10.00	10.00	7.50	2.50
		10.00	10.00	7.50	10.00	5.00	10.00	10.00	10.00	10.00	5.00
	E3	0.00	5.00	2.50	0.00	0.00	0.00	0.00	5.00	0.00	0.00
		2.50	7.50	5.00	2.50	0.00	0.00	2.50	7.50	0.00	0.00
		5.00	10.00	7.50	5.00	2.50	2.50	5.00	10.00	2.50	2.50
	E4	0.00	5.00	5.00	0.00	5.00	2.50	0.00	5.00	2.50	5.00
		0.00	7.50	7.50	0.00	7.50	5.00	0.00	7.50	5.00	7.50
		2.50	10.00	10.00	2.50	10.00	7.50	2.50	10.00	7.50	10.00
	E5	7.50	0.00	0.00	7.50	0.00	0.00	7.50	0.00	0.00	0.00
		10.00	0.00	0.00	10.00	0.00	0.00	10.00	0.00	0.00	0.00
		10.00	2.50	2.50	10.00	2.50	2.50	10.00	2.50	2.50	2.50
	E6	5.00	5.00	5.00	5.00	0.00	7.50	5.00	5.00	7.50	0.00
		7.50	7.50	7.50	7.50	2.50	10.00	7.50	7.50	10.00	2.50
		10.00	10.00	10.00	10.00	5.00	10.00	10.00	10.00	10.00	5.00
	E7	0.00	0.00	5.00	0.00	0.00	5.00	0.00	0.00	5.00	0.00
		2.50	0.00	7.50	2.50	0.00	7.50	2.50	0.00	7.50	0.00
		5.00	2.50	10.00	5.00	2.50	10.00	5.00	2.50	10.00	2.50
	E8	0.00	2.50	0.00	0.00	2.50	7.50	0.00	2.50	7.50	2.50
		2.50	5.00	0.00	0.00	5.00	10.00	0.00	5.00	10.00	5.00
		5.00	7.50	2.50	2.50	7.50	10.00	2.50	7.50	10.00	7.50

Table 5.8 Experts Evaluations for Project 4: Alternatives with respect to Criteria

Project 5		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
P5: Powdered (Dried) Milk in Erzurum	E1	2.50	2.50	5.00	0.00	7.50	5.00	2.50	5.00	0.00	2.50
		5.00	5.00	7.50	0.00	10.00	7.50	5.00	7.50	0.00	5.00
		7.50	7.50	10.00	2.50	10.00	10.00	7.50	10.00	2.50	7.50
	E2	0.00	5.00	7.50	7.50	2.50	7.50	5.00	7.50	7.50	0.00
		2.50	7.50	10.00	10.00	5.00	10.00	7.50	10.00	10.00	2.50
		5.00	10.00	10.00	10.00	7.50	10.00	10.00	10.00	10.00	5.00
	E3	0.00	0.00	0.00	5.00	2.50	0.00	0.00	0.00	5.00	0.00
		0.00	0.00	2.50	7.50	5.00	2.50	0.00	2.50	7.50	0.00
		2.50	2.50	5.00	10.00	7.50	5.00	2.50	5.00	10.00	2.50
	E4	5.00	2.50	0.00	5.00	5.00	0.00	2.50	0.00	5.00	5.00
		7.50	5.00	0.00	7.50	7.50	0.00	5.00	0.00	7.50	7.50
		10.00	7.50	2.50	10.00	10.00	2.50	7.50	2.50	10.00	10.00
	E5	0.00	0.00	7.50	0.00	0.00	7.50	0.00	7.50	0.00	0.00
		0.00	0.00	10.00	0.00	0.00	10.00	0.00	10.00	0.00	0.00
		2.50	2.50	10.00	2.50	2.50	10.00	2.50	10.00	2.50	2.50
	E6	0.00	7.50	5.00	5.00	5.00	5.00	7.50	5.00	5.00	0.00
		2.50	10.00	7.50	7.50	7.50	7.50	10.00	7.50	7.50	2.50
		5.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	5.00
	E7	0.00	5.00	0.00	0.00	5.00	0.00	5.00	0.00	0.00	0.00
		0.00	7.50	2.50	0.00	7.50	2.50	7.50	2.50	0.00	0.00
		2.50	10.00	5.00	2.50	10.00	5.00	10.00	5.00	2.50	2.50
	E8	2.50	7.50	0.00	2.50	0.00	0.00	7.50	0.00	2.50	2.50
		5.00	10.00	0.00	5.00	0.00	0.00	10.00	0.00	5.00	5.00
		7.50	10.00	2.50	7.50	2.50	2.50	10.00	2.50	7.50	7.50

Table 5.9 Experts Evaluations for Project 5: Alternatives with respect to Criteria

Averages	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
P1	3.75	2.81	1.88	3.13	3.44	2.19	3.13	3.13	3.75	1.25
	5.94	4.69	3.75	5.00	5.31	3.75	5.31	4.69	5.94	2.81
	7.81	6.88	6.25	6.88	7.50	6.25	7.50	6.88	8.13	5.31
P2	3.13	3.44	1.25	3.13	3.13	1.25	3.75	3.13	3.13	3.44
	5.00	5.31	2.81	5.00	4.69	2.81	5.63	5.00	4.69	5.31
	6.88	7.50	5.31	6.88	6.88	5.31	7.50	6.88	6.88	7.50
P3	3.44	3.13	3.75	1.25	3.13	3.13	3.44	1.25	3.13	3.75
	5.31	5.00	5.63	2.81	5.00	4.69	5.31	2.81	5.00	5.63
	7.19	6.88	7.50	5.31	6.88	6.88	7.50	5.31	6.88	7.50
P4	3.13	3.13	3.44	3.13	1.25	3.75	3.13	3.13	3.75	1.25
	5.31	4.69	5.31	5.00	2.81	5.63	5.00	4.69	5.63	2.81
	7.19	6.88	7.50	6.88	5.31	7.50	6.88	6.88	7.50	5.31
P5	1.25	3.75	3.13	3.13	3.44	3.13	3.75	3.13	3.13	1.25
	2.81	5.63	5.00	4.69	5.31	5.00	5.63	5.00	4.69	2.81
	5.31	7.50	6.88	6.88	7.50	6.88	7.50	6.88	6.88	5.31

Table 5.10 Averages of Criteria for each Project

<table>
<tr><th>Criteria weights
x
Experts' Criteria Evaluations</th><th>P1</th><th>P2</th><th>P3</th><th>P4</th><th>P5</th></tr>
<tr><td>$C1_w xC1_e$</td><td>0.71
2.02
3.67</td><td>0.59
1.70
3.23</td><td>0.65
1.81
3.38</td><td>0.59
1.81
3.38</td><td>0.24
0.96
2.50</td></tr>
<tr><td>$C2_w xC2_e$</td><td>0.56
1.59
3.16</td><td>0.69
1.81
3.45</td><td>0.63
1.70
3.16</td><td>0.63
1.59
3.16</td><td>0.75
1.91
3.45</td></tr>
<tr><td>$C3_w xC3_e$</td><td>0.26
1.16
3.44</td><td>0.18
0.87
2.92</td><td>0.53
1.74
4.13</td><td>0.48
1.65
4.13</td><td>0.44
1.55
3.78</td></tr>
<tr><td>$C4_w xC4_e$</td><td>0.56
1.70
3.30</td><td>0.56
1.70
3.30</td><td>0.23
0.96
2.55</td><td>0.56
1.70
3.30</td><td>0.56
1.59
3.30</td></tr>
<tr><td>$C5_w xC5_e$</td><td>0.48
1.65
4.13</td><td>0.44
1.45
3.78</td><td>0.44
1.55
3.78</td><td>0.18
0.87
2.92</td><td>0.48
1.65
4.13</td></tr>
<tr><td>$C6_w xC6_e$</td><td>0.44
1.28
2.88</td><td>0.25
0.96
2.44</td><td>0.63
1.59
3.16</td><td>0.75
1.91
3.45</td><td>0.63
1.70
3.16</td></tr>
<tr><td>$C7_w xC7_e$</td><td>0.63
1.81
3.45</td><td>0.75
1.91
3.45</td><td>0.69
1.81
3.45</td><td>0.63
1.70
3.16</td><td>0.75
1.91
3.45</td></tr>
<tr><td>$C8_w xC8_e$</td><td>0.72
1.64
2.89</td><td>0.72
1.75
2.89</td><td>0.29
0.98
2.23</td><td>0.72
1.64
2.89</td><td>0.72
1.75
2.89</td></tr>
<tr><td>$C9_w xC9_e$</td><td>0.75
2.02
3.74</td><td>0.63
1.59
3.16</td><td>0.63
1.70
3.16</td><td>0.75
1.91
3.45</td><td>0.63
1.59
3.16</td></tr>
<tr><td>$C10_w xC10_e$</td><td>0.29
0.96
2.28</td><td>0.79
1.81
3.23</td><td>0.86
1.91
3.23</td><td>0.29
0.96
2.28</td><td>0.29
0.96
2.28</td></tr>
<tr><td>AVERAGE</td><td>5.40
15.82
32.93</td><td>5.59
15.55
31.85</td><td>5.55
15.75
32.23</td><td>5.57
15.74
32.12</td><td>5.48
15.57
32.10</td></tr>
</table>

Table 5.11 Calculation (Multiplication) of Criteria Weights and Experts' Criteria Evaluations

Projects	1	2	3	4	5
Results	5.40 15.82 32.93	5.59 15.55 31.85	5.55 15.75 32.23	5.57 15.74 32.12	5.48 15.57 32.10
Defuzzification $\frac{a+2b+c}{4}$	**17.49**	**17.14**	**17.32**	**17.29**	**17.18**

Table 5.12 Application Results for Criteria 1

According to the above results, the best Project which meets the six sigma requirements is "Project 1". Frozen Chicken Facility in Kastamonu has been selected as the best project providing Six Sigma criteria.

The rank of the remaining alternatives from the best to the worst is 3>4>5>2.

Chapter 6

Conclusion

The Six Sigma methodology has similar applications like the other approaches for solving problems. The most significant differences are to remove the defects of the production and variances of the process by using statistical techniques. The mathematical methods can be used to solve problems with Six Sigma approach.

Fewer resources can be needed for training that can be specialized and during organizations adapting phase best people as project leaders are assigned due to Six Sigma methodology. This powerful approach overcomes manufacturing, engineering and business processes to achieve improvements. Variations on processes can be reduced by using this approach with advanced statistical knowledge.

This business strategy allows eliminating the defects and preventing them from occurring. It can identify and distribute different strategies which are used by the organizations. Purpose here is to enhance the abilities of the Engineering functions and to solve the problems in processes. Also new products or product changes of the project must be fulfilled in the goal of this approach.

Occasionally senior managements think that overall strategic plan can be generally achieved by current quality processes. Six sigma leads to exceptional improvements by enhancing existing quality processes and skills of key people using its concepts and tools. Project leaders possessing outstanding qualifications are required at projects which have large impacts, for that reason black belts are selected to execute the project and selection of these candidates is crucial for being successful.

Selected project leaders have detailed trainings about six sigma approach and its tools. (Urdhwareshe, Hemant, Symphony Technologies, 2006)

In this thesis, Six Sigma approach was applied under fuzziness to this numerical illustration. Project selection was performed using 10 criteria for 5 alternatives.

In conclusion, Kastamonu chicken facility came out the best project. Sensitivity analysis was applied to the weights and it was determined that decisions are not sensitive to small variations, so that, this acquired result is certain and robust.
For further research other multicriteria methods such as Fuzzy Analytic Hierarchy Process or Fuzzy ELECTRE or Fuzzy VIKOR.

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